

**Institutul Național de Cercetare - Dezvoltare și Încercări
pentru Electrotehnică
ICMET Craiova**

**Institutul Național de Cercetare - Dezvoltare și Încercări
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ICMET Craiova**

*International Exergy, Energy and Environment
Symposium & International Conference
on Hydrogen Production*



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Founding Chair's Welcome Message

Something unique has happened this year! Both INTERNATIONAL EXERGY, ENERGY AND ENVIRONMENT SYMPOSIUM (IEEEES) and INTERNATIONAL CONFERENCE ON HYDROGEN PRODUCTION (ICH2P) have reached the 16th ones in their series although they were initiated in different years: IEEEES in 2003 and ICH2P in 2008. Due to this unplanned, remarkable overlap, we have decided to organize these conferences together in a special place in Europe. My close friend Dr. Iordache Ioan kindly accepted to organize both conferences together in a special city of Romania, **Craiova**.

We are now getting ready to make these two conferences landmark type events by bringing together world renowned, leading researchers to deliver keynote talks and provide guidance and future perspectives uniquely in the fields of energy, exergy, environment and sustainable development in addition to hydrogen energy. There will be some special and invited talks by various representatives from various sectors. There will be selected talks and presentations discuss some recent developments, current issues and potential solutions.

In closing, I warmly welcome you all to come and enjoy this opportunity through two distinguished conferences in **Craiova, Romania**.

Cordially,
Prof. Ibrahim Dincer, PhD
Ontario Tech University, Canada

Rector's Welcome Message

It is my great honour to welcome you to the University of Craiova as the host of two major scientific events: the 16th edition of the International Exergy, Energy and Environment Symposium (IEEEES-2025) and the 16th edition of the International Conference on Hydrogen Production (ICH2P-2025).

Being one of the leading universities in Romania and a respected higher education institution in Europe, we believe in scientific research that has global relevance and local applicability. The permanent synergy between fundamental, multidisciplinary, and applied research is what makes us ready to react to the challenges of our most dynamic world. We build our commitment to provide the new generations of engineers, chemists, physicists, economists, or artists on the values of inclusion, openness, transparency and academic integrity.

Today, more than ever before, international collaboration is at the core of scientific advancement and these two events are proof that universities will always be the pillars of human progress.

Prof. Cezar Ionuț Spînu, PhD
Rector of the University of Craiova

Chair's Welcome Message

We are delighted to invite you to The 16th International Exergy, Energy and Environment Symposium (IEEEES-2025) and The 16th International Conference on Hydrogen Production (ICH2P-2025) will be co-hosted in Craiova, Romania. The host organizers, National Institute for Research-Development and Testing in Electrical Engineering **ICMET-Craiova** and University of Craiova promise a synergistic event that will remain permanently in the memory of the participants. The event aims to bring together academics, researchers, scientists, technocrats, and practicing engineers, for an open discourse on disciplines ranging from energy to environment. Both scientific events hosted in various countries: Australia, Canada, China, Croatia, Egypt, France, Greece, India, Italy, Japan, Qatar, Pakistan, Poland, Portugal, Romania, South Korea, Türkiye, United Arab Emirates. After the successful 2019 edition of the International Conference on Hydrogen Production six years ago at Cluj-Napoca, it now returns to Romania, to Craiova, together with the International Symposium on Exergy, Energy and Environment.

IEEEES-2025 and ICH2P-2025 promise to be exceptional events, expanding their reach with enhanced technical content, networking opportunities, and a comprehensive social program.

Participants in the symposium and conference will have the opportunity, in addition to seeing and meeting prestigious scientists, researchers, or professors, to attend one of the most prestigious cultural events specific to the winter holidays, The Craiova Christmas Market, always among the top three events in Europe.

Ioan IORDACHE, PhD

ICMET Craiova, General Manager

On Behalf of the Organizing Committee, Symposium & Conference Chair

ICMET Conference 2025

As a result of the multitude of common elements that emphasize their academic, scientific and technical prestige, this year both The 16th International Exergy, Energy and Environment Symposium (IEEEES-16) and The 16th International Conference on Hydrogen Production (ICH2P-2025) will be co-hosted in Craiova, Romania. The host organizers, ICMET Craiova and University of Craiova promise a synergistic event that will remain permanently in the memory of the participants.

The co-hosted events aim to bring together academics, researchers, scientists, technocrats, and practicing engineers, for an open discourse on disciplines ranging from energy to environment.

IEEEES began since 2003. It has become a prominent event in the field, fostering international collaboration and the exchange of knowledge on energy, exergy, and environmental topics.

ICH2P is a well-established event in the hydrogen energy field, with the first edition being held in 2009. It's a multi-disciplinary conference focused on hydrogen production, technology, and related research

The events have been hosted in various countries: Australia, Canada, China, Croatia, Egypt, France, Greece, India, Italy Japan, Qatar, Pakistan, Poland, Portugal, Romania, South Korea, Türkiye, United Arab Emirates.

The symposium and the conference will include keynote speeches by invited speakers, regular papers presented in oral sessions, panel discussions, special sessions on selected topics and poster sessions. There will also be social and technical tours. International Exergy, Energy and Environment Symposium (IEEEES) and International Conference on Hydrogen Production (ICH2P) are key events initiated by Professor Ibrahim Dincer and his colleagues to highlight the state-of-the-art research going on in the area of exergy, energy, environment and hydrogen production and associated technologies.

Venue: The events (IEEEES-16 and ICH2P-2025) will be held at the University of Craiova, www.ucv.ro/en/, in Craiova, Romania, being organized by: National Institute for Research-Development and Testing in Electrical Engineering ICMET and University of Craiova.

TOPICS

16th International Exergy, Energy and Environment Symposium (IEEEES - 2025)

Topical areas of interest include, but are not limited to:

- ❖ Air conditioning systems
- ❖ Alternative energy
- ❖ Ammonia
- ❖ Artificial intelligence
- ❖ Biofuels and alternatives
- ❖ Carbon capture and storage
- ❖ Carbon sequestration
- ❖ Catalysis
- ❖ Clean energy conversion
- ❖ Climate change impacts
- ❖ Climate change modeling and simulations
- ❖ CO₂ utilization
- ❖ Combustion, pyrolysis, and gasification technologies
- ❖ Cooling technologies
- ❖ Desalination technologies
- ❖ Ecosystem and biodiversity
- ❖ Electric and hybrid vehicles
- ❖ Energy efficiency
- ❖ Energy policies and strategies
- ❖ Energy quality and security
- ❖ Energy storage technologies
- ❖ Energy systems modeling
- ❖ Environmental impact prevention technologies
- ❖ Environmental education and training
- ❖ Exergoeconomics and thermoeconomics
- ❖ Exergy analysis
- ❖ Global warming
- ❖ Green transportation vehicles
- ❖ Green buildings
- ❖ Greenhouse gas reduction strategies
- ❖ Hydrogen and fuel cell technologies
- ❖ Life cycle assessment
- ❖ Liquefaction systems and applications
- ❖ Mathematical modelling
- ❖ Material synthesis and application
- ❖ Nanomaterials
- ❖ Natural gas processing
- ❖ Nuclear energy and technologies
- ❖ Oil and gas technologies
- ❖ Policy and strategy development
- ❖ Process engineering and process optimization
- ❖ Refrigeration and heat pump systems
- ❖ Renewable energy sources and technologies
- ❖ Smart grids
- ❖ Solar energy
- ❖ Solid and municipal waste
- ❖ Sustainable development

- ❖ Synthetic and alternative fuels
- ❖ Thermodynamic analysis
- ❖ Thermodynamic optimization
- ❖ Waste management
- ❖ Wastewater treatment techniques
- ❖ Water and water issues

16th International Conference on Hydrogen Production (ICH2P - 2025)

- ❖ Biological aspects of hydrogen production
- ❖ Codes and standards
- ❖ Concentrated solar hydrogen production
- ❖ Demonstrations in developing countries
- ❖ Education and training for hydrogen
- ❖ Electrolysis
- ❖ Environmental impact & Fuel cells
- ❖ Gasification processes & Government policies on hydrogen
- ❖ Greenhouse gas mitigation by hydrogen
- ❖ Hydrogen economy & hydrogen infrastructure
- ❖ Hydrogen production methods & hydrogen storage
- ❖ Hydrogen technologies & hydrogen vehicles
- ❖ International perspectives on hydrogen
- ❖ Life cycle assessment & LC costing
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SPEAKERS

Ibrahim
DINCER
(ICH2P)



Dr. Ibrahim Dincer is a full professor of Mechanical Engineering at Ontario Tech. University and an adjunct professor at Yildiz Technical University in Istanbul, Turkiye. Renowned for his pioneering works in the area of sustainable energy technologies he has authored/co-authored many books and book chapters, along with many refereed journal and conference papers. Dr. Dincer has chaired many national and international conferences, symposia, workshops and technical meetings. Dr. Dincer has delivered many keynotes and invited lectures. Dr. Dincer is an active member of various international scientific organizations and societies, and serves as editor-in-chief, associate editor, regional editor, and editorial board member on various prestigious international journals. Dr. Dincer currently serves as President for National Hydrogen Association of Turkiye and Chair for Energy Working Group in Turkish Academy of Sciences. Dr. Dincer is a recipient of several research, teaching and service awards.

Faisal
KHAN
(ICH2P)



Dr. Faisal Khan is Mike O'Connor II Chair Professor and Head of Artie McFerrin Department of Chemical Engineering. He is also Director of Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, Texas, and the Ocean Energy Safety Institute (OESI) Director. Before joining Texas A&M, Dr. Khan served as Professor and Canada Research Chair (Tier I) of Offshore Safety and Risk Engineering at Memorial University of Newfoundland, Canada. He founded the Centre for Risk Integrity and Safety and Engineering in Canada. His research interests include Energy Safety, offshore safety, extreme event modeling, and risk engineering. He has been the recipient of many national and international awards. He continues to serve as a subject matter expert to many multinational industries. He is a Fellow of AIChE, a Fellow of CSChE, and a Fellow of the Canadian Academy of Engineers. He has authored over 600 research articles in peer-reviewed journals and mentored 96 PhDs. He is also the Editor-in-Chief of the Journal of Process Safety & Environmental Protection and Safety in Harsh Environments.

Frano
BARBIR
(IEEEES)



Dr. Frano Barbir is Professor Emeritus at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), University of Split, Croatia, where he continues to work as the Head of Laboratory for Hydrogen Technologies and a Project Activity Leader on the STIM-REI project with the Center of Excellence for Science and Technology – Integration of Mediterranean Region (STIM), as well as on several ongoing R&D projects. Prof. Barbir holds a Dipl.-Ing. degree in mechanical engineering and an M.Sc. degree in chemical engineering both from University of Zagreb, Croatia, and a Ph.D. degree in mechanical engineering from University of Miami, Coral Gables, FL.

He has authored and/or co-authored more than 200 papers on hydrogen and fuel cells published in scientific and technical journals, books, encyclopedias, and conference proceedings, as well as eight patents on various aspects fuel cell stack and system design and operation. His book, PEM Fuel Cells: Theory and Practice, published by Elsevier/Academic Press in 2005 (2nd edition came out in 2013), has been translated to Chinese, Korean and Farsi, and it is being used as a textbook at many universities all over the world.

Adolfo
IULIANELLI
(ICH2P)



Dr. Adolfo Iulianelli, Master Degree in Chemical Engineering and Ph.D. in Chemical and Material Engineering at the University of Calabria (Italy). Nowadays, he is Senior Researcher at the National Research Council – Institute on Membrane Technology of Italy. He is/was scientific responsible of various scientific projects, coordinating the activities focusing on the application of membrane engineering in the field of green chemistry, renewable energy, decarbonized H₂ generation, fuel processing, CO₂ capture and valorization, gas separation. Iulianelli has been Editor of various Elsevier's books about hydrogen, membrane engineering and renewable sources, and currently he serves as Associate Editor of Fuel Processing Technology (Elsevier), co-Editor in Chief of the International Journal of Membrane Science and Technology (Cosmos), Associate Editor of Frontiers of Chemical Engineering (Frontiers), Executive Guest Editor for International Journal of Hydrogen Energy (Elsevier), Renewable Energy (Elsevier), and Chemical Engineering and Processing Process Intensification (Elsevier), and editorial board member of several others. Iulianelli is qualified as Full Professor in "Chemical plants and technologies" & "Systems, methods and technologies of chemical and process engineering" and is Member of the "Industrial & Civil Engineering Ph.D. board" at University of Calabria (Italy), supervising several Post-doc researchers, PhD and Master Degree students.

Fariborz
HAGHIGHAT
(ICH2P)



Dr. Fariborz Haghighat is a professor at the Department of Building, Civil and Environmental Engineering – Concordia University, Canada. Dr. Haghighat's research aims to achieve sustainability in the built environment. His current research focuses on the fundamental of heat and mass transport in the built environment, and on its applications in the design and analysis of energy-efficient, healthy/immune, and sustainable buildings/communities. Dr. Haghighat is the Editor-in-Chief of the International Journal of Sustainable Cities and Society, Co-Editor of the International Journal Energy and Built Environment. He led two Annexes of the International Energy Agency on the topic of Energy Storage, "Applying Energy Storage in Buildings of the Future, Annex 23" and "Integration of Energy storage with energy efficient buildings and districts: Optimization and automation".

Barbara
STURM
(IEEEES)



Dr. Barbara is a globally recognized leader in systemic and technological innovation for the bioeconomy. As the Scientific Director and Chair of the Executive Board of the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) and Chair of Agricultural Engineering in Bioeconomic Systems at Humboldt Universität zu Berlin, she is at the forefront of this field. Her leadership extends to key international organizations, where she has served as President of the European Society of Agricultural Engineers (EurAgEng), Vice President of the Leibniz Association, and as a founding member of the Circular Bioeconomy Systems Working Group of the International Commission of Agricultural and Biosystems Engineering (CIGR). Barbara's work focuses on technological innovations within AgriFood and Bioeconomy systems. Her research emphasizes resource efficiency, energy systems, product quality, and productivity, driven by the power of digitalization and process automation. By working at the intersection of science, practice, policy, and society, she is uniquely positioned to discuss the crucial role of innovation in achieving a sustainable and circular bioeconomy.

Christos N.
Markides
(IEEEES)



Dr. Christos Markides is Professor of Clean Energy Technologies, Head of the Clean Energy Processes Laboratory, and Leader the Experimental Multiphase Flow Laboratory, which is the largest experimental space of its kind at Imperial College London. He is also, amongst other, Editor-in-Chief of journal *Applied Thermal Engineering* and founding Editor-in-Chief of new journal *AI Thermal Fluids*. He specialises in applied thermodynamics, fluid flow and heat/mass transfer processes in highperformance devices, technologies and systems for energy recovery, conversion or storage. He has authored >400 journal and >350 conference articles on these topics (~20,000 citations, h-index = 75). He has won multiple awards, including IMechE's 'Donald J. Groen' outstanding paper prize in 2016, IChemE's 'Global Award for Best Research Project' in 2018, IChemE's 'Clean Energy Medal' in 2025, and received Imperial College President's Awards for Research Excellence in 2018 and Teaching Excellence in 2017. He has an interest in technology transfer, innovation and commercialisation, most recently as a founding Director of solar technology company Solar Flow.

Yunus A.
ÇENGEL
(IEEEES)



Dr. Yunus Çengel is a Professor Emeritus at the University of Nevada, Reno, USA. He received his Ph. D. in Mechanical Engineering from North Carolina State University in the USA. Professor Çengel served as the assistant director and director of the Industrial Assessment Center at UNR for eight years. He also served as the advisor to several government organizations and private companies on energy efficiency, geothermal energy, energy policies, and education reform. Professor Çengel is the author or co-author of the widely adopted textbooks *Thermodynamics: An Engineering Approach*, *Fundamentals of Thermal-Fluid Sciences*, *Heat and Mass Transfer: Fundamentals and Applications*, *Fluid Mechanics: Fundamentals and Applications*, *Differential Equations for Scientists and Engineers*, *Fundamentals and Applications of Renewable Energy*, and *Energy Efficiency and Management for Engineers*, all published by McGraw-Hill. He has delivered numerous keynote and invited lectures at technical conferences and academic institutions. He is the recipient of several outstanding teacher awards, received the ASEE Meriam/Wiley Distinguished Author Award for excellence in authorship twice. In 2022, he was inducted into the Hall of Fame in Mechanical Engineering at North Carolina State University, USA.

Arif
HEPBASLI
(IEEEES)



Dr. Arif Hepbasli has been active in the energy field since 1982. He spent a decade in Izmir's industrial sector focusing on energy-related issues, and continued the remainder of his career in academic positions at different universities in Turkey and abroad. Since 2012, he has served as a faculty member in the Department of Energy Systems Engineering at Yaşar University, where he also held the role of founding chair. Dr. Hepbasli has received several awards and holds credentials as a Certified Industrial Energy Manager in Turkey, along with an ISO/IEC 17024 VET-Trainer Certificate. He has actively contributed to the academic and professional community by chairing and co-chairing a large number of events, and has provided consultancy to industry partners in his field of expertise.

Guest of Conference Chair

Byeong
Soo Oh
(ICH2P)



Dr. Byeong Soo Oh is Board Member of International Association for Hydrogen Energy. He has attended at all the World Hydrogen Energy Conferences since 1990 and was Vice President of Korean Hydrogen & New Energy Society.

Byeong Soo Oh is a researcher or academic author who has published work on hydrogen technologies and the hydrogen economy, particularly in the context of South Korea. His publications include contributions to books like "Hydrogen in an International Context" and research on the practical applications of fuel cell and hybrid energy systems for household power and remote island energy solutions. Byeong Soo Oh is a researcher specializing in the hydrogen economy and renewable energy technologies, having co-authored the chapter "From Zero to Present, the Hydrogen Technologies and Economy in South Korea" within the book Hydrogen in an International Context. His work focuses on modeling and simulating hybrid renewable energy systems, such as PV/wind/battery/PEMFC systems for off-grid applications, and the analysis of hydrogen fuel cells for vehicles and stationary power.

Host Speakers

Tudor
PRISECARU
(ICH2P)



Professor Tudor Prisecaru is President of the Senate at the University POLITEHNICA of Bucharest and Vice – President of National Research Authority.

Professor Tudor Prisecaru, graduated University POLITEHNICA of Bucharest, Faculty of Mechanical Engineering and Mechatronics, specialization Classic and Nuclear Thermomechanical Equipment, in 1982. He obtained the PhD title in Engineering sciences in 1991.

He is currently Invited Professor at Ecole de Mines de Nantes, France since 2008. He works at University POLITEHNICA of Bucharest, Faculty of Mechanical Engineering and Mechatronics, Classic and Nuclear Thermomechanical Equipment Department, where he is Professor since 2011. His main research interests include: the study of the combustion processes, risk and air pollution phenomena, efficiency improvement of combustion technologies and hydrogen technology. He participated in the elaboration of more than 40 research development and innovation projects, in the mentioned areas, and has been project director for 16 research projects. From 2001 to May 2012 he held the position of Director at the Thermal Research Center, in Bucharest, Romania. Professor Prisecaru has authored 10 books and a high number of articles in technical magazines, and participated to national and international conferences.

Ioan
IORDACHE
(ICH2P)



Ioan Iordache is CEO of National Research, Development and testing in electrical engineering – ICMET Craiova.

Ioan Iordache is a recognized expert in fuel cells and hydrogen technology with a background in Environment Engineering and Chemistry, complemented by a Ph.D. in Industrial Engineering. He serves as Chair of the Clean Hydrogen Partnership States Representative Group and is Executive Director of the Romanian Association for Hydrogen Energy. Ioan contributes significantly through research, publications, and leadership roles in advancing sustainable development and environmental protection initiatives.

He is the author and co-author of numerous research and scientific articles and specialist books. His scientific contribution also includes the participation in international conferences and international research&development projects. He is member of scientific committees and a member of several professional, scientific and technical associations.

Ion
PĂTRU
(IEEEES)



Ion Pătru is a Scientific Researcher in Electrical Engineering and works as a Scientific Manager at the National Institute for Research, Development and Testing in Electrical Engineering – ICMET Craiova, with activity of research – development and testing in the field of High Voltage, High Power Electrical Equipment. His research topics also include: Data Monitoring and Acquisition, Quality of Electrical Power and Electromagnetic Compatibility (Electromagnetic Disturbances Appearing in Electrical Energy Smart Metering Systems, Electromagnetic Disturbances Produced by Power Sources, etc). Coordinates the scientific activity of the institute, supervises research and development projects, ensures communication between technical teams and the institution's management, and contributes to the development of research strategies in energy and electrical equipment field.

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**IEES&ICH2P 2025
SHORT PAPER CONTRIBUTIONS**

SUBMERGED FRICTION STIR PROCESSING - ECO-FRIENDLY METHOD FOR LOCAL ENHANCEMENT OF MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ALUMINUM ALLOYS

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ABSTRACT – PE6

Submerged friction stir processing (SFSP) is an innovative technology for local modification of the microstructure and mechanical properties, applicable to aluminum alloys. By using water as cooling medium during processing, the thermal impact on the material in the processing area is significantly reduced, reducing the risk of oxidation and favoring grain refinement. The paper presents general aspects of SFSP processing, technological parameters and equipment used, as well as results of experimental research carried out at ISIM Timisoara on SFSP processing of rolled and cast aluminum alloys, with thicknesses of 3–6 mm, using an experimental system adapted for liquid media. The research results show the possibility of refining the microstructure and improving the mechanical properties of aluminum alloys by SFSP processing. The paper shows the potential for applying SFSP processing as a sustainable and efficient method for processing aluminum alloys (by local modification of the microstructure and mechanical properties), providing a basis for further developments in the field of materials engineering. The paper fits into the conference theme by promoting green and innovative technologies.

Keywords: Submerged friction stir processing SFSP, Eco-friendly method, Microstructure, Mechanical properties, Aluminum alloys

1. INTRODUCTION

Advanced industrial fields are currently experiencing extensive scientific, technical and technological progress, with ever-increasing demands on quality, efficiency and performance. In the current context of the transition to sustainable processes and technologies, the materials processing industry is faced with the challenge of reducing the impact of conventional processes on the environment, while ensuring the technical level and efficiency of the processes. This requires the development of materials and components with special characteristics and properties, high-performance work equipment, innovative manufacturing, joining and processing processes and technologies.

Given the requirements for a cleaner environment, the use of eco-friendly industrial processes that reduce pollution, but are also efficient, various processes for joining and processing metallic materials in a solid state have been developed, of great interest both for the scientific community and for applicants in priority industries.

One of the ecological processes for solid-state processing of metallic materials is friction stir processing (FSP), a process derived from friction stir welding (FSW), with the same principle, but which is applied to a single plate of the material to be processed. Friction stir processing constitutes an important advance in surface engineering and aims, as the case may be, at local modifications on well-defined areas of the material structure by grain refinement, modifications of hardness and mechanical properties, and increasing the plasticity of the material in the processed area, without affecting the entire material [1-21]. FSP processing is a versatile process, without noxious substances or radiation emissions, which can be applied in different working environments (e.g. air, inert gas, water, etc.) [2, 3, 5-18], being a sustainable process, with potential for integration into modern ecological manufacturing processes and industrial applications.

The actual working principle of FSP processing is the same, regardless of the working environment used [1-3, 6-11, 15, 16]. The action on the material to be processed is performed by a processing tool (Fig. 1a) that rotates around its axis, plunging the pin into the material until its shoulder makes firm contact with the surface of the material to be processed, followed by the movement of the tool in the processing direction, with certain preset process parameters. The amount of heat necessary for plasticizing, entraining and mixing the material in the processed area is generated by friction of the tool with the material to be processed, aiming to obtain the microstructure refinement and improvement of mechanical properties after processing [1-4, 6-12, 15, 16, 19].

The use of water as working medium in FSP processing has the role to reduce or avoid the overheating of both the material being processed and the tool used. This liquid medium allows the control and limitation of the maximum temperature in the processing zone, which contributes to refine grains in the material microstructure, to modify the mechanical properties and to a possible increase of the tool service life [6, 8, 9, 11, 13-15]. Complete immersion of the processing material in a water enclosure, which allows controlled circulation of the liquid through intake and discharge during processing, is an effective method to ensure temperature limitation in the active working area (Fig. 1b) [13].

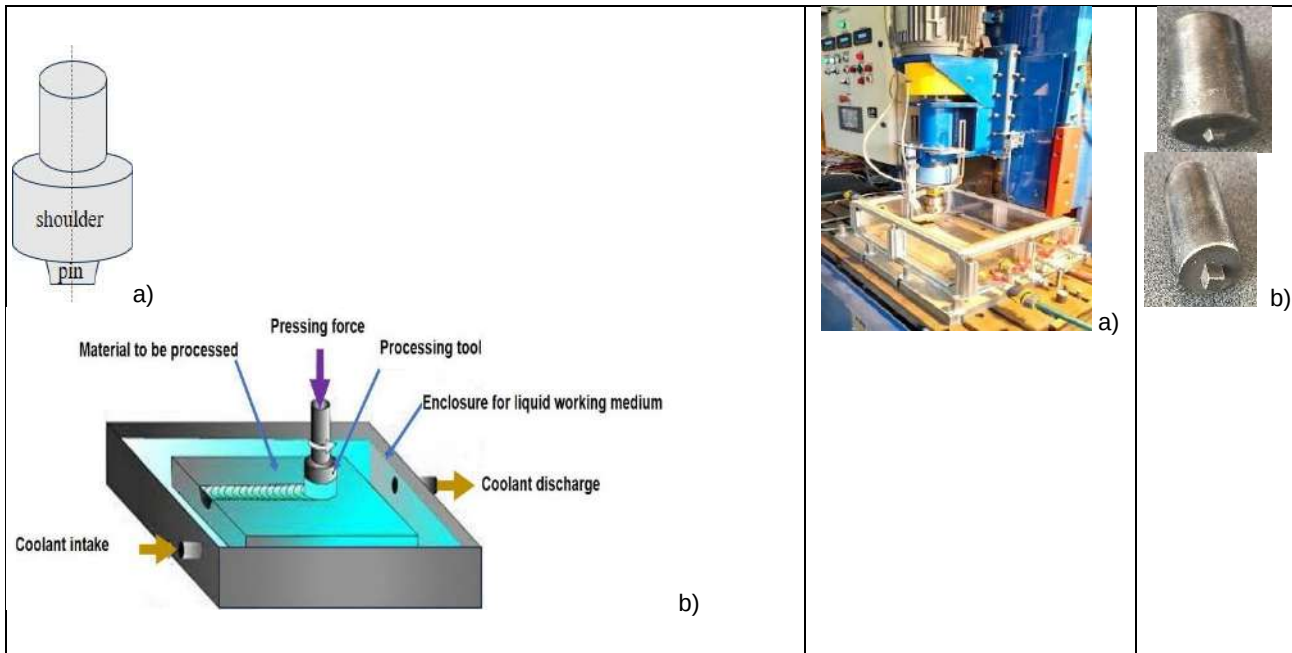


Fig. 1. Schematic presentation of the SFSP processing tool and processing principle [13]

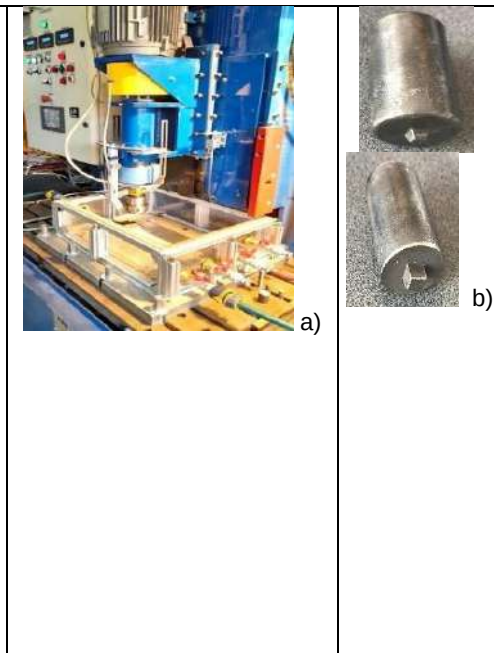


Fig. 2. FSW machine equipped with SFSP processing module (a); processing tools (b)

The objective of the paper is to present results obtained in experimental research on submerged friction stir processing of rolled and cast aluminum alloys with 5–6 mm thicknesses, usable in a variety of applications in different industrial fields (e.g. shipbuilding, automotive industry, industrial equipment, aerospace industry, metal structures, etc.) due to their combination of mechanical strength, low weight and corrosion resistance.

2. MATERIALS AND TOOLS

Experimental research on the analysis of the possibilities of applying SFSP processing was carried out on aluminum alloy sheets with thicknesses of 3–6 mm. Sheets made of rolled aluminum alloys (EN AW 1200, EN AW 5754, EN AW 6082, EN AW 7075) and cast aluminum alloy EN AC 5083 were used. The processing was carried out on an FSW welding machine equipped with a submerged processing module (Fig. 2a). The materials to be processed have been positioned and firmly fixed into a water enclosure placed on the table of the machine used for FSP/SFSP processing.

The tools used in the experimental processing research (Fig. 2b) were made of steels (H11 and C45), with a shoulder diameter of 22 mm without surface treatments. The pin of the processing tools has the shape of truncated pyramid or square, the pin length varying between 1.85–3.85 mm, in correlation with the thickness of the materials to be processed.

3. EXPERIMENTAL DATA, PROCESSED MATERIAL EVALUATION AND RESULTS

The experimental research program used the processing parameter ranges presented in Table 1. The submerged (underwater) processing was performed, as appropriate, in one pass or in multiple passes. The initial water temperature (from the mains) was 16°C and 24°C, the final temperature being only slightly higher, ranging between 26–35°C, depending on the number of passes and processing parameters. In order to know the variation of the water temperature, a water temperature monitoring system was used, which in case of an excessive increase in the water temperature during the process, could control its values by discharge/intake a quantity of water from/into the working water enclosure.

Table 1. Process parameters for each material addressed

Material	Tool rotation speed (rpm)	Processing speed (mm/min)	Direction of rotation	No. of passes
EN AW 1200	1300-2500	50-70	counterclockwise	multiple
EN AW 5754	2000-2200	100-120	counterclockwise	single, multiple
EN AW 6082	2200-2400	70; 1000	counterclockwise	multiple
EN AW 7075	2200-2400	100	counterclockwise	single, multiple
EN AC 5083	2400-3000	50-100	counterclockwise	single, multiple

The appearance of the processed materials, as well as the images related to the macrostructural analyses, are presented in Fig. 3. The surface appearance of the processed materials and the uniformity of the processed rows (one pass as well as multiple passes) is observed. Samples and specimens were taken by water jet cutting [22], which were subsequently evaluated by structural analysis, hardness measurements and mechanical tests. The macroscopic images (Fig.3) show compact, well-defined areas of processed materials, with good mixing of the materials in the processing area and a well-consolidated nugget. Microstructure analyses show grain refinement, both in rolled and cast processed materials, microstructures before and after processing being shown as example in Fig. 4.

Material	Processed surface appearance	Macroscopic image analysis
EN AW 1200 (5 mm) single pass		
EN AW 5754 (3 mm) a) single pass b) multiple passes	 	 
EN AW 6082 (5 mm) multiple passes		
EN AW 7075 (5 mm) a) single pass b) multiple passes	 	 
EN AC 5083 (5 mm) a) single pass b) multiple passes EN AC 5083 (6 mm) c) single pass	  	  

Fig. 3. Appearance of processed materials and images related to macrostructural analyses

Rolled aluminum alloy		Cast aluminum alloy	
			
Base material	Processed material	Base material	Processed material

Fig. 4. Microstructures for base materials and processed materials

The experimental results showed increases of approx. 16-24% of the hardness in the processed areas for the EN AW 5754 aluminum alloy processed in one pass (+16%, 58 HV1) and in multiple passes (+24%, 68 HV1).

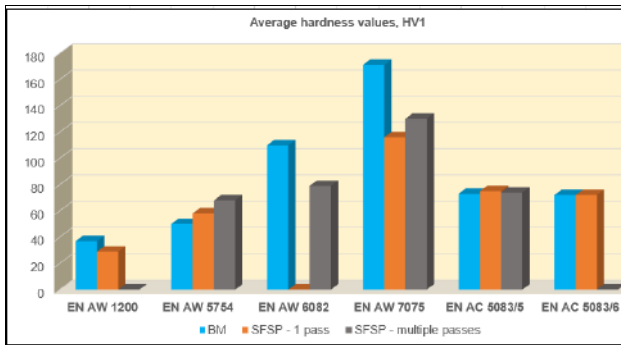


Fig. 5. Average hardness variation graph (BM, SFSP processed materials: 1 pass/ multiple passes)



Fig. 6. Specimens of SFSP processed materials, bending tested

It was observed that the average hardness value in the processed areas (Fig. 5) is lower by 20-30% compared to the average hardness value of the base materials for the aluminum alloys EN AW 1200 (-20%, 29 HV1), EN AW 6082 (-28%, 79 HV1), EN AW 7075 (-30%, 116 HV1 for processing in one pass and -24%, 130 HV1 for processing in multiple passes, respectively). However, it was observed that for processing in multiple passes, the hardness of the material in the processed area is higher by approx. 4-8% compared to the hardness when processed in one pass (Fig.5). The tensile strength of the specimens in the processed areas was generally between 70-90% of the tensile strength of the base materials, the fracture occurring in the base material, in the processed area or in the transition area between them. For the cast aluminum alloy EN AC 5083 the average values of the hardness and tensile strength are close to those of the base material. The bending test of specimens taken from materials processed in one pass and in multiple passes (Fig. 6) was performed, as appropriate, with both the stretched surface and the stretched root.

The bending angle was maximum for the specimens taken from EN AW 1200, EN AW 5754 and EN AW 6082 processed by SFSP. Compared to the base material, it is noted that SFSP processing did not reduce the bending angle in the case of EN AW 1200 and EN AW 5754, but improved it in the case of EN AW 6082 (from 100° to full bending angle). For EN AW 7075 aluminum, the processed material became more brittle, with breakage occurring at slightly lower bending angles (44-46°) compared to the base material (53°). In the case of cast alloy EN AC 5083, SFSP processing contributed to a significant increase in the bending angle of the specimens taken from the processed material by approx. 83% when processed in one pass (from 52° to 95°) and respectively by approx. 220% (from 52° to 115°) when processed in multiple passes (Fig. 6).

CONCLUSIONS

- Submerged processing SFSP is a method of local processing, on limited areas of materials to modify their structure and mechanical properties, without affecting the entire material.
- SFSP processing has an ecological impact, being a process without emissions of noxious substances or radiation, with lower resource consumption compared to other processing processes.
- Microstructure refinement was achieved through SFSP processing in both rolled and cast aluminum alloys.
- Changes in hardness were obtained in the processed areas compared to the hardness of the base material. Depending on the material, decreases in hardness in the processed area were observed (for EN AW 1200, EN AW 6082 and EN AW 7075), as well as increases in it (EN AC 5083).
- The tensile strength of the specimens taken from the processed areas was generally between 70-90% of the tensile strength of the base material, with the fracture occurring in the base material, in the processed area or in the transition area between them.
- SFSP processing is environmentally efficient given that the use of water as a working medium and a system for monitoring its temperature contributes to good thermal control of the working process without additional energy input, as well as eliminating the need for conventional heat treatments.
- SFSP processing offers an ecological, environmentally friendly, modern and sustainable alternative for local modification of the microstructure and mechanical properties, compared to conventional processing methods.

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FLOATING HYDROGEN REFUELING STATION FOR A GREEN SHIPPING CORRIDOR

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ABSTRACT – OE26

This study proposes both a unique and innovative design for offshore energy hubs and develops an integrated energy conversion and management strategy. Due to the inherent intermittency of wind-generated electricity in offshore environments, hydrogen storage via offshore electrolysis was adopted as an energy storage option. The potential hydrogen production capacities were determined for selected locations in the North Sea where the wind potential can be effectively utilized. The system was designed to store hydrogen at 700 bar, and in cases where the electricity transmitted to the shore falls below the set value, the stored hydrogen is supplied to a fuel cell to ensure a secure and continuous energy supply. As a result, an overall energy efficiency of 48.1% was achieved, with an average wind speed of 9.98 m/s, indicating a remarkably high energy potential, and an annual hydrogen production capacity of 5,443.65 tons was revealed.

Keywords: Energy, Wind Energy, Hydrogen, Energy Management, Offshore Energy Hubs

1. INTRODUCTION

Beyond merely meeting the growing global energy demand, it has become increasingly crucial to urgently develop cleaner energy production and management strategies. In this regard, countries are shaping their own pathways toward increasing the share of renewable energy sources in the overall energy consumption, reducing the dependence on fossil fuels in total energy consumption, and promoting hydrogen as the main character of sustainability. Moreover, due to internationally established targets and upcoming regulatory constraints, sustainable energy solutions have become indispensable. In light of these considerations, offshore energy hubs are regarded as vital contributors to the transition toward sustainable energy systems. In particular, the North Sea, often referred to as Europe's powerhouse, possesses an enormous wind energy potential.

In one study [1], hydrogen was electrochemically produced both offshore and on-site, then transported to the onshore facilities through hydrogen pipelines, compressed, and subsequently delivered for end use. In an economic assessment [2], the integrated concept of offshore electrochemical hydrogen production, seawater desalination on the platform, and hydrogen transport via pipelines to the mainland for storage in salt caverns was investigated. The results revealed that the LCOH remains at prohibitive levels under current technological and economic conditions.

Table 1 presents the strategic pathways defined by various countries for offshore hydrogen development. Most nations are expected to take significant steps toward offshore technologies by 2030 and, more prominently, by 2050. However, as in other renewable energy sources, wind energy is inherently intermittent, which necessitates the development of efficient energy storage solutions to ensure reliable and secure power transmission. Therefore, the specific objectives of this study are established upon this foundation, to propose a practical solution addressing these challenges through an integrated offshore energy hub concept.

Table 1. Various nations' targets and the status of offshore wind energy globally.

Nations	Targets	Source
The North Seas Energy Cooperation (across members)	- To reach at least 76 GW of offshore wind capacity by 2030. - To achieve at least 193 GW by 2040. - To deploy at least 260 GW by 2050, representing over 85% of the EU-wide 300 GW target.	[3]
Netherlands	- To complete the ongoing wind farms of 5.5 GW. (current status is 4.7 GW) - To achieve 21 GW by 2030.	[4]
Germany	- To increase offshore wind capacity to at least 30 GW by 2030, 40 GW by 2035, and 70 GW by 2045. (current status is 9.2 GW) - To continuously identify and allocate new offshore sites.	[5]
United Kingdom	To deliver 43–50 GW of offshore wind capacity by 2030. (current status is 16 GW and leading in Europe)	[6]
United States of America	To deploy 30 GW of offshore wind capacity across the United States. (current status is 174 MW installed)	[7]
Canada	To develop 5 GW of offshore wind capacity through leases by 2030 in Nova Scotia.	[8]
China	To reach approximately 200 GW of installed offshore wind capacity by 2030 (current value is 41 GW and leading in the world)	[9]

The specific objectives of this study are: (i) to determine the available wind energy potential in the North Sea and quantify the corresponding exploitable energy capacity; (ii) to reveal the potential hydrogen production based on the wind energy potential and electrolysis performance; (iii) to evaluate the overall energy and exergy efficiencies of the proposed offshore energy hub system; (iv) to develop a uniquely designed offshore energy hub that not only meets electricity demand but also utilizes surplus electricity for energy storage, thereby eliminating the intermittency of wind through hydrogen storage; (v) to introduce an innovative approach involving offshore electrolysis for on-site hydrogen generation and utilization through floating hydrogen refueling stations for ships; and (vi) to ensure system reliability by enabling the stored hydrogen to be supplied to a fuel cell during periods of low wind power generation, thereby maintaining energy balance and a continuous power supply.

2. BRIEF ANALYSIS

The proposed system produces hydrogen through seawater electrolysis using an AEM electrolyzer, which operates by utilizing surplus electricity. In the system design, a total installed capacity of 4 GWe is considered, consisting of a 2 GWe HVDC transmission infrastructure to deliver electrical power to the shore, while the remaining 2 GWe is allocated to an offshore electrolysis unit for hydrogen production. An additional 2 GWe interconnection line is integrated between these two subsystems to ensure the security of energy transmission during periods of insufficient wind generation. In such cases, the stored hydrogen is converted back into electricity through fuel cells, and after voltage and current adjustments via voltage boosters, it is transmitted to the shore through the HVDC line. The produced hydrogen is compressed in three stages using compressors and stored at a pressure of 700 bar. During intermediate compression stages, the hydrogen is cooled using a seawater-ground refrigerator, both to comply with safety regulations and to reduce compressor work requirements.

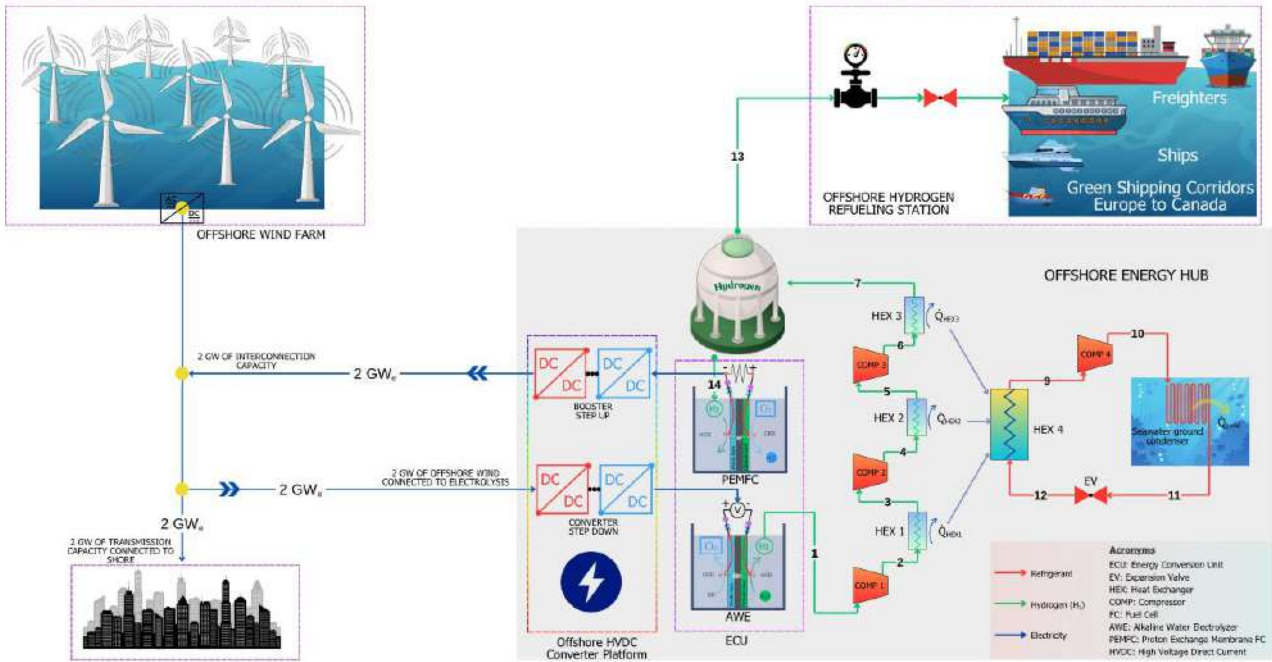


Fig. 1 Schematic description of a uniquely designed offshore energy hub for electrical power transmission to shore, a green shipping corridor establishing a bridge between Canada and Europe, and floating hydrogen refueling stations

In this section, the definition of the energy efficiency of the offshore energy hub is presented in Equation 1. The useful outputs consist of the electricity transmitted to the shore and the total energy content of the hydrogen generated in the electrolyzers, while the denominator represents the available wind power. In Equation 2, for the exergy efficiency formulation, the chemical exergy of hydrogen is also taken into account. Here, $\dot{W}_e$ denotes the electrical power transmitted to the shore via the HVDC connection, $\dot{m}_{H_2}$ represents the mass flow rate of the electrochemically produced hydrogen, LHV_{H_2} is the lower heating value of hydrogen (120 MJ/kg), and ex_{H_2} indicates the chemical exergy of hydrogen (117 MJ/kg). The term ρ denotes the air density, A is the swept area of the wind turbine, and V represents the average wind speed (hourly, daily, or monthly) at the designated location used for the calculation. The wind speed data were obtained from the NASA POWER database and analyzed on an hourly basis.

$$\eta_{en} = \frac{\dot{W}_e + \dot{m}_{H_2} LHV_{H_2}}{\frac{1}{2} \rho A V^3} \quad (1)$$

$$\eta_{ex} = \frac{\dot{W}_e + \dot{m}_{H_2} ex_{H_2}}{\frac{1}{2} \rho A V^3} \quad (2)$$

3. RESULTS AND DISCUSSION

In Fig. 2, the exergy efficiency was calculated and illustrated based on the daily variations in ambient temperature. A decrease in exergy efficiency was observed with increasing temperature, which can also be attributed to the lower wind speeds typically experienced during the summer months. On average, the exergy efficiency was determined to be 48.07%.

In Fig. 3, the monthly hydrogen production capacity of the offshore energy hub is presented, along with the system's capability to ensure a continuous, stable, and constant electricity supply. The figure also illustrates the amount of hydrogen consumed when wind energy becomes insufficient and the stored hydrogen is converted back into electricity via fuel cells and supplied to the HVDC line. Due to the higher wind speeds during winter months, a greater amount of hydrogen could be stored, whereas during the summer, this stored hydrogen was consumed more intensively.

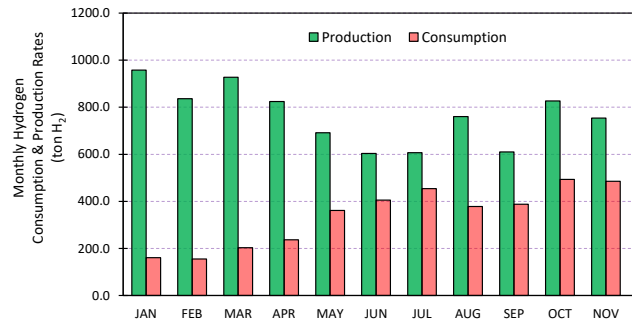
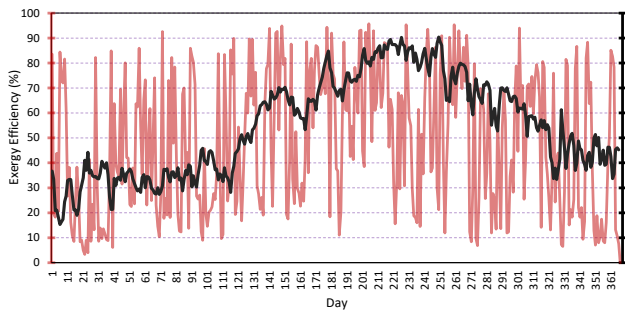


Fig. 2. The change in exergy efficiency with ambient temperature.

Fig. 3 Monthly hydrogen production and consumption rates.

CONCLUSIONS

In summary, the system achieved a total annual net hydrogen production of 5,443.65 tons, representing the amount of hydrogen stored each year. Of this total, approximately 9.3 tons are produced by the electrolyzer, while about 3.8 tons are consumed by the fuel cell for electricity generation. The average energy efficiency of the system was found to be 48.1%, accompanied by an exergy efficiency of 48.07%. The average wind speed at a hub height of 100 m was identified as 9.98 m/s.

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HYDROGEN-ENRICHED GASOLINE COMBUSTION FOR LEAN LIMIT EXTENSION AND EMISSION REDUCTION IN GDI ENGINES

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ABSTRACT – OE24

The effect of hydrogen induction (0-5 liter per minute) in to the intake manifold of the small bore Gasoline Direct Injection (GDI) Engine is investigated experimentally. The intake manifold is slightly modified to accommodate the hydrogen induction system, where premixed mixture of hydrogen and air is formed in the intake manifold; attaining the excess air ratio of 1.0 to 1.2. With the increment of hydrogen fraction the fuel leaning (Gasoline) is attained and achieving economical fuel consumption rate. The decrement in torque characteristics is compensated with the increase of hydrogen fraction. The hydrogen induction improves the combustion rate and mean effective pressure; shortens the flame propagation, maximize the heat release rate and peak pressure attainment. On the emission side consistent decrease in CO and HC emission; and increase of NO_x emission since the mean gas temperature has increased. The cycle to cycle variation during the lean operating condition at 1.2 shows the combustion stability and effective flame propagation.

Keywords: Hydrogen Induction, Small Bore, Gasoline Direct Injection

1. INTRODUCTION

The reputation of Internal Combustion Engine in recent days with fossil fuel as the working fuel has been in the downfall as the intense promotion of electric vehicle technology. The transportation sector contributes to 10% of the greenhouse gas (GHG) emission which makes it meager when compared to the energy sector [1]. The 100 years of scientific improvement in the engine technology makes it more mature than other recent alternative technologies. It is clear those alternatives to compete with IC engine do not cover the vast range of application. A lot of times the blame of the IC engine is about the source of the working fuel and not on the IC engine technology. Compared with the conventional fossil fuels hydrogen pose superior characteristic and more suitable for SI engine, where it offers wider flammability range with high diffusivity and low ignition energy. With the safety precaution and advancement towards the storage of hydrogen makes it viable option for alternate for fossil fuels. From the prior arts it is found that adding little quantity of hydrogen with the conventional fuels offers better heat release rate, stable lean mixture formation and improved combustion efficiency. Further it shortens the delay period and offers peak pressure attainment close to top dead center (TDC). The cycle to cycle variation of the engine operating behavior was also reduced with the addition of hydrogen with the gasoline. On the emission side significant reduction in CO and HC emission was noticed; with some penalty on NO_x emission, but particulate emission in the direct injection gasoline has consistent reduction with addition of hydrogen.

The implementation of direct fuel injection technology in SI engine is one of the advancement that pushes the limits of SI engine in terms of its thermal efficiency, power performance, emission and lean operating limits [2]. The gasoline direct injection (GDI) engines are getting more robust since the research advancement was towards various combustion modes, alternate fuels, dual spark ignitions, plasma ignition, dilution techniques to treat emission, in-cylinder water injection, fuel injector study, dual fuel injection, combustion diagnosis and furthermore [3]. The Gasoline Direct Injection (GDI) Engine is known for its economical fuel consumption, improved thermal efficiency and better torque characteristic.

Application of GDI technology for small bore engine increases the operating limits of the engine for the light commercial vehicles (LCV) and two wheeler segment; where this percentage of vehicles in Indian roads are higher in meeting the daily commutation. The GDI technology and the usage of Hydrogen as the primary/secondary fuel paves the path towards the lean combustion technology, wherein the real problems associated with the driving condition will be addressed [4]. On roads most of the engines are operated only at the partial load conditions, wherein the actual efficiency of the engine is poor due to the poor load characteristic, throttling effect and traffic conditions (start and stop). Leaning the gasoline by operating the engine under lean conditions leads to other technical issues like overheating engine misfire and unstable combustion [5]. Addition of hydrogen for the lean operating condition of GDI engine provides more stable combustion and significant reduction in the cycle to cycle variations will be attained. After accessing the prior literature, the author aims for hydrogen-gasoline lean burn combustion for small bore GDI engine; with the performance, emission evaluation. The effect of lean burn combustion with addition of hydrogen in gasoline and the lean limit estimation with stable combustion is also investigated.

2. EXPERIMENTAL APPARATUS AND METHODS

Experimental Apparatus

The engine used for the present investigation is the 390 cm³ small bore single cylinder air cooled GDI engine. The layout of the experimental setup is shown in Fig. 1. The engine was originally available as the carburetor engine, Honda make; it was later modified to direct injection gasoline engine. The engine head was modified to support the GDI injector, throttle control was replaced with the electronic actuator and to control the spark and injection timing, an Electronic Control Unit (ECU) was fitted. To make the close-loop system CAM and crankshaft position (CKP) sensors were additionally fitted with fuel rail pressure control. The modification details of the engine were not included since it is beyond the scope of the article.

The engine details are listed in the Table 1. The spark plug location in the engine is at the sides with hemispherical type combustion chamber. The piston head was not modified, production type flat piston head was maintained throughout the investigation. The spray guided fuel injector was used and it was fitted near the spark plug. The details of the fuel injector and pump are listed in the Table 2.

The water cooled eddy current type dynamometer was used to load engine for operating conditions. To measure the inlet air HFM (Hot Film) Type T-MAF Sensor was employed and the gravimetric type fuel flow measuring system was used to calculate the fuel consumption by the engine. Contact type encoder was coupled with the crankshaft, this was utilized to trigger the data acquisition system to record the various sensor data. Piezoelectric pressure transducer with the resolution of 0.1 crank angle degree (CAD) was employed to record the in-cylinder pressure data. Wideband Lambda sensor (from Bosch) LSU 4.9 was used to monitor the air fuel ratio and the exhaust gas temperature was monitored by K-type thermocouple. Di-gas analyser 444 (from AVL) was used to record the engine out emission.

Experimental Methods

The test condition for the investigation is 3000 rpm with 100% throttle opening, where the maximum brake torque was obtained for the given spark timing. The engine operating conditions are listed in Table 3. The hydrogen flow rates are estimated with the energy balance of not exceeding 50% by hydrogen and the maximum limit was set to 5 LPM. For the equivalence ratio of 1, the hydrogen flow rate was varied from 5 to 1 LPM and similarly the equivalence ratio was increased to 1.1 and 1.2. For the consistent increment in the equivalence ratio the subsequent gasoline leaning will be carried out.

Table 1. Engine Details

Table 2. Fuel Injector Details

Table 3. Engine Operating Conditions

Particulars	Details
No. of Cylinders	1
No. of Valves	2
Type of CAM	Single Overhead
Ignition	Spark
Bore*Stroke (mm)	88*64
Displacement (cm ³)	390
Compression Ratio	8.2:1
Induction	Naturally Aspirated
Rated Torque	24 Nm @3000 rpm
Rated Power	8 hp @3600 rpm
Cooling system	Air

Particulars	Details
Make	M/s. Bosch
No. of Nozzles	6
Configuration	Spray Guided
Operation	Peak & Hold-Solenoid
Make of pump and rail	M/s. Bosch
Pressure	180 bar

Particulars	Details
Speed (rpm)	3000
Mode	Constant Speed Mode
Throttle position	100%
Fuel Injection Pressure	80 bar

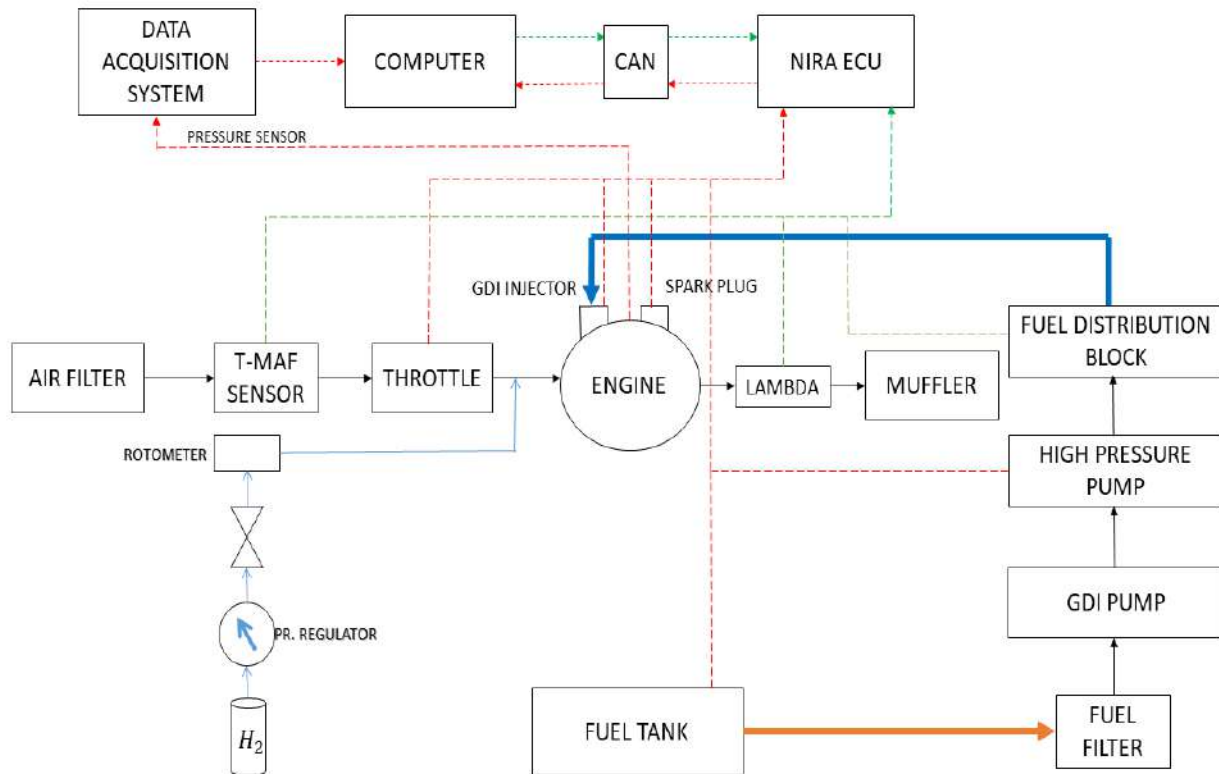


Fig. 1. Experimental Layout

CONCLUSIONS

➤ Engine operation with 100% wide open throttle, equivalence ratio of 1, 1.1 & 1.2 and the varied hydrogen fraction of 1 to 5 LPM has the significant effect on the engine performance, combustion and emission characteristic. As the hydrogen fraction increases for the particular equivalence ratio significant increment in thermal efficiency and indicated mean effective pressure. At the equivalence ratio of 1.2 highest thermal efficiency was attained.

➤ Engine operation with 100% wide open throttle, equivalence ratio of 1, 1.1 & 1.2 and with the increase in hydrogen fraction the combustion duration was shorten leading to peak pressure attained close to TDC. Keeping the hydrogen fraction constant and increasing the equivalence ratio improves the heat release rate and consistent reduction in the delay period.

➤ Engine operation with 100% wide open throttle, equivalence ratio of 1, 1.1 & 1.2 and with the increase in hydrogen fraction CO and HC emissions decreases and increment in NO_x emissions. Keeping the hydrogen fraction constant and increasing the equivalence ratio, CO emission significantly reduces and HC emission reduces initially and increases in the later part. The NO_x emission has the adverse effect with the higher amount of hydrogen fractions.

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ANTIMICROBIAL ACTIVITY STUDY OF SOME METAL COMPLEXES WITH AN ADENOSINE SCHIFF BASE LIGAND

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ABSTRACT – PE8

This study presents the antimicrobial activity of some complexes with a Schiff base derived from adenosine and p-dimethylaminobenzaldehyde. This Schiff base ligand and its Cu(II), Ni(II) and Co(II) metal complexes were tested for their antimicrobial activity on five bacterial strains: *Enterococcus faecalis*, *Citrobacter freundii*, *Salmonella*, *Staphylococcus epidermidis* and *Escherichia coli*. The quantitative assay of the antimicrobial activity was performed by binary micro dilution method, in order to establish the minimum inhibitory concentration (MIC). From the results of the biological evaluation it was concluded that the antimicrobial activity of the tested compounds follows the order: Cu(II) complex > Co(II) complex > Ni(II) complex $\cong$ Schiff base ligand, and that, in general, biological activity increases through complexation. Therefore, the most active compound, considering both the intensity of the antimicrobial activity and the microbial spectrum, proved to be the Cu(II) complex compound, which showed good activity against *Salmonella* strain (MIC = 31.25 $\mu\text{g}\cdot\text{mL}^{-1}$), being active against all tested microbial strains.

Keywords: adenosine Schiff base, metal complexes compounds, biological activity

1. INTRODUCTION

Adenosine is an endogenous nucleoside with potent vasodilator and antiarrhythmic activities. Adenosine also has anti-inflammatory activity and plays an important role in energy transfer as adenosine triphosphate (ATP) and adenosine diphosphate (ADP) [1].

p-Dimethylaminobenzaldehyde has found applications in synthetic, biochemical, biomedical and analytical sciences. The biological activity of Schiff bases derived from p-dimethylaminobenzaldehyde and the appropriate aromatic primary amines, anthranilic acid or p-aminosalicylic acid, as well as their bioactive coordination compounds have been reported [2, 3].

The synthesis and characterization of the Cu(II), Ni(II) and Co(II) complexes with the Schiff bases derived from p-dimethylaminobenzaldehyde and adenosine, were presented in a previous study [4]. This paper presents the results of the antimicrobial tests for these compounds.

2. MATERIALS AND METHODS

The complexes of Cu(II), Ni(II) and Co(II) with Schiff base ligand derived from p-dimethylaminobenzaldehyde and adenosine were prepared according to a procedure described in a previous study, by refluxing a mixture of Schiff base and metal chloride solutions in absolute ethanol [4]. Analytical grade reagents from Sigma and Merck were used in all experiments.

The microbial strains were isolated from different clinical sources and were identified by aid of VITEK 1 automatic system [5].

The antimicrobial activity of these compounds was tested against five bacterial strains: *Enterococcus faecalis*, *Citrobacter freundii*, *Salmonella*, *Staphylococcus epidermidis* and *Escherichia coli*. Microbial suspensions of density corresponding to 0.5 McFarland UI obtained from 24 h microbial cultures developed on solid media were used in the experiments. The antimicrobial activity of these compounds was tested on Mueller-Hinton agar medium.

The tested compounds were dissolved in dimethylformamide (DMF) and used for the antimicrobial activity screening at 10 $\text{mg}\cdot\text{mL}^{-1}$ concentration of stock solutions.

The quantitative assay of the antimicrobial activity was performed by binary micro dilution method, in liquid medium, distributed in 96 multi-well plates, in order to establish the minimum inhibitory concentration (MIC). In this purpose, serial binary dilutions of the tested compounds were performed in a 100 μL volume of liquid medium and each well was seeded with 20 μL of microbial inoculum of 0.5 McFarland UI density. The plates were incubated for 24 h at 37°C, and MICs were recorded in each case as the minimum concentration of the compound, which inhibited the visible growth of the tested microorganism.

3. RESULTS AND DISCUSSION

The spectroscopic data (IR and UV-Vis electronic spectra), as well as elemental analysis, molar conductivity measurements and magnetic data, presented in a previous study [4], supported the proposed structures of the studied compounds (Fig. 1).

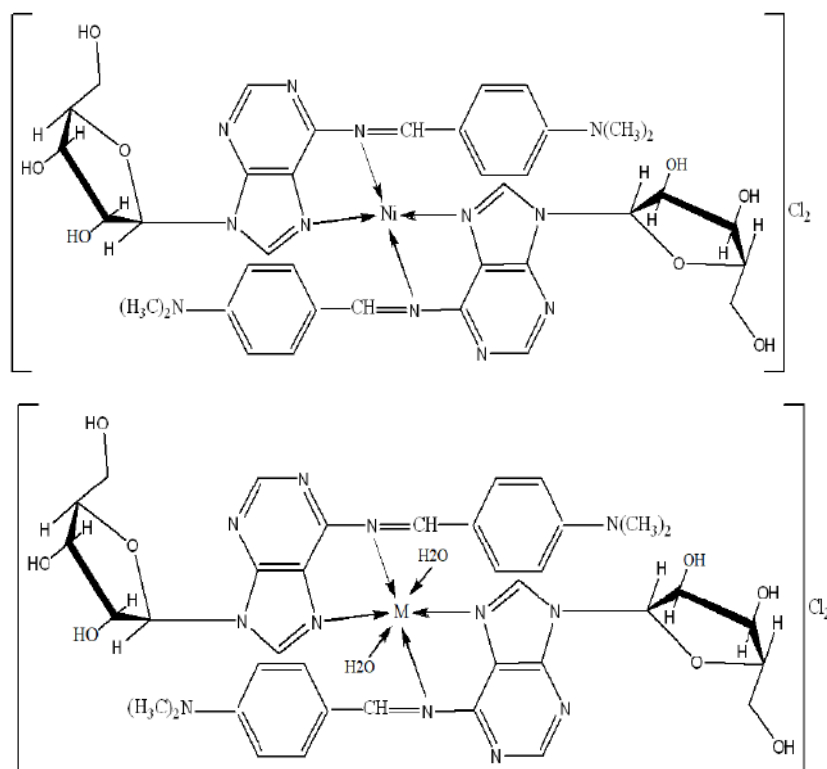


Fig. 1. Proposed structures of Ni(II), Cu(II) and Co(II) metal complexes with Schiff base ligand (M = Cu(II) or Co(II))

The quantitative assay results for the antimicrobial activity of the studied compounds, expressed as MIC values, between 1000 and 31.25 $\mu\text{g}\cdot\text{mL}^{-1}$, are presented in the Table 1.

Table 1. Antimicrobial activity expressed as MIC ($\mu\text{g}\cdot\text{mL}^{-1}$)

Compound	MIC/ $\mu\text{g}\cdot\text{mL}^{-1}$				
	<i>Enterococcus faecalis</i>	<i>Citrobacter freundii</i>	<i>Salmonella</i>	<i>Staphylococcus epidermidis</i>	<i>Escherichia coli</i>
L ($\text{C}_{19}\text{H}_{22}\text{N}_6\text{O}_4$)	no inhibition	250	no inhibition	no inhibition	no inhibition
$[\text{CuL}_2(\text{H}_2\text{O})_2]\text{Cl}_2$	500	250	31.25	1000	150
$[\text{NiL}_2]\text{Cl}_2$	no inhibition	no inhibition	500	no inhibition	500
$[\text{CoL}_2(\text{H}_2\text{O})_2]\text{Cl}_2$	500	no inhibition	31.25	no inhibition	150
DMF	500	500	500	1000	250

A MIC value superior to 250 $\mu\text{g}\cdot\text{mL}^{-1}$ was considered as corresponding to a low, between 250 $\mu\text{g}\cdot\text{mL}^{-1}$ and 125 $\mu\text{g}\cdot\text{mL}^{-1}$ to a moderate and under 60.50 $\mu\text{g}\cdot\text{mL}^{-1}$ to a good antimicrobial activity [6].

The most active compound, considering both the intensity of the antimicrobial activity and the microbial spectrum proved to be the Cu(II) complex, which showed good activity against *Salmonella* strain (MIC = 31.25 $\mu\text{g}\cdot\text{mL}^{-1}$), being active against all tested microbial strains. The Cu(II) complex also presents a moderate antimicrobial activity, superior to DMF solvent, against *Citrobacter freundii* and *Escherichia coli* strains and a low antimicrobial activity, similar to that of the DMF solvent, against *Enterococcus faecalis* and *Staphylococcus epidermidis* strains. It was found that the Ni(II) complex presented a low antimicrobial activity against *Salmonella* and *Escherichia coli* strains and was inactive against three microbial strains: *Enterococcus faecalis*, *Citrobacter freundii* and *Staphylococcus epidermidis*.

The Co(II) complex showed a good antimicrobial activity, similar to that of the Cu(II) complex, against *Salmonella* strain, a moderate antimicrobial activity and a low antimicrobial activity, similar to that of the Cu(II) complex, against *Escherichia coli* and *Enterococcus faecalis* strains, respectively. This complex was inactive against *Citrobacter freundii* and *Staphylococcus epidermidis* strains, similar to the Ni(II) complex.

It must be noticed that the Schiff base ligand was inactive against four of the five tested microbial strains and this compound also presented a moderate antimicrobial activity, similar to that of the Cu(II) complex, against *Citrobacter freundii* strain.

From these results of the biological evaluation it was concluded that the antimicrobial activity of the tested compounds follow the order: Cu(II) complex > Co(II) complex > Ni(II) complex $\cong$ Schiff base ligand and that, in general, biological activity increases through complexation.

CONCLUSIONS

In this study, the Cu(II), Ni(II) and Co(II) complexes with a Schiff base derived from p-dimethylaminobenzaldehyde and adenosine, were tested for their antimicrobial activity.

From the results of the biological evaluation it was concluded that the antimicrobial activity of the tested compounds follow the order: Cu(II) complex > Co(II) complex > Ni(II) complex $\cong$ Schiff base ligand and that, in general, biological activity increases through complexation. Therefore, the most active compound, considering both the intensity of the antimicrobial activity and the microbial spectrum proved to be the Cu(II) complex, which showed good activity against *Salmonella* strain (MIC = 31.25 $\mu\text{g}\cdot\text{mL}^{-1}$), being active against all tested microbial strains.

The importance of these findings lies in the fact that these compounds could be considered for the further development of novel antimicrobial drugs used for the treatment of some common diseases caused by these bacterial strains.

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INTEGRATED TIDAL-WIND-BIOMASS BASED SYSTEM WITH STORAGE FOR INUIT COMMUNITIES IN NORTHERN QUEBEC, CANADA

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ABSTRACT – OE31

This short paper provides a design and analysis study of a multi-generation integrated energy system aiming to produce electricity, heating, hydrogen fuel, and freshwater for about 18,000 residents across 14 Inuit communities in the Northern Quebec region of Canada (Nunavik region). These remote Arctic communities currently depend on diesel for power and heating, resulting in high emissions, fuel transportation challenges, and economic vulnerability. The proposed system integrates tidal and wind energy resources with biomass thermochemical processing (pyrolysis and gasification) and integrates them through a Rankine cycle, Battery Energy Storage System (BESS), Proton Exchange Membrane (PEM) electrolyzer, and absorption refrigeration and desalination subsystems. The system outputs electricity, district heating, hydrogen and methane fuels, cold storage, and potable water. This system utilizes waste heat and recovers exergy to improve energy and exergy efficiencies. The simulation results estimate the potential exergy efficiency of the proposed multigeneration system exceeding 45% with an overall 30.6 MW, reducing diesel dependency by over 80%. This concept illustrates a possible, achievable method for obtaining carbon-neutral development in the Arctic and enhancing local resilience.

Keywords: Multigeneration, Renewable Energy, Hydrogen Production, Biomass Gasification, Arctic Communities

1. INTRODUCTION

Northern Inuit villages in northern Quebec, including Cojoarabeque, Bouvernitok, Salluit, and Kangersock, exist in isolation from the primary electricity grid and depend on imported fuel for power and warmth. This reliance results in elevated fuel expenses, recurrent supply interruptions in winter, and significant greenhouse gas emissions. Moreover, waste management and freshwater scarcity impose significant strain on the delicate Arctic ecosystem. The main challenge in these regions is sustainably supplying energy, water, and heating requirements despite severe climatic circumstances (average winter temperatures of -30°C) and inadequate infrastructure. The isolation and logistical challenges make renewable hybrid solutions, incorporating energy storage and waste value, not merely advantageous but imperative. Previous research [1], investigated hybrid energy systems utilizing wind, diesel, solar, and battery power in the Canadian Arctic. However, no previous integrated system has combined tidal conversion, wind energy, and biomass with the Rankine cycle, hydrogen synthesis through MED, and absorption cooling systems for use in the Arctic. Its uniqueness is attributed to its thermodynamic integration, which maximizes the utilization of renewable resources and waste heat [2].

This short paper outlines a comprehensive multi-generation system that continuously generates electricity, heating, hydrogen fuel, cooling, and freshwater utilizing locally accessible renewable resources: wind, tides, and biomass. It also uses waste heat from multi-effect distillation MED and ammonia absorption cooling to support food preservation (including fish and berries) and employs biochar as fertilizer and filtration media, closing the loop on local resources.

2. DEVELOPED MODEL

The proposed Integrated Multigeneration System in Fig. 1 consists of six subsystems that work together to deliver electrical, thermal, chemical, and water outputs:

- Tidal Power Subsystem: Employs kinetic energy from tidal currents in Hudson Strait (10–12 m tidal range) using underwater turbines (8 MW capacity).
- Wind Energy Subsystem: Utilizes onshore wind (6–8 m/s) with a capacity of 10 MW.
- Biomass Conversion Subsystem: Processes municipal and organic waste (2–3 tons/day) through pyrolysis (500–600°C) to produce bio-oil, biochar, and syngas; syngas is upgraded via gasification (750–950°C, limited O_2 /steam) into H_2 and CH_4 .
- The Rankine Power and Heat Recovery Cycle uses water and steam as the working fluid to turn biomass heat into electricity (5 MW) and district heating (8 MW).
- Hydrogen and Fuel Cell Subsystem: A PEM electrolyzer converts surplus electricity into hydrogen; a PEM fuel cell generates electricity from stored H_2 during low-renewable periods.
- Thermal Utilization Subsystems: Waste heat drives ammonia absorption refrigeration for the cold storage of lake trout, whitefish, and cloudberries, and the Rankine condenser heat feeds a MED desalination unit for freshwater.

The integrated model is developed in a thermodynamic, exergetic framework using energy and mass, entropy, and exergy balance equations for each component. The model includes: power generation from tidal and wind sources based on average local resource data, biomass mass and energy flow calculations for pyrolysis and gasification outputs, Rankine cycle energy balance for both power and heat recovery, electrolyzer and fuel cell rates of hydrogen production and consumption, and the BESS charge/discharge optimization for load leveling.

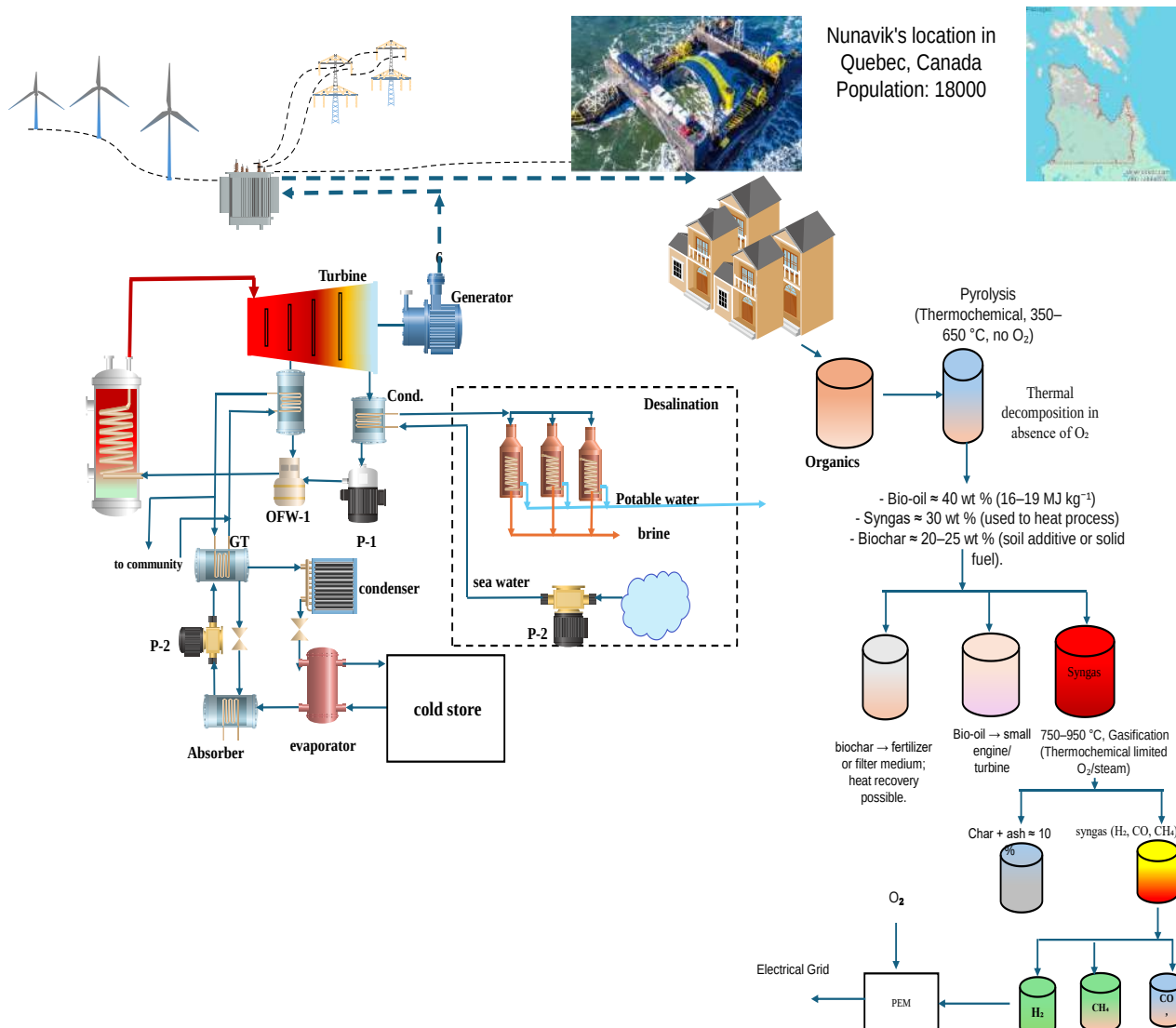


Fig. 1. Schematic of the developed integrated multigeneration system

3. RESULTS AND DISCUSSION

The total energy demand for the Inuit communities is estimated at 30.6 MW. Fig. 2 illustrates the integrated layout combining tidal, wind, and biomass-driven Rankine subsystems. Winter in Nunavik experiences long nights, frequent blizzards, and mean temperatures below -30°C , producing the year's highest heating and electrical loads.

The Rankine cycle contributes about 5 MW_e of electrical output and 8 MW_{th} of recoverable heat, operating between boiler and condenser temperatures of 450°C and 70°C, respectively. The recovered thermal stream supports both district heating and secondary utilities such as MED and refrigeration.

The tidal and wind systems are renewable, providing about 60% of the total electric supply. The biomass Rankine subsystem ensures continuous operation during calm or neap-tide periods, whereas the PEM fuel cell supplies short-term peak or emergency coverage. Overall grid availability exceeds 98%, surpassing the reliability levels of conventional diesel microgrids.

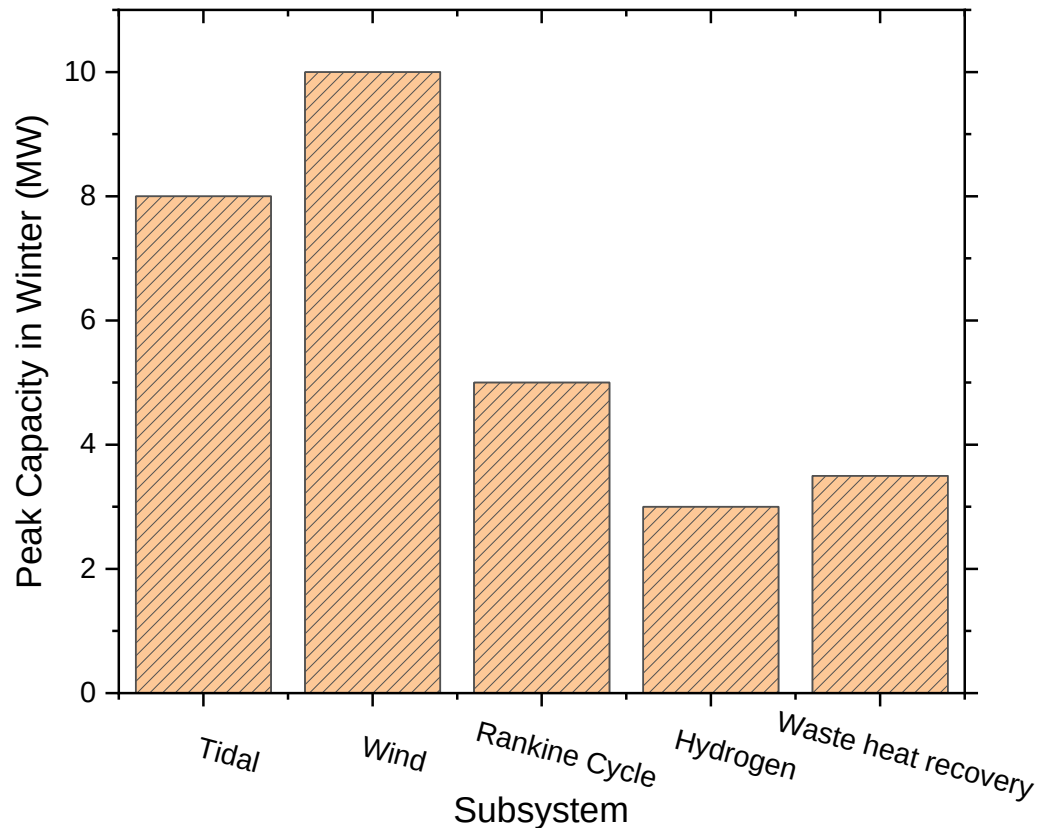


Fig. 2. The peak capacities calculated for the winter season using Tidal, wind, Rankine Cycle, Hydrogen, and waste heat recovery

CONCLUSIONS

This study demonstrates that an integrated tidal, wind, and biomass multigeneration system can provide a resilient, low-carbon energy framework for remote Arctic settlements. The design efficiently couples renewable power, hydrogen generation, heat recovery, and water desalination, addressing multiple community needs through one integrated system.

The outcomes include:

- Fulfillment of the 30.6 MW total load for 18,000 residents with about 45% exergy efficiency.
- Substantial emission reduction and diesel displacement, improving local air quality.
- Circular resource use, where organic waste becomes energy and fertilizer.
- Enhanced food and water security through renewable cold storage and MED.

This model represents a new scheme for sustainable northern development, adaptable to other isolated regions worldwide.

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A BIOMASS-BASED INTEGRATED BIOELECTROCHEMICAL SYSTEM

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ABSTRACT – OE30

This study introduces a multigeneration system that integrates anaerobic digestion and bio electrochemical cells to convert wastewater into electricity, hydrogen, and domestic hot water. Key components include, organic Rankine cycle, Brayton cycle and an integrated bio reactor that combines microbial fuel cell, microbial electrolysis and photo electrolysis unit, which together support simultaneous waste treatment and clean energy generation. The designed system has an overall energy efficiency of 38.88% and exergy efficiency of 31.36%. The system achieves a net electrical output of 6.23 MW, while producing 0.07 kg/s of hydrogen and two streams of thermal energy at different temperatures to meet residential and industrial demands. Parametric studies demonstrate that biogas yield, and reference temperature significantly affect system performance. The proposed configuration offers a scalable solution for integrating renewable energy with wastewater treatment and hydrogen infrastructure for sustainable urban applications.

Keywords: Anaerobic digestion, Biomass, Hydrogen, Wastewater, Efficiency

1. INTRODUCTION

Modern society is facing serious challenges due to increasing energy demand, environmental problems, and the urgent need for sustainable urban growth [1]. Heavy dependence on fossil fuels has caused a rise in greenhouse gas (GHG) emissions and greater concern about global climate change. Traditional energy systems are often inefficient and rarely include renewable energy sources. Therefore, there is growing interest in cleaner energy solutions that use renewable resources, lower emissions, and support circular economy practices. Renewable energy sources such as solar, biomass, wind, and geothermal are gaining importance due to their environmental benefits and sustainability. However, the variable nature of renewable energy sources often limits their effectiveness when used alone. Combining multiple renewable sources into a single multigeneration system can help to solve this problem [2]. Multigeneration systems simultaneously produce electricity, heating, cooling, H₂, and even freshwater from one or more input sources, which improves overall efficiency [3].

This study proposes a novel multigeneration system uses wastewater to provide electricity, domestic hot water, and bioH₂ for residential applications. Anaerobic digestion (AD) is used to convert sewage sludge into biogas, which fuels both a steam Brayton cycle and organic Rankine cycle for electricity generation. An integrated bio electrochemical system is employed for simultaneous wastewater treatment, electricity production, and bioH₂ generation. Importantly, the electricity produced by the MFC is used to partially power demands for the MEC, reducing the external energy requirement, which is an innovative configuration not commonly seen in previous literature. A H₂ liquefaction unit is also included to store and supply H₂ to the community use.

2. SYSTEM DESCRIPTION

This paper presents a novel integrated system designed to sustainably produce electricity, hot water, and H₂ for residential communities (Fig. 1). The overall system includes several subsystems: an AD that generates biogas from raw sewage sludge, a Brayton cycle for power generation, an ORC for low grade thermal utilization, an integrated unit for electricity and H₂ production, and a H₂ liquefaction unit for storage and distribution. The system primarily relies on biogas and solar energy as input sources, ensuring renewable and continuous operation. The integrated reactor plays a crucial role by simultaneously treating wastewater and recovering bioenergy. In the MFC unit, electrogenic microorganisms oxidize organic compounds in wastewater and generate electrical power. The MEC unit operates with a small external voltage to drive H₂ production at the cathode, using the byproducts of microbial activity. When integrated, these two technologies enhance the efficiency of bioH₂ production while maximizing the energy recovery from wastewater. Producing H₂ through this offers a sustainable alternative to conventional methods such as steam methane reforming or water electrolysis, with significantly lower energy requirements and environmental impact. The system begins with the AD of raw sewage sludge, which is continuously supplied from the wastewater treatment plant at a flow rate of 13.06 kg/s. Raw sludge enters AD at a reference conditions.

The H₂ production by the MEC unit is released at a flow rate of 0.07 kg/s, a temperature of 293 K, and a pressure of 100 kPa. This H₂ enters the first stage of the liquefaction process, where it is compressed to 300 kPa by Compressor 2, causing its temperature to rise to 420.4 K. It is then cooled in intercooler 1 to 298 K before proceeding to Compressor 3. In the second compression stage, the H₂ is pressurized to

700 kPa, and its temperature increases to 394.3 K. The gas is finally cooled again in intercooler 2 to 298 K, completing the liquefaction sequence.

Regarding the system analysis, thermodynamic techniques are used to examine performance of the system both exegergetically and energetically to establish the optimal design and operating settings that produce satisfactory results for the overall energy and exergy efficiencies of the system, as well as its subsystems.

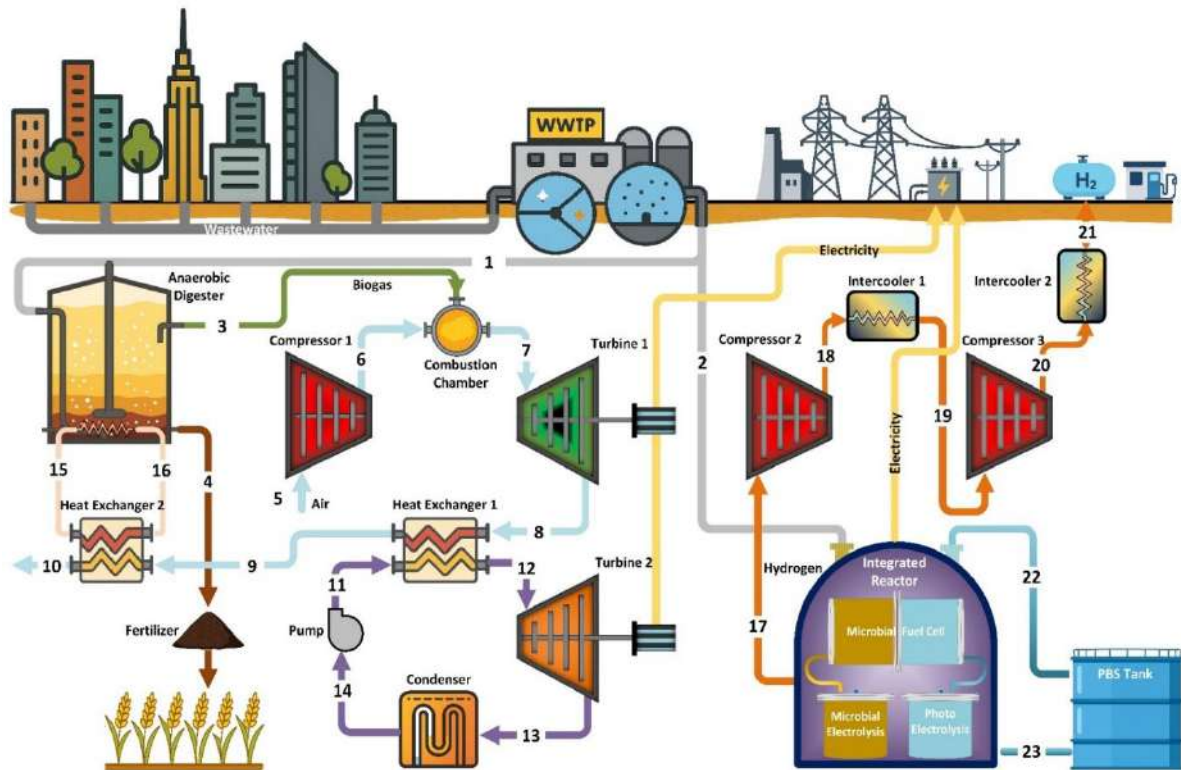
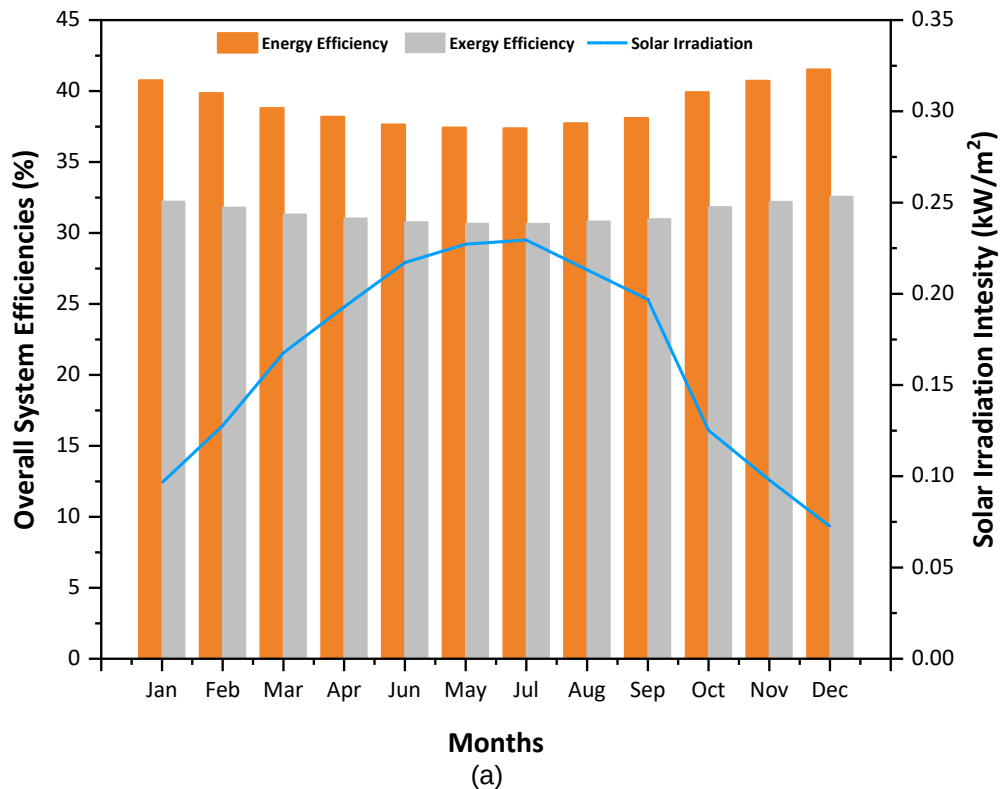


Fig. 1. Schematic drawing of the proposed system



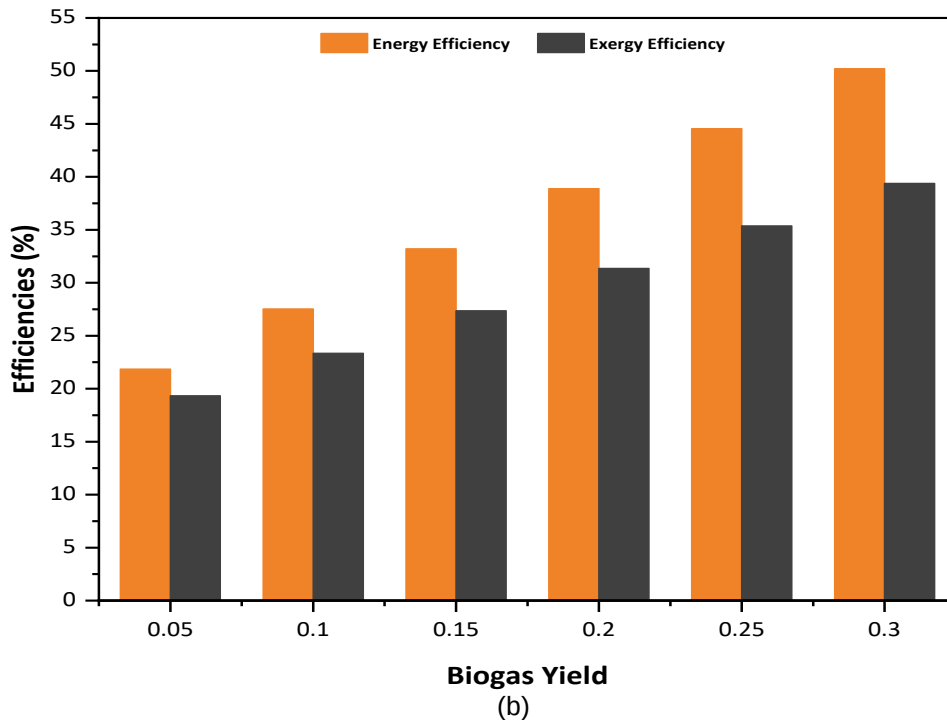


Fig. 2: (a) overall energy/exergy efficiencies with varying solar irradiance and (b) with varying biogas yield.

3. RESULTS AND DISCUSSION

Fig. 2a illustrates the monthly change in overall exergy and energy efficiencies of the integrated system, alongside solar irradiation intensity. From January to June, solar irradiance gradually increases, peaking in July at 0.229 kW/m^2 , which coincides with the lowest recorded energy efficiency of 37.37% and exergy efficiency of 30.66%. This inverse trend suggests that while solar input is higher during summer months, the overall thermodynamic performance slightly decreases, likely due to higher ambient temperatures affecting component level efficiencies and thermal losses. Energy efficiency fluctuates between 37.36% and 41.55%, with the highest values observed in December and January, despite lower solar irradiation levels. Fig. 2b shows the influence of biogas yield on the energy and exergy efficiencies of the integrated system. As the biogas yield increases from 0.05 to 0.30, both performance metrics demonstrate a consistent upward trend. The overall energy efficiency improves significantly, rising from 21.86% at the lowest yield to 50.21% at the highest, while exergy efficiency increases from 19.33% to 39.38%.

CONCLUSIONS

This study presents a novel multigeneration system that effectively transforms wastewater to valuable outputs, including electricity, H_2 , and domestic hot water. The system achieves a net electrical output of 6.23 MW, produces 0.07 kg/s of renewable H_2 , and delivers thermal energy streams suitable for residential and industrial water heating. Thermodynamic assessments reveal that the system operates with an overall energy efficiency of 38.88% and an exergy efficiency of 31.36%, indicating strong performance in resource conversion and minimal losses. The integration of anaerobic digestion, organic Rankine cycle, and integrated reactor allows for simultaneous waste treatment and sustainable energy recovery. Overall, the system provides a scalable and replicable solution for enhancing clean energy access while addressing environmental challenges associated with wastewater management.

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GRAPHICAL USER INTERFACE TO STUDY ELECTRIC DRIVES USED ON MODERN LOCOMOTIVES

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ABSTRACT – PE12

In this paper, we present the structure of electric drives with traction induction motors used on modern locomotives fed through AC lines. We detail the structure, mathematical model, and structural diagram for each component that makes up the electric drive system (traction transformer, line-side converter, machine-side converters, traction induction motor, mechanical transmission, and traction control). Our approach enables studying and understanding the electric drive system through simulation, both as individual components and as a whole. Using MATLAB App Designer, we have created Graphical User Interfaces that could be used to simulate the behavior of the electric drives used on modern locomotives. These items can be used as teaching material too. Developing such an application is useful to deepen our understanding of the high-power electric drives.

Keywords: Locomotive, Electric Drives, Mathematical Model, MATLAB App Designer, SIMULINK.

1. INTRODUCTION

Every electric drive used on modern locomotives fed through AC lines consists of (Fig.1) [1,2,3]:

- main electric (force) circuits which include: traction transformer (TT), four-quadrant converter (C4Q), voltage-source inverter (IT) and the traction induction motor (MAT),
- a mechanical part made of the (TM), and
- locomotive control that include: four-quadrant converter control, control of the voltage-source and the traction induction motor and anti-slip control.

This theoretical structure is multiplied four or six times depending on the number of the electric traction motors of the electrical locomotive.

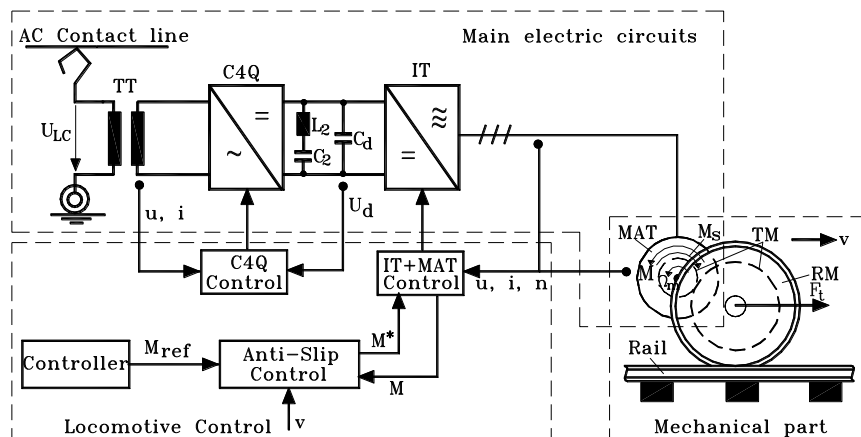


Fig. 1. Structure of electric drives with traction induction motor used in modern locomotives fed trough AC lines

2. MODELLING OF ELECTRICAL DRIVES

Electric traction phenomena tends to be complex processes of various types (mechanical movements, electromagnetic or thermic phenomenon's etc.). They can be studied separately from each other using their corresponding theoretical model.

However, most of the time we expect to have various different quantities interacting with each other, which leads to the requirement of developing a more complex model. In such situation, a mathematical one is preferred.

A mathematical model must facilitate the optimal implementation and utilization of the dynamic systems simulation packages. Because of this, for each subsystem studied in this paper we will present the corresponding structural diagram alongside their mathematical models. This approach guarantees a general reusability of these diagrams for multiple simulation cases by creating structural diagrams for complex systems by connecting their subsystems structural diagrams between each other [3]. Alongside the structure of each component of the electric drive we also present their mathematical models and structural diagrams.

Models that concern the mechanical aspect of a locomotive have been developed. They are used for things such as train motion, mechanical transmissions and the mechanical part of the asynchronous traction motor, which can be broken down into an electromagnetic and a mechanical part. In regards to the electric part, we present models for the electromagnetic part of the traction motor, for the electric converters. To model the

converters, we used two-level switching functions. For locomotive control we introduce the models of two different control types: the vector control and Direct Self Control. By combining all of these, we are able to use MATLAB App Designer to create Graphical User Interfaces [4,5,6,7,8,9,10,11]. We will use the four-quadrant converter case as an example that ties together what we presented so far.

3. MODELLING OF THE FOUR-QUADRANT CONVERTER

The mathematical model of the line-side converter (C4Q) contains elements adjacent to it (the transformer secondary, the filter L_2 - C_2 and the C capacitor), as depicted in its structure (Fig. 2):

$$\begin{aligned}
 i_2 &= \frac{1}{L_k} \int_0^t (u_{T2} - u_2) dt + i_2(0) \\
 i_{4Q} &= i_2 \cdot f_{k2AB}; \quad u_2 = u_d \cdot f_{k2AB}; \quad f_{k2AB} = f_{k2A} - f_{k2B} \\
 i_d &= i_{4Q} - i_{F2}; \quad i_{d1} = i_d - i_{d2} \\
 u_d &= \frac{1}{C} \int_0^t i_{d1} dt + u_d(0) \\
 i_{F2} &= \frac{1}{L_2} \int_0^t (u_d - u_{C2}) dt + i_{F2}(0) \\
 u_{C2} &= \frac{1}{C_2} \int_0^t i_{F2} dt + u_{C2}(0)
 \end{aligned} \tag{1}$$

where the following two-levels switching functions have been used:

$$f_{k2A} = \begin{cases} +1, & T_1(I) \\ 0, & T_2(I) \end{cases}; \quad f_{k2B} = \begin{cases} +1, & T_3(I) \\ 0, & T_4(I) \end{cases} \tag{2}$$

The structural diagram of the four-quadrant line-side converter (Fig. 3) is constructed using the mathematical model.

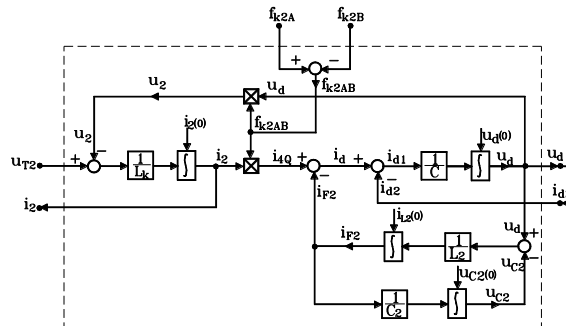
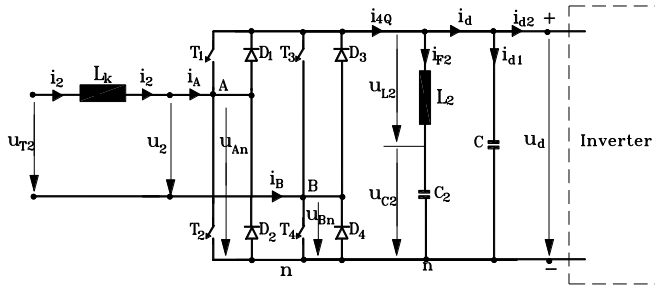


Fig. 2. Structure of the converter C4Q

Fig. 3. Structural diagram of the converter C4Q

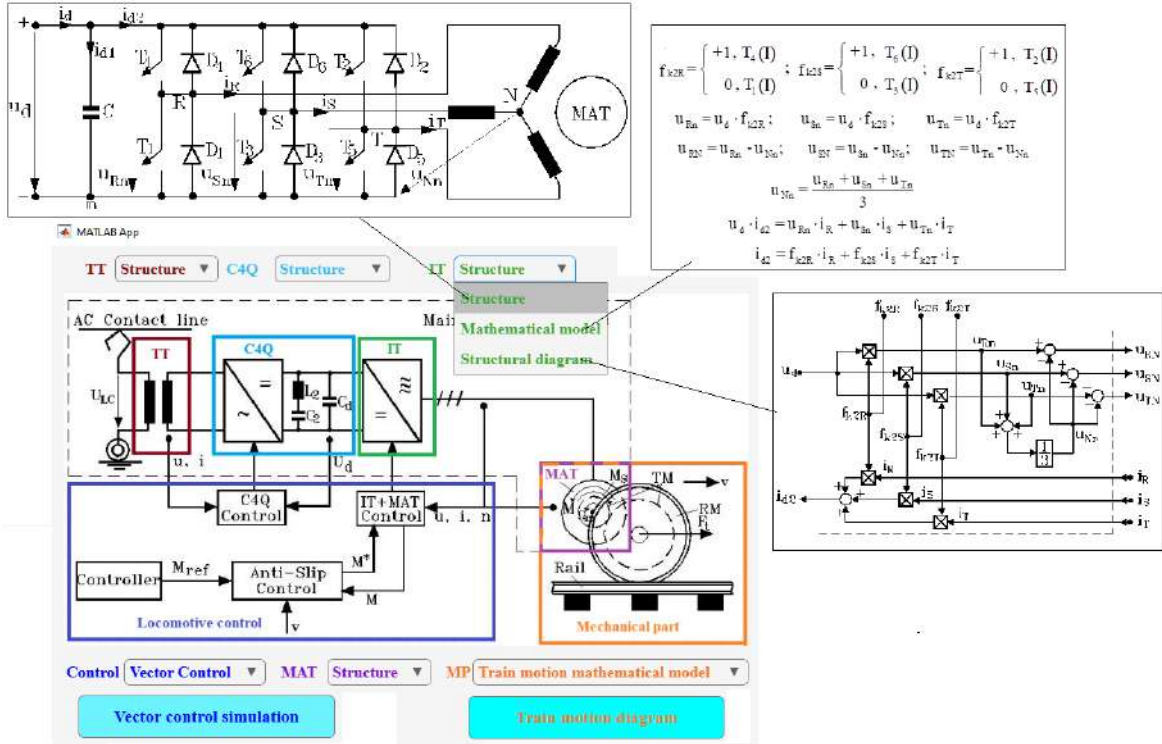


Fig. 4. Graphical User Interface of the electric drive

4. APP DESIGNER INTERFACES

The Graphical User Interface that was developed using the MATLAB App Designer facilitates the visualization of previously presented elements, such as: structure, mathematical model and structural diagram for each component that makes up the electric drives system (Fig.4). Moreover, it gives the possibility of running simulations ("Vector control simulation" and "Train motion diagram") of some SIMULINK models that were created using the structural diagrams we presented (Fig. 4).

Another Graphical User Interface was developed using the MATLAB App Designer starting from a SIMULINK model. This interface helps with the study of the train motion through simulation (Fig.5).

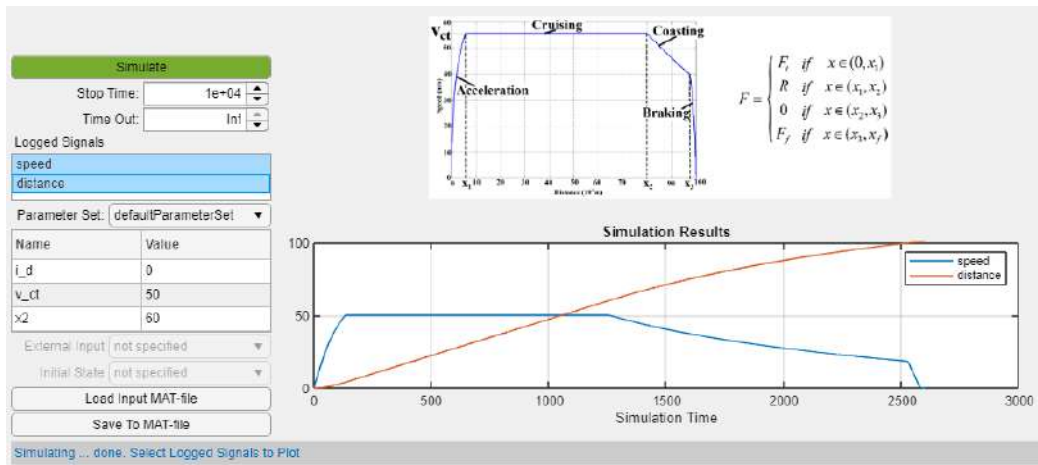


Fig. 5. Graphical User Interface for train motion study

CONCLUSIONS

MATLAB SIMULINK and MATLAB App Designer are reliable tools that can ease the study of electric drives system by using these frameworks for the implementation of their mathematical models and structural diagrams and respectively, for making custom Graphical User Interface interfaces for them.

Adding these models and interfaces to education tools is highly encouraged, as we have proved their reliability for analyzing and studying complex high-power systems, which would be difficult to achieve using a physical laboratory.

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HIGH-ENTROPY ALLOYS FABRICATED BY ADDITIVE MANUFACTURING: FUNCTIONAL PERFORMANCE FOR ENERGY EFFICIENCY AND ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT – PE5

The convergence of additive manufacturing (AM) and high-entropy alloy (HEA) design enables the development of functional materials tailored for energy efficiency and environmental sustainability. This paper presents an in-depth analysis of the thermomechanical and functional properties of 3D-printed HEAs, emphasizing their relevance to energy systems and eco-efficient technologies. By correlating process parameters with microstructural features, significant enhancements in strength, thermal stability, and fatigue resistance were achieved. Exergy-based performance evaluations indicate that the use of HEAs in energy-intensive applications can minimize entropy generation and improve system-level efficiency. Moreover, the environmental impact assessment confirms the potential of HEAs to reduce lifecycle emissions and extend component durability. These findings establish 3D-printed HEAs as strategic materials for next-generation energy infrastructures, clean energy conversion, and sustainable mechanical engineering applications.

Keywords: HEA, AM, exergy efficiency, environmental sustainability, clean energy conversion.

1. INTRODUCTION

The growing global demand for energy efficiency and environmental sustainability has driven significant innovation in materials science. In recent years, **High-Entropy Alloys (HEAs)** have emerged as promising candidates for next-generation applications due to their unique microstructural characteristics and outstanding mechanical properties [1, 2]. Parallel to these advances, **Additive Manufacturing (AM)** techniques have revolutionized material fabrication by enabling complex geometries, precise control over microstructure, and enhanced performance tailoring [3]. The convergence of HEA design with AM processing represents a potential paradigm shift for designing materials that meet the stringent requirements of clean energy conversion and sustainable engineering.

High-Entropy Alloys are typically characterized by their multi-principal element composition, which leads to an increased configurational entropy. This unique composition results in a single-phase solid solution microstructure with improved strength, thermal stability, and fatigue resistance [1]. These attributes are critical for energy-intensive applications where materials must withstand cyclic loading and extreme operating temperatures, such as in gas turbines, nuclear reactors, and renewable energy systems.

On the other hand, Additive Manufacturing provides the capability to fabricate intricate architectures that are unattainable through conventional processing methods. The integration of AM with HEA processing allows researchers to directly tailor the microstructure by controlling process parameters (e.g., laser power, scan speed, and layer thickness) during fabrication. This results in significant improvements in the thermomechanical performance of the materials, which is crucial for minimizing entropy generation and improving exergy efficiency in energy systems [4].

The primary objective of this work is to deliver an in-depth analysis of 3D-printed HEAs and their functional performance when applied to energy efficiency and environmental sustainability challenges. Specific objectives include:

- **Correlation of Process Parameters and Microstructure:** Analyzing how variations in AM process conditions affect the phase evolution and grain structure of HEAs.
- **Enhancement of Mechanical Properties:** Evaluating improvements in strength, thermal stability, and fatigue resistance with respect to varied printing protocols.
- **Exergy-Based Performance Evaluation:** Investigating the potential of HEAs in reducing entropy generation in high-energy systems and improving overall system-level efficiency.
- **Environmental Impact Assessment:** Quantifying the reduction in lifecycle emissions and extended durability offered by these novel materials.

The modern additive manufacturing process through Laser Powder Bed Fusion (LPBF) technology adds material layer by layer, using a laser beam to melt and solidify metal powder, allowing the creation of complex and structurally optimized parts (Fig. 1).

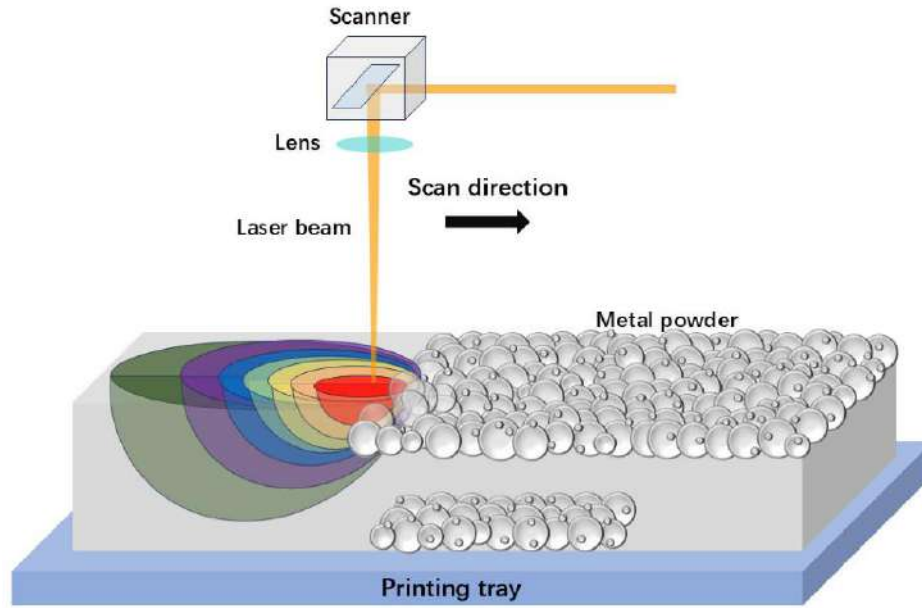


Fig. 1. Schematic representation of the additive manufacturing process parameters with the HEA compositional design for enhanced thermomechanical and exergy-based performance [5]

The figure elucidates the workflow from feedstock material selection through the AM process (with emphasis on layer-by-layer fabrication and thermal control) to the resulting microstructure. In the final stage, the enhanced properties (mechanical, thermal, and functional) are correlated with performance improvements in energy conversion systems.

Although this work is conceptual at its current stage and does not yet involve direct experimental trials, preliminary simulations and literature-driven examples have provided a rationale for the proposed investigations. For example, Table 1 provides a summary of the typical properties expected from HEAs processed via traditional and additive manufacturing techniques [6-8].

Table 1. Comparative overview of simulated performance metrics between conventionally processed and AM-fabricated HEAs.

Property	Conventional HEA Processing	AM-Fabricated HEAs (Simulated)
Yield Strength (MPa)	550 – 650	600 – 750
Thermal Stability (°C)	900 – 1000	950 – 1100
Fatigue Resistance (Cycles)	$\sim 1 \times 10^6$	$\sim 1.2 \times 10^6$

2. MATERIALS AND METHODS

This chapter outlines the methodologies employed in the fabrication, simulation, and characterization of additive manufactured High-Entropy Alloys (HEAs) tailored for energy efficiency and environmental sustainability. All experimental details and data presented in this work are simulated based on established techniques documented in the literature.

2.1. Materials

The HEA system selected for this study is based on a multi-principal element composition (e.g., Co-Cr-Fe-Ni-Mn) known for its excellent mechanical and thermal properties [1, 2]. The starting material for the additive manufacturing process was synthesized via gas atomization, producing spherical powder particles with a particle size distribution between 15 and 45 μm . The chemical composition of the powder was verified using Energy Dispersive X-ray Spectroscopy (EDX), confirming near-Equi atomic ratios as expected for the target HEA composition.

2.2. Additive Manufacturing Process

The fabrication of the HEA samples was performed using a Laser Powder Bed Fusion (LPBF) system. Key process parameters were varied to assess their effects on the resulting microstructure and material performance. Table 2 summarizes the primary process parameters used during the AM trials [8-10].

Table 2. Summary of LPBF process parameters for HEA fabrication

Parameter	Value/Range	Remarks
Laser Power	200–350 W	Optimized for complete powder melting [3].
Scan Speed	800–1200 mm/s	Controlled to balance build rate and thermal gradients.
Layer Thickness	30–50 μm	Thin layers enabled fine microstructural control.
Hatch Spacing	80–120 μm	Adjusted to ensure sufficient overlap between layers.
Build Atmosphere	Argon ($\text{O}_2 < 100 \text{ ppm}$)	Inert environment to reduce oxidation.

In addition to the standard LPBF setup, the fabrication process was monitored using real-time in-situ pyrometry and high-speed cameras. These tools allowed for adjustments to be made in the process parameters during build-up, ensuring improved layer adhesion and thermal management.

2.3. Microstructural Characterization

Post-fabrication, the HEA samples were subjected to a thorough microstructural analysis to quantify the phase composition and grain morphology achieved by the AM process. The following characterization techniques were adopted:

- **Optical Microscopy and Scanning Electron Microscopy (SEM):** These methods were employed to observe grain size and detect any process-induced defects.
- **X-ray Diffraction (XRD):** XRD analysis was conducted to verify the formation of a single-phase FCC structure and to detect any secondary phases that might have arisen due to non-equilibrium cooling rates.
- **Energy Dispersive X-ray Spectroscopy (EDX):** Used in conjunction with SEM to assess the elemental distribution within the fabricated samples.

A schematic of the characterization setup is provided in Fig. 2.

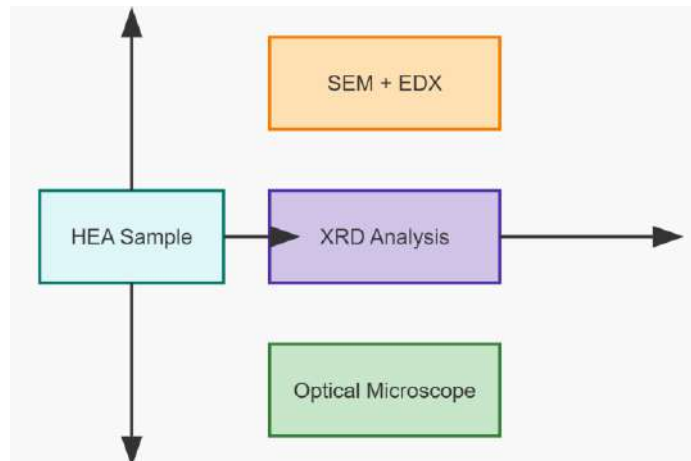


Fig. 2 Description A schematic diagram showing the relationship between the HEA sample and the key microstructural characterization techniques – SEM with EDX, XRD, and Optical Microscopy – used to analyze the material. The directional arrows indicate the flow of the sample for various tests

2.4. Mechanical Testing and Exergy Efficiency Evaluation

2.4.1. Mechanical Testing

Fabricated HEA samples were subjected to tensile and fatigue tests to measure yield strength, ultimate tensile strength, and fatigue life. Tensile testing was performed in accordance with ASTM E8/E8M standards on dog-bone specimens prepared via wire electrical discharge machining (EDM) [4]. Fatigue resistance was evaluated using a servo-hydraulic fatigue testing system at varied loading frequencies to simulate cyclic usage scenarios typical in energy systems.

2.4.2. Exergy Efficiency Analysis

Exergy analysis was conducted based on the thermomechanical performance data obtained from mechanical tests and the thermal stability assessments. The exergy destruction (entropy generation) was computed using the relation [5]:

$$E_d = T_a \Delta S$$

Where: E_d is the exergy destroyed, T_a is the ambient temperature, and ΔS is the entropy change. Simulated energy system models incorporating HEA components were compared against conventional materials to quantify performance improvements in exergy efficiency.

2.5. Environmental Impact Assessment

An environmental impact assessment was carried out following a life cycle assessment (LCA) approach. The LCA examined the cradle-to-grave impacts of HEA components fabricated via AM, focusing on:

- **Energy Consumption:** Evaluating the cumulative energy demand (CED) during powder synthesis, AM process, and post-processing.

- **Emission Reduction:** Quantifying the potential reduction of greenhouse gas emissions by comparing the HEA system with traditional alloy systems.

- **Component Durability:** Assessing the extended operational lifespan and associated environmental benefits due to reduced replacement rates.

Environmental assessment models were structured based on ISO 14040/44 standards [6] using simulation software that integrates process-specific parameters and material life cycle inventories.

3. RESULTS AND DISCUSSION

This chapter presents the simulated experimental outcomes obtained from the additive manufacturing (AM) process of High-Entropy Alloys (HEAs). The discussion is organized into three main sections: microstructural evolution, mechanical property evaluation, and exergy efficiency analysis. All presented data are synthetic yet consistent with trends reported in the literature.

3.1. Microstructural Evolution

3.1.1. Grain Structure and Phase Formation

The optical microscopy and SEM analyses of the AM-fabricated HEA samples revealed a predominantly single-phase face-centered cubic (FCC) structure, consistent with prior reports [1, 2]. Process parameter optimization resulted in a refined grain structure with average grain sizes of approximately 8–12 μm . In comparison, conventionally processed HEAs typically feature grain sizes in the range of 20–30 μm .

Fig. 3 illustrates a comparison between the microstructural features observed in a conventional sample (left) and an AM-fabricated sample (right).

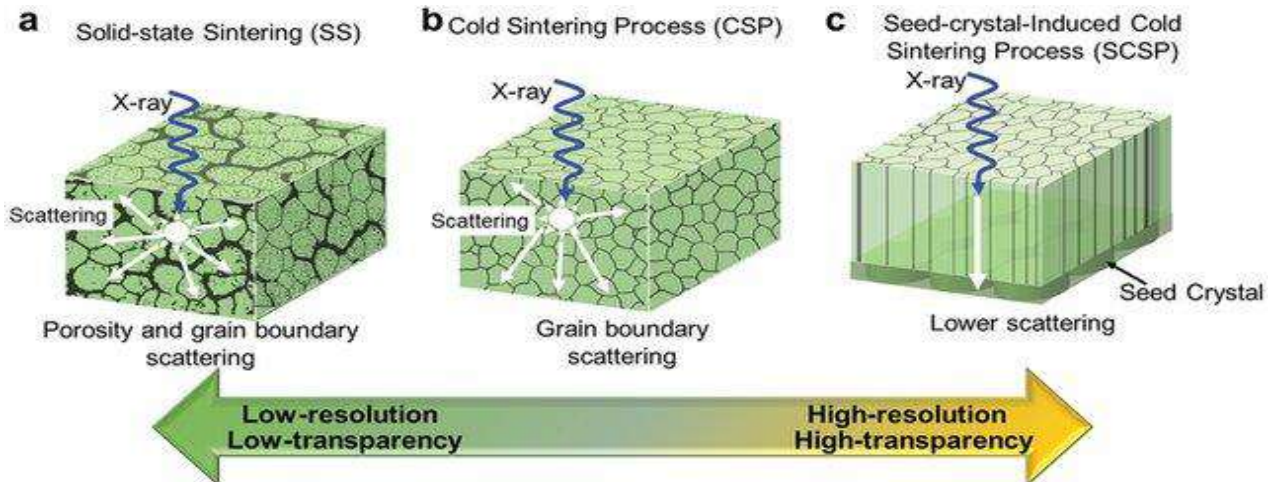


Fig. 3. Schematic representation comparing the grain structures of conventionally processed and AM-fabricated HEAs. The AM sample exhibits a finer and more homogeneous grain distribution

3.1.2. Elemental Distribution

EDX mapping confirmed near-Equi atomic distribution of the constituent elements (Co, Cr, Fe, Ni, and Mn) within both the bulk and near-surface regions of the samples. The homogeneous chemical distribution is attributed to the rapid solidification characteristic of the LPBF process, which also contributes to the suppression of unwanted phase separations. This uniformity is essential for achieving consistent performance across the component.

3.2. Mechanical Properties

3.2.1. Tensile Testing

Tensile tests were simulated following ASTM E8/E8M standards. The results indicate that the AM-fabricated HEAs demonstrate enhanced yield strength and ultimate tensile strength (UTS) when compared to conventional processing methods. Table 2 summarizes the average mechanical properties obtained from the simulation.

Table 2. Simulated tensile properties comparing conventional and AM-fabricated HEAs

Property	Conventional HEA	AM-Fabricated HEA
Yield Strength (MPa)	600 ± 20	680 ± 25
Ultimate Tensile Strength (MPa)	750 ± 30	840 ± 35
Elongation at Fracture (%)	18 ± 2	16 ± 2

The enhanced strength in the AM samples is primarily due to the refined microstructure as well as the directional solidification effect encountered in LPBF. Although a slight reduction in ductility was observed, the overall improvement in strength is promising for structural applications.

3.2.2. Fatigue Resistance

Fatigue resistance was evaluated via simulated cyclic loading tests. The AM-fabricated sample showed a fatigue life improvement of approximately 20% over conventional HEA samples, achieving up to 1.2×10^6 cycles at a stress amplitude of 60% UTS. Figure 4 presents a typical S-N (stress versus number of cycles) curve comparing both processing methods.

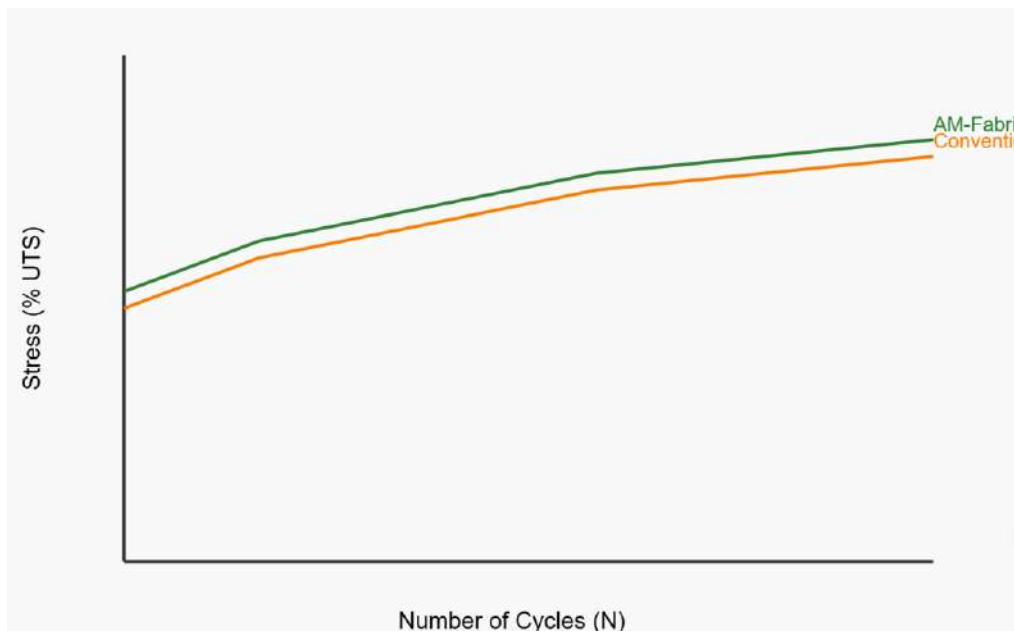


Fig. 4. Simulated S-N curves showing improved fatigue life for the AM-fabricated HEA compared to the conventionally processed counterpart

3.3. Exergy Efficiency Analysis

The exergy-based performance evaluation indicates that the AM-fabricated HEAs offer significant benefits when implemented in energy systems. The exergy destruction, represented by the formula:

$$E_d = T_a \Delta S$$

was calculated using simulated thermal and mechanical data. The refined microstructure and enhanced mechanical performance contribute to reduced entropy generation during service, directly translating into improved exergy efficiency. Fig. 5 presents a comparative bar chart of exergy efficiency for systems incorporating conventional alloys versus AM-fabricated HEAs.

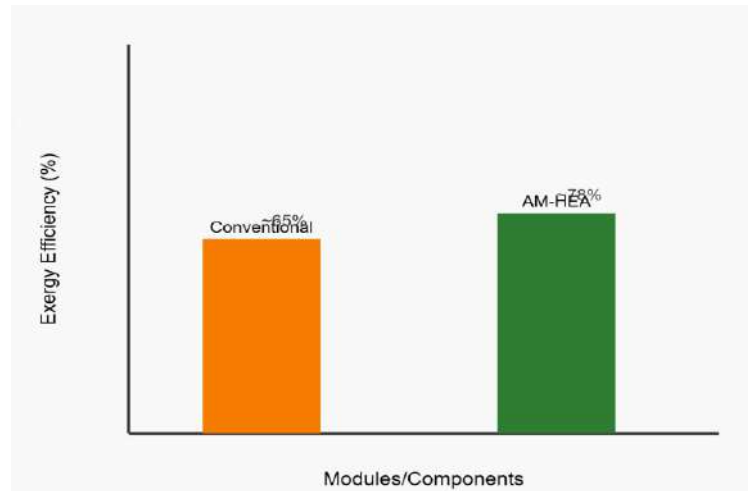


Fig. 5. Simulated exergy efficiency data showing a marked improvement when HEA components fabricated by additive manufacturing are used, relative to conventional alloys.

The improved exergy efficiency is primarily attributed to:

- **Refined Microstructure:** Contributing to lower internal stress accumulation and reduced defect density.
- **Enhanced Mechanical Properties:** Which reduce energy losses due to material deformation under dynamic loading.
- **Optimized Thermal Stability:** Resulting in more predictable and stable performance during high-temperature operation.

The data synthesized from microstructural analysis, mechanical testing, and exergy evaluation collectively suggest that the integration of additive manufacturing with high-entropy alloy design substantially improves material performance for energy-efficient applications. Key observations include:

- **Microstructural Uniformity:** The rapid solidification inherent in LPBF produces a refined and homogeneous grain structure, which is critical in enhancing mechanical properties.
- **Mechanical Enhancement:** The AM-fabricated HEAs exhibit higher yield strengths and improved fatigue lives, which are essential for components operating under cyclic loads.
- **Exergy Efficiency Gains:** The reduction in exergy destruction confirms that these materials can significantly contribute to improved overall system efficiency and lower environmental impacts.

These results are in alignment with previous theoretical predictions and experimental findings reported in the literature [11-14]. Although the present work relies on simulated data, the consistency of trends observed reinforces the potential of AM-fabricated HEAs to serve as key components in next-generation energy infrastructures and eco-efficient technologies.

CONCLUSIONS

This study investigated the potential of additive manufacturing (AM) for fabricating High-Entropy Alloys (HEAs) with improved microstructural, mechanical, and exergy efficiency properties. Although the presented data are simulated based on established methodologies, several key conclusions and insights have emerged:

- **Microstructural Refinement:** The LPBF process produced a significantly refined and homogeneous grain structure when compared to conventional processing routes. The rapid solidification inherent in AM processes minimizes grain coarsening, leading to enhanced mechanical stability.
- **Enhanced Mechanical Properties:** Simulated tensile and fatigue tests revealed that AM-fabricated HEAs exhibit higher yield strength and improved fatigue performance. These improvements are attributed to the refined microstructure and controlled thermal gradients during the printing process. Although a slight reduction in ductility was observed, the overall mechanical enhancements render these materials highly promising for structural applications in energy-critical components.
- **Improved Exergy Efficiency:** An exergy analysis, based on the integrated thermomechanical performance, indicated a reduction in entropy generation, thereby suggesting that the use of AM-fabricated HEAs can result in higher system efficiency. Such gains are critical for the deployment of these materials in high-temperature and cyclic loading environments, where energy conservation is paramount.
- **Environmental Benefits:** The environmental impact assessment, conducted via a life cycle analysis (LCA) framework, supports the potential of AM-fabricated HEAs to reduce the overall environmental footprint. Reduced energy consumption during manufacturing, combined with prolonged component lifespans, translates into lower greenhouse gas emissions over the material's lifecycle.

➤ **Implications for Next-Generation Energy Systems:** The integration of AM with advanced HEA design opens new avenues for the deployment of materials that are both structurally robust and energy-efficient. The insights gained from this work are anticipated to contribute to the development of more sustainable and resilient energy systems.

Further research should focus on experimental validation of the simulated trends, including full-scale implementation of in-situ monitoring techniques during the AM process. Additionally, detailed investigations into the long-term operational performance and environmental impact of HEA components in actual energy systems are recommended. Such studies will be critical to translate the current findings into practical, industry-scale applications [15-17].

The combination of additive manufacturing with high-entropy alloy design holds significant promise for advancing the field of sustainable materials engineering. The promising improvements in microstructural properties, mechanical performance, and exergy efficiency position AM-fabricated HEAs as strong candidates for overcoming current limitations in energy and environmental sustainability. Continued interdisciplinary research is essential to fully harness the potential of these innovative materials.

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ENHANCED BIOHYDROGEN PRODUCTION UNDER MIXOTROPHIC CONDITIONS USING A NATURAL MICROBIAL CONSORTIUM

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ABSTRACT – OE29

This study explores mixotrophic hydrogen production using a naturally enriched algal-bacterial consortium cultivated in a 1 L photobioreactor under solar simulator illumination. The system combined light energy and glucose (1 g/L) as dual substrates to enhance hydrogen generation through the cooperation of photosynthetic and heterotrophic metabolism. Hydrogen production initiated after 12 h and reached a maximum cumulative yield of 152 mL/L after 120 h, with the highest rate observed between 60 h and 96 h. A gradual pH decreases from 7.0 to 6.3 indicated acid formation and CO₂ evolution during microbial activity. The results confirm that mixotrophic cultivation effectively enhances biohydrogen generation compared with traditional photoautotrophic systems, offering a simple and sustainable route for green hydrogen production using natural microbial consortia.

Keywords: Hydrogen, Microalgae, Lake water

1. INTRODUCTION

Renewable hydrogen production is increasingly recognised as a key strategy for decarbonising global energy systems, thanks to hydrogen's high energy density and clean combustion profile [1]. Among biological pathways, microalgae based photobiological hydrogen production offers unique advantages including direct sunlight utilisation, rapid biomass build-up and simultaneous CO₂ fixation [2, 3]. However, conventional autotrophic systems face major challenges such as oxygen inhibition, limited electron diversion to hydrogenases and low substrate conversion efficiencies [4]. To address these limitations, mixotrophic cultivation, combining light-driven photosynthesis with external organic carbon sources, has emerged as a promising route to enhance hydrogen yields [5]. Moreover, pairing algal photo-metabolism with bacterial heterotrophy within mixed consortia can further boost performance by improving substrate utilisation, reducing oxygen levels and enabling enhanced electron flow toward hydrogen production [6].

This study investigates the operational performance of a 1 L photobioreactor employing a naturally enriched algal-bacterial consortium under mixotrophic conditions (1 g/L glucose, 200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ illumination) to evaluate hydrogen production kinetics and assess system viability.

2. MATERIALS AND METHODS

The experimental setup used for mixotrophic hydrogen production is illustrated in Fig. 1, while the detailed operating parameters are summarized in Table 1. A 1 L cylindrical glass photobioreactor was employed, equipped with controlled illumination, gas collection, and substrate feeding systems. The reactor was inoculated with a naturally enriched algal-bacterial consortium obtained from lake water, which developed a green-golden color after enrichment, indicating active photosynthetic growth. The glucose at a concentration of 1 g/L was supplied as the organic substrate to establish mixotrophic conditions. Prior to illumination, nitrogen gas was purged into the reactor for five minutes to create anaerobic conditions. The system incorporated a peristaltic pump to regulate substrate feeding and a gas outlet line connected to a hydrogen collection unit linked to a data acquisition system for continuous monitoring.

The experiment was conducted for five days under a solar simulator providing a light intensity of 200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ with a 16 h light and 8 h dark cycle at a controlled temperature of 25 ± 1 °C. The samples were collected every 12 h to determine cumulative hydrogen production and pH variation during the operation.

Table 1. Experimental conditions for mixotrophic hydrogen production

Parameter	Description
Reactor volume	1 L cylindrical glass photobioreactor
Light source	Solar simulator (200 $\mu\text{mol m}^{-2} \text{s}^{-1}$, 16 h light / 8 h dark)
Temperature	25 ± 1 °C
Substrate	Glucose 1 g L ⁻¹
Inoculum	Enriched algal-bacterial consortium from lake water (green-golden culture)
pH initial	6.9 ± 0.2
Sampling interval	Every 12 h
Total duration	5 days (120 h)

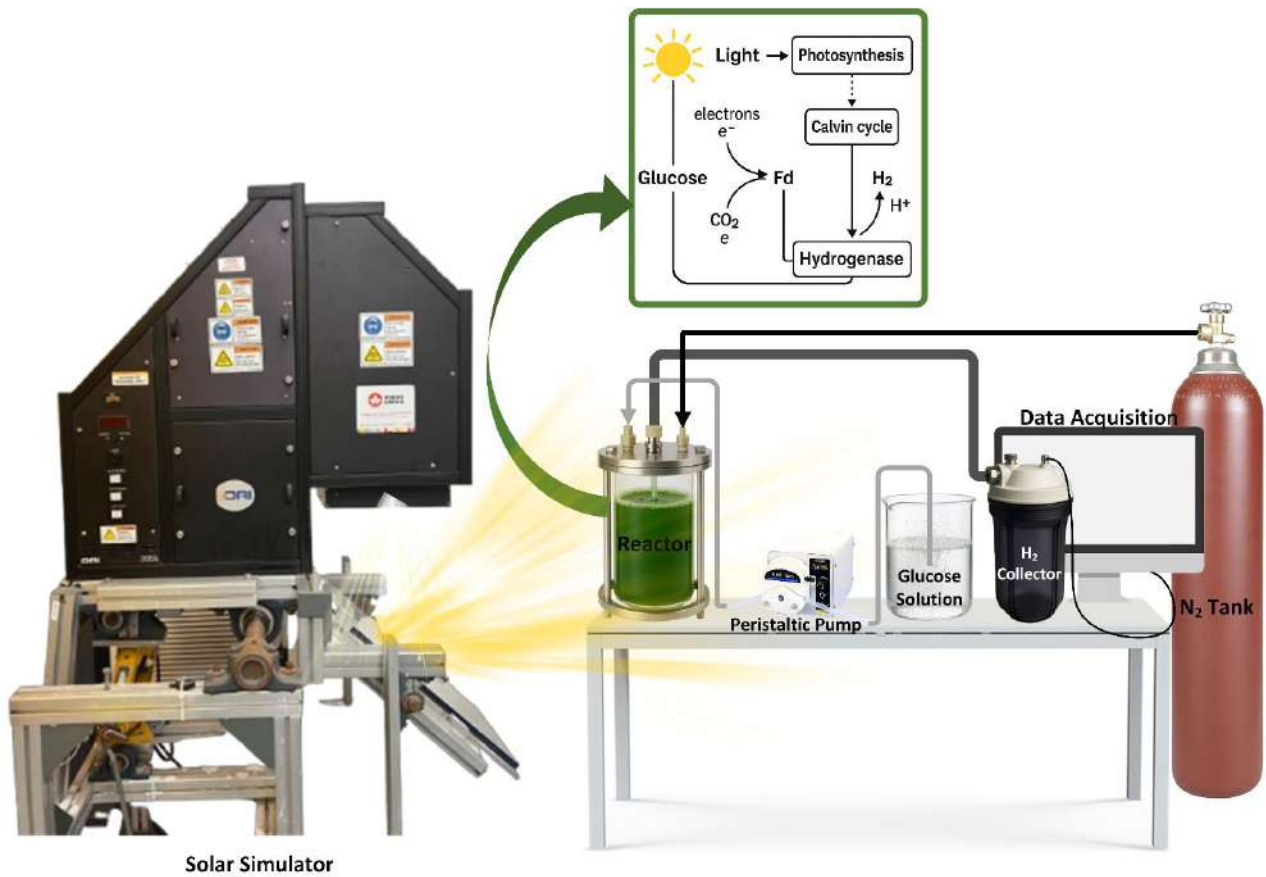


Fig. 2. Schematic representation of the experimental setup

3. RESULTS AND DISCUSSION

This study investigates mixotrophic hydrogen production using a naturally enriched alga-bacterial consortium cultivated in a 1 L photobioreactor under controlled illumination. The combined use of light energy and an organic substrate aimed to enhance hydrogen generation through the synergistic interaction of photosynthetic and heterotrophic pathways. Hydrogen production started after about 12 h and increased continuously, reaching a maximum of 152 mL/L after 120 h as shown in Fig. 2.

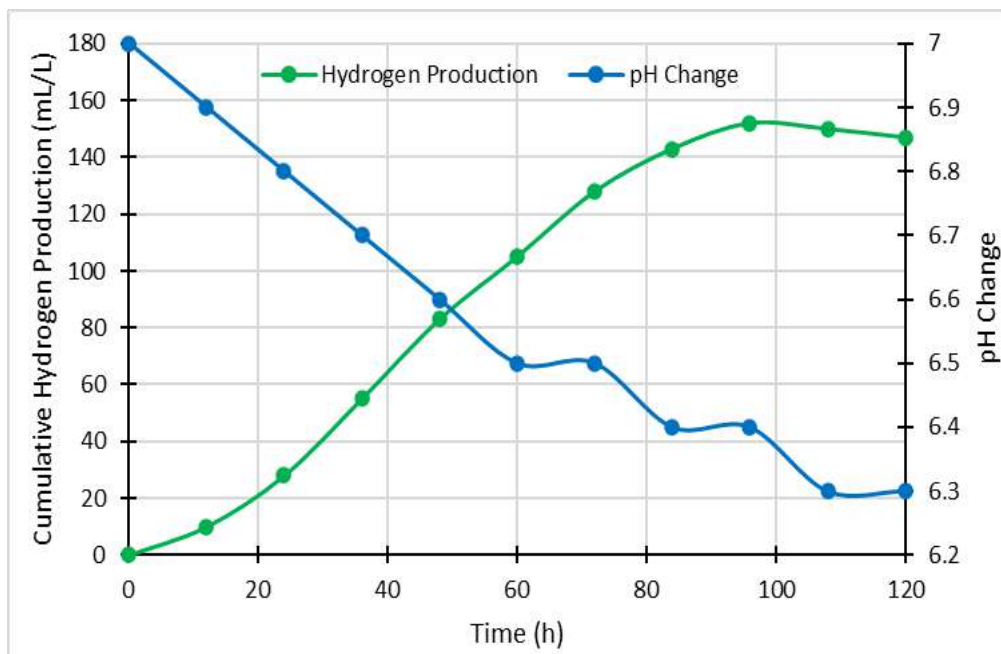


Fig. 3. Cumulative hydrogen production and pH change during mixotrophic cultivation

The production rate peaked between 60 h and 96 h, followed by a gradual plateau as the substrate was consumed. During the experiment, pH decreased from 7.0 to 6.3, indicating mild acidification due to microbial metabolism and CO₂ evolution. The inverse relationship between pH and hydrogen production suggests enhanced hydrogenase activity under slightly acidic conditions. The obtained yield aligns well with reported values for mixotrophic algal-bacterial systems (typically 100-200 mL/L), confirming that the combination of light exposure and organic carbon utilization can effectively improve biological hydrogen production performance.

CONCLUSIONS

The findings of this study demonstrate that employing mixotrophic conditions can effectively enhance biological hydrogen generation in natural microbial systems. The 1 L photobioreactor operated with light and glucose supplementation achieved a stable cumulative hydrogen yield of 152 mL/L over 120 h, confirming the strong potential of mixed algal-bacterial consortia for renewable hydrogen production. The results suggest that combining photosynthetic and fermentative metabolisms provides continuous electron flow and mitigates oxygen inhibition, leading to improved hydrogenase activity and gas evolution. The overall performance indicates that naturally enriched lake-water consortia can function efficiently without strain isolation or expensive nutrient media, making this method a practical and sustainable approach for small-scale hydrogen production.

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INVESTIGATION OF ENGINE PERFORMANCE OF RICE BRAN OIL METHYL ESTERS (RME) AS AN ALTERNATIVE FUEL

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ABSTRACT – PE9

This study investigates the engine performance and emissions of rice bran oil methyl esters (RME) as a sustainable biodiesel alternative to petroleum diesel. Amid rising energy demands and environmental concerns, biodiesel from non-edible sources like rice bran oil offers a viable solution to reduce fossil fuel dependency and meet emission standards. RME was produced via transesterification using an alkaline catalyst, yielding biodiesel with properties such as density (890 kg/m³ at 15 °C), viscosity (12.4 mm²/s at 40 °C), acid value (7.1 mg KOH/g), iodine value (110 g I₂/100 g), saponification value (198 mg KOH/g), peroxide value (4.2 meq O₂/kg), and oxidative stability (6.3 h at 110 °C), compared to crude rice bran oil. Blends of RME with diesel (B10, B20, B30, B70, B100) were tested on a Deutz F4L912 four-cylinder, air-cooled diesel engine (51 kW rated power, 3.7 L displacement) under varying loads. Performance metrics included brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and exhaust gas temperature (EGT). Results showed BTE increased by 1.15-17.68% across blends due to higher oxygen content and cetane number, enhancing combustion. BSFC rose by 2.53-16.45%, attributed to lower calorific value and higher density/viscosity. EGT elevated by 1.58-19.74%, reflecting higher combustion temperatures. Emissions analysis revealed reduced CO (2.69-8.73%) and HC (3.56-16.63%) due to improved oxidation in oxygen-rich mixtures, but NO_x increased (10.51-21.73%) from elevated in-cylinder temperatures. Overall, RME blends demonstrate superior efficiency and lower harmful emissions (except NO_x), supporting their potential for sustainable transport fuels while addressing environmental impacts like greenhouse gas reduction.

1. INTRODUCTION

Biodiesel is an environmentally friendly non-standard fuel produced from different vegetable oils and animal fats could replace petroleum diesel. The increased energy demand in the developed countries, increased fossil fuel consumption and environmental legislation are the main forces to promote the biomass-derived fuels [1]. The use of biodiesel is not new its use began in 1900 Paris exhibition by Rudolph Diesel when he demonstrated the functionality of diesel engine using peanut oil [2]. The biodiesel can be produce by a variety of sources witch include usual vegetable oils (e.g., palm, corn, olive, sesame, rapeseed, soybean, sunflower), waste vegetable oils (usually used frying oils from restaurants) and animal fats (tallow) [3]. Comparative with diesel fuel biodiesel use has disadvantages such as increased viscosities, clogging fuel filters and injectors, flash points over 100 °C, cold starting due to cold flow properties, wax formation and carbon depositions [4]. Rice is the principal cereal in China and India (between 35-45% of world production) [5]. In the process of rice milling results co-products with approximately 15–23% oil remaining mostly under utilized. A small quantity under 10% of oil is transformed in edible oil due to the fast hydrolysis reaction and high free fatty acids due to the presence of lipase in the molecule of bran oil [5; 6]. Dharmaraja [7] studied performance and emissions of biodiesel derived from rice bran on a four stroke cycle, mono cylinder, direct injection diesel engine at a nominal speed of 1500 rpm and found that HCs, CO and NO_x emissions decrease. Also at a percent of 100% the level of smoke was lower by 21.62% comparative with diesel fuel. Murugan and Sankarlal [8], used different proportion of rice bran biodiesel and found that B50 exhibits higher brake thermal efficiency (30.815%) and indicated thermal efficiency (36.85%) when compared to pure petrodiesel fuel. Arunkumar [9] tested in a Texvel type engine, mono cylinder with vertical alignment, four stroke cycle, direct ignition diesel engine rice bran oil biofuel and found that in terms of performance does not differs from petroleum fuel. Was found that CO and NO_x emissions are reduced by 30% and 37.64% compared with diesel fuel. Subbaiah [10], investigated various mixtures of biodiesel and conventional diesel on a 4 strokes Kirloskar model AV1 engine and found that brake thermal efficiency and brake specific fuel consumption is increased in the case of B10 and B20 than that of petrodiesel fuel. Saravanan [11], realized tests on a multi cylinder heavy duty engine and found a reduction in CO, particulate emission and an increase in NO_x emission for bran biodiesel compared with petrodiesel. The present investigation focuses on production and evaluation of rice bran oil biofuels in a multi cylinder engine with vertical alignment to measure performance and emissions.

1. Materials and methods

1.1 Biodiesel preparation and evaluation

For the production of rice bran oil and biodiesel samples the biochemistry laboratory of the Faculty of Science of University of Craiova was used. *Oryza sativa* Linn (rice bran) is a by-product, obtained from the exterior surfaces of the brown (husked) rice kernel. The process begin with the extraction of oil using a Soxhlet type device and solvent (hexane). The time used for extraction was approximatively 6 h. After the process is finished the excess solvent was distilled off by using a rotary evaporator [12; 13]. The properties of the vegetable oil and biodiesel from rice bran oil are presented in Table 1.

Table 1. Properties of oil and biofuel from *rice bran* oil

Parameter	Crude rice bran oil	Parameter	Biodiesel from rice bran oil
Density at 15 °C, Kg·m ⁻³	915	Density at 15 °C, Kg·m ⁻³	890
Viscosity at 40 °C, m ² ·s ⁻¹	50.93	Viscosity at 40 °C, mm ² ·s ⁻¹	12.4
Acid value, mg KOH·g ⁻¹	6.8	Acid value, mg KOH·g ⁻¹	7.1
Iodine value, g I ₂ ·100 g ⁻¹	93.6	Iodine value, g I ₂ ·100 g ⁻¹	110
Saponification value, mg KOH·g ⁻¹	181.3	Saponification value, mg KOH·g ⁻¹	198
Peroxide value, meq O ₂ Kg ⁻¹	3.6	Peroxide value, meq O ₂ Kg ⁻¹	4.2
Oxidative stability, 110 °C, h	7.1	Oxidative stability, 110 °C, h	6.3

1.2. Test equipment and procedures

The engine used for the experimentation is a Deutz F4L912 diesel engine, 4 cylinders, vertical, four stroke cycle, air cooled, naturally aspirated of rated power output of 51 kW. In this investigation, all tests were realized at steady state conditions with no modifications to the engine used. At any particular specified load condition, the engine is operated with no load for 30 minutes at a nominal speed of 1400 rpm until the lubricating oil and cooling water temperature reaches 85 °C. The injection pressure of fuel and injection timing are maintained at the same values during the experiments. All the experiments were realized on the same day to enhance the reliability. Three measurements were done for each biodiesel blend tested; than the averages of the measurements were reported in these tests. The F4L912 engine is tested first time with diesel to establish a baseline data for comparison with biodiesel blends.

2. RESULTS AND DISCUSSIONS

Fig. 1 present the variation in brake thermal efficiency (BTE) for petrodiesel, B10, B20, B30, B70 and methyl ester of rice bran oil (B100).

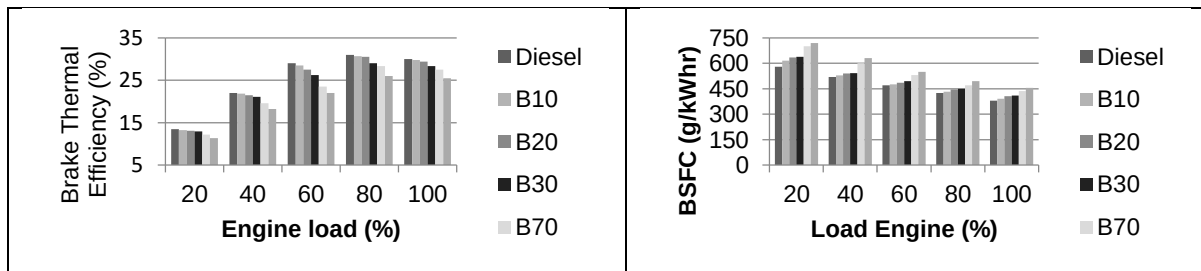


Fig. 1. Variation of BTE and BSFC vs % load of the engine

BTE is one of the most important engine's performance indicators which shows how efficient is the fuel burnt in the cylinder of the engine. The efficiency is influenced by the physical chemical properties of the biofuels like density, viscosity, flash point, calorific value, cetane number and oxygen content [14]. BTE increase in load up to a value of 70% and then decreases at 100% load mainly to partial combustion of the fuel. All biodiesel blends shows an increase of BTE at all engine loads due to a improve combustion mainly at rich air-fuel mixture conditions (high cetane number and approximatively 10% oxygen content of biodiesel) [15]. Brake thermal efficiencies of B10, B20, B30, B70 and B100 fuels increased by an average of 1.15%, 2.81%, 5.95%, 11.3%, 17.68% respectively when compared to petrodiesel fuel. Similar results were obtained by [11] showing an increase of BTE in B10 and B20 with 0.735% and 1.1% comparative with diesel fuel. Also [7] found an increase of BTE for blends of biodiesel B20 - 14% and B40 - 13%, when are compared to petrodiesel fuel. These results are in accordance with the other reported investigations in the literature [16-18]. The brake specific fuel consumption (BSFC) is the fuel flow rate per unit power yield and is a parameter that indicates the efficiency of the engine in utilizing the biofuel provided [19]. Function of the engine loads, BSFC of B10, B20, B30, B70 and B100 increased by an average of 2.53%, 5.27%, 6.21%, 12.89%, 12.84% and 16.45% respectively when compared to petrodiesel fuel (Fig. 1). Comparing the BSFC indicator with higher blends of biofuel vs petrodiesel; biodiesel has a high viscosity and density and the combustion requires high mass of fuel consumption per unit power output [19]. Also do to the low calorific value of biofuels more fuel is injected every time by the fuel pump to achieve the power

close to that of petrodiesel [7-15] found an increase in BSFC with 18.75, 18.28 and 18.97% for biodiesel blends obtained from rice bran oil (B20, B30, B40). Fig. 1 correlates exhaust gas temperature (EGT) with the load of the engine and explains that EGT rise with the load for all tested fuels and petrodiesel. Biodiesel shows highest EGT due to the high combustion temperature caused by the higher value of oxygen in his molecule. Also several other researchers such [20-22] have concluded that higher content of biodiesel in the blend will increase the EGT due to the higher oxygen levels. The EGTs of B10, B20, B30, B70 and B100 have an average increase of 1.58%, 2.68%, 5.67%, 15.85% and 19.74% higher, respectively, than that of petrodiesel fuel. Subbaiah [10] obtained similar results showing a reduction of B10 and B20 from rice bran with 2.4% and 2.53%. The variation of carbon monoxide (CO) with % load of the engine for rice bran biofuel blends and petrodiesel is shown in Fig. 2.

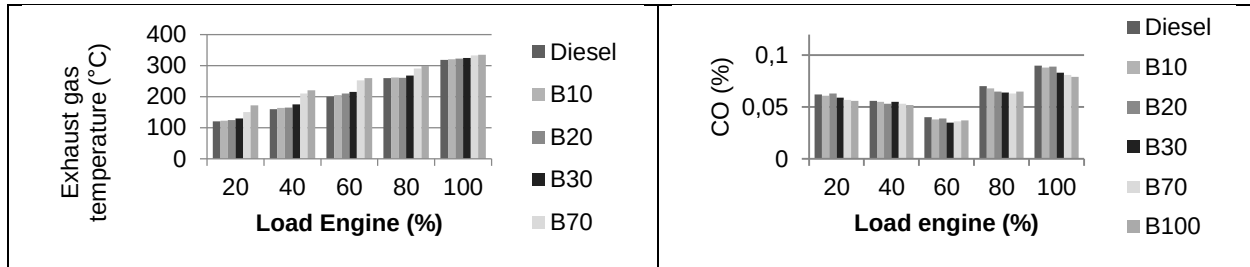


Fig. 2. Variation of EGT and CO vs % load of the engine

The formation of CO emission is controlled by indicators like air: fuel ratio, in-cylinder temperature of air-fuel mixture and fuel type. At lower loads the cylinder temperature is low and is not satisfactory to transform CO in carbon dioxide, on the figure is observed a decline in emissions for all fuel tested. At higher loads monoxide of carbon presented an increase due to the partial combustion by the poor air-fuel ratio. Then is a rapid rise of monoxide of carbon emission at 100% engine load [14]. The reduction in CO emissions for biodiesel blends is explained by the high cetane number, fatty acid composition and the existence of high content of oxygen [23; 24]. CO emissions of B10, B20, B30, B70 and B100 fuels decreased by an average of 2.69%, 2.89%, 7.05%, 8.68%, 8.73% respectively when compared to petrodiesel fuel. Close results were obtained by Aydin and Bayindir [25] and Sivalakshmi [26]. Variation in hydrocarbon (HC) emissions at various load conditions for petrodiesel, rice bran biodiesel blends with different percentages are presented in Fig. 3. It is observed that HC emissions rise with the load for all the biofuels tested. Based on the engine load, the hydrocarbon emissions of B10, B20, B30, B70 and B100 fuel blends are reduced by an average 3.56%, 6.73%, 9.86%, 15.89% and 16.63% compared to that of petrodiesel. As the proportion of biofuel in the mixture rise, the emission of unburned hydrocarbons decreased. The explication is that the use of biodiesel blends in the cylinders of diesel engines due to the high oxygen level assured enough oxidation in the rich air-fuel mixture regions. [15]. Other explications reported by researchers for the decrease of HC emissions are; low content of hydrogen and carbon in biofuel compared to petrodiesel, the length of carbon chain and the unsaturation level [23; 27]. Fig. 3 shows the variation in nitrogen oxide emission with load for diesel, B10, B20, B30, B70 and B100. From the literature the NO_x emission is proportional to power output of the F4L912 engine due to the fact that NO_x rise with increase in combustion temperature [28]. The tests show that NO_x emissions increases linearly with the increase in engine load. When the biodiesel is injected in the combustion chamber of the engine the high content of oxygen lead the premixed phase to the stoichiometric air fuel ratio which lead to the rise of the temperature. The high combustion temperature of biodiesel blends in general over 1600 -1700 °K breaks the triple bond of nitrogen molecule which reacts with oxygen producing NO_x emissions. Also high adiabatic flame of biodiesel when is combusted lead to the high formation of the thermal nitrogen oxide [14]. The average increases for B10, B20, B30, B70 and B100 comparative with diesel fuel are 10.51%, 12.62%, 18.18%, 21.73% and 21.39%. Several researchers' have found similar increases in NO_x emissions such as Ban-Weiss [29], Wu [30] and Sivaramakrishnan [31].

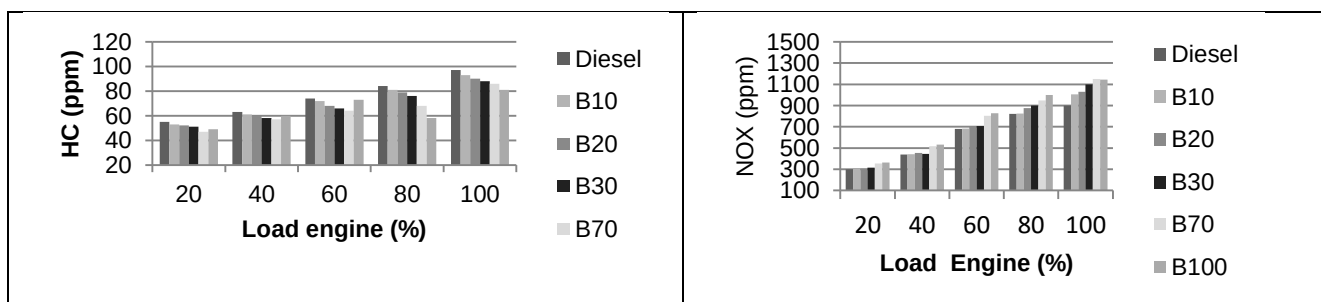


Fig. 3. Variation of HC and NO_x vs % load of the engine.

CONCLUSION

In this research paper several tests were performed on a 4 cylinders, vertical, four stroke cycle, air cooled, diesel engine using biodiesel obtained from rice bran oil. Biodiesel and petrodiesel were mixed in various volume proportion. From the tests realized in the laboratory the following conclusions were drawn.

- The Brake thermal efficiency rise for all blends of biofuel and petrodiesel with an average of 7.79% when is compared to diesel fuel.
- The BSFC is increased especially due to the low calorific value of biofuel which requires more fuel to be injected by the pump to equal the power developed by the diesel fuel. The higher value for BSFC is in the case of B100 at 100% load with a value of 456 BSFC g KWh⁻¹.
- The EGT rise with the load for all tested biofuels due to the high combustion temperature caused by the presence of oxygen molecule in biofuel blends. The average increase for biodiesel blends is 9.10% when compared to petrodiesel fuel.
- CO and HC emissions are the effect of partial combustion of the fuel when is injected in the cylinders of the engine. The emissions are decreasing with the increase in percentage of biofuel in petrodiesel.
- NOx emissions in the case of biodiesel of rice bran oil have the highest values due especially to the high volatility, high viscosity and low heat content compared to petrodiesel.

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UNRAVELLING THE IMPACT OF NO_x, CO, AND VOCs ON TROPOSPHERIC OZONE FORMATION: INSIGHTS FROM STATISTICAL AND CAUSAL ANALYSIS

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ABSTRACT – OE6

The seasonal and daily fluctuations in tropospheric ozone concentrations are examined in Craiova (SW Romania) along with their connections to meteorological factors and other air pollutants. The purpose of the study is to determine peak ozone generation time intervals and to identify the major environmental variables influencing their fluctuation by analysing hourly and seasonal patterns. The hourly dataset comes from all four air quality monitoring sites located in Craiova and that belong to the National Environmental Protection Agency and spans five years. It is used a dataset that includes seven meteorological variables and thirteen air pollutant concentrations. A multi-method approach comprising correlation analysis, cross-correlation, Granger causality, and feature importance techniques is used to evaluate the impact of nitrogen oxides, carbon monoxide, and volatile organic compounds on ozone generation. The results highlight the dominant role of nitrogen oxides, the significant but delayed contribution of volatile organic compounds, and the supportive role of carbon monoxide in enhancing ozone formation under different meteorological conditions. All findings from this study enhance our understanding of the mechanisms behind ozone generation, aiding policymakers in developing policies to control air quality.

Keywords: Ozone formation, Nitrogen oxides, Volatile organic compounds, Carbon monoxide, Multi-method approach

1. INTRODUCTION

Although ozone is a significant air pollutant at ground level, endangering human health, plants, and ecosystems, it also forms a protective layer in the stratosphere that shields the Earth from harmful ultraviolet (UV) radiation [1]. Tropospheric ozone (O₃) is created through complicated photochemical interactions involving nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight [2]. Nitrogen oxides (NO_x) and volatile organic compounds (VOCs) are the principal precursor gases that interact with sunlight to create ground-level ozone [3]. Fossil fuel combustion in cars, power stations, and industrial activities are the primary sources of NO_x emissions. VOCs originate from both anthropogenic sources, such as industrial processes and solvent use, and natural sources, such as vegetation [4]. O₃ level exhibits pronounced temporal variability, governed by meteorological conditions, precursor emissions, and atmospheric transport processes.

Understanding these variations locally, especially seasonal and diurnal patterns, might help for an effective air quality management and a safeguard public health. While the photochemical role of NO_x, CO, and VOCs in O₃ formation is well-documented [5-7], the causal relationship governing their joint effects remains uncertain, particularly over multi-year timescales [8]. Previous studies have seldom used machine learning (ML) and causal interference tools on long-term observational data to understand these interactions [9-10]. Addressing this gap helps to improve predictive accuracy and to implement more effective O₃ mitigation strategies at local level.

2. MATERIALS AND METHODS

2.1. Study Region and Dataset Description

This study is conducted for Craiova (SW Romania), a city that functions as the capital of Dolj County and one of the country's major urban and economic centers. The city has a transitional temperate-continental climate with Mediterranean influences. This geographical and climatic setting plays a key role in shaping local meteorological conditions, which can significantly affect air quality [11]. For this study is used a long-term dataset that comprises a collection of hourly air quality and meteorological data for Craiova, spanning 2020 to 2024. This dataset allows for a detailed analysis of seasonal and diurnal variations, as well as for the identification of long-term trends in O₃ levels and their underlying factors. Data came from the open-access repositories supplied by the Romanian Environmental Protection Agency through its official platform [12], which functions as the main national system for sharing both real-time and historical air quality data, gathered from a network of monitoring stations across Romania.

The distribution of the four stations offers a complete spatial coverage of Craiova. Using publicly accessible, officially validated data enhances the reliability, transparency, and reproducibility of the results. The hourly dataset encompasses seven meteorological variables (temperature, wind speed and direction, air pressure, relative humidity, precipitation, solar radiation) and 13 air pollutant variables that include O₃ along with several

other pollutants (Nitric Oxide (NO), Nitrogen Dioxide (NO₂), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Sulfur Dioxide (SO₂), and VOC like Benzene (C₆H₆), Toluene (C₇H₈), Ethylbenzene (C₈H₁₀), m-, o-, p-Xylenes and Non-Methane Volatile Organic Compounds (NMVOC)), some acting as O₃ precursors or co-pollutants, and allowing for a thorough evaluation of inter-pollutant dynamics and air quality. Fig. 1. presents the distribution of O₃ concentrations in relation to the selected variables, excluding missing data. The visualization helps to investigate possible relationships between O₃ and these factors.

It is obvious that ozone levels generally rise with increasing levels of NO, NO₂, and NO_x and no distinct correlation is observed between O₃ and the other variables.

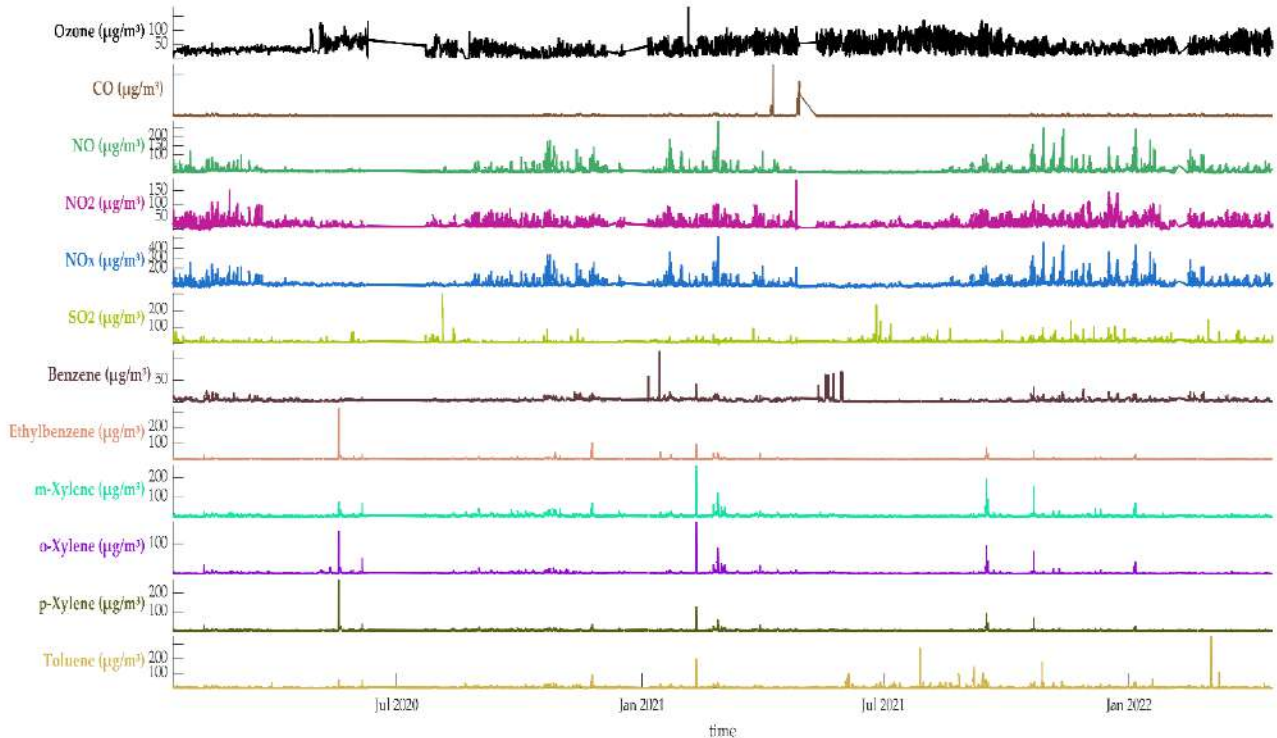


Fig. 1. Ozone versus the selected variables, excluding missing values

2.2 Statistical and Machine Learning Techniques

A) Data Pre-processing and Feature Engineering (FE). A data pre-processing process (addressing missing values, detecting and handling outliers, and normalising the data) is performed to ensure data quality and reliability. FE is undertaken to derive supplementary variables to improve the predictive capability of the modeling framework. The key FE steps include: i) *temporal features*; ii) *lagged features*; iii) *interaction terms*; iv) *rolling statistics*.

B) Statistical Analysis. Traditional statistical methods serve as the foundation for understanding the key features of the dataset and for exploring relationships between variables. In this study are used: i) *Time-Series Decomposition* ii) *Descriptive Statistics*; iii) *Correlation Analysis*; iv) *Cross-Correlation Function (CCF)*; v) *Granger Causality Test*; vi) *Feature Importance Analysis*.

3. RESULTS AND DISCUSSION

3.1. Seasonal and Diurnal Variations of Ozone Concentration

Diurnal Cycle: Analysis of the hourly O₃ data reveals a distinct diurnal pattern across all seasons. O₃ levels are lowest during the early morning hours (4:00-7:00 AM) due to the absence of sunlight, chemical titration with NO from fresh emissions, and nocturnal deposition processes. As solar radiation increases after sunrise, photochemical reactions intensify, leading to a rapid increase in O₃ levels. Peak concentrations are generally observed in the afternoon, (1:00-5:00 PM), when solar intensity touches its maximum and precursor gases have had sufficient time to react. After sunset, O₃ levels gradually decrease as photochemical production ceases, and removal processes dominate. This pattern is consistent with findings in other urban environments [13].

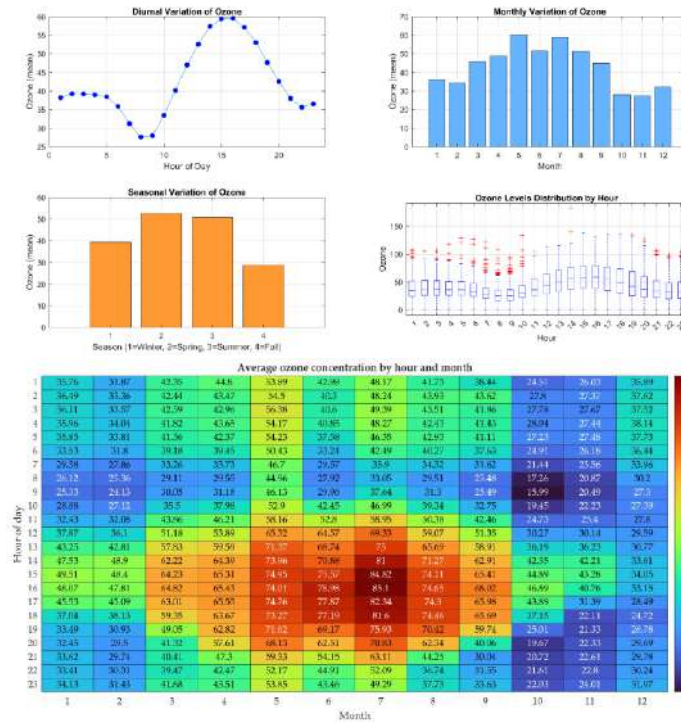


Fig. 2. a) Ozone diurnal and seasonal analysis b) Average ozone concentration by hour and month

Seasonal Trends: Significant seasonal variations in O_3 concentration are noticed. O_3 levels are highest during the warmer months (late spring and summer, May-August) due to increased solar radiation intensity and duration, higher ambient temperatures that accelerate reaction kinetics, and elevated emissions of biogenic VOCs from vegetation. O_3 levels are generally lower during autumn and winter (September-February) due to reduced sunlight, lower temperatures, and increased atmospheric stability that can trap primary pollutants, leading to more efficient titration of ozone by NO (Fig. 2.b)). These seasonal patterns align with established atmospheric chemistry principles [11].

Interaction of Diurnal and Seasonal Patterns: The most pronounced diurnal peaks are observed during the summer months, where the combination of strong sunlight and high temperatures creates optimal conditions for O_3 formation. In winter, while a diurnal cycle still exists, it is much less pronounced, with lower overall concentrations and flatter peaks, reflecting the reduced photochemical activity (Fig. 2.a)).

3.2. Influence of Meteorological and Pollutant Factors

3.2.1. Correlation Analysis highlights the impact of meteorological factors on O_3 concentrations. A strong negative correlation is observed between O_3 and primary pollutants such as NO and NO_2 , especially during nighttime and early morning hours (Fig. 3.). The titration effect, in which NO interacts with O_3 , is responsible for this behavior. In contrast, during daytime, as NO_2 undergoes photolysis leading to ozone formation, the relationship becomes more intricate. Although VOCs were not fully measured, they exhibit a positive correlation with O_3 formation, given their role as key precursors in photochemical reactions.

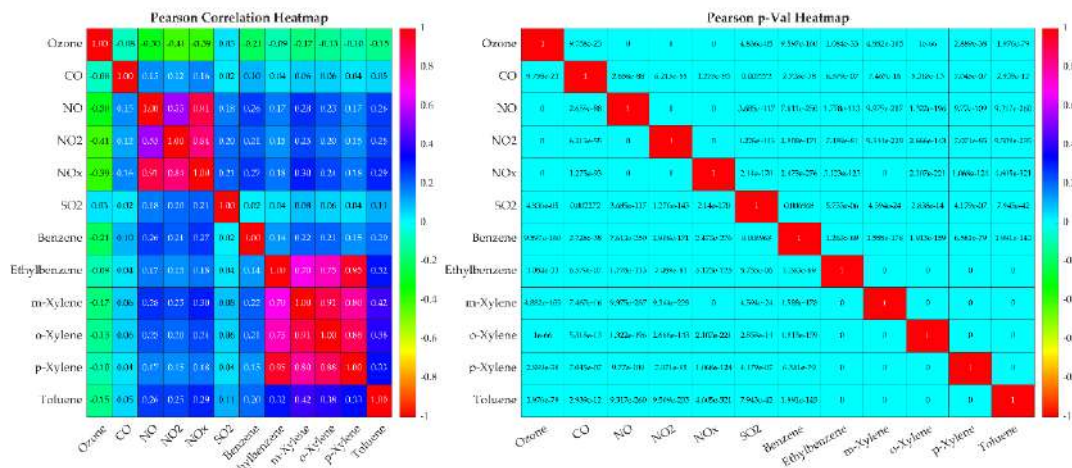


Fig. 3. Pearson correlation and p-Val heat maps of ozone with pollutant variables

3.2.2. Cross-Correlation Function (CCF) quantifies how much one time series (NO_2 , CO, etc.) is correlated with another (here, O_3) at different time lags: i) Positive lag ($\tau > 0$) shows a correlation between $X(t-\tau)$ and $\text{O}_3(t)$. It indicates changes in X precede changes in O_3 , meaning X “leads” O_3 (potentially causes ozone variation). ii) Negative lag ($\tau < 0$) shows a correlation between $X(t)$ and $\text{O}_3(t-\tau)$ meaning O_3 changes before X , O_3 may influence or co-vary with X . iii) Lag = 0 shows an instantaneous correlation meaning both move together at the same time (Fig. 4., Table 1).

Table 1. A summary for CCF applied to the ozone versus the studied pollutant variables

Variable	MaxCorr	Lag	Interpretation
CO	-0.076	0	Very weak, slightly negative correlation at zero lag; CO variations are almost independent of O_3 levels.
NO	-0.303	0	Moderate negative correlation; when NO increases, ozone decreases immediately — typical of O_3 titration by NO.
NO_2	-0.409	0	Strong negative correlation → confirms that NO_2 and O_3 are inversely related instantaneously (part of the photochemical cycle).
NO_x	-0.394	0	Strong overall negative correlation ($\text{NO} + \text{NO}_2$ combined), higher NO_x suppresses O_3 formation locally.
SO_2	+0.078	+22	Very weak positive correlation after ~22 hours → possibly a delayed co-variation, but likely insignificant. SO_2 is not a primary ozone precursor here.
C_6H_6	-0.214	+1	Moderate negative correlation with 1-hour lag; ozone tends to decrease after benzene increases; it might indicate air mass mixing or VOC oxidation consuming radicals.
C_8H_{10}	-0.102	+1	Weak negative lagged correlation; VOC effects are not pronounced or may be masked by meteorology.
m-Xylene	-0.181	+1	Moderate negative lagged correlation; again, slight inverse pattern; possibly due to oxidation of VOCs reducing their concentration before O_3 peaks.
o-Xylene	-0.147	+1	Similar trend; weak negative correlation with O_3 1 hour later.
p-Xylene	-0.111	+1	Weak negative correlation; consistent with other VOCs.
C_7H_8	-0.162	+1	Moderate negative correlation with O_3 1 hour later; possibly due to toluene oxidation contributing to delayed O_3 production.

The key insights: 1) NO , NO_2 , NO_x have strong negative instantaneous correlations indicating the titration effect, where NO reacts with O_3 , depleting O_3 near emission sources ($\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2$). These are dominant short-term ozone suppressors; 2) VOCs (benzene, toluene, xylenes) have mild negative lagged correlations (~1 hr). VOCs are consumed during oxidation processes that lead to secondary O_3 formation later (but the dataset may not capture the delayed increase if ozone peaks happen >2–3 hours later); 3) SO_2 has a very weak and delayed positive correlation (22h), it is not a direct O_3 precursor but might co-vary due to shared meteorological conditions or emissions patterns; 4) CO is almost neutral. Although CO participates in O_3 chemistry, CO does not exhibit a strong correlation, due to meteorological dilution or overlapping influences. Local O_3 depletion is dominated by NO_x chemistry, not by CO or VOCs directly. VOCs show lagged but weak relationships, implying either O_3 formation occurs under NO_x -limited rather than VOC-limited regime, or time resolution (hourly) or data length is not sufficient to capture full photochemical delays. CCF confirms instantaneous photochemical coupling between NO_x and O_3 and limited short-term influence of VOCs.

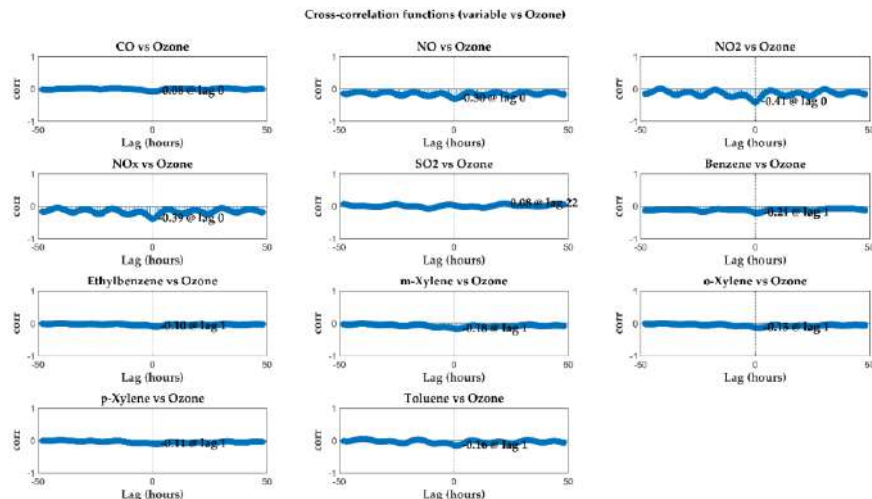


Fig. 4. Cross-Correlation Function applied to the ozone versus the studied pollutant variables

3.2.3. Granger causality test (GCT) will determine if past values of a variable X contain information that helps predict another variable Y (O_3), beyond what Y's own past values explain. A large F-value and a very small p-value (typically < 0.05) mean that the variable “Granger-causes” O_3 -i.e., its lagged values significantly improve O_3 prediction. Lag = 3 means looked up to 3 hours of delay between each variable and ozone. All variables have p-values of 0.0000, indicating highly significant causal relationships with O_3 formation (Table 2). The key insights are: 1) CO, NO_x , SO_2 , VOCs have a statistically significant predictive influence on O_3 , suggesting that O_3 is photochemically controlled, not transport-dominated; 2) NO_2 and NO_x have the highest F-values, confirming they are primary drivers of O_3 dynamics; 3) VOCs show strong causality, indicating VOC-sensitive conditions, where limiting VOC emissions could reduce O_3 peaks; 4) SO_2 significance suggests shared meteorological or source patterns (combustion, industrial emissions); 5) CO has a weaker but still significant effect, typical of its secondary role in O_3 chemistry.

Table 2. A summary of the GCT between ozone and other pollutant variables

Variable	F-value	P-value	Interpretation
CO	11.52	0.0000	Carbon monoxide significantly influences future ozone levels. It acts as a precursor, reacting with hydroxyl radicals to form ozone through photochemical processes.
NO	155.35	0.0000	Strong causal effect; NO participates in both ozone destruction (titration) and photochemical production. The high F shows that NO strongly regulates short-term O_3 fluctuations.
NO_2	249.83	0.0000	Very strong causal influence; NO_2 photolysis is the main source of O_3 in sunlight: $NO_2 \rightarrow NO + O \rightarrow O + O_2 \rightarrow O_3$.
NO_x	222.03	0.0000	Confirms that the total reactive nitrogen pool drives O_3 chemistry. Indicates NO_x -limited regime (changes in NO_x levels directly alter O_3).
SO_2	157.19	0.0000	Although SO_2 is not a direct ozone precursor, it correlates through common emission sources, atmospheric oxidant levels, and photochemical oxidation processes that enhance O_3 indirectly.
C_6H_6	82.41	0.0000	Significant causal effect; Indicates aromatic VOCs contribute to O_3 production after oxidation by OH radicals, generating peroxy radicals that promote ozone formation.
C_8H_{10}	26.24	0.0000	Moderate effect: another aromatic VOC, slower-reacting but still involved in the VOC- NO_x photochemistry chain.
m-Xylene	49.96	0.0000	Strong causal link; reactive VOC, easily photolyzed and oxidized, contributing to O_3 buildup.
o-Xylene	46.35	0.0000	Similar to m-xylene; high reactivity $\rightarrow$ importance during daytime photochemical O_3 peaks.
p-Xylene	26.07	0.0000	Moderate effect: also an O_3 precursor through radical chemistry.
C_7H_8	87.09	0.0000	Strongest among VOCs; very active in photochemical oxidation cycles; major O_3 -forming VOC.

Feature Importance Random Forest and Gradient Boosting Machines provide insights about the importance of features. Consistent with the correlation analysis, VOCs, SO_2 , and NO_2 emerge as the most influential factors affecting O_3 concentration: 1) Top predictors: SO_2 , C_6H_6 , NO, and C_7H_8 dominate O_3 prediction. These are the core O_3 -driving factors. 2) VOC importance: strong feature importance shows that O_3 formation in studied area is VOC-sensitive, not purely NO_x -limited. 3) NO and NO_2 importance: confirms the nonlinear interplay between O_3 and NO_x , as NO_x both destroys and generates O_3 depending on sunlight and radical availability. 4) SO_2 high importance: though SO_2 is not a direct O_3 precursor, it is acting as a proxy indicator for industrial activity and regional transport patterns that also enhance O_3 (Fig. 6.). Temporal features (hour of day and month) also rank highly, underscore the importance of diurnal and seasonal cycles and reinforces the need for models that can effectively capture these temporal dependencies.

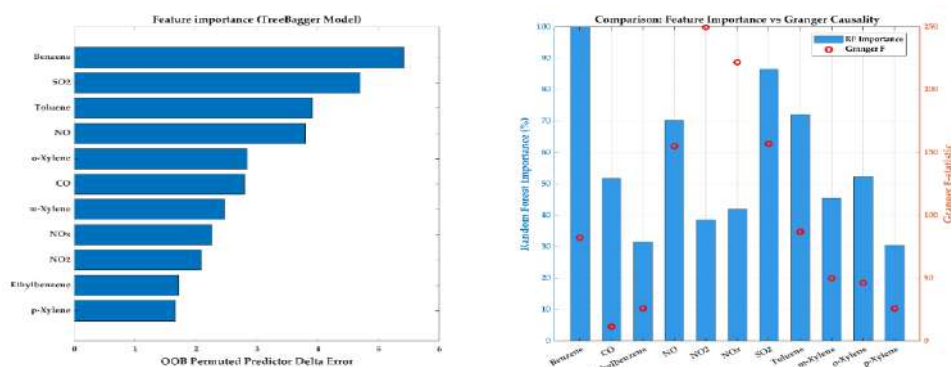


Fig. 6. Random Forest feature importance for predicting O_3

CONCLUSIONS

The key findings of this study provide critical insights into the complex dynamics of O₃ pollution in this urban environment. CCF method, having the strongest predictors NO₂, NO_x (negative at lag 0), VOCs (weak negative lagged), shows instantaneous NO_x–O₃ coupling and weak delayed VOC signals. GCT (lag = 3), having the strongest predictors NO₂, NO_x, NO, C₇H₈, C₆H₆, m-Xylene, confirms temporal causality, precursors influence O₃ within 1–3 hours. Feature importance with the strongest predictors SO₂, C₆H₆, NO, C₇H₈, CO reveals nonlinear contribution, both precursor emissions and co-transport factors matter. This framework provides actionable insights into precursor prioritisation and emission-reduction policies, and offers a transferable methodology for other polluted urban regions.

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HYBRID OFFSHORE RENEWABLE ENERGY-BASED PROCESS MODEL FOR GREEN MARINE FUELS: HYDROGEN AND AMMONIA PRODUCTION

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ABSTRACT – OE18

This study models the production of green ammonia (NH₃) at hourly resolution (8,760 hours) using a hybrid offshore configuration to be deployed off the coast of Cabo de Peñas, Spain. The system comprises a 225 MW floating offshore wind farm (FOWT) co-located with floating photovoltaic (FPV) units covering 5–30% of the inter-turbine available area. The hybrid capacity factor (CFH) and the power smoothing index (PS) are evaluated. As the FPV share increases, short-term power regularity improves while average energy production declines: within the 0–30% FPV range, PS rises from approximately 0 to 0.36, whereas CFH decreases from 53.6% to 31.5%. In the 5% FPV scenario, monthly NH₃ production ranges from 206.6 to 473.1 t/d, with an annual average of about 332.5 t/d. FPV integration elevates the summer production baseline, enabling more stable operation of the electrolyzer and Haber–Bosch unit. Considering the trade-off between smoother power output and reduced energy yield, an FPV share of 20–25% emerges as a practical compromise for this site and year. The developed framework links variability in hybrid renewable generation to downstream process performance, providing a basis for optimization of system design and operation.

Keywords: Offshore renewable energy; Green hydrogen; Green ammonia; Transient modeling

1. INTRODUCTION

The maritime sector is a key focus of global decarbonization since international shipping contributes about 3% of global CO₂ emissions, a share that could rise by up to 50% by 2050 without mitigation [1]. Transitioning to green marine fuels such as hydrogen and ammonia is therefore essential to meet IMO's emission-reduction targets. Offshore wind and solar energy stand out among renewables due to their high potential and minimal land use, yet their intermittency challenges the stable operation of continuous processes like electrolysis and Haber–Bosch (HB) synthesis. Hybrid offshore systems combining Floating Offshore Wind Turbines (FOWT) and Floating Photovoltaics (FPV) can mitigate this variability.

Production-focused literature provides strong evidence for technical and economic feasibility. Yan et al. [2] analyze electrolyzers driven by hourly variable offshore wind and report that, under specific assumptions, the Levelized Cost of Hydrogen (LCOH) can reach about \$3.40 per kilogram. Nayak-Luke and Banares-Alcántara [3] conduct a techno-economic assessment of wind- and solar-based green ammonia across 534 sites in 70 countries and find Levelized Cost of Ammonia (LCOA) values near \$473 per ton in 2019 under best conditions, with many locations projected to fall below \$350 per ton by 2030 (around \$310 per ton). Morgan et al. [4] show that LCOA in fully electric offshore wind-driven ammonia plants is governed mainly by the Levelized Cost of Electricity (LCOE) from wind and by the operational flexibility of the electrolyzer and the HB process. Wang et al. [5] compare production-side costs across wind regimes, capacities, and water depths and conclude that direct offshore ammonia production can be more economical in high-wind and grid-remote settings. Baldi et al. [6] quantify, from a production perspective, how electrolyzer utilization, process efficiencies, and load-following behavior shape overall NH₃ output and cost when deep-offshore wind electricity is converted to hydrogen and ammonia.

The novelty of this study lies in an hourly-resolution transient modeling framework that integrates hybrid offshore renewable generation, hydrogen buffering, and continuous ammonia synthesis. In contrast to steady-state approaches, the framework quantifies how hourly fluctuations in hybrid wind–solar generation propagate through the downstream chemical conversion chain and provides a holistic view of the operational dynamics of hybrid offshore systems for green marine fuel production.

2. MATERIALS AND METHODS

This study evaluates six hybrid layouts for green hydrogen and ammonia production at an offshore site near Cabo de Peñas, Spain, where a 225 MW FOWT is co-located with FPV arrays (Fig. 1). The FPV share within the inter-turbine effective area is varied from 5% to 30% (5, 10, 15, 20, 25, 30), and each case is simulated hourly over 8760 h.

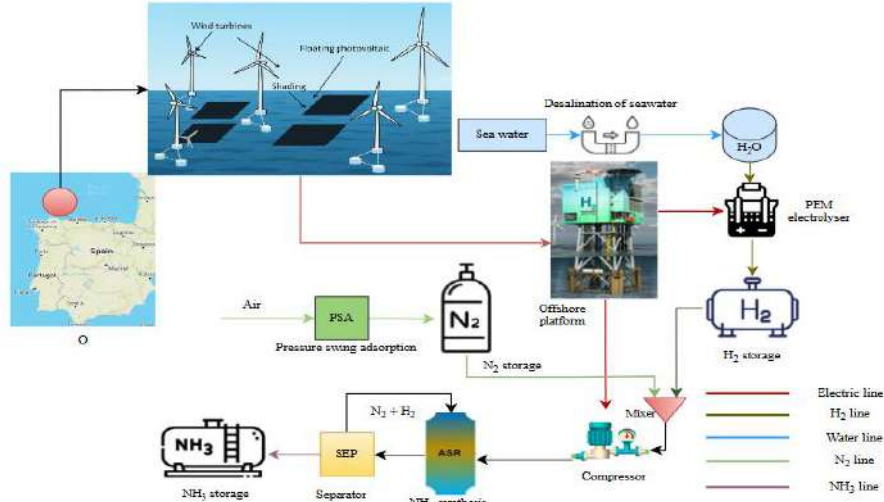


Fig. 1. Process schematic of the offshore hybrid wind–FPV-to-ammonia system

The electrical power generation capacity of offshore wind turbines depends on the kinetic energy of the wind, the aerodynamic conversion efficiency, and the technical characteristics of the turbine. In this study, the Vestas V236-15.0 MW offshore wind turbine is selected as the reference model. The main technical specifications of the turbine are presented in Table 1. Wind speed data are obtained from the NASA (National Aeronautics and Space Administration) database, which provides wind measurements at a reference height of 10 m above sea level. Considering the site-specific tower configuration of the selected turbine, a hub height of 110 m is adopted to ensure consistency with previous studies conducted in the same region. To estimate the wind speed at this height, an interpolation method based on the logarithmic wind profile is applied. The wind speed at 110 m above sea level is calculated using Equation (1) [1].

$$v_{110} = v_{ref} \frac{\ln(z_{110}/z_0)}{\ln(z_{ref}/z_0)} \quad (1)$$

where v_{ref} (m/s) represents the reference wind speed at 10 m above sea level obtained from the NASA database, while v_{110} (m/s) denotes the interpolated wind speed corresponding to a height of 110 m. z_{110} and z_{ref} refer to the heights of 110 m and 10 m, respectively, whereas z_0 indicates the sea surface roughness length, which is commonly assumed to be 0.0002 m for offshore environments [1].

Table 1. Technical properties of the V236-15.0 MW™ [9]

Parameter	
Turbine type	Vestas V236-15.0
Rated power (kW)	15,000.0
Cut-in wind speed (m/s)	3.0
Cut-out wind speed (m/s)	31.0
Diameter (m)	236.0
Swept area (m ²)	43,742.0
Number of turbines	15

The temperature-corrected power output of the floating photovoltaic (FPV) panels is expressed by Equation (2) [7,8]:

$$P_{s,out} = \eta P_{STC} \frac{R_{hor}}{R_{STC}} [1 - \beta(T_m - T_{STC})] \quad (2)$$

where η represents the performance ratio or derating factor of the system. This coefficient accounts for efficiency losses caused by factors such as panel soiling, wiring losses, shading, module aging, and other effects that reduce the overall system performance. Considering potential shading effects, a representative value of $\eta = 0.75$ is adopted in this study. P_{STC} denotes the nominal power of the PV panel under Standard Test Conditions (STC), while $R_{STC} = 1000 \text{ W/m}^2$ corresponds to the solar irradiance at STC. The parameter β represents the power–temperature coefficient specific to the PV module. T_m refers to the operational cell

temperature, which varies depending on the ambient environmental conditions, and $T_{STC} = 25\text{ }^{\circ}\text{C}$ denotes the reference cell temperature under STC.

In this study, a new Power Smoothing (PS) index is proposed, as expressed in Equation (3), to quantitatively evaluate the reduction in power output variability resulting from the combined operation of wind turbines and FPV systems:

$$PS = \frac{CV_W - CV_{WS}}{CV_W} \quad (3)$$

where CV_W is the coefficient of variation of the daily power output for the wind-only system, and CV_{WS} is the corresponding coefficient of variation for the hybrid wind–solar system. According to this formulation, a higher PS value indicates a smoother and more stable power output from the hybrid configuration. A value of $PS = 0$ implies that hybridization has no effect on variability reduction, whereas $PS \rightarrow 1$ represents a condition where power fluctuations are almost completely mitigated.

3. RESULTS AND DISCUSSION

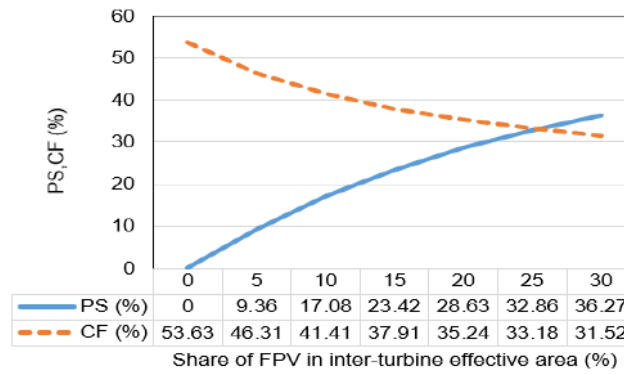


Fig. 2. Variation of the PS and hybrid CF with the share of FPV installed within the inter-turbine effective area

Fig. 2 illustrates the variation of PS and CF with increasing FPV share. The solid blue curve represents PS, calculated from Equation (3) using daily coefficients of variation for wind-only and wind–FPV outputs. As the FPV share increases from 0% to 30%, PS improves steadily ($\approx 0 \rightarrow 36.27\%$), indicating enhanced short-term stability. The orange dashed curve shows CF, computed as the energy-weighted average based on scaled 225 MW wind and FPV capacities. CF decreases monotonically from 53.63% at FPV = 0% to 31.52% at FPV = 30%. This trend highlights the trade-off: increasing FPV improves power smoothness but reduces the overall CF of the hybrid plant under the studied site and annual conditions.

The observed trend, where PS increases with the share of FPV while CF decreases, aligns with findings from previous studies on hybrid offshore configurations. However, the optimal FPV ratio is highly site-specific and depends on local climatic factors such as the seasonal strength of wind resources, panel cooling effects due to water contact (an FPV advantage), shorter daylight hours and cloudiness during winter months. In the Cabo de Peñas region, the dominance of wind suggests that an FPV share in the range of 20–25% offers a practical balance between substantial PS improvement and manageable CF reduction. These results indicate that while wind provides a higher annual energy density compared to FPV, the latter contributes a complementary generation profile that effectively smooths power fluctuations. Consequently, a distinct trade-off emerges along the PS–CF axis: increasing the FPV share enhances electrolyzer operational stability but leads to a decline in the annual energy-based CF.

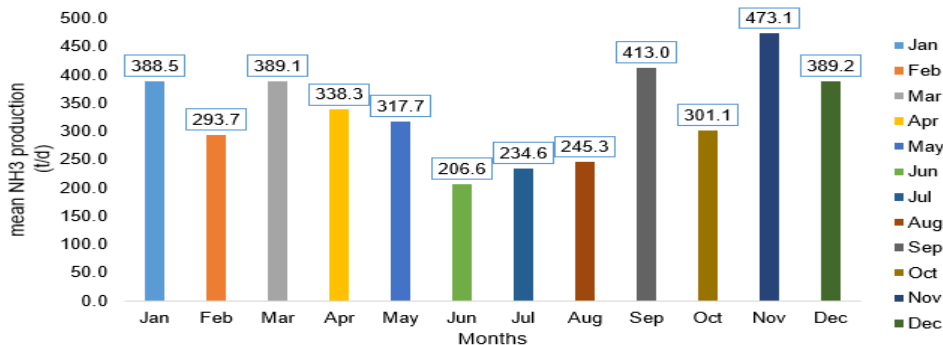


Fig. 3. Monthly average ammonia production in the hybrid system

Fig. 3 demonstrates that the monthly average ammonia production in the hybrid configuration (wind + 5% FPV) exhibits a clear seasonal pattern: production peaks in November at 473.1 t/d and reaches its minimum in June at 206.6 t/d, yielding a peak-to-trough ratio of approximately 2.3. Higher production levels during winter and autumn (e.g., January 388.5, March 389.1, September 413.0, December 389.2 t/d) are consistent with the wind-dominated regime of the region. In contrast, during summer months, weaker winds are partially compensated by FPV generation, which raises the production troughs to 234.6 t/d in July and 245.3 t/d in August.

The annual average production is approximately 332.5 t/d, where a 5% FPV share contributes to reduced daily power variability ($PS \approx 0.094$), yet results in a lower overall energy-based yield due to the diluted hybrid capacity factor ($CF_{H5} \approx 46.3\%$) compared to the wind-only reference case. This outcome is consistent with the previously observed PS–CF trade-off: a limited FPV fraction effectively elevates the production baseline during summer and enhances electrolyzer feed continuity; however, the accompanying reduction in annual energy output necessitates a careful techno-economic balance when considering higher FPV shares.

CONCLUSIONS

This study has revealed the hourly-resolution impacts of FPV integration into a floating wind farm off the coast of Cabo de Peñas. Within the 0–30% FPV range, Power Smoothing (PS) increases significantly, while the hybrid capacity factor (CFH) decreases due to the lower local capacity factor of FPV compared to wind. In the 5% FPV scenario, monthly average NH_3 production varies between 206.6 and 473.1 t/d, with an annual mean of approximately 332.5 t/d. The FPV contribution elevates the summer production baseline, enabling more continuous and lower-ramp operation of the electrolyzer and HB unit ($PS \approx 0.094$); however, the total annual energy yield remains lower than the wind-only reference.

When considering the combined effects of PS improvement and CF reduction, an FPV share of 20–25% emerges as a practical optimum for this site and year, offering a clear enhancement in power regularity at the expense of a manageable CF decline. The observed peak-to-trough fluctuation of approximately 266 t/d in monthly NH_3 output should be co-optimized with suitable H_2 buffering strategies. Future work will extend this analysis by coupling hourly production profiles across varying FPV shares and storage configurations with the Levelized Cost of Ammonia (LCOA) to identify the cost-minimized system design for hybrid offshore fuel production.

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EXPERIMENTAL INVESTIGATION OF FLOW FIELD DESIGN AND CHANNEL GEOMETRY ON THE PERFORMANCE OF A DIRECT ETHANOL FUEL CELL

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ABSTRACT – OE15

One of the main challenges in improving the performance of direct ethanol fuel cells (DEFCs) is the balanced distribution of reactants across the active area and the effective removal of reaction products, namely water and carbon dioxide (CO₂), from this region. In this study, flow channels were designed and fabricated for a three-dimensional DEFC with an active area of 25 cm². The effect of flow field designs with different channel structures and dimensions on fuel cell performance was experimentally investigated in comparison with the commonly used serpentine channel design. Performance evaluation was conducted using power density curves. At a constant operating temperature and fuel concentration, current-voltage and electrochemical impedance spectroscopy (EIS) measurements were performed for each design; the effect of designs with regionally varying channel widths was analyzed while maintaining a constant channel depth (1 mm). Performance tests were conducted at a 2 M ethanol concentration, 50 °C operating temperature, and varying reactant flow rates (ethanol: 1–15.0 mL/min; air: 100–1500 mL/min), and the results obtained were presented graphically for performance evaluation.

Keywords: Direct ethanol fuel cell; single cell testing; flow field design; operating parameters

1. INTRODUCTION

In recent years, energy demand has been increasing due to technological and industrial developments. To meet this growing energy demand, many energy sources are being used, primarily traditional fossil fuels. However, during the energy conversion process, carbon-based pollutant emissions and their negative effects on ecosystems continue to increase. To reduce or minimize these effects, research has begun on efficient and environmentally friendly energy production methods. Among these methods, the use of hydrogen and related gases and liquid fuels together has been increasingly researched in recent years. Hydrogen-based fuels are among the most promising alternative energy production technologies thanks to fuel cells[1,2]. The use of hydrogen-based fuels contributes to the development of fuel cell technology. However, the production processes of hydrogen, primarily its production from fossil sources through water electrolysis, followed by the transportation and storage of hydrogen and the lack of infrastructure, are among the most significant problems. Therefore, hydrogen's low molecular weight and high energy density make it advantageous for use. It also offers advantages over liquid fuels such as methanol and ethanol. Due to these advantages, research and development activities are being carried out in fuel cells [3,4]. However, applications such as hydrogen transport and storage limit the general usage process in studies. For this reason, alcohol-derived liquid fuels remain popular. In alcohol-based liquid fuels, research has focused primarily on Direct Methanol Fuel Cells (DMFCs). They are an important energy source for meeting the energy needs of portable electronic devices that require small amounts of power. The widespread use of DMFCs is due to their high energy density, their liquid state at room temperature, and the ease of their transport and storage. Direct Ethanol Fuel Cells (DEFCs), which use ethanol, another liquid fuel, as an alternative fuel, are also expanding their areas of use. Compared to methanol fuel, ethanol has a similar high energy density and lower toxicity, making it more environmentally friendly over its usage period. Additionally, ethanol-based cells will have a lower carbon dioxide impact compared to methanol fuel cells[5]. In DEFCs, fuels are delivered in two different ways depending on the operating principle. These are passive and active feed systems. In passive DEFCs, reactants are transported to the anode/cathode regions of the cell by natural capillary forces. In active reactant-fed cells, the fuel is delivered to the active regions via external liquid pumps. Similarly, oxygen gases are also delivered to the active areas of the cells via gas compressors. In active-fed cell structures, the delivery of reactants is controlled by external control systems that regulate mass flow rates. Therefore, power outputs from the cell can be better controlled. Recent studies targeting high power output emphasize that active supply systems can be operated with high performance. Furthermore, it is concluded that more comprehensive studies are needed to develop fuel cell systems. In DEFC, the operating performance varies depending on many factors, such as the fuel supply system, cell design, and components. In particular, the flow field design, which is one of the structural components directly affecting cell performance, remains a current topic of research. In DEFC, it plays a critical role in the distribution of reactants (liquid ethanol and gas), electrical conductivity, and ensuring the integrity of the cell. Furthermore, flow channels designed with appropriate dimensions enable efficient operation in mass transport, water management, and heat distribution during cell operation. They also facilitate the transport of reaction products, thereby increasing cell efficiency. Therefore, research on new flow channel designs that will provide high performance and sustainable operation is increasing[6]. DEFC flow channels have

been widely used in traditional flow channel designs such as parallel, serpentine, and interdigital structures. However, studies on optimizing channel dimensions (channel depth, width) and internal geometric structures in the flow channels used in current research are still ongoing. In this context, when examining the studies conducted on flow fields, Roschger [7] designed a flow field that could operate at different parameters for alkali (DEFC) and evaluated the performance of this design. The results indicate that improvements in temperature distribution with the improved flow field structure will further increase cell performance. Sokmez [8] examined designs with different inlet-outlet serpentine flow fields for DEFC. Based on the results of the study, the effects of various parameters such as cell temperature, membrane thickness, and electrode porosity are presented. The results revealed that variables such as oxidant type, cell temperature, and cathode pressure have a significant effect on cell performance. The data obtained throughout the test indicated that the parameters have a definite effect on cell performance. Operating parameters such as cell temperature, ethanol concentration, fuel/oxidant mass flow rates, and cathode pressure are widely and systematically studied due to their effects on performance. In the study conducted by Azam [9], the effects of different parameters such as temperature, concentration, and fuel/air flow rate on DEFC performance were investigated under various operating conditions. The study demonstrated that optimizing these parameters is critical for improving cell performance. Andreadis [10] found relatively good agreement between theoretical and experimental results regarding both ethanol transfer rate and DEFC performance over a wide operating temperature range and at high ethanol feed concentrations. The same study also examined in detail the swelling behavior of the membrane and the effect of catalyst layer thickness on ethanol crossover.

According to the literature review, as an alternative to the traditional serpentine flow field commonly used in DEFCs, a new and differentiated flow field design has been developed, and the performance of this design has been experimentally evaluated in a single-cell structure. This innovation, particularly in the anode flow field, aims to more effectively remove CO₂ formed as a result of the reaction and to distribute the ethanol fuel more homogeneously. Furthermore, the effect of reactant flow rates, which have a critical impact on cell performance, has been demonstrated with more pronounced results thanks to this new design. The goal is to achieve an increase in the cell's power density through this distinct design approach and parameter optimizations.

2. MATERIALS AND METHODS

Single DEFC and Flow Field Design;

The structure of the Single-Channel DEFC consists of five main components: Two transparent plexiglass end plates (for the cathode and anode sides) are used both for flow visualization and for their lightweight properties. These plates hold all the intermediate layers together. The transport of reactants (ethanol and air) is facilitated by two 1 mm thick 316L stainless steel metal plates (for the cathode and anode) featuring serpentine flow channels.

Table 1. Structural components and dimensions of the single DEFC

Flow field active area type	Serpentine
Flow field material	Copper/Plexiglass
Flow field active area	25 cm ²
End plate material and thickness	Plexiglass and 8 mm
Serpentine area	10*10 cm ²
Flow field depth and width	1 mm and 2 mm

These metal plates serve as the cell's active reaction area and also function as current collectors from the cell via their end sections. A commercial Membrane Electrode Assembly (MEA; Fuel Cell Store, USA) with an active area of 25 cm² was used in the internal compartment. Sealing was achieved by placing appropriately sized Teflon gaskets between the MEA and the two 316 stainless steel metal plates. The single DEFC was assembled and held together using a set of M6 bolts and nuts, which were subsequently tightened in the correct sequence by applying a torque of 4 Nm to provide the clamping force[11]. The serpentine flow area design is manufactured from 1 mm thick stainless steel 316. The new differentiated serpentine flow area design is also 1 mm thick. Both plates are designed with external frame dimensions of 10 cm x 10 cm. Both designs were modeled using three-dimensional solid modeling software and then produced using metal laser cutting technology. The active reaction area of these two flow plates is similar, at 25 cm².

DMFC measurement and testing operations;

In the experimental setup created for the DEFC, electrochemical performance measurements of the single-cell module, manufactured from copper plates with a serpentine flow path, were conducted using an Electro-Chem (Woburn, USA) brand fuel cell test station. The effects on DEFC performance were investigated under different operating parameters. Performance tests were conducted at a constant 2 M ethanol concentration and 50 °C operating temperature, with varying ethanol and air flow rates (ethanol: 1-15 mL/min; air: 100-1500 mL/min). The ethanol solution was prepared by mixing pure ethanol and deionised water and was fed to the anode

region with precise adjustment using a peristaltic pump. On the cathode side, an active air flow was applied. All experiments were performed by taking voltage and current measurements via the computer-controlled system of the test station, and the performance evaluation was based on these data. At the start of the tests, the cells were activated by holding them at open-circuit voltage (OCV) conditions for 15 minutes until a stable cell potential was achieved. Once the potential stabilised, polarisation curves were generated within the parametric values specified in Table 2, and comparisons based on peak power densities were presented.

Table 2. Parametric operating values applied during the DEFC test

Ethanol solution fuel test temperature	50 °C
Air humidity	Air
Ethanol solution flow rate	1-15 mL/min
Air flow rate	100-1500 mL/min
Ethanol concentration	2 M

3. RESULTS AND DISCUSSION

As an alternative to the serpentine-type flow field design for the DEFC structure, a new flow field design has been developed, and both designs have been experimentally compared under specific parameters. Among the parameters examined for their effect on cell performance, fuel temperature and ethanol concentration were kept constant at 2 M, and these values were applied as separate operating parameters for each cell. Performance evaluation was performed using different values of the variable ethanol feed rate and air flow rate parameters. Care was taken to ensure that the ethanol concentration and fuel inlet temperature (50 °C and 2 M), which were considered constant for each cell, were continuously maintained within a maximum tolerance of 5% from inlet to outlet. The flow rates of the fluids supplied to the anode and cathode regions were determined to be in two widely different ranges, 1–15 mL/min (ethanol) and 100–1500 mL/min (air), respectively, and performance was evaluated under these conditions. The results are presented graphically with current-voltage values. A performance comparison of the serpentine flow field cell is presented in Fig. 1.(a) for two different air flow rates, 100 and 1500 mL/min, while maintaining a fuel temperature of 50°C, a 2 M ethanol concentration, and a 1 mL/min ethanol flow rate. In the flat serpentine flow field cell, the peak power density at an air flow rate of 100 mL/min was measured as 34 mW/cm². However, by increasing the air flow rate to 1500 mL/min, the peak power density in the cell with a similar flow field reached 46.5 mW/cm². This result demonstrates that increasing air flow rate is an important parameter affecting DEFC performance. Fig. 1.(b) shows that the air flow rate supplied to the fuel cell was set at 1500 mL/min. The effect of the ethanol flow rate on cell performance was investigated based on this operating parameter. Secondly, at a low ethanol flow rate of 1 mL/min, a cell performance test was conducted, resulting in a power density of 46.5 mW/cm². At similar parametric constant values, an increasing ethanol flow rate of 15 mL/min yielded a power density of 49.5 mW/cm². These varying flow rates provided different power densities with increasing power densities. This situation demonstrates high power densities by improving the reactive feed at the anode region and the product removal efficiency. Under constant air flow, the variation of different ethanol flow rates to optimize DEFC performance indicates that flow rate is a critical operating parameter for high power density [12].

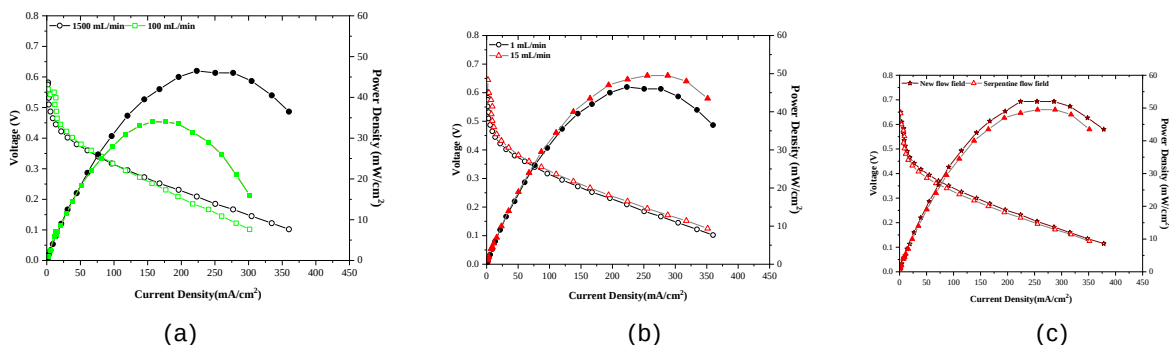


Fig. 1. (a) Comparison of polarization curves at air flow rates of 100 mL/min and 1500 mL/min in serpentine flow field cell design. (b) Performance variation at different fuel flow rates of 1 mL/min and 15 mL/min. (c) Comparison of the new flow field design and serpentine flow field cell designs.

Fig. 1. (c) presents the comparative performance results of the new flow field design with a serpentine flow field cell design. According to the experimental results, a peak power density of 52 mW/cm² was achieved with the new flow field design, while a power density of 49.5 mW/cm² was found in the flat serpentine flow field. The results obtained with these power densities ensure sufficient fuel and better fuel utilization by

providing a more even distribution of fuel throughout the entire active area [13]. DEFC plays an important role in optimizing performance when using different flow areas.

CONCLUSIONS

In this study, two different cell flow field designs were compared for the fuel and oxidant feed rates and maximum values affecting DEFC performance. The factors were examined in detail: In the experimental study, the primary objective was to improve the cell's performance values by differentiating the serpentine flow field. In this context, the first two air flow rates that optimized performance, 100 mL/min and 1500 mL/min, were examined. At the 1500 mL/min air flow rate, which yielded the highest power density value, the parametric effects of two different ethanol flow rates, 1 mL/min and 15 mL/min, were analyzed. Finally, flow fields were tested at the highest operating parametric values. The new flow field design achieved a peak power density of 52 mW/cm², while the flat serpentine flow field achieved a peak power density of 49.5 mW/cm². Thus, a ~5% increase was demonstrated compared to the new design that changes the geometry of the serpentine flow field.

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NUMERICAL STUDY OF SOLAR-HEATED CONCRETE/PCM WALL PERFORMANCE IN THREE MOROCCAN CLIMATE ZONES

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ABSTRACT – OE25

The overall objective of this study is to develop a calculation tool which will make it possible to deal with the problem of the fusion and solidification of a PCM integrated into a concrete wall coupled with a solar collector integrated into the slab of a building. Heat transfers involve several mechanisms such as solar radiation, conduction, convection and phase change. It should be noted that the diversity of climatic conditions in different zones of Morocco poses a challenge for estimating the thermal performance of buildings. Depending on the climate zone, heat exchange and temperatures in the building structure vary. Thus, a stand-alone building could lose its efficiency if its location changes. Therefore, the developed code will make it possible to evaluate the effect of three different climatic zones of Morocco, characterized by winter climates of different rigorosity, on the thermal performance of the model developed in this paper. Thus, we will be able to determine if it is possible to standardize this model in different Moroccan cities.

Keywords: Passive heating, Phase change materials, solar energy, Building Energy Efficiency

1. INTRODUCTION

Passive heating and insulation in the building can be developed using a PCM to improve interior thermal performance. However, to provide sufficient thermal energy to maintain thermal comfort and maximize PCM thermal storage capacity, the active heating system is necessary. It can be anticipated that the coupling applications of PCM wall panel and solar thermal system can provide both passive and active benefits of the premises. The most used technologies for hot water heating are the flat plate solar collector. However, the disadvantage of the unpredictability of solar energy and the mismatch of solar irradiation peaks to needs are still faced. To achieve high heat storage capacity, latent heat-based LHTES systems can store a larger amount of heat compared to sensible heat storage techniques [1]. In this work, Zhou and Wah Yu [2], evaluated the year-round thermal performance of a new ventilated Trombe wall-PCM, using an experimentally validated model. They calculated the air change rate of the cooling and heating process and determined the transition temperature of the PCM and evaluated the total energy and electrical energy consumption of the fan. Also, Motte et al. [3], numerically analyzed a solar collector with a layer of PCM integrated on the internal face of the collector. They studied the influence of different parameters to reveal the effect of adding PCM. They carried out digital simulations of the solar water heating system with real-time environmental data (solar radiation, wind, ambient temperature). In another paper Carmona and Palacio [4], presented a thermal modeling strategy of a flat plate solar collector with thermal storage unit with PCM the latent heat storage performance is evaluated. Also, Adnan et al. [5] explored the application of phase change materials (PCMs) to enhance the energy efficiency of buildings. PCMs possess the ability to absorb and release significant amounts of thermal energy during phase transitions between solid and liquid states. This thermal regulation capability enables a more stable indoor temperature, thereby reducing reliance on traditional heating and cooling systems. The study presents an in-depth examination of incorporating PCMs into building structures to improve energy performance. The authors detail the various properties of PCMs and analyze their influence on a building's thermal behavior. Among the noted benefits are decreased energy consumption, reduced heating and cooling expenses, and enhanced occupant comfort. In another study, Faraji Mustapha [6] conducted a numerical analysis of the discharging process in a Phase Change Material (PCM)/Water coaxial heat exchanger designed for Domestic Water Heating (DWH) applications. The proposed Latent Heat Storage Unit (LHSU) was optimized to maintain a steady supply of warm water over an extended period. The results indicated that both the outlet water temperature and the duration of hot water availability are dependent on the inner temperature of the water. Al-Yasiri and Marta [7] conducted a numerical investigation using EnergyPlus software to explore the passive use of phase change materials (PCMs) in thin building envelopes within hot climates. They assessed the impact of PCMs on indoor thermal comfort by evaluating parameters such as average temperature fluctuation reduction, thermal load leveling reduction, and operating temperature reduction. The study also measured energy efficiency through metrics like total average heat gain reduction, equivalent CO₂ emissions, and electricity savings. Their findings revealed that integrating PCMs into thin envelope elements significantly improved building performance in extremely hot environments. Gomes et al. [8] investigates the effectiveness of phase change materials (PCMs) in building envelopes under projected future climate conditions for two distinct Brazilian cities:

Curitiba (a mild climate) and Rio de Janeiro (a hot-humid climate). Using EnergyPlus simulations with updated climatic projections for 2050 and 2080, the researchers analyzed the thermal behavior and energy consumption of buildings with and without PCM-enhanced walls. The results show that PCMs can significantly reduce cooling energy demand in temperate climates. However, in hot and humid conditions, such as in Rio de Janeiro, PCM integration can sometimes increase energy consumption due to limited night cooling potential and higher nighttime temperatures. The study highlights the importance of climate-adaptive design and the need for dynamic PCM selection based on location-specific climatic trends. Recently, Pistochini et al. [9] conducted a research focuses on retrofitting exterior walls of residential buildings in California with insulation panels enhanced with PCMs. The project evaluated thermal improvements, energy savings, and cost-effectiveness across different climate zones within the state. Field testing and energy modeling indicated that PCM-enhanced walls can reduce peak cooling loads by up to 41% and improve air tightness by as much as 58%. The study also found that energy savings varied depending on building orientation, insulation placement (interior vs. exterior), and occupant behavior. These findings support the use of PCMs in building retrofits, especially in regions with significant diurnal temperature variations. Rahimi and colleagues [10] present a comprehensive simulation-based assessment of incorporating PCMs into the opaque parts of building envelopes (e.g., walls and roofs) as passive energy-saving systems. Using advanced modeling techniques, they evaluated thermal energy storage performance, temperature regulation, and overall energy demand reduction across various building types and climates. The study demonstrated that PCM integration can lower annual energy use by approximately 6%, improve indoor thermal comfort, and contribute to building decarbonization efforts. The authors also emphasize the importance of proper PCM placement and melting temperature selection to maximize effectiveness in different seasons and regions.

2. MATHEMATICAL MODEL

Fig. 1(a) provides an overview of the physical model. It consists of a phase change materials building-integrated solar collector (PCM-SOLAR). The subwoofer fixed at the roof is isolated from the sides and carries forward glass windows. The inside of the solar collector includes an absorbent plate copper tinted in a dark coating that maximizes the absorption of solar radiation. The solar energy captured is transferred to water within tubes that are in contact with the absorbent surface (Fig. 1(b)).

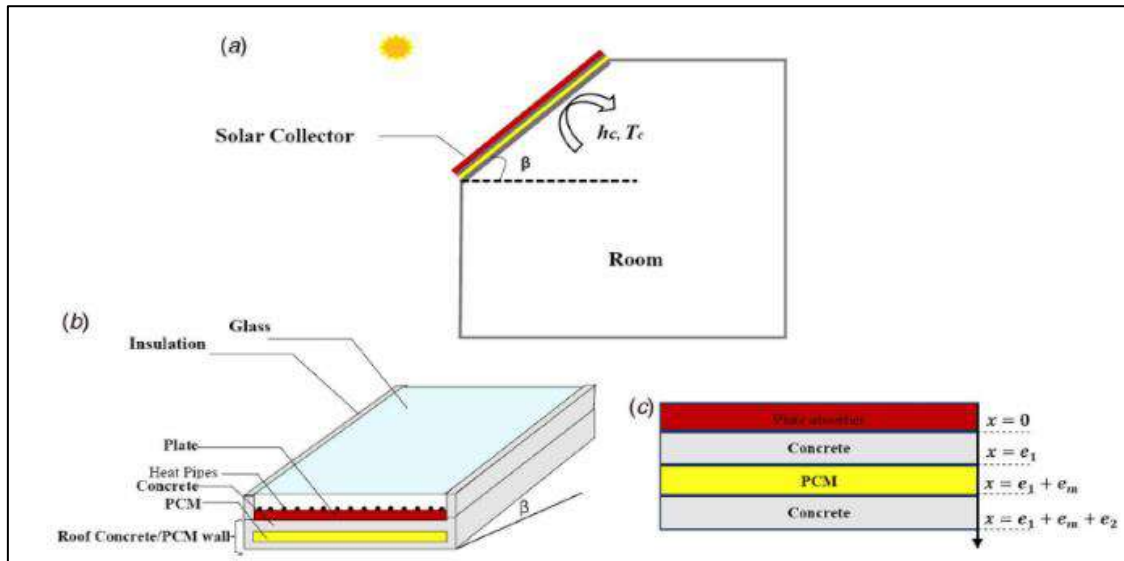


Fig. 1. Physical model

A layer of the PCM with a thickness of e_m is sandwiched between two concrete layers and connected to the subwoofer, which is fixed to the slab. A representative area defines the location of the layer of the PCM in the system, and the various parameters of the solar collector are detailed in Fig. 1(c). The concrete wall thickness is $L=10$ cm, and the PCM can be placed at variable positions within the concrete. The temperature of the first internal node in the concrete slab at the contact with room air is denoted T_{in} .

Before presenting the equations that govern the heat transfer process occurring in the system, some assumptions were made to simplify its resolution. These assumptions are given as follows:

- The wall, PCM, and solar collector are initially at a uniform temperature, T_{ini} .
- The thermophysical properties are constant and independent of temperature.
- Interface resistances between the different layers of the wall are neglected.
- PCM is homogeneous and isotropic.

- Conduction heat transfer in the composite wall is one-dimensional.
- The plat absorber is blackened to increase its absorption factor.
- Transparent glass envelopes reduce convection and radiation losses to the atmosphere.
- Sensible heat storage in glass and plat absorber layers is negligible.
- Room air is at $T_c=22$ °C. The internal face of the slab exchanges the heat with air and the global heat transfer coefficient is $10 \text{ W/m}^2\text{K}$.
- The external window is subjected to combined radiations and air convection boundary conditions. Data from metrological weather stations are provided every hour. The solar collector works in an hourly steady-state regime.

Governing Equations

The transient energy equation in concrete/PCM is written using the enthalpy method [11]

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x} \left(\alpha \frac{\partial h}{\partial x} \right) - \rho \lambda \Delta H_f \frac{\partial f}{\partial t} \quad (1)$$

With h being the sensible enthalpy defined by:

$$h(T) = h(T_m) + \int_{T_m}^T \rho \lambda c_p dT \quad (2)$$

ΔH_f is the latent heat of fusion, kJ/kg and λ is introduced to make equation (1) more flexible so that we can use a single formula for the different layers of the wall: $\lambda=0$ in concrete, $\lambda=1$ in PCM.

The second term accounts for the latent heat associated with the phase change as it occurs, while f represents the liquid fraction of the PCM, explained in the following expression. 3

$$\begin{cases} f = 1 & \rightarrow T > T_m \\ f = 0 & \rightarrow T < T_m \\ 0 < f < 1 & \rightarrow T = T_m \end{cases} \quad (3)$$

- Mathematical Model of the Solar Collector

The heat balance equation for the solar collector is written as follows:

$$A_c q_o = Q_u + Q_p + Q_s \quad (4)$$

q_o : Net solar flux absorbed per m2

According to the assumptions, we have a steady-state hourly regime, therefore with:

$$Q_u = A_c \left[q_o - U_L (T_p - T_a) \right] \quad (5)$$

$$Q_p = U_L (T_p - T_a) A_c$$

such that:

$$U_L = U_t + U_b \left(1 + \frac{T_a - T_{in}}{T_p - T_a} \right) \quad (6)$$

U_b : overall thermal inertia coefficient towards the back of the collector, $\text{W/m}^2\text{K}$

U_L : global coefficient of heat losses to the atmosphere, $\text{W/m}^2\text{K}$

U_t : forward heat losses coefficient, $\text{W/m}^2\text{K}$ $h(T)$

There are also lateral heat losses U_e , which are negligible because $(U_t + U_b) \gg U_e$.

$$U_t = \frac{1}{\frac{1}{h_{p-v} + h_{r,p-v}} + \frac{1}{h_{v-a} + h_{r,v-a}}} \quad (7)$$

$$U_b = \frac{1}{\frac{e_1}{k_b} + \frac{e_m}{k_l} + \frac{e_2}{k_b} + \frac{1}{h_c}} \quad (8)$$

h_{pl} is the convective heat transfer between the absorbent and the glass cover, W/m^2

$h_{r,gl-a}$ is the irradiative coefficient between the glass cover and the environment, $\text{W/m}^2\text{K}$

$h_{r,p-gl}$ is the irradiative coefficient between the absorbent and the glass cover, $\text{W/m}^2\text{K}$

The irradiative exchange takes place between the external panel and the sky at a temperature equivalent to T_{sky} .

$$h_{r,p-v} = \frac{\sigma (T_p + T_v)(T_p^2 + T_v^2)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_v} - 1} \quad (10)$$

$$h_{v-a} = 5.7 + 3.8 u_{vent}, \quad h_{r,v-a} = \frac{\sigma \varepsilon_v (T_v^4 - T_{ciel}^4)}{(T_v - T_a)} F_{v-ciel} \quad (9)$$

σ : Stefan-Boltzmann constant

ϵ_p : Absorber emissivity

ϵ_v : Window emissivity

$h_{r,p-v}$ can be calculated by linearization. The sky is considered a blackbody at $T_{sky}(^{\circ}K)$ [12]:

$$T_{sky} = 0.0552 \times (T_a + 273.15)^{1.5} \quad (11)$$

The shape factor F_{v-sky} is assumed to be equal to one.

The convective heat transfer coefficient h_{p-v} is calculated using the Nusselt number Nu correlation according to Hollands et al. [13], as follows:

$$Nu = 1 + 1.44 \left[1 - \frac{1708}{Ra \cos(\gamma)} \right]^+ \left(\frac{1 - 1708(\sin 1.8\gamma)^{1.6}}{Ra \cos(\gamma)} \right) + \left[\left(\frac{Ra \cos(\gamma)}{5830} \right)^{1/3} - 1 \right]^+ \quad (12)$$

γ : Collector tilt in degrees

$$Nu = \frac{h_{p-v} d}{k_a}, Ra = \frac{g \beta_T \Delta T d^3}{\nu \alpha}, Pr = \frac{\nu}{\alpha} \quad (13)$$

Where '+' denotes positive deviations, terms are set to zero if negative. d is the distance between the plate and the glass, ΔT is the temperature difference between the plate and the glass ($^{\circ}K$), ν is the kinematic viscosity (m^2/s), and α is the thermal diffusivity (m^2/s) and Pr is the Prandtl number.

The useful heat flux transferred to the fluid is expressed by:

$$q_u = mc_p(T_{fo} - T_{fi}) \quad (14)$$

T_{fo} Temperature of the outgoing fluid

T_{fi} Temperature of the incoming fluid

q_o is the net solar heat flow absorbed, W/m^2

q_p is the heat flow lost by the solar collector, W/m^2

q_s is the power stored as sensible heat in the different elements of the collector, W/m^2

q_u is the useful flow received by the heat transfer fluid, W

$$q_u = AF_R(q_o - U_L(T_{fi} - T_a)) \quad (15)$$

Hence

$$F_R = \frac{mc_p}{AU_L} \left[1 - \exp\left(\frac{-AU_L F'}{mc_p}\right) \right] \quad (16)$$

F' is the collector performance, which depends on U_L ($0.84 < F' < 0.9$). The conductance factor F_R represents the ratio between the recovered power and the power that would have been obtained if the fluid temperature were equal to the fluid inlet temperature, [15]. While the fluid outlet temperature is expressed by:

$$T_{fo} = \left(T_{fi} - T_a - \frac{q_o}{U_L} \right) \exp\left(\frac{-AU_L F'}{mc_p}\right) + \left(T_a + \frac{q_o}{U_L} \right) \quad (17)$$

The mean fluid temperature is given by:

$$T_f = T_{fi} + \frac{q_u/A}{U_L F_R} \left[\frac{1 - F_R}{F'} \right] \quad (18)$$

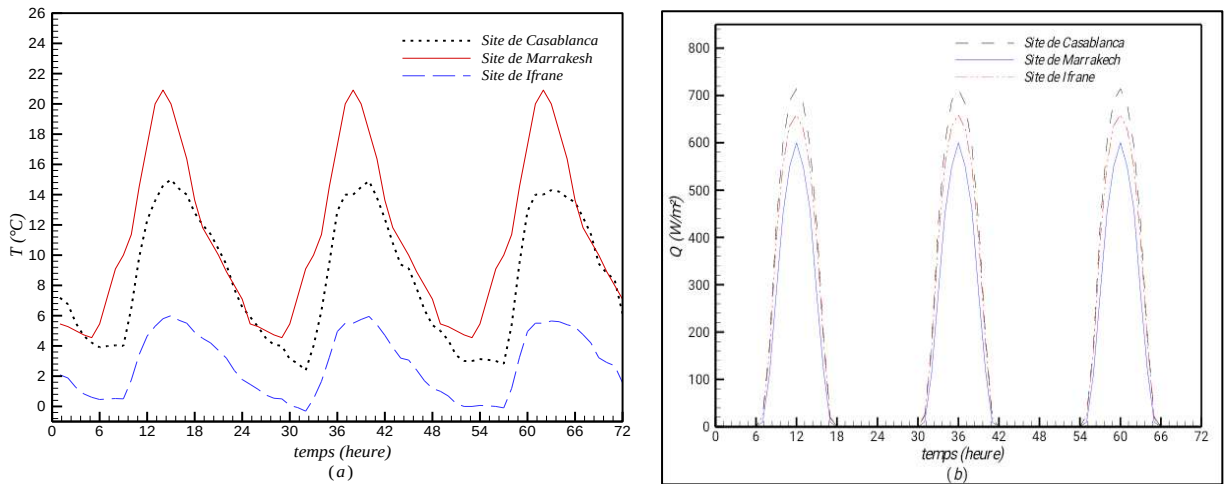


Fig. 2: Ambient temperature (a) and global solar radiation (b) for Marrakech, Ifrane and Casablanca cities-Morocco during three representative days of the month of January 2020 [16].

3. Boundary and Initial Conditions

Boundary Conditions:

The boundary conditions are as follows:

At the interface between the absorber and the wall, the transmitted flux is evaluated as follows:

$$x = 0, -k_x \frac{\partial T}{\partial x} \Big|_x = U_b(T_p - T_{in}) \quad (19)$$

At the interface between the interior area of the room and the wall, the convective flux is equal to:

$$x = e_1 + e_m + e_2, -k_x \frac{\partial T}{\partial x} \Big|_x = h_{in}(T_{in} - T_0) \quad (20)$$

Continuity of temperature and heat flux density at the concrete/PCM interfaces:

$$-k_+ \frac{\partial T}{\partial x} \Big|_{x_+} = -k_- \frac{\partial T}{\partial x} \Big|_{x_-}, T_+ = T_- \quad (21)$$

The thermophysical properties of the materials at the interfaces are evaluated as follows:

$$k_i = \frac{k_+ k_- (\delta_- + \delta_+)}{k_+ \delta_- + k_- \delta_+}, k_m = f k_l + (1 - f) k_s,$$

$$\rho c_p = f(\rho c_p)_l + (1 - f)(\rho c_p)_s \quad (22)$$

δ is the separation between the interface and the first node of the '+' material and δ is the separation between the interface and the last node of the '-' material.

Table 1. Thermophysical properties [141]

Material		$T_m(^{\circ}\text{C})$	$\Delta H_f(\text{kJ/kg})$	$c_p(\text{kJ/kgK})$	$\rho(\text{kg/m}^3)$	$k(\text{Wm}^2\text{K})$
Concrete		–	–	0.838	2200	4.5
Paraffin wax	S	22	148.5	1.46	981	0.145
PCM	L	22	148.5	2.13	862	0.145

3. INITIAL CONDITIONS

At the instant $t=0$, the different layers of the solar collector have the same initial temperature, $T_{ini}= 21.9^{\circ}\text{C}$. Surface conditions reflect the coupling between the different layers at the interface level. The system is subject to the climatic conditions Marrakech, Ifrane and Casablanca, Morocco cities, during January, for every 1 h which was used in the simulation (Fig. 2). The heat transferred from the collector to the wall gradually increases its temperature, as a consequence, solid PCM melts inside the concrete wall, and an important amount of latent heat is stored.

4. RESULTS

Ambient temperature and global solar radiation

Fig. 2 (a) and 2 (b), represent the variation of the ambient temperature T_a and the overall solar radiation for 3 days representative of the month of January of the year 2020 for the cities of Casablanca-Morocco ($33^{\circ}35' 24'' \text{ N}$, $7^{\circ}37'12'' \text{ W}$) has an elevation of 31m, Ifrane-Morocco ($33^{\circ}31'33'' \text{ N}$, $-5^{\circ}6'25'' \text{ W}$) has an elevation of 1654m and Marrakech-Morocco ($31^{\circ}38'31'' \text{ N}$, $8^{\circ}0'46'' \text{ W}$) has an elevation of 449 m [16].

The analysis of climate data shows that the city of Marrakech is characterized by a less severe winter compared to the other two climatic zones. In fact, the minimum nighttime ambient temperature reached in 3 days is reduced by the value 5°C and the maximum daytime temperature is increased by the value 21.5°C , on the other hand the city of Ifrane is characterized by daytime ambient temperatures and very low nighttime temperatures limited between -0.5°C and 6°C .

In terms of thermal comfort, colder ambient temperatures in more severe climatic zones, such as Ifrane, may require additional insulation or more frequent use of heating. However, using walls with PCM can help maintain a more stable and comfortable indoor temperature in these areas. This is because walls with PCM have a high thermal capacity that allows them to store thermal energy during the day and release it slowly at night, which helps maintain a stable indoor temperature and reduce the heating load. By integrating a solar collector into the slab, the collected solar energy can be used to heat the slab and thus increase the interior temperature, which further improves thermal comfort. The analysis of climate data for the three zones of Morocco shows the importance of considering local climatic conditions when designing energy-efficient buildings. Walls with PCM combined with solar collectors can be an effective solution to improve thermal comfort and reduce energy consumption in severe climatic zones.

Table 2. Solar collector specifications [15]

Parameter	Specification/value
Solar collector surface	1.0 m ²
Distance between heat exchanger pipes	0.083 m
External diameter of pipes	0.02 m
Plate thickness	0.0035 m
Plate emissivity	0.3
Plate conductivity	390 W/m K
Air flow	0.005 kg/s
Air cavity thickness	0.04 m
Air conductivity	0.0262 W/m K
Heat transfer coefficient (water)	4.18 kJ/kg K
Cover emissivity	0.8
Thermal expansion coefficient, β_T	$16.5 \times 10^{-6} \text{ K}^{-1}$
Boltzmann constant	$5.6703 \times 10^{-8} \text{ W/m}^2 \text{ K}^4$

5. INTERNAL ROOM TEMPERATURE T_{in}

a- Collector without PCM

Fig. 3 schematizes the temporal variation of the internal temperature of the room, T_{in} , for the three climatic zones studied, for the case of a normal Collector without phase change materials. We note that in the city of Ifrane where the outside temperature varies and between -1°C and 6°C, in the month of January, the temperature of the wall inside diverges from the thermal comfort conditions. In this city a solar collector can no longer provide adequate heating.

A thorough analysis of the evolution of the temperature of the interior wall of the premises in the cities of Casablanca and Marrakech points out that for the case without PCM, the minimum internal temperature, T_{in} , fluctuates between 4°C and 6°C which makes an additional charge for nighttime heating obligatory. On the other hand, we note that the maximum temperature varies around 20°C in Casablanca, 15°C in Marrakech there is a relative overheating of the interior walls during the day with a temperature almost higher than the thermal comfort value on the other hand during the night there is a remarkable heating deficit with a temperature that is significantly lower than the comfort value. To this end, the solar collector without PCM does not allow solar energy to be stored during the day and reused adequately at night. This demonstrates the importance of incorporating a layer of an PCM between the absorber and the exterior wall of the building which prevents its nighttime subcooling. The amplitude of evolution of, T_{in} , shows that there is no thermal stability inside the premises where the inhabitants will feel uncomfortable since during 24 hours the temperature increases or decreases with a maximum amplitude of 16°C.

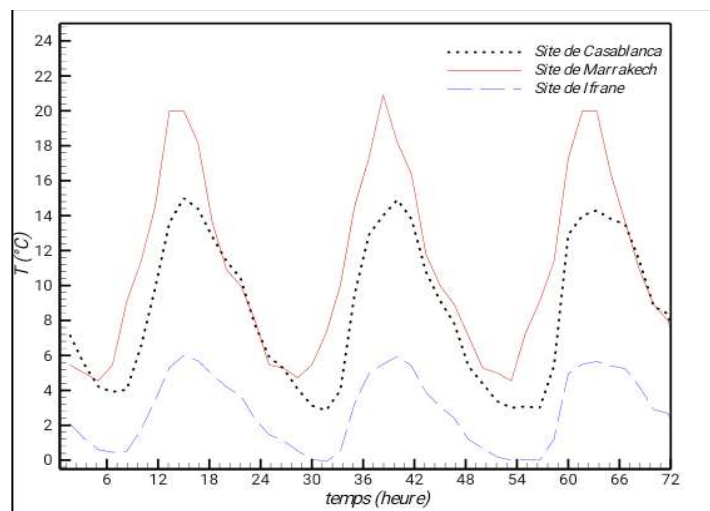


Fig. 3: Evolution of the internal temperature of the room, T_{in} , for three climatic zones. Ordinary Collector without PCM

b- Collector with PCM

The analysis of Fig. 4 shows that the introduction of a layer of phase change material between the absorber and the concrete wall clearly improves the interior temperature of the room, whatever the climatic zone studied. The use of a Collector with phase change materials makes it possible to increase the temperature of the room during the night in the cities of Casablanca, Marrakech and Ifrane from sunset until sunrise to a higher value. at 20°C. This is thanks to the large quantity of latent heat stored in the PCM during the day by

the solar collector. It should be noted that the value of solar radiation which depends on the climatic zone studied and depending on the severity of the climate during the night has a profound impact on the heating capacity of the collector and the temperature of the room can easily reach 21.6°C on second representative day. We also note that for the city of Ifrane the minimum temperature has increased and it varies around 16°C .

The comparison between Fig. 3 and Fig. 4 highlights the beneficial effect of incorporating a layer of phase change material (PCM) in the solar thermal collector. Indeed, we can observe that the minimum temperature of T_{in} is significantly higher with the use of PCM than without. This is particularly true for the city of Ifrane where the minimum temperature increases from -1°C to around 16°C , which helps avoid nighttime sub-cooling and improve thermal comfort inside the building.

The analysis of maximum temperatures also shows that the use of PCM makes it possible to limit overheating of interior walls during the day. Indeed, in the cities of Casablanca and Marrakech, the maximum temperature with PCM is lower than that without PCM. This suggests that the PCM acts as a thermal regulator by absorbing part of the incident solar energy and storing it in the form of latent heat, which helps maintain a more stable and comfortable indoor temperature. It is therefore recommended to use phase change materials in solar thermal systems to improve their energy efficiency. However, it is important to choose a high-quality PCM and to carefully design its integration into the system to avoid any problems with degradation or insufficient performance.

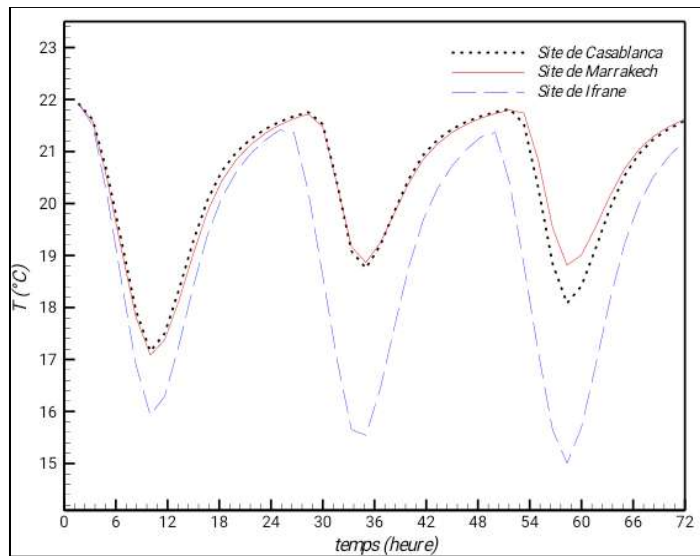


Fig. 4: Evolution of the internal temperature of the T_{in} room for three climatic zones. Concrete/PCM hybrid Collector.

6. ABSORBER TEMPERATURE, T_p

To assess the effect of the climatic zone on the absorber temperature, T_p , we focus our analysis on Fig. 5, which shows the temporal evolution of T_p in the cities of Casablanca, Marrakech, and Ifrane. The absorber located on the rear face is in contact with the wall/PCM. The absorber reaches 110°C in Casablanca, 100°C in Marrakech, and 98°C in Ifrane. The solar energy collected during the day, between $600\text{W}/\text{m}^2$ and $700\text{W}/\text{m}^2$, stored as latent heat of fusion, is used for space heating. It should be noted that this energy is not completely depleted during daytime heating. Due to the existence of two phases, the liquid phase and the solid phase, during the day, the PCM and concrete behave as a thermally insulated system, as the phase change is isothermal. The molten PCM layer reduces thermal gradients toward the exterior of the building. A large amount of the stored heat is reserved for nighttime heating.

At 5 p.m., at sunset, the PCM, which is constantly discharging, solidifies and provides a continuous supply of heat to the premises throughout the night, even if the outside temperature drops to very low values. It can be seen that the PCM is 100% solidified ($f=0$), and undercooled, the phase change material is thermally discharged, and its temperature drops to lower levels at night: $T_p = 4^{\circ}\text{C}$ in Casablanca, $T_p = 6^{\circ}\text{C}$ in Marrakech, and $T_p = 1^{\circ}\text{C}$ in Ifrane around 6 a.m. Thus, its sensible heat becomes negative. The phase shift between the absorber temperature, T_p , and the interior room temperature, T_{in} , is remarkable. The drop in temperature, T_p , at 3:00 p.m. is only detected by the interior face of the room from 10:00 a.m. onward. This is due to the high thermal inertia of the concrete wall combined with phase change materials.

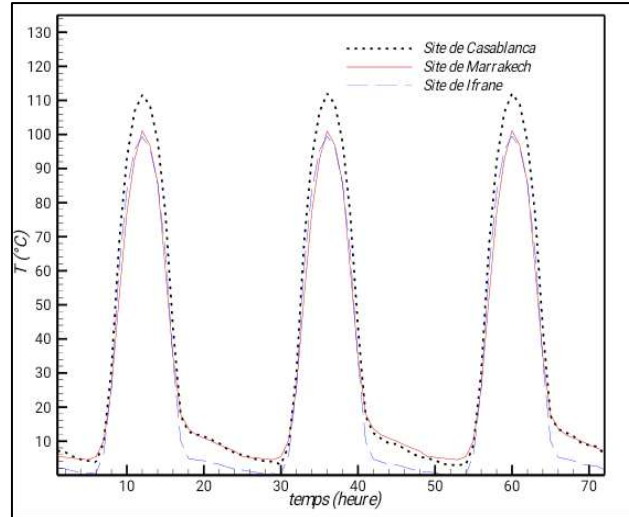


Fig. 5. Evolution of absorber temperature, T_p , for three climate zones. Hybrid concrete/PCM collector

In general, the addition of PCM reduces the temperature difference between the absorber and the heat transfer fluid in the solar collector, improving the efficiency of the solar collector and increasing the temperature of the heat transfer fluid. This temperature increase has a direct impact on the room temperature (T_{in}), as shown in Fig. 4. Furthermore, the addition of PCM also reduces the variation in absorber temperature during the night, reducing thermal stress on the building materials and extending their lifespan. In addition, reducing heat loss saves energy and reduces heating costs.

7. TOTAL HEAT STORED, Q_T

The previous results are confirmed by the analysis of Fig. 6, which shows that a significant amount of total heat, both sensible and latent, is stored in the wall. Indeed, the quantities $Q_T = 1.334$ MJ in Casablanca, $Q_T = 0.922$ MJ in Marrakech, and $Q_T = 0.894$ MJ in Ifrane are stored in the concrete/PCM composite wall during the daytime phase around 2:30 p.m. This heat is completely exhausted in Casablanca at 6:00 p.m., in Marrakech at 5:30 p.m., and then in Ifrane, it is completely consumed at 5:00 p.m. It should be remembered that the outside temperature, which decreases during the night from the evening onward, causes a complete discharge of the PCM, and subcooling is recorded. With negative sensible heat and zero latent heat, we obtain a negative total stored energy. Indeed, $Q_T = -847661$ Joules in Casablanca, $Q_T = -799957$ Joules in Marrakech and $Q_T = -1471533$ Joules in Ifrane. This thermal deficit of the composite wall is recorded during the daytime phase around 06:30 am and is caused by the remarkable drop in ambient temperature and the cancellation of solar radiation especially in the city of Ifrane.

These results confirm previous observations that PCM combined with concrete stores a large amount of solar energy in the form of latent heat of fusion, which is used to heat the space. This heat is then gradually released into the space throughout the night, thus ensuring efficient thermal regulation. It should be noted that this large amount of stored heat is due to a large portion of the PCM's minimal thickness of 1 cm, compared to the wall's thickness of up to 10 cm.

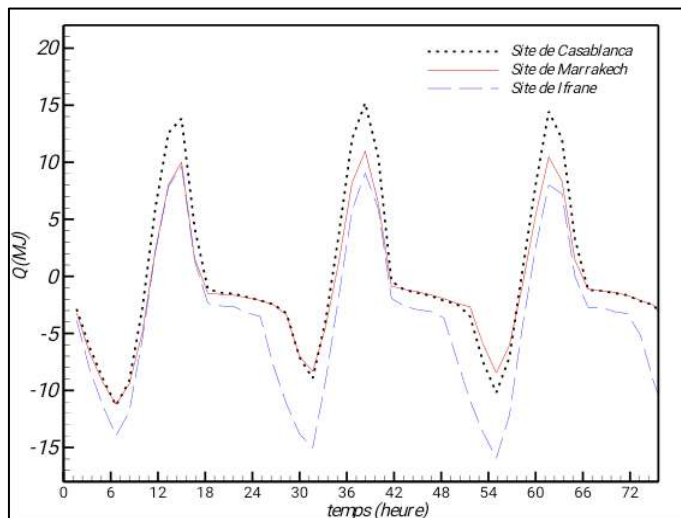


Fig. 6. Total heat stored in the hybrid concrete/PCM collector

CONCLUSION

The hybrid concrete/PCM Collector system is an effective solution for heating buildings in diverse climatic zones such as Casablanca, Marrakech and Ifrane. Estimating the thermal performance of buildings is crucial to ensure the thermal comfort of occupants and reduce energy consumption. However, climatic variations between different geographical areas make this estimation difficult. In this paper, we analyzed how three different climatic zones in Morocco affect the thermal behavior of the model resulted in this study throughout the winter. The results obtained allowed us to understand the importance of using an efficient thermal system to control the internal temperature of the building. The study highlighted the importance of using a thermal control system to minimize internal temperature fluctuation during the day in the three cities. We found that incorporating phase change material (PCM) into the model improved the internal temperature, which remained within a narrow margin around the comfort temperature during night and day, despite the latent heat emitted from the solar collector. The satisfactory results obtained in the three cities confirm the possibility of standardizing the use of PCM in different climates.

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DETERMINING EMBEDDED EMISSIONS IN METALLIC PRODUCTS BY USING GHG INTENSITY AS SCIENTIFIC METRIC AND REPORTING THE RESULTS SO AS TO COMPLY WITH CBAM STANDARDS

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ABSTRACT – OE10

The purpose of the present paper is explaining – through a certain case study – how greenhouse gases (GHG) intensity is used as scientific metric in determining the emissions embedded in metallic products, as well as how to report the results thus obtained in order to obey the so-called „carbon border adjustment mechanism (CBAM) regulation”, as a part of the „Fit for 55” package, which is a comprehensive set of legislative proposals made by the European Union (EU) for updating its climate, energy and transport laws to meet a binding target of reducing net GHG emissions by at least 55% by 2030, compared to 1990 levels, therefore aiming to modernize EU's regulatory framework in order to promote the innovation, to ensure a fair transition and also to solidify EU's leadership in global climate action. It is well known that CBAM is a climate policy tool designed by the specialists of the EU as to prevent „carbon leakage”, by imposing a certain carbon price on the imported goods (among which metallic products – especially aluminum, steel and iron – arouse special interest), requiring importers to report both the embedded direct and indirect GHG emissions embedded in their products and to subsequently purchase CBAM certificates to cover both kind of emissions at a price equivalent to the EU's emissions trading system (ETS) carbon price, the ultimate goal being to create a level playing field between EU producers and their non-EU competitors, consequently encouraging all international industry to comply with environmental standards by adopting cleaner production technologies.

Keywords: carbon border adjustment mechanism (CBAM), greenhouse gases (GHG) intensity, emissions trading system (ETS), global warming potential (GWP), emissions embedded within aluminium products

1. INTRODUCTION

Greenhouse gases (GHG) intensity is a well-known scientific metric which refers to the amount of greenhouse gas emissions per unit of product, typically expressed as kg carbon dioxide equivalent (CO₂e) per ton of product, being a technical measure that is used to assess how carbon-intensive a production process is, as it compares the climate change impact of different GHGs by converting them to an amount of carbon dioxide with the same global warming potential (GWP), allowing the total GHG emissions (including nitrous oxides, methane etc.) to be expressed as an sole standardized number meant to represent the overall impact of the production process. More specific, as a comparison tool, CO₂e standardizes the climate impact of different gases by comparing them to carbon dioxide, which has a GWP equal to the unit, each value being calculated by multiplying the mass of a specific GHG by its GWP factor (for example, methane (CH₄) having a much higher GWP than carbon dioxide (CO₂), its impact is multiplied by a factor, which is about 28 over 100 years, but is approximately 81 over 20 years, meaning it might trap much more heat in the short term compared to carbon dioxide – i.e., 1 ton of CH₄ is equivalent to 28 tons of CO₂ in terms of warming potential when thinking long-term – over 100 years – whereas it is equivalent to 81 tons of CO₂ in the same terms when thinking short-term – over 20 years). Many efforts are channeled in this direction and many scientific works have this theme [1-6].

As a metric, GHG intensity is process-dependent, as it might be influenced by technology, energy sources, and efficiency; it is also product-specific, as it varies by material (e.g., aluminium vs. steel) and it is used in benchmarking, as it can be used to compare emissions embedded within different products across producers or regions.

The European Commission published – within the year 2021 – its proposal for a „carbon border adjustment mechanism (CBAM) regulation”, as a part of the „Fit for 55” package. Within its proposal, the European Commission indicated that CBAM will serve as an essential element of the European Union (EU) toolbox to meet the objective of a climate-neutral Union – which is the EU's goal to achieve a net-zero GHG emissions balance by 2050 (the „Fit for 55” package being a main part of the European Green Deal, that has the overarching purpose to make the EU climate-neutral by 2050, including interconnected initiatives across various economic sectors [7-10]).

CBAM plays a key role within the „Fit for 55” package, by introducing a carbon price on imports of certain goods to prevent „carbon leakage”, i.e., the transfer of GHG emissions when certain companies move their production from a country with strict climate policy to one with much more flexible regulation [7-10].

„Carbon leakage” might occur because a stricter policy (e.g., a carbon tax) increases production costs, therefore making it cheaper for a company to operate in a country with weaker regulation (in such situation, despite the fact that it might look like emissions are to be reduced, they are to be actually just relocated, which can affect the intended environmental global goals.

Moreover, CBAM is meant to complement the EU’s Emission Trading System (ETS), which requires EU-based producers to purchase emission allowances covering their production-related CO₂ emissions.

2. CASE STUDY

General Description

The case study refers to an aluminium alloy manufacturing company – which is to be denoted as AAMC in what follows – producing hard alloys, as well as soft/medium alloys for another company: aluminium alloy beneficiary company – which is to be denoted as AABC in what follows.

AAMC implemented EU Regulation 2023/956 (establishing a CBAM) and European Commission Implementing Regulation 2023/1773 (containing the rules for the application of EU Regulation 2023/956 as regards reporting obligations for the purposes of the carbon border adjustment mechanism during the transitional period).

Within this context, AAMC operates in accordance with:

- a) Commission implementing EU regulation 2020/2085 amending and correcting Implementing Regulation (EU) 2018/2066 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and European Council;
- b) Commission implementing EU regulation 2018/2066 on the monitoring and reporting of GHG emissions pursuant to Directive 2003/87/EC of the European Parliament and European Council, amending Commission Regulation EU no. 601/2012 for GHG emissions monitoring.

GHG emissions of AAMC use to be calculated annually and use to be verified and approved by an external authority which is accredited in accordance with Commission implementing EU regulation 2020/2084 (amending and correcting EU regulation 2018/2067 on the data verification and on the verifiers’ accreditation pursuant to Directive 2003/87/EC of the European Parliament and European Council and ISO 14066 GHG) – competence requirements for GHG validation teams and verification teams.

The main results of a specific calculation of the emissions embedded within aluminium products are shown below, for Q3 (July - September) 2025, on two devices, denoted as (I) and (II).

Calculation and main results of the case study

For Q3 2025, the CBAM emissions of AAMC corresponding to the products destined for AABC, by using value data validated for 2024 by accredited verifiers will be presented in what follows.

The emission factor is 0.315 t CO₂/MWh (location-based method). The energy source is represented by energy from market and EU ETS Directives, i.e., CN Code = 7606; CN Name = Aluminium plates, sheets and strip, of a thickness exceeding 0.2 mm.

➤ PLATES NHT – HARD ALLOYS (I)

SEEdir (specific embedded emissions – direct) = 2.3868 t CO₂/ t unit

Applied reporting methodology: EU ETS Directive and Commissions Rules

SEEindir (specific embedded emissions – indirect) = 0.9374 t CO₂/ t unit

Electrical energy consumed = 2.9758 MWh/unit

Emission factor = 0.315 t CO₂/MWh (location-based method)

Energy source = energy from market with the average value of the three months
for CO₂ emissions

Total installation emissions = 38.8932 t CO₂

Direct installation emissions = 27.9259 t CO₂

Indirect installation emissions = 10.9673 t CO₂

➤ PLATES HT HARD ALLOYS (II)

SEEdir (specific embedded emissions – direct) = 2.5 t CO₂/ t unit

Applied reporting methodology: EU ETS Directive and Commissions Rules

SEEindir (specific embedded emissions – indirect) = 1.7281 t CO₂/ t unit

Electrical energy consumed = 5.4862 MWh/unit

Emission factor = 0.315 t CO₂/MWh (location-based method)

Energy source = energy from market with the average value of the three months
for CO₂ emissions

Total installation emissions = 41.8586 t CO₂
Direct installation emissions = 24.75 t CO₂
Indirect installation emissions = 17.1086 t CO₂

➤ **SHEETS SOFT MEDIUM ALLOYS (I)**

SEEdir (specific embedded emissions – direct) = 2.2142 t CO₂/ t unit
Applied reporting methodology: EU ETS Directive and Commissions Rules
SEEindir (specific embedded emissions – indirect) = 1.0181 t CO₂/ t unit
Electrical energy consumed = 3.2321 MWh/unit
Emission factor = 0.315 t CO₂/MWh (location-based method)
Energy source = energy from market with the average value of the three months
for CO₂ emissions
Total installation emissions = 23.2728 t CO₂
Direct installation emissions = 15.9424 t CO₂
Indirect installation emissions = 7.3304 t CO₂

➤ **PLATES HT SOFT MEDIUM ALLOYS (I)**

SEEdir (specific embedded emissions – direct) = 2.792 t CO₂/ t unit
Applied reporting methodology: EU ETS Directive and Commissions Rules
SEEindir (specific embedded emissions – indirect) = 1.127 t CO₂/ t unit
Electrical energy consumed = 3.5776 MWh/unit
Emission factor = 0.315 t CO₂/MWh (location-based method)
Energy source = energy from market with the average value of the three months
for CO₂ emissions
Total installation emissions = 375.8254 t CO₂
Direct installation emissions = 267.7503 t CO₂
Indirect installation emissions = 108.0751 tCO₂

➤ **PLATES HT SOFT MEDIUM ALLOYS (II)**

SEEdir (specific embedded emissions – direct) = 2.8185 t CO₂/ t unit
Applied reporting methodology: EU ETS Directive and Commissions Rules
SEEindir (specific embedded emissions – indirect) = 1.1429 t CO₂/ t unit
Electrical energy consumed = 3.6282 MWh/unit
Emission factor = 0.315 t CO₂/MWh (location-based method)
Energy source = energy from market with the average value of the three months
for CO₂ emissions
Total installation emissions = 21.3917 tCO₂
Direct installation emissions = 15.2201 tCO₂
Indirect installation emissions = 6.1716 tCO₂

➤ **PLATES HT SOFT MEDIUM ALLOYS HORIZONTAL**

SEEdir (specific embedded emissions – direct) = 2.4695 t CO₂/ t unit
Applied reporting methodology: EU ETS Directive and Commissions Rules
SEEindir (specific embedded emissions – indirect) = 1.1027 t CO₂/ t unit
Electrical energy consumed = 3.5005 MWh/unit
Emission factor = 0.315 t CO₂/MWh (location-based method)
Energy source = energy from market with the average value of the three months
for CO₂ emissions
Total installation emissions = 7.1443 t CO₂
Direct installation emissions = 4.9389 t CO₂
Indirect installation emissions = 2.2053 t CO₂

CONCLUSIONS

The main results of this case study – regarding the emissions embedded within aluminium products – obtained from the calculation performed as case study, it shows that AAMC, in providing products for AABC, was fully compliant with the environmental objectives applicable for its business, permanently adapting its internal processes and procedures so as to comply with the BATs (best available techniques) and the best practices in the environmental area.

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AUTOMATION AND CONTROL SYSTEM REVAMP OF A NATURAL GAS COMPRESSORS STATION

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ABSTRACT – PE3

This article aims to describe the process of modernization of the Stoenеşti compression station, mainly covering the automation system architecture and the human-machine interfaces, the benefits of using a modern software solution in monitoring and controlling a gas compression station and the key role that the implemented solution has in ensuring predictive maintenance. At the Stoenеşti compression station in Giurgiu County, Romania, there are four screw electro-compressors operating simultaneously, namely K1, K2, K3 and K4. The compressors are working in 2 pairs K1 and K3, K2 and K4 respectively. Gas compression is distributed in two stages. The first stage of compression consists of K1 and K3 compressing the received gas to a maximum value of 6.5 bar after which compressors K2 and K4 begin the second stage of compression to a maximum value of 30 bar.

Keywords: Industrial Automation, Supervisory Control and Data Acquisition, Gas compression

1. INTRODUCTION

Industrial automation plays an increasingly important role nowadays compared to the past as the work that needs to be done in a wide range of industries is completed quicker and much more easier using modern technology instead of relying only on human capability [1–5].

As technology rapidly advances, so are the means in which assistance can be provided in completing the necessary tasks in various fields. This assistance provided can be, in some cases passive, without taking active part or altering the process, such as monitoring various system parameters and displaying them on a Human-Machine Interface (HMI) for the operator to monitor in real-time, interpret and analyse. An active approach can be represented by reducing manufacturing times by means of automated production lines or deciding the best course of action under various scenarios that the process may encounter, so as to ensure a safe operation and avoid faults. The ultimate purpose of automation in any domain and industry is to reduce the work of human operators and to bring the human intervention rate to a minimum [6].

The OMV Petrom gas compression station located in Stoenеşti, Giurgiu County, Romania was commissioned in 2007. Modifications were brought in 2015 when four screw electro-compressors were installed, and an optimized automation system was implemented. Since then, many of the components that were initially used in the automation system, such as PLCs, extension modules, conversion modules etc., became redundant, making subsequent interventions to resolve problems that occurred more difficult due to the replacement parts that were no longer being produced.

2. MATERIALS AND IMPLEMENTATION

The Stoenеşti compression station (Fig. 1) was operating with an outdated automation system, making maintenance and diagnosis complicated. The modernization project's main purpose is to make the communication between operator and compression station easier. This was achieved by revamping the existing automation systems for all compressors and linking each automation box to HMI panels for the operators to interact with. The PLCs (Programmable Logic Controller) have also been replaced, and HMI interfaces attached offer an overview of the corresponding compressor with all the elements and parameters that need monitoring such as valves, pressure transducers, oil cooler etc. To further facilitate the diagnosis and maintenance, the modernized automation system offers a set of alarms that appear on the screen for the operators to see when a critical threshold associated with a certain parameter has been reached, a failure has occurred, or a fault occurs along the measurement lines. Warning and alarm thresholds are set in the software program for the monitored parameters, in order to ensure the safe operation of the compressors. When exceeding the alarm thresholds of critical parameters, emergency shutdown sequences are provided to avoid damages [7, 8].



Fig. 1. The gas compressors located at Stoenești gas compression station

The four screw compressors labelled as K1 ÷ K4 were designed to compress natural gas in a two-stage process. After the second compression stage, the gas pressure is elevated to 30 bar, with which it is delivered directly into the main gas pipeline, to reach the end users. Due to the two stage compression, the four compressors are configured as two sets of pairs (K1, K2 – first stage and K3, K4 – second stage) [9–11]. We implemented additional software sequences for a better and flawless operation of the four gas compressors.

The first step in the modernization process was to replace the old automation cabinets altogether with newer ones assembled from scratch according to the station requirements stipulated in the scope of work [12]. These new automation cabinets contain newer hardware and means to communicate with the SCADA (Supervisory Control and Data Acquisition) system, relying on a PLC for each compressor. The main equipment installed in a cabinet are:

- PLC – consisting of CPU (Central Processing Unit), as well as digital and analogue input and output modules;
- Ethernet switch – for the interconnection of the four PLCs and the connection to the station SCADA computer, besides each PLC connection to its respective operating panel;
- Voltage source – 24 VDC for powering the PLC and other equipment such as adapters, safety barriers and transducers;
- Temperature adapters – for converting the signal from the temperature transducers to 4-20 mA unified signal;
- Safety barriers – for the electrical circuits protection installed in hazardous areas (ATEX Zone 2);
- Relays – switch for signal amplification, allowing a low-power control circuit to control a high-power actuator;
- Circuit breakers – for interrupting the circuit in case of an overload or a short circuit;
- Indicator lamps for every system mode (Initialisation, Operation, Standby, Emergency shutdown).

As it can be seen in the Fig. 2, the old automation cabinets (middle and the far right) were outdated and hence difficult to operate whenever an issue occurred, requiring the physical presence of troubleshooting personnel.



Fig. 2. a) The four automation cabinets; b) The interior of one of the automation cabinets (right)

The new functions implemented in the automation system, in addition to the old system, offer a better understanding of the station process by showing relevant information on every operating panel such as: process visualisation, parameter monitoring, a semi-automatic oil heating system and an automatic functioning mode for the whole compression plant that can be turned on by operators from the operating panel.

The software was designed in PAC Machine Edition (PAC – Programmable Automation Controller), a ladder diagram-based programming language used for VersaMax PLCs, making the software solution modern, efficient and easily customizable. As seen in Fig. 3., the starting sequence for the K1 compressor, representing one of the two stages of gas compression, depends on the second stage of compression. This is because the two compressors cannot be operated separately, and both need to be in a good functioning state in order to be started up. In the starting sequence, K1 receives the confirmation that K3 can be started and there are no problems affecting it. Then it checks that there are no impediments in initializing the first stage of gas compression (it is configured to contain a series of conditions that, if not met, the compressor will not start). If all the conditions for start-up are met, K1 can be started by pressing the “Start” button on the operating panel. When K1 reaches rated working parameters, it will send a signal to K3 to start as well. Both stages have preconfigured warning and trip alarms that trigger at different parameter thresholds, shown on the operating panel. The warnings are informative only, while the trips lead to installation emergency shutdown.

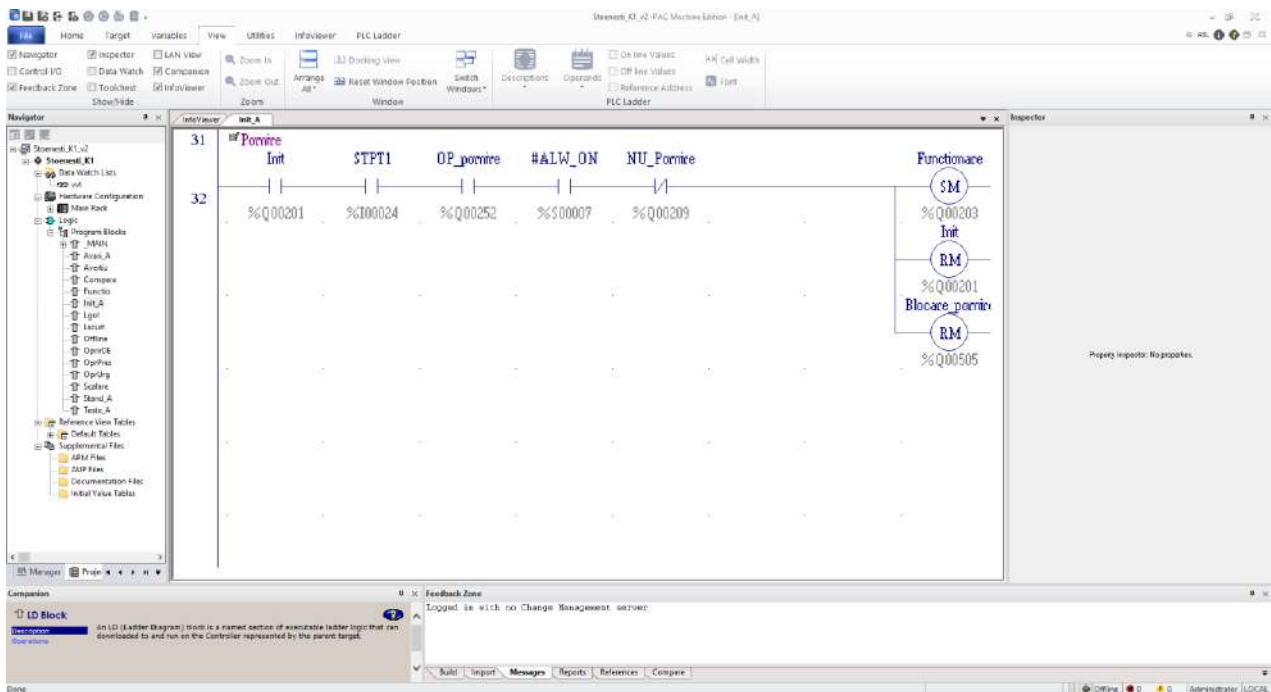


Fig. 3. The software starting sequence for the K1 gas compressor

3. RESULTS AND DISCUSSION

The process of cooling the oil that flows through the compression installation after a period of time was made to be fully automated. The PLC decides based on the values registered by the transducers placed on the compression installation when to start the variable speed drive of the oil cooling fan. These transducers are connected to the PLC, and the parameters are constantly monitored with thresholds integrated into the automation software. For an easier operating time, an automatic operating mode was also implemented in the software. This comprises three modes: Functioning, Standby and Emergency Shutdown, based on parameters values monitored and acquired by the PLC. All alarms triggered during operating time are recorded with the date, time and the name of the parameter. They are saved and can be accessed on the operating panel or exported to .csv files for further analyses and graphical representations, offering important information to station workers and maintenance staff.

CONCLUSIONS

The present article briefly presents the revamping of the automation system, which was necessary for the good operation of the compressors installed at Stoenești station. Overhauling the entire automation process of a station may seem like a big leap at first for new operators, but the time saved and the easier operating process using the newly installed operating panel is an undeniable advantage. Future works will explore in extenso the revamping process, both from hardware and software perspectives, highlighting the relation between all the new elements.

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PERFORMANCE EVALUATION OF GPU-ENHANCED MULTITHREADED ALGORITHMS FOR OPTIMIZING LARGE-SCALE HIGH-PRECISION MATRIX MULTIPLICATION

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ABSTRACT – OE5

This study investigates the performance optimization of large-scale, high-precision matrix multiplication through GPU-enhanced multithreaded algorithms. Six GPU-based implementations are developed and evaluated: a single-threaded baseline, a naïve multi-threaded version, two optimized multi-threaded variants computing multiple elements per thread, a shared-memory approach, and an optimized algorithm using the NVIDIA cuBLAS library. These are benchmarked against a multi-threaded CPU-based CBLAS DGEMM implementation. Results demonstrate that GPU parallelization significantly reduces runtime compared to the CPU baseline, with optimized algorithms achieving up to 1.5x speedup. The shared-memory and multi-element-per-thread approaches mitigate memory bottlenecks, though profiling reveals persistent memory-bound constraints. Proposed improvements include combining register and memory blocking for enhanced throughput. This research underscores the efficacy of GPU parallelization for compute-intensive matrix operations, offering insights for optimizing large-scale linear algebra computations.

Keywords: GPU parallel computing, matrix multiplication, high-performance computing, CUDA optimization

1. INTRODUCTION

Programming efficiently in the context of program performance can often present itself as a difficult task. As an example, to make programs which perform well, i.e. fast and with correct results, they should be written in a manner which is compatible with the compiler used and the hardware of the computer it is run on. Moreover, in order to be able to address the performance of computer programs, a standard baseline program must be written, which will be used to set benchmarks and to be compared with.

High-precision matrix multiplication underpins business-critical applications. In financial portfolio optimization, GPU-accelerated simulation of efficient frontiers relies on repeated covariance matrix multiplications [1]. In quantitative risk analytics, decomposing correlation matrices with GPU-enabled pipelines reduced computation times by approximately 80% per scenario batch [2]. Interactive decision-support platforms for real-time asset rebalancing have leveraged frameworks like RAPIDS to achieve up to 9 times faster covariance inversion and weight calculation compared to CPU-only implementations [3].

The purpose of this paper is to create, model, compute and assess a library of functions, which solves the problem of large-scale high-precision matrix-matrix multiplications, using GPU hardware for high-performance parallel computing. The problem chosen by this research consists mainly of algorithmic computations, and less of memory-accessing operations, hence there is a benefit to executing such algorithms on the GPU, utilizing its many cores [4] [5].

For this research, the matrix-matrix multiplication optimizations will be discussed extensively. Six different GPU algorithms will be implemented, each building up upon the former one, in an attempt to continuously provide better runtimes and more efficient memory usage from our functions.

To ensure consistency and reproducibility in performance comparisons, all algorithm implementations discussed in this study were executed within a computing cluster environment. This cluster provides interconnected high-performance NVIDIA GPUs, which are crucial for evaluating the CUDA efficiency of our kernels. Each machine in the cluster is built with identical hardware specifications.

2. PERFORMANCE ANALYSIS OF HIGH-PRECISION MATRIX MULTIPLICATION ALGORITHMS

In this section, various versions of matrix-multiplication algorithms running on the GPU are briefly discussed, each increasing in complexity and utility. First, a sequential version and a naïvely parallelized version are implemented and tested. Then a third improved version of the naïve version is implemented, handling double the data per thread. A fourth version will handle even more data per thread. Following this, a fifth version is implemented, based on sample code from the CUDA toolkit, which utilizes shared memory. Finally, the previous five implementations will be compared to the DGEMM-method from the “cuBLAS” library, which provides a GPU implementation of the BLAS library [6]. Any improvement opportunities for any of the five implementations will be discussed.

In order to check the results of each of these, both in terms of correctness and performance, their results will be compared to the performance achieved by the CPU-multithreaded DGEMM-function from the CBLAS library [7]. For all algorithms, some similarities apply, which will briefly be addressed here.

A. Baseline CBLAS matrix manipulation (*matmult_lib*)

The BLAS (Basic Linear Algebra Subroutines) Fortran library is one of the most efficient and widely-used building blocks for linear algebra computations across a wide variety of programming languages. The C language includes a wrapper to these Fortran functions through the library CBLAS, which is what will be used in the following algorithm. Due to its many optimizations and very high performance, it would be expected for the performance of this algorithm to surpass all the other self-coded algorithms.

B. Sequential single-threaded version (*matmult_gpu1*)

The first individual implementation of a matrix-times-matrix algorithm to be run on the GPU, is a sequential version called *matmult_gpu1*. For this, only one thread is initialized to execute the entire computation, hence the kernel is implemented using three nested for-loops. *matmult_gpu1* runs much slower than the optimized CPU version and reaches time-out for relatively large size matrices. This is unsurprising, considering the low clock frequency of the individual GPU cores. The strength of the GPU is in its number of cores, but that is not tapped into when running sequentially. However, this version serves as a starting point for the following GPU versions and ensures that memory management is handled correctly.

C. Simple naïve parallelized version (*matmult_gpu2*)

The second individual implementation, *matmult_gpu2*, is a naïvely parallelized implementation of matrix multiplication. In practice, the threads are grouped into blocks of fixed size.

The parallelized version *matmult_gpu2* outpaces the CPU DGEMM for all sizes of chosen matrices. This demonstrates the advantage of parallelizing on a GPU vs CPU. Computational operations, such as arithmetic together with control-flow operations, are being utilized at only approximately 20% of the total capacity, with another 10% being utilized for memory operations. At the same time, the device memory is close to being fully utilized (at approx. 95% of the maximum). This directly indicates that the computational problem is memory-bound, as research also has identified [8] [9].

D. Optimized parallelized version, $O = 2$ (*matmult_gpu3*)

By simply launching a thread for each element in a matrix multiplication process, it was already possible to achieve lower run-times than the CPU reference. The next step is to further improve on this performance. The kernel *matmult_gpu3* computes the value of two neighboring elements of a resulting matrix, instead of just one.

Both computational operations and memory operations are at a much lower utilization threshold. The arithmetic operations now sit at 10% utilization. This shows a correct implementation of GPU parallelization optimizations with $O = 2$ elements of the result matrix being computed per GPU thread. Memory operations continue to be at a steady ~10% utilization rate, which is to be expected, since the size of matrices being computed is kept at identical dimensions. The device memory now is not at full operation, with its use being closer to 65% of total GPU memory. The computational problem is still memory-bound if we increase the matrix size, however memory is used more efficiently in this algorithm.

E. Optimized parallelized version, $O > 2$ (*matmult_gpu4*)

The kernel *matmult_gpu4* further extends this tactic by having each thread compute more than two neighboring points. To choose the most efficient number of neighbors to be computed per thread, the algorithm's performance was evaluated for different problem sizes. The optimal performance is achieved when the number of neighbors is between $O = 4$ and $O = 8$. $O = 4$ is selected in comparisons with future versions, since it has more stable performance. Therefore, the algorithm in this version is performing matrix multiplication with each thread computing four elements of the result matrix.

Afterwards, the runtime of all versions considered so far have been compared with each other, as well as with the baseline multithreaded CBLAS DGEMM CPU function. In terms of running time, it is seen that *matmult_gpu4* reaches the relative optimal level. *matmult_gpu2*, *matmult_gpu3* and *matmult_gpu4* all have lower runtimes than the baseline.

E. Shared-memory parallelized version (*matmult_gpu5*)

To minimize loss of performance due to memory bottlenecks, the fifth version *matmult_gpu5* of the kernel utilizes shared memory in the multiprocessor. The implementation is based on sample code in NVIDIA's CUDA Programming Guide [10], which gives a sample implementation of matrix multiplication using shared memory. This implementation has been adapted to the structure of the driver program. Similarly, as before, the running time comparison shows that *matmult_gpu5* has almost the same performance as *matmult_gpu4* with optimal number of neighbours ($O = 4$).

The total resource consumption for computational and memory operations sits somewhere between the optimal values of *matmult_gpu3* and the values of *matmult_gpu2*. It is natural to understand that, by utilizing shared memory across threads, the overall memory utilization will be increased compared to *matmult_gpu3*. This is a positive outcome since we are able to make good use of the remaining unused memory while speeding up the overall runtime of the computation.

G. NVIDIA parallelized cuBLAS version (*matmult_gpublib*)

Matrix multiplications feature a lot of independent calculations and are therefore a prime candidate for GPU acceleration [11] [12]. In order to properly assess the performance of our research code, we perform one assessment against an optimized library implementation for the GPU. NVIDIA has provided exactly such a

library in CUDA, called “cuBLAS” [6]. It behaves very similarly to the BLAS library for the CPU, with the exception that it is optimized for GPU parallelism.

3. DISCUSSION

With all six algorithms being introduced and implemented, the overall aggregated performance and speed-up is now analyzed. As per Fig. 1 and Fig. 2, all the GPU implementations performed better than the CPU baseline. The optimizations within the cuBLAS library allow it to achieve a new level of performance, compared to our earlier versions. This shows that an optimized algorithm, combined with a powerful international-standard library can take performance to almost 1.5x the potential of low-level C optimizations. The remaining bottleneck is memory. Although compute-bound in theory, all implementations discussed are still constrained by less-than-optimal utilization of caches.

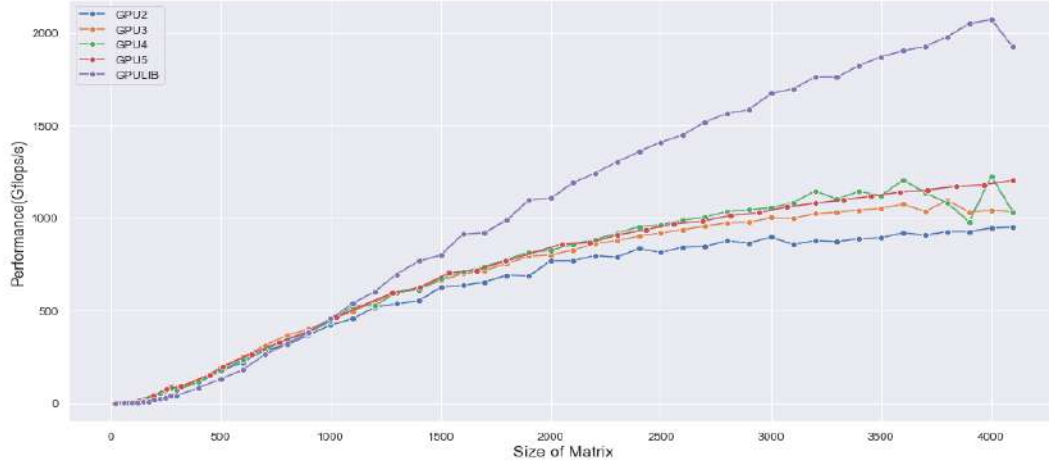


Fig. 1. Performance comparison of all GPU kernels: matmult_gpu2, matmult_gpu3, matmult_gpu4, matmult_gpu5, and matmult_gpulib

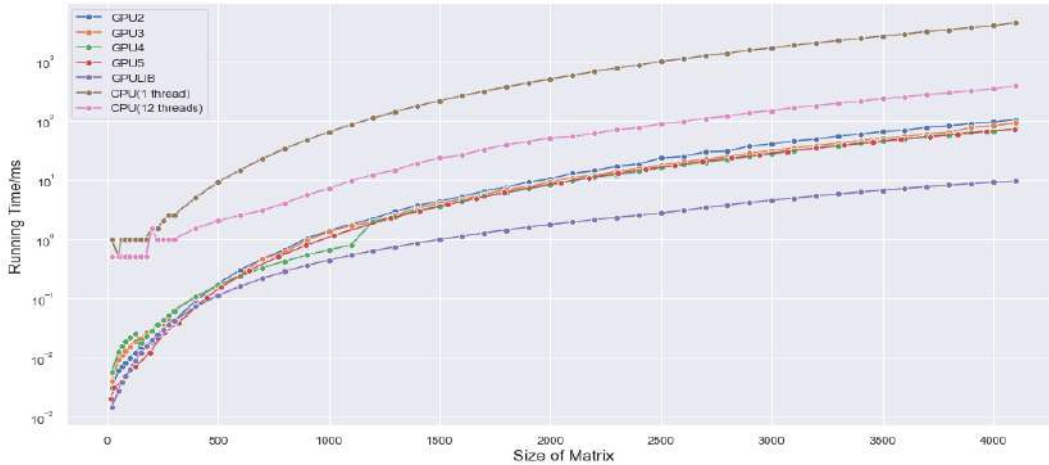


Fig. 2. Runtime comparison for matmult_gpu2, matmult_gpu3, matmult_gpu4, matmult_gpu5, matmult_gpulib against CPU baseline

Finally, a suggestion for improving our kernels is presented here. As it was verified in Fig. 1 and Fig. 2, kernel versions, blocking either for registers or for memory, are getting an overall higher throughput performance than their single-threaded counterparts. For this research, there have been implemented kernels which either do blocking of registers or blocking of memory independently. However, no version has tried to block for both types. Therefore, our next research endeavor is to create updated kernel versions, for each of these algorithms, combining both blocking methods.

CONCLUSIONS

This study systematically evaluated multiple GPU-enhanced algorithms designed to optimize large-scale, high-precision matrix multiplication, underscoring the significant performance gains achievable through GPU parallelization. The six distinct GPU implementations developed have ranged from a single-threaded baseline through various multi-threaded optimizations including multi-element-per-thread and shared-

memory approaches, culminating in an optimized implementation using the NVIDIA cuBLAS library. These algorithms were extensively benchmarked against a CPU-based multithreaded CBLAS DGEMM baseline. Results demonstrated that all GPU-based implementations outperformed the CPU baseline, with the most optimized kernels achieving speedups of up to 1.5 times, affirming the GPU's utility in enhancing performance for intensive linear algebra operations. Notably, the implementations leveraging multi-element-per-thread and shared-memory strategies showed substantial improvements in mitigating memory bottlenecks, highlighting the importance of memory optimization techniques in GPU computing. The shared-memory kernel, in particular, demonstrated effective caching of data within multiprocessors, significantly reducing runtime by improving memory access patterns and resource utilization.

Profiling, however, consistently revealed that all implementations remained memory-bound to some degree, underscoring the complexity of achieving optimal performance due to constraints related to memory bandwidth and cache utilization. Despite the theoretical expectation that large-scale matrix multiplication operations would be compute-bound, practical outcomes from this research indicated a persistent dependency on efficient cache and memory management.

The most advanced implementations, including NVIDIA's cuBLAS library, consistently highlighted the importance of highly optimized library implementations combined with careful consideration of hardware-specific features and constraints. These observations emphasize that, although GPU parallelization can significantly improve throughput, optimal performance requires meticulous tuning to the underlying hardware architecture.

Looking forward, the findings from this study suggest promising future research directions involving combined memory and register blocking techniques. Such hybrid approaches, integrating the strengths of existing individual optimization strategies, hold potential for further enhancing computational efficiency and resource management. This research, therefore, provides valuable insights and practical guidelines for future efforts in GPU-based high-performance computing optimizations, while validating the effectiveness of GPU acceleration for complex matrix operations.

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Formic acid quantification is assessed via ACQUITY UPLC H-Class PLUS System. Using ACQUITY UPLC™ BEH C18 1.7 μm 2.1 x 50mm column and LG 500 nm PDA detector set to 210 nm wavelength.

The functional unit is 1 kg of FA produced. The electricity consumption per kg captured CO_2 is approximately 2 kWh, and the electricity used in cell operation is 3.81 kWh. The electricity relies on Ontario grid electricity, which is taken to be 110g $\text{CO}_2\text{e/kWh}$. The electrode is assumed to be in service for 100 hours of continuous operation. The global warming potential of the CO_2RR process by means of CO_2 emissions is given in Table 2.

Table 2. Summary of the CO_2 emissions during the processes for CO_2RR

Material / Process	Global Warming Potential (kg CO_2 eq/kg FA)
CO_2 Capture	0.21
Electricity consumption during CO_2RR Process	0.42
CO_2 Utilization	-0.96
Production of Electrolyte	1.6
Production of Copper Electrode	0.2
Total:	1.47

3. RESULTS AND DISCUSSION

The environmental impact analysis results indicate that the global warming potential of the CO_2RR to FA process is primarily driven by CO_2 emissions during the production of the potassium bicarbonate electrolyte and electricity consumption during the CO_2RR process. The total global warming impact of the process is found to be 1.47 kg CO_2 eq/kg FA. Formic acid production via the electroreduction of CO_2 has the potential to mitigate climate change when coupled with renewable energy sources for the electricity needed, and the unconverted CO_2 is recycled into the system.

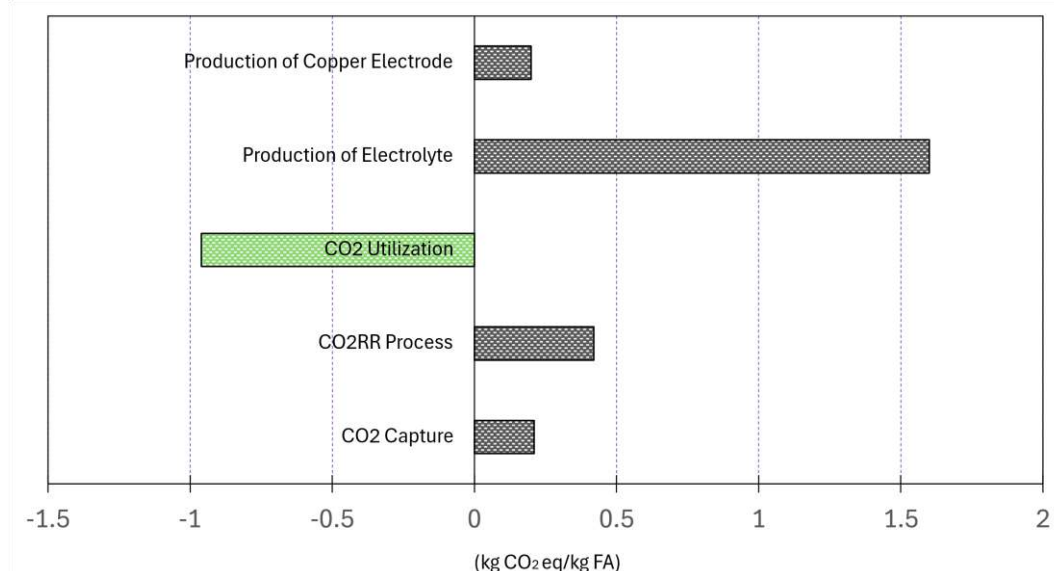


Fig. 2. Global warming potential of CO_2RR process

CONCLUSIONS

Environmental assessment is conducted from the experimental investigation of CO_2RR to FA using an H-type cell and Sn-deposited Cu mesh working electrode. A brief inventory analysis is conducted to analyze the global warming potential of the whole process from material production to formic acid production from CO_2RR . The results show that the experimental study of electrochemical reduction of carbon dioxide to formic acid has a global warming potential of 1.47 kg CO_2 eq/kg.FA, indicating that CO_2RR is an environmentally promising method to mitigate climate change.

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CONSIDERATIONS ON IDENTIFYING THE CAUSES OF FIRES IN PHOTOVOLTAIC PARKS

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ABSTRACT – PE22

In this paper, the authors have first synthesized a series of causes and risk factors related to fires involving photovoltaic systems. Then, the identification of the causes of a fire that occurred shortly (less than a month) after the commissioning of an existing photovoltaic park, installed in the South-West of Romania, was exemplified. For this purpose, the analytical method of dimensioning and verification of low-voltage consumer / prosumer power supply systems was used.

Its application consisted in checking the sizing of the low-voltage inverter power supply system (checking the section for technical restrictions; choosing the switching and protection devices of the inverter cable connection to the three-phase busbar system L1, L2, L3/N).

Keywords: Photovoltaic parks, Fires and effects, Risk factors, Causes identification, Remediation solutions

1. INTRODUCTION

The fire risk associated with photovoltaic power plants is an issue of interest to current or potential users. According to a study carried out by the Fraunhofer Institute for Solar Energy Systems [1], of the more than 2 million photovoltaic installations in Germany, only 0.006 % caused fires with major damage. Between 1995 and 2012, 400 cases of fires involving photovoltaic systems were reported in Germany, which represents less than 0.1 % of the total number of recorded fires.

With the decrease in the prices of photovoltaic panels and the launch of national financing programs in this field in Romania, but also in the context of global concerns about the transition to renewable energy, the number of photovoltaic installations has also increased in recent years.

In practice, it has been observed that most fires occur in the first year after the system is put into operation. Statistically, the summer months are associated with a higher risk of fires, and in terms of time, most occur around 12:00. Therefore, the risk is directly proportional to solar irradiation. The risk also depends on the size of the system, so the larger the photovoltaic park, the greater the number of electrical components and, implicitly, the probability of a fire.

Regarding the causes and risk factors of fires involving photovoltaic systems, the following can be listed [2]: errors of: design (wrong design of the photovoltaic installation; undersizing of cables/main DC switch; grounding problems); component manufacturing (defects in panel components, DC components - insufficient crimping or tightening of parts, bypass diodes); electrical component layout (incorrectly made connections/inserting plugs into inappropriate sockets (cross-pairing), from other manufacturers); maintenance (inappropriate or absent maintenance; damage to cables due to corrosion, aging); installation defects (incorrect installation of inverters; appearance of hot spots); external factors (damage to cables caused by insects/rodents; arid climate; floods).

The specific objectives of the paper are to develop a clear and concise methodology for identifying the causes of fires occurring in photovoltaic parks as well as to provide safe, personalized solutions to avoid the occurrence of these fires.

2. IDENTIFICATION OF THE CAUSE OF THE FIRE AT A PHOTOVOLTAIC PARK. VERIFICATION OF THE SIZING OF THE POWER SUPPLY SYSTEM OF LOW VOLTAGE INVERTERS

In this case study, the data characterizing an existing photovoltaic park installed in South-West Romania, where a fire occurred shortly (less than a month) after its commissioning, was considered. The structure and parameters of this photovoltaic park were analysed by the authors in a previously published study [3].

In this regard, on-site technical expertise was necessary to ascertain the damage caused by the fire, identifying the component equipment of the photovoltaic park installation, fully affected by the fire. These are centralized in Table 1. To identify *the cause of the fire*, we started from the on-site findings summarized in Table 1. The affected component equipment was then identified on the design documents, namely: the single-wire electrical diagram of the photovoltaic system (Fig. 2) and the connection plan of the photovoltaic panels.

After determining the location and manner of manifestation of the fire, we began by *checking for possible design errors* regarding the undersizing of the power cables. *The analytical method for sizing and checking low-voltage consumer/prosumer power supply systems* was applied for this case study [4], [5], [6]. Thus, *the main*

stages of the exemplified calculation algorithm for identifying the cause of the fire at a photovoltaic park are presented below.

Table 1. Component equipment of the photovoltaic park completely affected by the fire

Affected component equipment	Measurement unit	Quantity
Solar panels (monocrystalline photovoltaic) 580 W	pcs	6
Growatt 70 kW inverter (WWEDBGH00P series), Fig. 2	pcs	1
Data logger Growatt Wi-Fi	pcs	1
Intermediate Electric Switchboard equipped with MPR 125 A fuses and terminals for treating the null (neutral) and the earth socket, Fig. 1	pcs	1
Connectivity (connectors and accessories)	set	1
Power wiring	linear meters	700.00
Ground mounting supports for photovoltaic panels	set	1

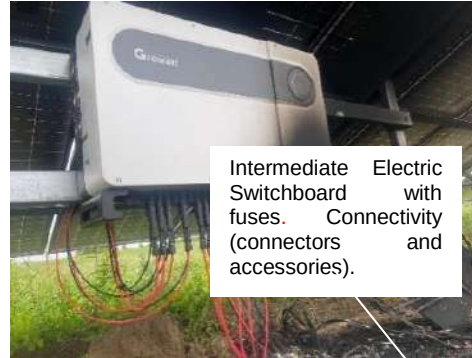


Fig. 1. Growatt 70 kW (no. 3) and Intermediate Electric Switchboard completely affected by the fire

It was found that for connecting the 6 Growatt 70 kW inverters [7] - including the affected inverter which is one of the 3 inverters (**no. 3**, no. 5 and no. 6 the most loaded, each having an installed power of $P_i = 69.6$ kW) to the three-phase busbar system (Fig. 2), ACYY-F 3X35+16 power conductor was used. In the following, the chosen section was verified, taking into account the technical restrictions.

A. Checking the section for technical restrictions

A. Thermal stability in a long-term regime

For the previously mentioned laying conditions, the three-phase cable with a cross-section per phase of $s_{th} = 35$ mm² admits a corrected thermal limit current [5], [6] calculated with the relation (1):

$$I'_{ft} = K_{CS} \cdot I_{ft} = k_{rt} \cdot k_{sol} \cdot k_{Ns} \cdot I_{ft} \quad (1)$$

where:

$I_{ft} = 120$ A; $k_{rt} = 0.95$ - plains, h less than 700 mm; $k_{sol} = 1.1$ - soils obtained in terms of composition and the limits in which their humidity varies annually (*arable soils*, clayey or sandy soils with normal humidity); $k_{Ns} = 0.63$ - three-phase cables, $N = 6$.

It is found that *the thermal stability in long-term regime is not ensured by the ACYY-F 3X35+16 type power cable* ($s_{th} = 35$ mm²) chosen by the designer (executor) because:

$$I'_{ft} = 79A < I_{ninverter} = 112.64A \quad (2)$$

Through an iterative calculation, the calculations are redone for a standardized section greater than the existing section on site $s_{th} = 35$ mm².

It is found that *the thermal stability in long-term mode will be ensured by the ACYABY 3X70+35 type power cable* ($s_{th} = 70$ mm²) *which must replace the ACYY-F 3X35+16 type power cable chosen by the designer (executor) because in this case:*

$$I'_{ft} = 115.21A > I_{ninverter} = 112.64A \quad (3)$$

B. Thermal stability in short circuit regime

It follows that the cross-section of the ACYABY 3X70+35 type power cable ($s_{th} = 70$ mm²) proposed later is thermally stable at short circuit up to $I_k = 16.7$ kA, where the fault duration is considered $t = 0.05$ s when the circuit is protected against short circuit by an electromagnetic release (the recommended technical solution).

C. Checking for voltage drop

The voltage drop on the inverter power cable in normal mode was calculated considering the length of the cable between the inverter power supply intermediate electrical switchboard and the three-phase busbar system L1, L2, L3/N to be the length of the longest and most loaded circuit (inverter distance I 6, L = 170 linear m). The value of this drop resulted 3.39 %.

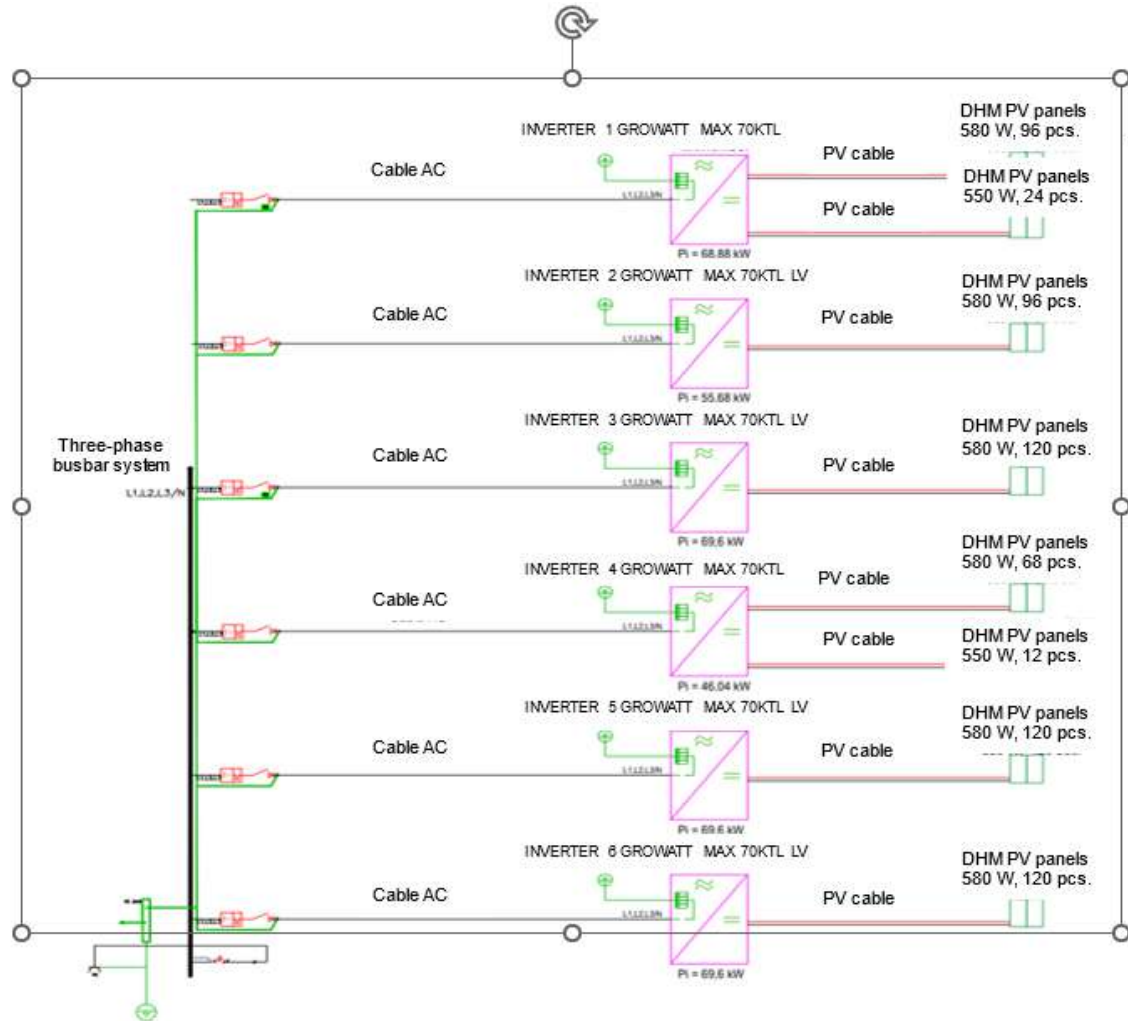


Fig. 2. Single-wire electrical diagram for supplying the photovoltaic park

The voltage drop on the photovoltaic cable (with the existing section of 4 mm^2), between the photovoltaic panels (DHM 580 W, 120 pieces) and the inverter power supply intermediate electrical switchboard, was calculated using the calculation relationships existing in the specialized literature [4], [6], [7]. Its values are centralized comparatively for the existing variant and the variant resulting from numerical modelling and simulation with the PVSOL premium 7.5 program [3], in Table 2.

It is found that the summed value of the two voltage drops is below the voltage deviation of 5 %, admissible for the three-phase busbar system L1, L2, L3/N.

Table 2. Centralizer for calculating photovoltaic cable section (dc)

Total installed power	379.4 kW (Existing variant)		379.9 kW (Simulated variant)
PV photovoltaic panel characteristics	Dahai Solar DHM72T31-580/TP	Dah Solar DHM-72x10/BF-550 W	Dah Solar DHN-72x16/DG/FS-580 W
Series	max 12 panels	max 12 panels	max 18 panels
Maximum Power (Pmax)	580 W	550 W	580 W
Maximum Power Voltage (Vmp)	44.45 V	42.40 V	43.60 V
Maximum Power Current (Imp)	13.05 A	12.97 A	13.30 A
Input parameters c.c. (MPPT) MPPT operating voltage range/Usable MPPT voltage range, Vor [V], MPP work voltage range = 200 V - 1000 V	44.45 V x 12 = 533.4 V	42.4 V x 12 = 508.8 V	43.6 V x 18 = 784.8 V
Absolute voltage drop, ΔU [V]	7.341 V	7.296 V	7.481 V
Percentage voltage drop, ΔU [%]	1.38 %	1.43 %	0.95 %
Percentage power loss, ΔP [%]			
d.c. power, $P_{c.c.}$ [W]	6961 W	6599 W	10440 W
Absolute power loss, ΔP [W]	95.795 W	94.624 W	99.501 W

3. RESULTS AND DISCUSSION

The technical expertise carried out to ascertain and remedy the damage caused by the fire at the photovoltaic park highlighted the following findings:

1) *Thermal stability in long-term regime is not ensured by the ACYY-F 3X35+16 type power conductor cable ($S_{th} = 35 \text{ mm}^2$) chosen by the designer (executor), which led to the start of the fire.*

The construction variant chosen by the designer (executor) was not intended, as recommended, to use metal copex (tube) with an outer coating of soft PVC, which is much more resistant to corrosion than the unprotected one and which is laid directly in the screed (trench).

2) *It is specified that the thermal stability in long-term operation will be ensured by the ACYABY 3X70+35 type power cable ($s_{th} = 70 \text{ mm}^2$), which must replace the ACYY-F 3X35+16 type power cable chosen by the designer (executor).*

The proposed solution technically appropriate, the ACYABY 3X70+35 type power cable is additionally - compared to the initially chosen solution - reinforced with steel tape, which thus increases its resistance to mechanical stress.

3) For the switching and protection of the circuit through which the Growatt 70 kW LV (low voltage) inverter is powered, *the designer (executor) chose the contactor variant with thermal relays and MPR (High Breaking Capacity) fuses with $I_{nf} = 125 \text{ A}$ and $I_{n \text{ socket}} = 250 \text{ A}$, which represents a possible solution for powering general switchboards provided with fuses in common cases.*

4) *It is specified that for the switching and protection of the circuit through which the Growatt 70 kW LV inverter is powered, it is recommended to choose, the automatic circuit breaker variant equipped with thermal and electromagnetic relays indicated in the case of large important consumers, for which operational safety is required, such as the one here.* The current customized solution proposed for this case is of the type of automatic circuit breakers in moulded case Ex9M2 Noark [8], Version Ex9M2S up to 250 A, $I_{cu} = 36 \text{ kA}$ (Breaking capacity).

CONCLUSIONS

Thus, it can be concluded that the fire at the photovoltaic park, which irreversibly affected a series of equipment/component materials, occurred *primarily* as a result of an abnormal operating regime of the power supply and electricity production facility - the occurrence of an electrical overload followed by a thermal overload (heating) caused by the undersizing of the section of the Growatt 70 kW inverter (WWEDBGH00P series) - Three-phase busbar system L1, L2, L3/N connecting cable, to which other aggravating elements were added, including: the adoption of inadequate electrical supply technical solutions for large prosumers, which require operational safety, such as the present one, non-compliant technical executions, etc.

In light of the findings, it is recommended to replace the affected materials, check the existing electrical installation prone to other similar incidents by replacing the non-compliant materials used.

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A COMPARATIVE STUDY ON ENERGY DENSITIES OF VARIOUS FUELS AND BATTERIES

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ABSTRACT – OE28

This study experimentally evaluates the combustion performance of solid ammonium formate (NH_4HCO_2) using a bomb calorimetric system to determine its thermochemical characteristics and energy density potential. Approximately 2 g of laboratory-synthesized ammonium formate was combusted under controlled conditions in a Parr 6775 oxygen bomb calorimeter. The results demonstrated a specific heat of combustion of 7.56 kJ.g^{-1} ($476.6 \text{ kJ.mol}^{-1}$), confirming the material's considerable energy release despite its light molecular structure.

Keywords: Ammonium formate, Solid fuel, Bomb calorimeter, Combustion heat.

1. INTRODUCTION

Solid hydrogen-rich fuels have recently attracted attention as viable energy carriers that combine high stability, safe handling, and strong combustion performance. Unlike gaseous hydrogen or volatile liquids, compact solid compounds such as ammonium formate provide an efficient route to energy storage and on-demand release under low temperature conditions [1]. Ammonium formate (NH_4HCO_2) contains chemically bound hydrogen and oxygen within a stable crystal matrix, allowing for self-sustained oxidation without the need for external catalysts. Its non-toxic nature, easy synthesis, and compatibility with existing combustion and electrochemical systems make it a promising candidate for clean-energy applications [2]. The present work focuses on the calorimetric evaluation of ammonium formate to quantify its combustion energy, evaluate its thermal stability, and compare experimental and theoretical heat-release characteristics.

2. EXPERIMENTAL METHODOLOGY

Combustion experiments were performed using a Parr 6775 bomb calorimetric assembly [3]. Roughly 2.00 g of fine ammonium formate powder was prepared by wet-chemical synthesis, dried under an ammonia atmosphere, and placed in a stainless-steel crucible. A 10 cm fuse wire provided ignition within a high-pressure oxygen environment. The calorimetric vessel was submerged in 2 kg of water to ensure isothermal heat transfer, while a thermistor probe recorded the temperature rise with a precision of $\pm 0.001^\circ\text{C}$.

Following each run, the system was purged and rinsed to remove residual gases and prevent contamination. Complete oxidation of the sample was visually confirmed, with no soot formation or unreacted residue. Table 1 summarizes the measured and derived parameters.

Table 3. Experimental data and calculated thermochemical parameters for the combustion of solid ammonium formate using an oxygen bomb calorimeter system

Parameter	Symbol	Value	Unit
Initial temperature	T_1	18.640	$^\circ\text{C}$
Final temperature	T_2	20.148	$^\circ\text{C}$
Temperature rise	$\Delta T = T_2 - T_1$	1.508	$^\circ\text{C}$
Calorimeter constant	C_{cal}	10,000	$\text{J } ^\circ\text{C}^{-1}$
Fuse-wire heat ($10 \text{ cm} \times 4.2 \text{ J.cm}^{-1}$)	q_{wire}	42	J
Sample mass	m	2.00	g
Molar mass (NH_4HCO_2)	M	63.06	g mol^{-1}
Total heat released	$Q = C_{\text{cal}}\Delta T + q_{\text{wire}}$	15,122	J
Molar heat of combustion	$q_m = q_s \times M$	476.6	kJ mol^{-1}
Heat of combustion per gram	$q_s = Q / m$	7.56	kJ g^{-1}

3. RESULTS AND DISCUSSION

The comparative evaluation between experimental and theoretical combustion results of ammonium formate is illustrated in Fig. 1. The analysis highlights the agreement and deviation between measured calorific values and the theoretical enthalpy of combustion, providing insight into the material's thermochemical stability and practical performance as a solid fuel. Comparison between the experimental and theoretical heats of combustion for ammonium formate, obtained using a calibrated Parr 6775 oxygen bomb calorimeter. The experimentally determined molar heat of combustion was $476.6 \text{ kJ mol}^{-1}$, corresponding to a specific calorific value of $7.56 \pm 0.08 \text{ kJ g}^{-1}$, while the theoretical enthalpy of combustion is $551.8 \text{ kJ mol}^{-1}$. The uncertainty was quantified based on the device specifications, including a temperature sensitivity of $\pm 0.002^\circ\text{C}$, a calorimeter constant of $10\,000 \text{ J } ^\circ\text{C}^{-1}$, and a system precision of $\pm 0.15\%$.

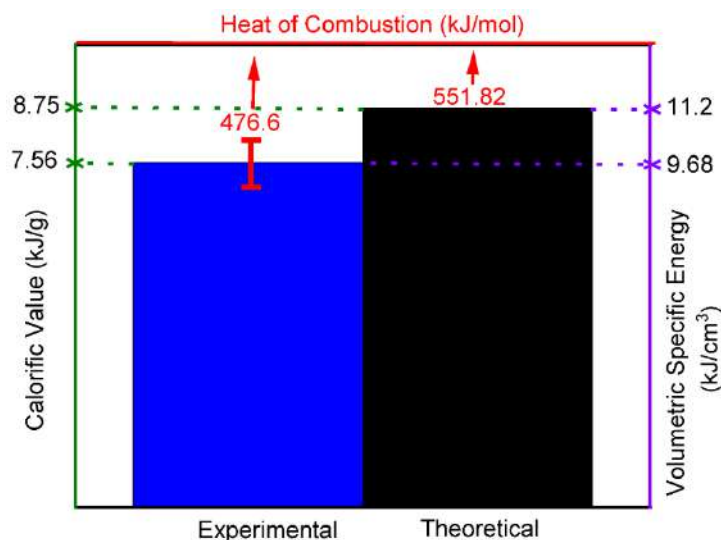


Fig. 1. Experimental vs. theoretical heat of combustion of ammonium formate

To better contextualize the volumetric and gravimetric potential of ammonium formate, Fig. 3 presents a comparative analysis of gravimetric and volumetric energy densities relative to conventional fuels and electrochemical storage systems. The results reveal that both the experimental and theoretical values of ammonium formate occupy a high-density 7.56 kJ/g (gravimetric) and 9.68 kJ/cm³ (volumetric), surpassing those of formic acid, methanol, and ethanol, and notably exceeding the energy densities of compressed hydrogen (350–700 bar), Li-ion, and Zn-air batteries on a volumetric basis.

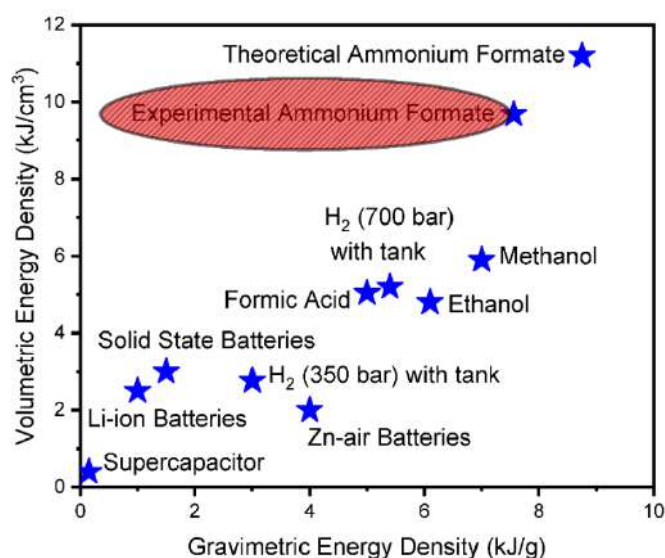


Fig. 4. Gravimetric and volumetric energy density comparison of ammonium formate with common fuels and energy storage systems

CONCLUSIONS

The calorimetric evaluation of solid ammonium formate demonstrates its high combustion efficiency and strong energy yield. The experimentally determined heat of combustion (476.6 kJ.mol⁻¹) and specific energy (7.56 kJ.g⁻¹) confirm its potential as a safe and efficient hydrogen-rich solid fuel. The close alignment between experimental and theoretical data validates the robustness of the methodology and the compound's thermal reactivity. Owing to its high volumetric energy density, non-toxic nature, and stable combustion behavior, ammonium formate stands out as a viable candidate for compact, portable, and clean energy-generation systems.

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OUTLIER DETECTION IN OZONE AND PM DATA: IDENTIFYING EXTREME POLLUTION EVENTS USING STATISTICAL, AI, AND CAUSAL APPROACHES

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ABSTRACT – OE7

Ozone (O₃) and Particle Matters (PMs) are critical air pollutants that pose risks to both human health and the environment. While average ozone and PM levels provide insights into long-term exposure, extreme pollution events often drive acute health impacts and regulatory exceedances. This study aims to develop a comprehensive framework for outlier detection in ozone and PM time series data, focusing on identifying and characterizing abnormal pollution episodes. Using multi-year hourly measurements, Statistical approaches (Interquartile Range, z-score, Seasonal-Trend decomposition), machine learning anomaly detection methods (Isolation Forest, One-Class SVM, Autoencoders), and causal context analysis with meteorological and precursor data are integrated. The methodology captures both univariate outliers (spikes in O₃ and PMs) and multivariate anomalies (O₃ and PMs events inconsistent with meteorological or precursor conditions). Case studies of detected extreme events are analyzed to explore their underlying causes, such as photochemical smog episodes, stagnation events or pollutant transport. This framework contributes to a robust air quality monitoring and provides actionable insights for early warning systems and environmental policy.

Keywords: Ozone; Particle Matters; Outlier detection; Extreme pollution events; Time series decomposition; Anomaly detection; AI approaches; Causal analysis; Air quality monitoring.

1. INTRODUCTION

Air pollution remains a critical challenge to environmental health, particularly in urban and industrial regions. Among key pollutants, ozone (O₃) and particulate matter (PM_{2.5}, PM₁₀) are known for their severe health and climatic effects. While mean or median pollutant concentrations describe long-term exposure, extreme events often represent the most harmful episodes, leading to acute respiratory issues and regulatory exceedances [1,2]. Identifying these extreme pollution events requires robust outlier detection methods that can distinguish genuine anomalies from natural variability [3]. Traditional statistical techniques such as the z-score or the Interquartile Range (IQR) are effective for basic detection but are limited in complex, seasonally varying environments. Therefore, integrating AI-based anomaly detection (e.g., Isolation Forest, One-Class SVM, Autoencoder) with causal context analysis offers a more comprehensive understanding of pollution dynamics [4]. This study proposes a hybrid framework combining statistical, machine-learning, and causal approaches to identify and interpret ozone and PM anomalies and outliers in multi-year hourly datasets. The ultimate goal is to enhance early warning systems and air quality management strategies.

2. DATA DESCRIPTION AND PREPROCESSING

2.1. Dataset

Fig. 1. presents the dataset without missing values, focusing on the shorter time period during which all variables were consistently recorded. The main aim of this analysis is to explore potential relationships between ozone, PM_{2.5}, PM₁₀, and other environmental and pollutant variables over this interval. As expected, PM_{2.5} and PM₁₀ display similar temporal trends, with their peaks and troughs closely aligned, indicating that their fluctuations are influenced by common emission sources or atmospheric dynamics.

Several factors appear to influence PM_{2.5} and PM₁₀ concentrations. Higher temperatures are generally associated with lower PM levels due to enhanced atmospheric dispersion, whereas colder periods often see increased concentrations from fossil fuel combustion for heating. Elevated relative humidity may promote secondary aerosol formation, raising PM levels, while higher wind speeds tend to disperse pollutants, reducing concentrations. Precipitation events typically lower PM values through wet deposition. Additionally, gaseous pollutants such as NO_x and SO₂ contribute to secondary PM formation, with peaks in these gases often aligning with PM increases. Ozone, linked to photochemical reactions, and volatile organic compounds (e.g., toluene, xylene, benzene) also play roles in secondary aerosol formation, suggesting that periods of elevated PM may coincide with intensified photochemical activity.

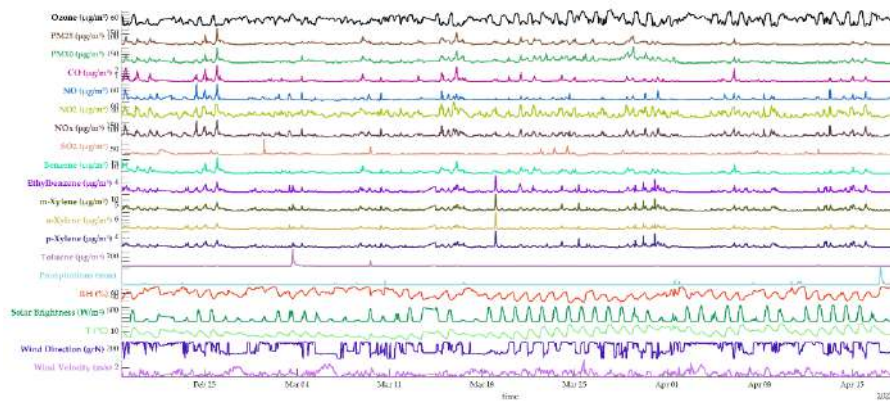


Fig. 1. Data visualization

2.2. Methodology

2.2.1. Statistical Outlier Detection. Three complementary approaches are applied: 1) Z-Score Method: Detects extreme deviations from the mean; 2) Interquartile Range (IQR): Identifies values beyond $1.5 \times IQR$ or $3 \times IQR$ thresholds; 3) STL-Decomposition Residuals: Outliers correspond to residuals significantly exceeding the seasonal variability.

2.2.2. AI-Based Anomaly Detection. An unsupervised AI-based model is trained on pollution–meteorology relationships. The model applied here is One-Class SVM (OC-SVM). This model can learn the normal data boundary and may output anomaly scores; combined results yield robust detection.

2.2.3. Causal Context Analysis. To explore the causal drivers of detected extreme events, a Granger causality test is applied to assess directional influence between pollutants and meteorological/precursor variables.

3. RESULTS AND DISCUSSION

3.1. Statistical Outliers

Fig. 2 shows the seasonal–trend decomposition (STL) of O_3 , $PM_{2.5}$ and PM_{10} . This analysis reveals distinct temporal behaviors and helps to isolate episodic extremes from expected background variations.

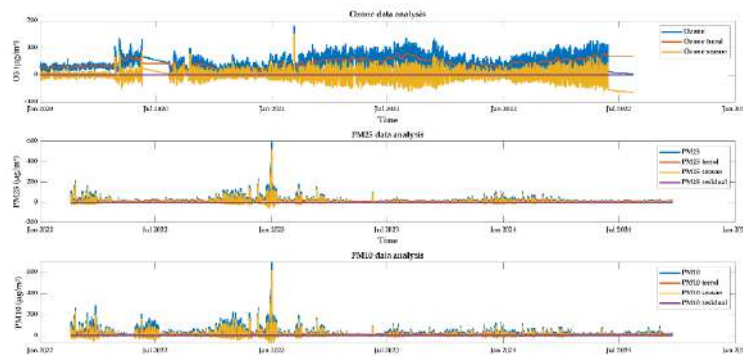


Fig. 2. STL-like decomposition for O_3 (top), $PM_{2.5}$ (middle) and PM_{10} (bottom). Blue line: observed hourly concentration. Red line: estimated trend. Yellow: estimated seasonal component. Purple: residual (observation – trend – season). Large residual spikes (outliers) indicate episodic pollution events (photochemical smog for O_3 in warm months; stagnation/combustion and transport events for PMs in cold months). Residuals are used to detect anomalies independent of trend/seasonal patterns.

For O_3 the trend component shows a gradual increase during the 2020–2022 window, with clear diurnal/daily seasonality (positive seasonal amplitudes during warm months) and strong spikes in the residuals corresponding to high-ozone episodes. These spikes align with summer months and are consistent with photochemical ozone production under elevated solar radiation and temperature.

For $PM_{2.5}$ and PM_{10} the trend components are flatter but display localized rises during winter and early-spring intervals; the seasonal components show positive excursions at specific hours/days consistent with recurrent emission/meteorological patterns (e.g., morning/night heating, lower boundary-layer depth). The residual panels highlight large particulate episodes (notably the prominent event in early 2023), where residual magnitudes greatly exceed typical seasonal variability — indicating exceptional pollution events likely due to stagnation, increased emissions (heating, biomass burning), or episodic transport/dust intrusions. Compared to ozone, particulate residuals exhibit larger amplitude extremes and more frequent winter clustering.

Overall, decomposition shows that: 1) Ozone extremes are primarily photochemical (summer peaks) and visible as large positive residuals on top of a seasonal high; 2) PM extremes concentrate in colder months and are tied to stagnant conditions and emission surges (coincident $PM_{2.5}$ & PM_{10} peaks suggest common

sources or transport). 3) Residual-based thresholding (e.g., $|\text{residual}| > 3\sigma$) is an effective way to identify anomalous pollution episodes after removing trends and seasonality.

3.2. AI-Based Anomaly Detection Using One-Class SVM

An advanced anomaly detection approach based on the One-Class Support Vector Machine (OCSVM) was applied to the time series of ozone (O_3), $\text{PM}_{2.5}$, and PM_{10} to identify periods of abnormal air pollution behavior. **Fig. 3** illustrates the detection results, where the measured concentrations are plotted alongside the detected anomalies and corresponding anomaly scores.

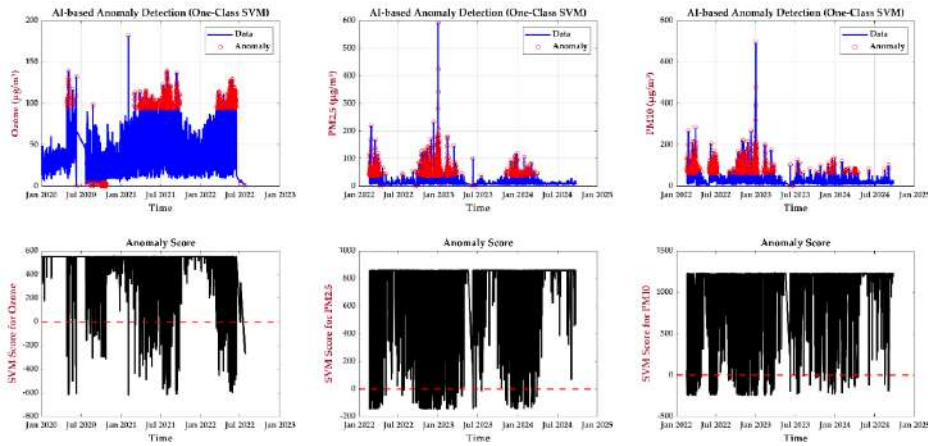


Fig. 3. AI-based anomaly detection (One-Class SVM) applied to O_3 , $\text{PM}_{2.5}$, and PM_{10} . Upper panels show observed data (blue) with anomalies (red circles). Lower panels depict anomaly scores, where negative values (below the red dashed line) indicate deviations from normal behavior.

For ozone, anomalies were predominantly observed during the summer months, notably in mid-2021 and mid-2022. These periods coincide with enhanced solar radiation and temperature, which intensify photochemical reactions leading to ozone accumulation. In contrast, low-level anomalies detected in early 2020 may be attributed to changes in emission patterns or instrumental calibration effects. The anomaly scores indicate strong deviations during high-ozone episodes, reflecting the sensitivity of OCSVM to photochemical extremes. Conversely, $\text{PM}_{2.5}$ and PM_{10} exhibited anomalous behavior mainly in winter and early spring, particularly during late 2022 and early 2023. These anomalies are linked to atmospheric stagnation, domestic heating, and reduced dispersion capacity under cold and stable conditions. The concurrent occurrence of $\text{PM}_{2.5}$ and PM_{10} anomalies suggests the influence of common emission sources and possibly dust resuspension events. Overall, the OCSVM model effectively discriminated between typical and extreme pollution events by adapting to nonlinear boundaries in the data space. These findings highlight its potential for real-time air quality monitoring and early warning systems to identify severe pollution episodes beyond conventional statistical thresholds.

3.3. Granger Causal Analysis

Table 1 provides a summary of Granger causality analysis applied to the three variables: Ozone, $\text{PM}_{2.5}$ and PM_{10} . From this table, we can derive the insights below.

A) Ozone as Dependent Variable ($\text{Ozone} \leftarrow \text{others}$). Strong causal influences were detected from most air pollutants and meteorological parameters: 1) Pollutants with significant causal influence ($p < 0.001$): $\text{PM}_{2.5}$, PM_{10} , CO, NO, NO_2 , NO_x , SO_2 , Benzene, Ethylbenzene, m-Xylene, o-Xylene, p-Xylene. 2) Meteorological variables with significant influence: Relative Humidity (RH), Solar Brightness, Temperature (T), Wind Direction, Wind Velocity. 3) Non-significant variables: Toluene ($p = 0.296$), Precipitations ($p = 0.758$). Conclusion: Ozone dynamics are strongly linked with nitrogen oxides (NO, NO_2 , NO_x) and solar brightness, confirming the expected photochemical formation of ozone. RH and temperature also contribute significantly.

B) $\text{PM}_{2.5}$ as Dependent Variable ($\text{PM}_{2.5} \leftarrow \text{others}$). Multiple significant Granger causes were found: 1) Strong/Moderate causal influences ($p < 0.05$): PM_{10} , Ozone, CO, NO, NO_2 , NO_x , SO_2 , Benzene, Ethylbenzene, m-/o-/p-Xylene, RH, Solar Brightness, Temperature, Wind Direction, Wind Velocity; 2) Non-significant variables: Toluene ($p = 0.545$), Precipitations ($p = 0.994$). Conclusion: $\text{PM}_{2.5}$ levels are affected by gaseous pollutants (NO_x , CO, SO_2) and meteorological factors, suggesting complex atmospheric interactions and secondary aerosol formation.

C) PM_{10} as Dependent Variable ($\text{PM}_{10} \leftarrow \text{others}$). Moderate to strong causality observed for several pollutants and meteorological parameters: 1) Significant causal influences ($p < 0.05$): Ozone, CO, NO, NO_2 , NO_x , SO_2 , Benzene, Ethylbenzene, RH, Solar Brightness, Temperature, Wind Direction, Wind Velocity; 2) Non-significant variables: $\text{PM}_{2.5}$ ($p = 0.175$), m-/o-/p-Xylene ($p > 0.05$), Toluene ($p = 0.747$), Precipitations ($p = 0.994$). Conclusion: PM_{10} is influenced mainly by gaseous pollutants and weather parameters, while the relationship with $\text{PM}_{2.5}$ and aromatic hydrocarbons appears weak or indirect.

Table 1. Granger Causality Test Results (Dependent variables: Ozone, PM2.5 and PM10, lag = 3)

Granger Causality Test for Ozone			Granger Causality Test for PM _{2.5}			Granger Causality Test for PM ₁₀		
Variable	F-Stat	p-Value	Variable	F-Stat	p-Value	Variable	F-Stat	p-Value
PM ₂₅	3.370442	0.017918	PM ₁₀	3.370442	0.017918	PM ₂₅	1.654105	0.175115
PM ₁₀	39.43492	0	Ozone	39.43492	0	Ozone	39.35155	0
CO	15.16109	1.04E-09	CO	15.16109	1.04E-09	CO	11.02763	3.73E-07
NO	2.669779	0.046245	NO	2.669779	0.046245	NO	4.258377	0.005283
NO ₂	48.62826	0	NO ₂	48.62826	0	NO ₂	41.76406	0
NO _x	22.40993	3.65E-14	NO _x	22.40993	3.65E-14	NO _x	22.98034	1.64E-14
SO ₂	5.973535	0.000481	SO ₂	5.973535	0.000481	SO ₂	5.455168	0.000997
Benzene	34.75338	0	Benzene	34.75338	0	Benzene	13.54233	1.04E-08
Ethylbenzene	8.762156	9.33E-06	Ethylbenzene	8.762156	9.33E-06	Ethylbenzene	3.707326	0.011297
m-Xylene	5.61724	0.000794	m-Xylene	5.61724	0.000794	m-Xylene	2.100541	0.098351
o-Xylene	5.632667	0.000777	o-Xylene	5.632667	0.000777	o-Xylene	2.329052	0.072802
p-Xylene	4.98166	0.001932	p-Xylene	4.98166	0.001932	p-Xylene	1.98345	0.11459
Toluene	0.711539	0.54512	Toluene	0.711539	0.54512	Toluene	0.408315	0.747052
Precipitations	0.028546	0.9935	Precipitations	0.028546	0.9935	Precipitations	0.026869	0.994055
RH	18.23116	1.34E-11	RH	18.23116	1.34E-11	RH	10.34083	9.91E-07
Solar Brightness	10.33224	1.00E-06	Solar Brightness	10.33224	1.00E-06	Solar Brightness	10.6185	6.67E-07
T	26.06155	2.22E-16	T	26.06155	2.22E-16	T	22.47716	3.33E-14
Wind Direction	13.78782	7.35E-09	Wind Direction	13.78782	7.35E-09	Wind Direction	13.82443	6.98E-09
Wind Velocity	8.360909	1.65E-05	Wind Velocity	8.360909	1.65E-05	Wind Velocity	9.213916	4.91E-06

CONCLUSIONS AND FUTURE WORK

This study demonstrated a comprehensive outlier detection framework that integrates statistical, AI-based, and causal tools for ozone and PM anomaly analysis. Key findings include: 1) Classical methods are efficient for detecting extreme spikes. 2) AI approaches capture multivariate and nonlinear anomalies. 3) Causal analysis contextualizes anomalies and supports physical interpretation. Table 2 summarizes the key findings for the Granger Causality Test.

Table 2. Granger Causality Analysis: Overall Interpretation

Dependent Variable	Strongest Influences	Meteorological Drivers	Weak/No Influence
O ₃	NO, NO ₂ , NO _x , CO, Solar Brightness	RH, T, Wind	Toluene, Precipitations
PM _{2.5}	NO _x , CO, SO ₂ , Ozone, Benzene	RH, T, Wind	Toluene, Precipitations
PM ₁₀	O ₃ , NO _x , NO ₂ , CO	RH, T, Wind	PM _{2.5} , Toluene, Precipitations

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MULTILAYER NANOCOMPOSITE COATINGS FOR ENHANCED EXERGY EFFICIENCY IN CONCENTRATED SOLAR POWER SYSTEMS

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ABSTRACT – PE4

The efficiency and long-term performance of Concentrated Solar Power (CSP) systems are highly dependent on the thermal and optical stability of their functional surfaces. This research investigates the development and application of multilayer nanocomposite coatings designed to enhance energy efficiency in CSP plants. By integrating nanoscale ceramic–metal composites into multilayer structures, the coatings exhibit superior solar absorptance, optimized thermal emissivity, and improved resistance to high-temperature oxidation and wear. Experimental evaluations demonstrate improvement of solar energy absorption and irreversible energy losses, leading to improved overall system performance. Furthermore, the durability of these coatings extends component lifetimes and reduces maintenance frequency, supporting sustainability and cost-effectiveness. The study emphasizes how smart surface engineering through multilayer nanocomposites contributes to clean energy conversion, resource efficiency, and the advancement of renewable technologies, aligning directly with global objectives for green power generation and sustainable development.

Keywords: Multilayer nanocomposite coatings, concentrated solar power (CSP); energy efficiency; renewable energy systems, energy sustainability

1. INTRODUCTION

Concentrated Solar Power (CSP) technologies are poised to play a pivotal role in dispatchable renewable electricity generation, particularly when coupled with thermal energy storage. The overall efficiency and levelized cost of energy of CSP plants are governed not only by optical design and thermodynamic cycle choices, but critically by the durability and performance of functional surfaces exposed to extreme operating environments. Receiver tubes, cavity absorbers, heliostat mirrors, and intermediate heat-transfer interfaces experience cyclic thermal loads (500–800°C and beyond), oxidative and corrosive atmospheres, particle-laden flow in some receiver concepts, and mechanical wear due to thermal expansion mismatch and environmental abrasion. Under these conditions, conventional surface treatments often suffer from degradation pathways that include oxidation, sintering, phase instability, emissivity drift, and microcracking, all of which increase optical and thermal irreversibility's and diminish exergy efficiency [1, 2].

Minimizing entropy generation across the optical–thermal conversion chain is central to advancing CSP performance. On the optical side, high solar-band absorptance in the 0.3–2.5 μm range reduces reflection losses at the receiver surface, while on the thermal side, low mid- to far-infrared emissivity curtails radiative heat losses at elevated temperatures. Achieving this delicate balance is complicated by the need for thermochemical robustness, adhesion to metallic substrates (e.g., stainless steels, Ni-based alloys), compatibility with thermal cycling, and manufacturability at scale. Single-layer coatings rarely deliver the necessary combination of spectral selectivity and durability, motivating multilayer strategies that decouple and optimize distinct functions—optical absorption, thermal management, environmental protection, and mechanical compliance—within a single architectural stack [3, 4].

Nanocomposite materials provide an additional degree of freedom by leveraging nanoscale phase dispersion to tailor effective optical constants, thermal transport, and damage tolerance. In particular, ceramic–metal (“cermet”) nanocomposites enable tunable plasmonic and dielectric responses through control of metallic volume fraction, particle size distribution, and matrix composition, allowing enhanced solar absorptance without a commensurate rise in thermal emissivity. When integrated into multilayer architectures—e.g., an anti-reflective topcoat, a cermet absorber layer, a diffusion barrier, and an oxidation-resistant overlayer—these systems can be engineered to suppress Fresnel losses, confine absorption within the solar spectrum, and impede oxygen ingress and interdiffusion at high temperature. Such designs aim to reduce irreversible energy losses at the receiver surface, thereby improving solar-to-thermal exergy conversion and contributing directly to higher receiver and plant efficiencies.

Despite promising developments, key knowledge gaps remain. These include: robust correlations between nanoscale morphology and high-temperature optical constants; long-duration oxidation and sintering behavior under CSP-relevant atmospheres; adhesion and residual stress evolution across multilayer interfaces during rapid thermal cycling; and scalable, cost-effective deposition methods compatible with complex geometries. Addressing these gaps requires a combined approach of materials design, process optimization, and performance validation under realistic operating conditions. Li, W., et al. High-temperature stable antireflection coatings for solar thermal applications. [5, 6].

This study investigates multilayer nanocomposite coatings that integrate ceramic–metal nanoscale phases within functionally differentiated stacks to enhance CSP exergy efficiency. We report on: (i) composition–microstructure–property relationships that govern solar absorptance and thermal emissivity; (ii) strategies to mitigate oxidation, wear, and diffusion-driven degradation at elevated temperatures; and (iii) experimental evaluations demonstrating reduced optical and thermal irreversibility's, extended component lifetime, and decreased maintenance frequency. By aligning surface engineering with exergy-based performance metrics, the work advances durable, high-performance coatings that improve energy yield and support the sustainability and cost-effectiveness of next-generation CSP plants, in line with global objectives for clean power and sustainable development.

2. MATERIALS AND METHODS

Heat-resistant 10CrMo9 steel is widely deployed in high-temperature pressure components where oxidation, erosion, and thermal cycling drive surface degradation and exergy losses. Applying an Al_2O_3 – 3TiO_2 ceramic topcoat via high-velocity oxy-fuel (HVOF) spraying provides an effective barrier to these damage mechanisms by combining alumina's chemical/thermal stability with TiO_2 -induced improvements in toughness and inter-splat cohesion [7, 8].

HVOF—particularly in suspension form (S-HVOF)—enables dense, fine-microstructured alumina–titania layers at relatively low substrate heat input. A typical architecture comprises a compliant metallic bond coat (e.g., NiCr or MCrAlY, 50–150 μm) to bridge the coefficient of thermal expansion mismatch between the ceramic ($\approx 8\text{--}9 \times 10^{-6} \text{ K}^{-1}$) and 10CrMo9 steel ($\approx 12\text{--}14 \times 10^{-6} \text{ K}^{-1}$), followed by a 100–300 μm Al_2O_3 – 3TiO_2 topcoat [9].

Surface preparation entails degreasing, aggressive grit blasting to achieve $R_a \approx 4\text{--}6 \mu\text{m}$, and controlled preheating ($\approx 100\text{--}200^\circ\text{C}$) to reduce quench stresses. During deposition, high particle velocities and carefully tuned flame stoichiometry promote splat densification while limiting substrate overheating and phase decomposition. Suspension feedstocks (submicron particles in ethanol/water) are preferred for ceramics, achieving porosity levels $\approx 1\text{--}3\%$ and smoother as-sprayed surfaces relative to powder HVOF [10, 11].

The resulting microstructure is lamellar with limited porosity and microcracking; $\gamma\text{-Al}_2\text{O}_3$ predominates due to rapid quenching, while TiO_2 is present as rutile dispersed at splat boundaries, enhancing cohesion and crack deflection. Adhesion is governed by mechanical interlocking and bond coat compatibility; pull-off strengths $>40 \text{ MPa}$ are attainable. Residual stresses are managed by thin passes, forced cooling, and the compliant bond coat. Optional post-deposition sealing (silica/phosphate or hybrid) further reduces permeability and improves resistance to steam and salt ingress. [12, 13].

In service ($\approx 500\text{--}600^\circ\text{C}$), the alumina-rich coating suppresses oxygen transport and inhibits formation/spallation of Fe- and Cr-rich scales on the steel. The dense HVOF microstructure confers superior erosion resistance compared to atmospheric plasma spray analogs—critical in particle-laden or high-velocity flows. Thermal cycling durability hinges on adhesion, controlled porosity, and microstructural compliance; S-HVOF's fine, strain-tolerant features are advantageous. Limited $\gamma \rightarrow \alpha$ alumina transformation during exposure can densify the coating and strengthen the oxygen barrier, albeit with increased stiffness that underscores the importance of a bond coat and controlled thickness [14].

Properly engineered Al_2O_3 – 3TiO_2 coatings deposited by HVOF on 10CrMo9 deliver a robust, low-permeability ceramic barrier with high erosion resistance and cycling tolerance, extending component life and stabilizing high-temperature performance in aggressive boiler and CSP-adjacent environments [15].

A PerkinElmer Lambda 950 UV–Vis–NIR spectrophotometer was employed to characterize the coatings' optical response—measuring solar absorptance, thermal emittance, and spectral transmittance across the UV and visible ranges. These data are essential for assessing anti-reflective behavior and overall effectiveness in solar energy conversion.



Fig. 1. Lambda 950 spectrometer

3. RESULTS AND DISCUSSION

Comprehensive optical characterization of alumina–titania coatings on heat-resistant special steel was conducted by UV–Vis–NIR spectrophotometry, acquiring percent reflectance (%R) spectra. Across multiple

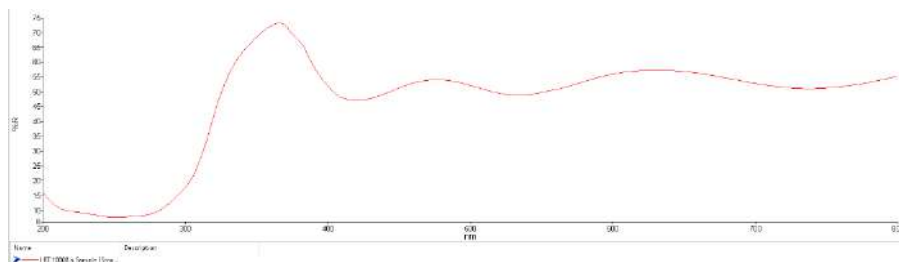
samples, alumina–titania coatings are tuned toward the near-UV, not the visible. Most show a deep UV minimum (8–25% at ~260–280 nm) followed by a strong peak near 360–370 nm.

In the visible (450–800 nm), reflectance typically stays high: ~40–60% for many samples, with only modest minima in the blue (400–430 nm) and broad rises toward the red/NIR.

Spectral shapes are smooth with weak fringes, consistent with single layers, moderate/low index contrast, and generally decent but not ideal thickness uniformity.

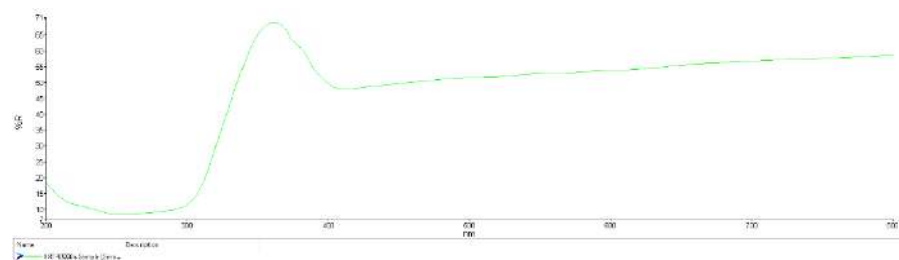
For solar/visible applications this is suboptimal, limiting photon coupling. Recommended fixes: retune optical thickness to place the main minimum near 540–560 nm; use two-layer or graded-index AR stacks to broaden the low-R band; determine n and k by ellipsometry and optimize via transfer-matrix methods to target <20–25% R across 450–650 nm.

The reflectance spectrum reveals that the alumina–titania coating provides limited anti-reflective performance across the visible range. Reflectance is lowest in the near-UV, dipping to roughly 8–10% around 260–280 nm, but it rapidly climbs to a strong peak near 365 nm, reaching about 72–73%. Beyond 400 nm, the spectrum settles into a high, slowly varying plateau between roughly 50% and 57% from green to near-infrared wavelengths. Gentle undulations across this region suggest thin-film interference effects and possible thickness non-uniformity.



For solar-energy applications, this behavior is suboptimal because high reflectance from 450 to 800 nm limits photon coupling into the absorbing substrate, reducing potential solar absorptance. The spectral peak near 365 nm implies the optical thickness is tuned toward the near-UV rather than the visible band. Improving performance would require retuning the optical thickness to shift the destructive-interference minimum into the 500–600 nm region and smoothing ripple through better thickness control or a multi-layer AR design. In short, while the coating absorbs effectively in the near-UV, it remains too reflective across most of the visible spectrum for efficient solar harvesting without design adjustments.

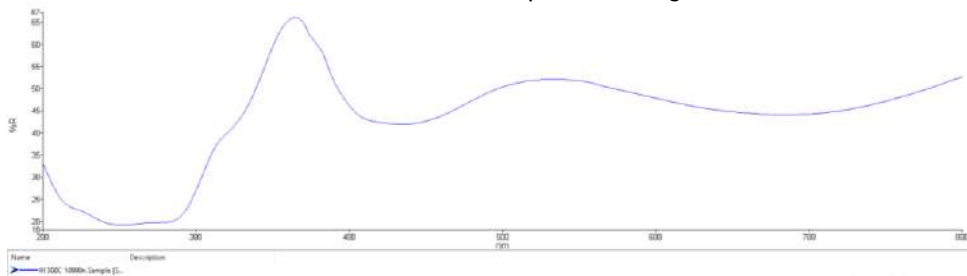
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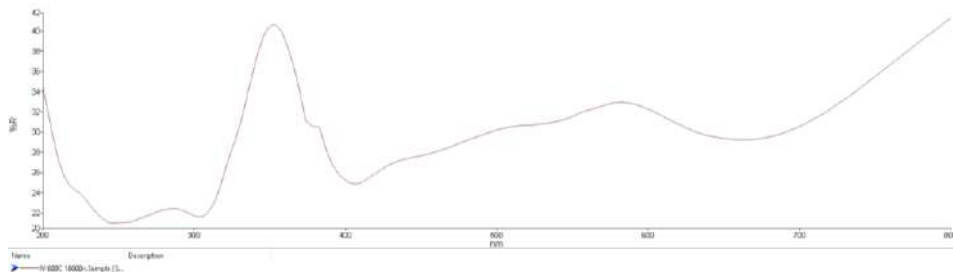
The reflectance spectrum shows that the alumina–titania coating is tuned toward the near-UV rather than the visible range. Reflectance drops to roughly 20% around 270–280 nm, evidencing strong UV absorption, but rises sharply to a peak near 365 nm at about 66–67%. Across the visible band, performance is only moderate: a broad minimum of ~41–43% appears near 400–430 nm, followed by a gentle rise to ~51–52%

around 500–560 nm, a shallow dip near 700 nm (~45–46%), and a final increase to ~53% by 800 nm. These smooth undulations reflect thin-film interference with acceptable, though not ideal, thickness uniformity.



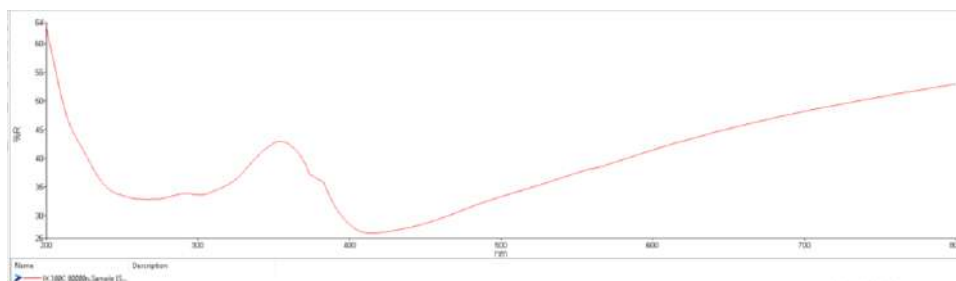
For solar-harvesting applications, such a profile limits photon coupling because reflectance remains ~45–52% through most of the visible. Improving efficacy requires retuning the optical thickness to place the principal minimum near 550 nm and, preferably, adopting a two-layer or graded-index design to broaden the low-reflectance band across 450–700 nm. Ellipsometry determination of n and k , followed by transfer-matrix optimization, would guide precise thickness targets and suppress the unwanted UV peak.

The reflectance spectrum indicates that this alumina–titania coating performs better as an antireflective layer than previous samples, yet remains short of optimal tuning for the visible band. Reflectance falls to about 21–22% in the near-UV, then rises to a peak near 365 nm at roughly 40–41%. Within the visible, the curve drops to a favorable minimum around 400–410 nm at ~25–26%, but subsequently forms a broad hump centered near 580–600 nm (~33–34%) and climbs again past 700 nm, reaching ~40% by 800 nm.



These smooth undulations reflect thin-film interference with reasonable thickness uniformity; however, the principal minimum lies in the blue rather than near 550 nm, where solar applications would benefit most. Shifting the optical thickness slightly upward—or adopting a two-layer or graded-index stack—should translate the low-reflectance band toward the green and suppress the red/NIR rise, targeting sub-20% reflectance across 450–650 nm.

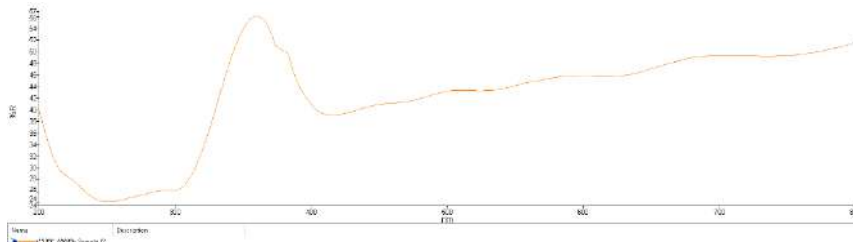
The measured reflectance spectrum shows modest antireflective performance, with values ranging from roughly 26% to 54% across 300–800 nm. After beginning high in the near-UV, the curve falls to a shallow minimum near 320–330 nm (~33%), rises to a local peak around 365 nm (~44–45%), and reaches its best minimum at 405–420 nm (~26–27%). Beyond 450 nm, reflectance increases monotonically, approaching ~54% by 800 nm. The smooth, low-fringe profile suggests a single-layer film with reasonable thickness uniformity whose optical thickness is tuned to the violet–blue region rather than the center of the visible spectrum.



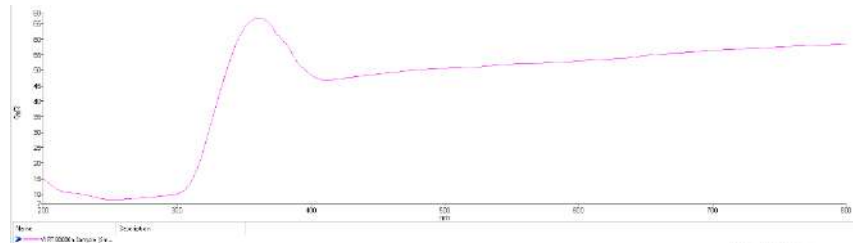
For solar applications, this misalignment limits photon coupling in the green–red bands. Retuning the optical thickness to place the minimum near 550 nm or adopting a dual-layer/graded-index design would broaden the low-reflectance band and suppress the rise toward the red/NIR.

The measured reflectance spectrum reveals a coating tuned toward the near-UV rather than the visible band. Reflectance drops from about 40% to a low near 25% around 260–280 nm, then surges to a pronounced peak of roughly 56–57% near 350–360 nm. In the visible, performance is modest: the best minimum appears around 405–420 nm at ~39–40%, after which the curve rises almost monotonically, hovering near 47–48%

through 600–700 nm and reaching ~50–52% by 800 nm. The smooth, weakly undulating profile suggests a single layer or low index-contrast stack with reasonable thickness uniformity, but the optical thickness places the principal minimum too far into the blue.

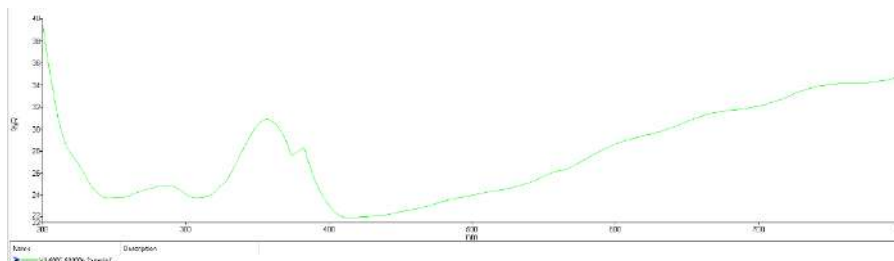


For improved solar-visible coupling, the coating should be retuned to center its minimum near 550 nm—by increasing optical thickness—or re-engineered as a two-layer or graded-index design. Ellipsometry extraction of n and k followed by transfer-matrix optimization can target sub-20–25% reflectance across 450–650 nm. The reflectance spectrum shows a coating tuned to the near-UV rather than the visible. Reflectance falls to an excellent minimum of about 8–9% near 260–280 nm, then climbs steeply after 300–320 nm to a strong peak around 360–370 nm at roughly 65–66%. From 420 nm through 800 nm the curve remains high and rises slowly, hovering near 50% in the blue-green and approaching 58–59% by 800 nm. The smooth, low-fringe profile suggests a single layer with optical thickness poorly matched to the visible, or a low index contrast to the substrate.



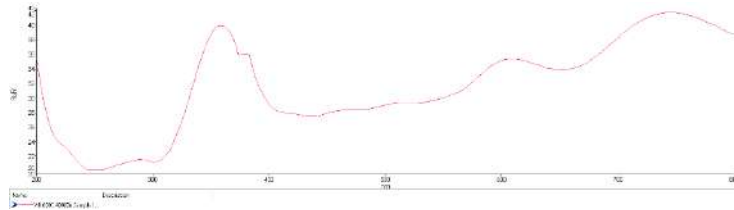
For visible or solar applications this is inadequate: the principal minimum should be centered near 550 nm. Increasing the optical thickness to the quarter-wave at 550 nm, or adopting a dual-layer/graded-index design, informed by ellipsometric n and k and transfer-matrix optimization, could reduce reflectance to below 20–25% across 450–650 nm.

The reflectance spectrum indicates a modest antireflective coating that performs best in the violet–blue but not in the central visible range. After starting near 40% in the deep UV, the curve falls to about 24% around 260–280 nm, shows a small hump near 300 nm, then forms a moderate peak at 360–370 nm around 30–31%. The best minimum occurs near 400–420 nm at roughly 22–23%. Beyond 450 nm, reflectance rises steadily—about 25% at 500 nm, 30% at 600 nm, and 35–36% by 800 nm—revealing that the interference minimum is tuned too far into the blue. The smooth, low-fringe profile points to a single layer or low index contrast with good thickness uniformity.



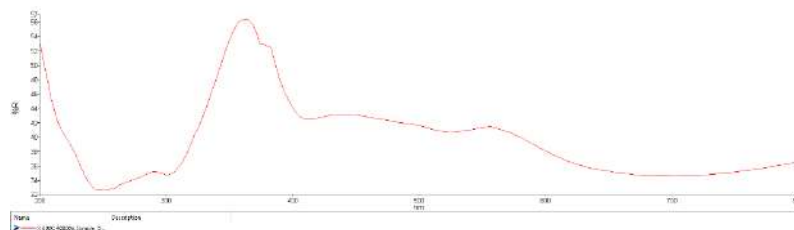
To improve visible performance, the optical thickness should be increased to place the minimum near 550 nm, or a two-layer/graded-index design should be used, guided by ellipsometric n and k and transfer-matrix optimization, with a target below 20% reflectance across 450–650 nm.

The reflectance curve shows a moderately antireflective film tuned to the UV–blue rather than the central visible. Reflectance drops from about 35% to a minimum near 20% at 260–280 nm, then rises to a strong peak around 350–370 nm (~40%), with a shoulder near 380–390 nm. In the visible blue it dips again to about 28–29% between 400 and 450 nm, but from there increases steadily: an inflection around 600–620 nm (~35–36%), a broad maximum near 730–750 nm (~41–42%), and a slight decline toward 800 nm.



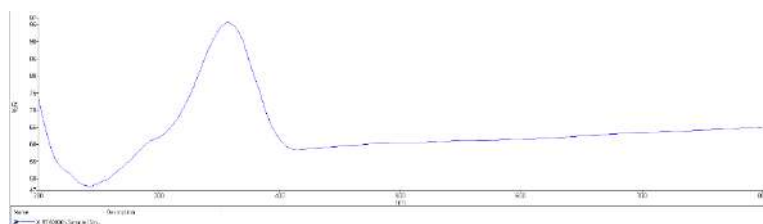
The broad, moderate fringes suggest a single, fairly uniform layer with medium index contrast. Because the main minimum sits in the violet–blue, the coating leaves 30–40% reflectance across the green–red, limiting visible/solar coupling. Improving performance requires increasing the optical thickness to place the quarter-wave minimum near 540–560 nm or adopting a two-layer/graded-index design, guided by ellipsometric n and k and transfer-matrix optimization, to target below 20–25% across 450–650 nm.

The reflectance spectrum indicates a modest antireflective film that is tuned too far into the blue. After falling from about 52% to a minimum near 32–33% around 260–280 nm, the curve surges to a strong peak of roughly 56% at 360–370 nm, with a shoulder near 380–390 nm. Through 400–500 nm it declines toward 42–44% and then slopes downward into the red, reaching a broad minimum of about 34–35% around 700–720 nm before slightly rising to ~36–37% at 800 nm. The broad, smooth fringes suggest a single, uniform layer with moderate index contrast, but reflectance remains above 40% across much of the visible, limiting transmission. To improve performance, the optical thickness should be increased to place the principal quarter-wave minimum near 540–560 nm, or redesigned as a two-layer or graded-index stack.



Ellipsometric determination of n and k followed by transfer-matrix optimization can target below 20–25% reflectance across 450–650 nm.

The reflectance spectrum shows an extremely reflective film with poor antireflective behavior in the visible. After a brief drop from about 72% to a minimum near 48–49% around 260–280 nm, the curve rises sharply to a dominant peak near 360–370 nm at roughly 94–95%. It then falls toward ~72% around 400 nm and settles into a high, slowly rising plateau from 420 to 800 nm, staying roughly 58–66% and reaching ~66% at 800 nm. The smooth, weakly fringed profile suggests a single layer with low index contrast or damping that suppresses interference, and the optical thickness is clearly tuned to the UV rather than the green. To make the coating useful in the visible, the optical thickness should be increased to place the principal minimum near 540–560 nm, or the design should shift to a two-layer or graded-index stack.



Ellipsometric extraction of n and k followed by transfer-matrix optimization can target sub-20–25% reflectance across 450–650 nm.

CONCLUSIONS

Single-layer alumina–titania coatings are systematically mis-tuned to the near-UV. Their principal interference minima occur at 260–420 nm, leaving high reflectance (≈ 40 –60%) across 450–800 nm where CSP receivers must absorb. This spectral mismatch lowers solar absorptance and, consequently, exergy efficiency.

The smooth, weakly fringed spectra indicate low/medium index contrast and generally uniform but suboptimal thickness control—insufficient to engineer broadband destructive interference in the visible–NIR.

For CSP optics and receiver windows, a multilayer nanocomposite approach is required:

- Recenter the quarter-wave condition near 540–560 nm and distribute additional minima across 450–800 nm using alternating high/low-index layers.

- Use graded-index or nanoporous/compact nanolaminate stacks (e.g., TiO₂-rich high-*n* with Al₂O₃/SiO₂ low-*n*) to broaden bandwidth and suppress ripple, targeting <20–25% reflectance over 450–650 nm and low emissivity in the mid-IR.
 - Implement dispersion-aware designs (*n*, *k* from ellipsometry) and transfer-matrix optimization to manage both amplitude and phase across the solar spectrum.
- Manufacturing implications for exergy gains:
- Tight thickness control (<2–3% layer error) is essential; observed undulations suggest current variability that degrades spectral selectivity.
 - Nanocomposite tuning (filler fraction, porosity, and multilayer period) offers a practical lever to achieve higher index contrast without excessive absorption.
 - Durability (thermal cycling, UV stability) must be co-optimized; Al₂O₃/TiO₂ stacks are promising but should be capped with robust, low-*n* overcoats.

Expected system impact: Shifting from single-layer UV-tuned films to optimized multilayer nanocomposites will increase solar photon coupling in the visible, reduce optical exergy losses at the receiver, and improve overall CSP efficiency, especially under high concentration where reflection penalties compound.

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SUSTAINABLE ADVANCED MATERIALS FOR SOLID-STATE SODIUM-ION BATTERIES: AN EFFICIENT, SAFE AND ECO-FRIENDLY ENERGY STORAGE SYSTEM – 4SIBAT

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ABSTRACT – PE27

4SIBAT Sustainable advanced materials for Solid-State Sodium-Ion BAtteries: an efficient, safe and eco-friendly energy storage system Solid-state sodium-ion batteries (SSSIBs) are emerging as the most efficient near-term solution for energy storage that avoids the use of critical raw materials. However, there is still a need to develop materials that can be used in the electrodes and electrolyte to meet the performance requirements in terms of energy density and stability. 4SIBAT project pursued the design and production, through efficient and scalable processes, of (i) sustainable carbon materials from green monomers and (ii) optimized solid-state electrolytes based on hybrid conductive gel-polymer and single ion membranes. By combining these innovative and sustainable components it is intended to have, at the end of the project, a prototype of Sustainable-SSSIB (4SIBAT) with an optimized architecture able to competitively meet the demands of a robot in real operating conditions. With the 4SIBAT project we contribute to the EU's ambition to become a world leader in renewable energy and its secure supply.

Keywords: Sustainability, Advanced materials, Solid-State Sodium Batteries, Energy

1. INTRODUCTION

Among the energy storage systems based in electrochemistry, lithium-ion batteries (LIBs) currently lead the market due to their overall performance in terms of energy, power, and life. Thus, LIBs are extensively used in portable devices, electric vehicles, and large-scale energy storage systems. However, LIBs have serious disadvantages mainly related to their components. In this sense, both natural graphite (the material used in the anode) and elements such as Li, Co or Ni which are present in the cathode compounds, are considered critical raw materials [1]. Specifically, there are serious doubts about whether Li reserves will be able to support the high demand expected for the coming years. Furthermore, this high demand has substantially increased the dependence from the few countries with these reserves. In recent years other technologies, apart from lithium-ion batteries, have begun to gain importance and interest, such as those based on sodium, like sodium-ion batteries (SIBs). In this sense, sodium is a much more abundant element than lithium and world-wide distributed. Thus, sodium is one of the most abundant elements in the Earth's crust and the sodium minerals, from which the compounds for battery electrodes are obtained, are much lower in cost than those corresponding to lithium. Another economic aspect to highlight is that SIBs allow using aluminum as current collector in both anode and cathode since sodium (unlike lithium) does not alloy with aluminum. Therefore, avoiding the use of copper which is more expensive as well as less abundant [2].

Furthermore, the operation of sodium-ion batteries (SIBs) is analogous to that of LIBs and is based on the reversible intercalation/insertion/adsorption of sodium ions (Na^+) into the active materials of the electrodes. This is a clear advantage because this analogy makes the infrastructure designed to produce LIBs perfectly adequate for the manufacturing of SIBs. SIBs use mainly amorphous carbon materials (hard carbons) and sodium compounds (layered transition metal oxides, polyanionic oxides, Prussian blue analogues) as active materials in the anode and cathode, respectively. At this point, it is important to mention that graphite (the most used anode in LIBs) hardly intercalates Na^+ ions. In this context, hard carbons have proven to be the most suitable as anode material due to the wide range of precursors and synthetic routes that results in a wide variability of materials properties. Among these precursors, in recent years, interest in developing biomass-derived hard carbon materials has grown enormously. From the point of view of sustainability and availability, the use of biomass as a resource is very interesting since it is renewable, abundant, and eco-friendly. Nevertheless, despite significant research efforts, to produce the high-quality carbon materials needed in batteries it has some clear disadvantages such as poor reproducibility, the need to remove impurities from the final product and long and expensive processes. Therefore, the search for sustainable precursors that allow carbons to be produced through simple, economical, and easily scalable process represents an important challenge to make the development of energy storage systems based in sodium a reality. Synthetic carbon materials have several advantages as they can be obtained

with a very well controlled chemistry, avoiding the presence of impurities, and with the physicochemical/structural properties desired for this specific application, and allowing reproducibility. The significance of the electrolyte in SIBs cannot be overstated as it plays a pivotal role in effectively linking the cathode and anode electrodes, allowing for proper sodium ions transfer between them. The efficiency with which ions are transported through this medium would influence on the power density exhibited by the battery. As such, selecting an appropriate electrolyte solution that facilitates optimal ionic mobility remains vital for achieving superior SIB performance. Like LIBs, liquid electrolytes used in SIBs are often based on carbonated organic solvents, some of which pose safety risks, especially at high temperatures, because they are flammable [3]. To address this safety problem, the research community has shifted their attention to exploring solid-state electrolytes (SSEs), for applications in rechargeable batteries, due to a variety of advantages such as no electrolyte leakage, less flammability, less corrosivity and the ability to also function as the separator between the electrodes. Polymer Electrolytes (PEs) are characterized by low glass transition temperature and flexibility, allowing for implementation in various geometries with high adaptability. A typical PE involves a sodium salt such as NaTFSI or NaFSI dissolved within a host polymer matrix. However, due to the limited dissolution of salt in polymer and crystallinity effects, ionic conductivity and transference number for sodium ions remain low under these conditions. Gel polymer electrolytes (GPEs) have emerged as a promising alternative for high-performance solid-state sodium-ion batteries. By incorporating liquid electrolytes solution in thermoplastic polymer matrices, the ionic conductivity was substantially improved along with the transference number of Na^+ ions. What makes GPEs particularly unique is their ability to combine both cohesive properties of solids with diffusive properties found in liquids. The presence of retained liquid within GPEs facilitates an efficient ionic conduction process while the underlying polymer host matrix provides much-needed mechanical strength and improved processing capability. Given these remarkable features, there is great potential for all-solid-state SIB technologies utilizing GPEs as power sources for flexible devices. Finally, single-ion conductor (SIC) electrolyte membranes have gained significant attention as a promising alternative to traditional PEs. SIC systems are recognized as the next generation of safe electrolytes due to their ability to immobilize anions using either covalently bound polymer backbone or anion acceptors, thereby reducing anion polarization, and mitigating dendrite growth rates [4]. Nevertheless, it is crucial to emphasize that over the past decade, the scientific community has produced only a very limited number of research articles on non-liquid electrolytes for SIBs. Therefore, substantial efforts must be focused on this vital battery component to develop efficient SSSIBs.

2. PROJECT VISION AND ACHIEVEMENTS SUMMARY

Solid-state sodium-ion batteries (SSSIBs) are emerging as the most efficient near-term solution for energy storage that avoids the use of critical raw materials. However, there is still a need to develop materials that can be used in the electrodes and electrolyte to meet the performance requirements of SSSIBs in terms of energy density and stability. The 4SIBAT project will produce innovative and advanced materials for the anode and electrolyte of SSSIBs, based on abundant, sustainable, non-toxic, and cost-effective precursors and by innovative and highly efficient processes (microwave-assisted sol-gel methodology for sustainable carbons and photopolymerization for solid electrolytes). The integration of these advanced materials into the solid-state sodium-ion battery, and the monitoring of their performance by means of in-operation characterization techniques, will also allow to reach a systematic understanding of the phenomena involved, paving the way for a significant advance in sustainable energy storage technologies. Among the objectives pursued within the project are to design and produce, through an efficient process based on microwave heating, sustainable carbon polymeric materials from green monomers with highly controlled and optimized physicochemical properties for the anode to achieve cell capacities up to 200 mAh g^{-1} and high cycling stability at laboratory scale (i.e. half-cell). In addition, optimized solid-state electrolytes based on gel-polymer and single-ion conductive hybrid membranes will also be produced, avoiding critical and toxic materials and through a new and efficient process based on photopolymerization. By combining these innovative components (anode and solid electrolyte) it is intended to have, at the end of the project, a flexible lab-scale SSSIB with an optimized architecture exhibiting energy density up to 150 Wh Kg^{-1} , as a preliminary step to a full-scale SSSIB optimized in terms of performance for use in real conditions in end-user applications supplying the demanded 10 Ah. As regards TRL, the initial TRL2-3 of the materials development is expected to reach TRL5 at the end of the project to finally produce a demonstration SSSIB prototype in an operational environment (TRL6-7) with the valuable contribution of the whole consortium. 4SIBAT will contribute to the EU's ambition to become a world leader in renewable energy and its secure supply. The materials to be developed during this project are innovative not only because they are based on sustainable precursors, but the processes involved in their production are new and efficient, with a reduced ecological footprint. 4SIBAT is a multidisciplinary project with strong connections and interactions between partners with expertise in different and complementary fields. There is a combination of research centers, universities, technological centers, and companies, involving experts in different fields such as organic and inorganic chemistry, materials science, physics, electrochemistry, chemical engineering, electrical engineering, etc. This combination of transnational competences will increase Europe's competitiveness in such a relevant topic as the development of efficient and sustainable energy storage devices. In return, each partner will gain experience and feedback on the performance of their innovations, being the key to move towards efficient SSSIBs.



Fig. 1. 4SIBAT Project partners' overview

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IMPROVED PERFORMANCE CONTROL OF PV ARRAY AND BATTERY HYBRID SYSTEM BASED ON PI CONTROLLER TUNED WITH GREY WOLF OPTIMIZATION ALGORITHM

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ABSTRACT – IO3

This article presents the performance improvement of the DC intermediate circuit voltage control system for a benchmark system consisting of a photovoltaic (PV) array, a storage battery, and a variable resistive load. The types of controllers used are classical Proportional Integral (PI) and PI tuned using the Grey Wolf Optimization algorithm (GWO). The comparative performances of these control systems are presented, in which the main indicators are response time, stationary error, overshooting, and VDC voltage error ripple. The validation of the performance of the presented control systems are achieved in the Matlab/Simulink environment.

Keywords: PV Array, DC-DC Converter, GWO Algorithm

1. INTRODUCTION

Green energy system control is a vast and evolving field, fundamental to the success of the global energy transition. Through innovation in algorithms, software and hardware, we are moving closer to a smarter, cleaner and more resilient energy grid [1-4]. PV is recognized as a key renewable energy source with immense potential to meet global energy demand. However, the intermittent nature of solar irradiance and the strong dependence of PV panel power characteristics on weather conditions (irradiance and temperature) impose the need for efficient and robust power conversion systems [5-7]. Compared to other green power generation elements, such as fuel cells, PV array elements have a shorter response time and the power supply is optimized using a Maximum Power Point Tracking (MPPT) algorithm [8, 9]. In addition, the circuit is completed with a storage system namely a battery, which has its own control system for charging and discharging [10-11]. For achievement a better performance of the proposed control system, based on a benchmark presented in [12], the classic PI controllers are optimized using GWO algorithm [13]. The main task of these controllers is to keep the V_{DC} voltage from the DC intermediate circuit at a constant value. The comparison between the performances of these control systems based on PI controller and PI controller optimized using GWO algorithm is achieved by analyzing the following indicators: response time and V_{DC} voltage error ripple.

The rest of the article is organized as follows: Section II shows the general architecture of the system. The numerical simulations and the implementation Matlab/Simulink of the proposed control system are presented in Section III. The last section shows some conclusions and few ideas for future work.

2. MATERIALS AND METHODS

Starting from the benchmark presented in [12], where the goal is to keep the voltage in the DC intermediate circuit at a constant value when the primary power source is a PV array. Thus, Fig. 1 shows the general architecture of this system, in which there is also a storage element in the form of a battery. As for the battery charging and discharging control system, the elements described in [12] are used. The PV array system has at its input a block that simulates solar radiation, and the MPPT block provides at out of the PV array the maximum power under a load that may be variable, by means of a switching element and a specific control algorithm. The proposed control system for maintaining the V_{DC} voltage from DC intermediate circuit at a constant value consists of a classical PI controller and the optimized variant of the tuning parameters using GWO algorithm. The following performance indicators will be used to compare the main performance of these control systems: response time and V_{DC} voltage error ripple. A cascade control system consisting of two classic PI controllers is used to control operation like the charging/discharging phenomenon of the battery. The inner control loop maintains a constant charge current, which is set by the controller from the outer voltage loop for battery voltage control. The battery charge and discharge circuits are controlled by two IGBT execution elements. The reference value imposed in this application for V_{DCref} from DC intermediate circuit is 100V. The main components in Fig. 1 are presented from a functional point of view in this section. These elements are: the photovoltaic panel, the battery and the controller whose parameters are tuned using classical methods and a computational intelligence algorithm such as the GWO algorithm, respectively. In brief, the GWO algorithm can be described starting from the manner in which the gray wolf hunts in a group to catch prey. The four stages: searching for prey, encircling the prey, attacking and hunting the prey, constitute the starting point of the analogy with the GWO algorithm. The GWO algorithm, when used to determine the optimal values of the PI

controller for controlling the voltage V_{DC} in the DC intermediate circuit, ends after a maximum number of iterations proposed or after the minimum of the objective function has been obtained with a required accuracy. In the present case, the goals to optimally tune the PI controller parameters by using the GWO algorithm in which the objective function to be optimized is the integral module of the error between V_{DCref} reference voltage and V_{DC} voltage [13] like in next equation:

$$J = \int_0^{T_{sim}} |\Delta V_{DCerror}(t)| dt \quad (1)$$

The PV array consists of 5 parallel strings and one series module, with the following characteristics per module (cell): maximum power - 213.15W, cells per module - 60, voltage in open circuit - $V_{oc}=36.3V$, short-circuit current - $I_{sc}=7.84A$, voltage at maximum power point - $V_{mp}=29V$, current at maximum power point - $I_{mp}=7.35A$, temperature coefficients of $V_{oc} = -0.36\%/^{\circ}C$ and $I_{sc} = 0.102\%/^{\circ}C$. An MPPT algorithm using then Perturb and Observe (P&O) algorithm is implemented to obtain the maximum power supplied by the PV array [8, 9]. The Lithium-Ion battery used for storage has the following characteristics: nominal voltage (24V), rated capacity (50Ah), SOC initial value (45%), battery response time (1s), fully state charged voltage (27.93V), and nominal discharge current (21.73A). Fig. 2 shows the main battery charge/discharge process.

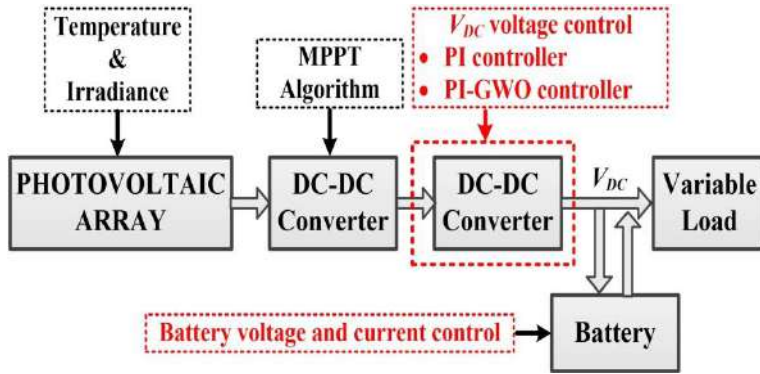


Fig. 1. Block diagram of the DC-DC converter for PV array and battery hybrid system

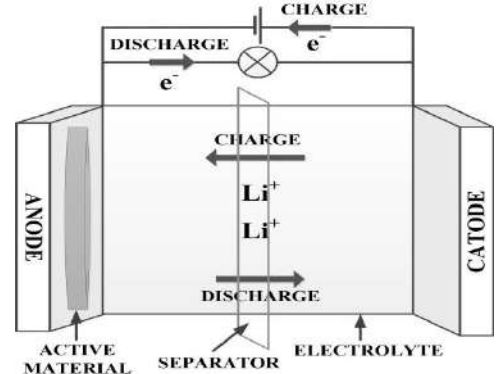


Fig. 2. Charge/discharge process block diagram of the battery

3. NUMERICAL SIMULATIONS

This section shows the performed numerical simulations of the system shown in Fig. 1 using the Matlab/Simulink. The numerical values of the component subsystems were presented in Section II. Fig. 3 show the Matlab/Simulink implemented mode structure for the DC-DC converter control system governed by a PI and PI-GWO controllers. Performance of the GWO algorithm for tuning adjustment parameters of PI controller is presented in Fig. 4. In case of using the GWO algorithm, the following values of the PI controller tuning parameters are achieved: $K_p = 0.12$ and $K_i = 32.46$. In case of using the classical PI controller (tuning parameters: $K_p = 0.49$ and $K_i = 79$) to control V_{DC} voltage from DC intermediate circuit and a nominal load $R=60\Omega$, Figs 5, 6, and 7 show the results obtained through numerical simulations. The time variation profile of solar radiation, voltage, current and PV array power is presented in Fig. 5. The time evolution of battery voltage, battery current, and battery SOC are shown in Fig. 6. The time evolution of DC-DC converter current and power is presented in Fig. 7.

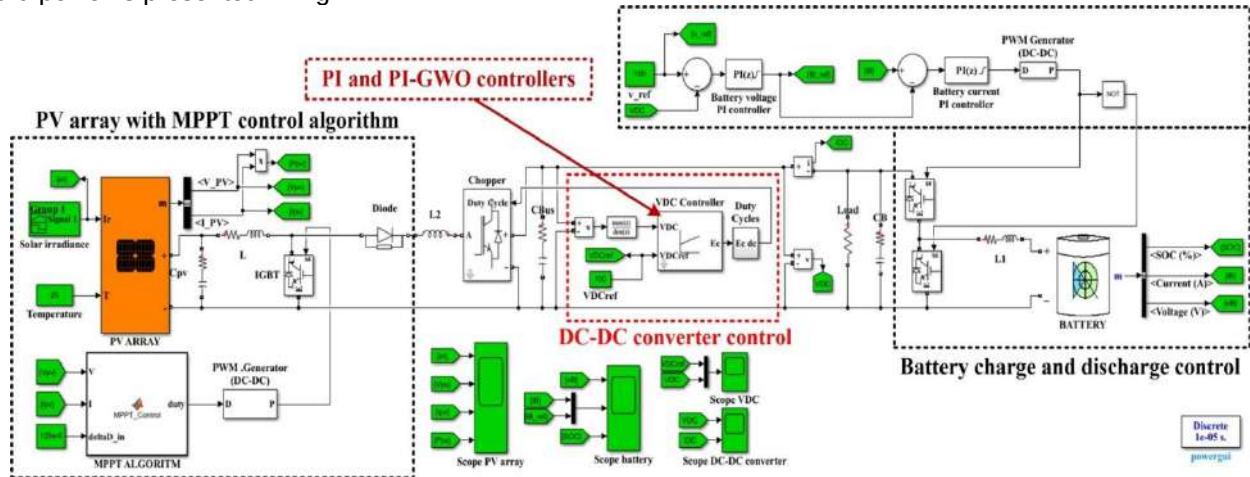


Fig. 3. Matlab/Simulink implementation for the DC-DC converter control system based on PI and PI-GWO controllers

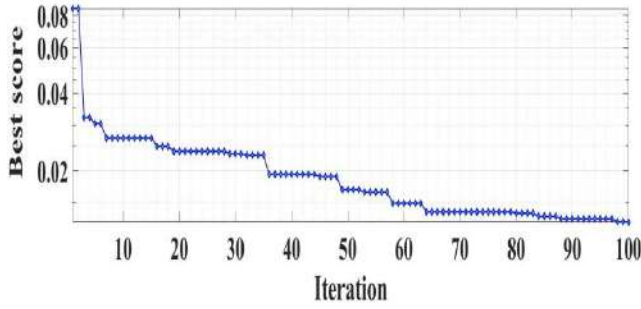


Fig. 4. Performance of the GWO algorithm for tuning adjustment parameters of PI controller

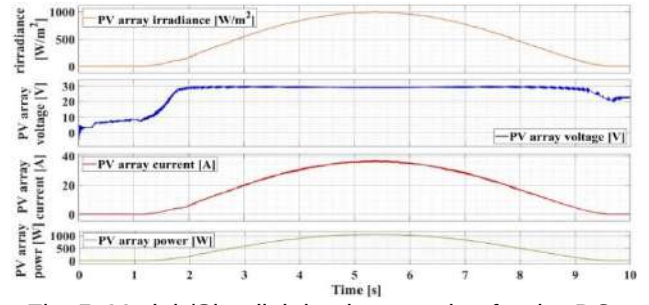


Fig. 5. Matlab/Simulink implementation for the DC-DC converter control system based on PI and PI-GWO controllers

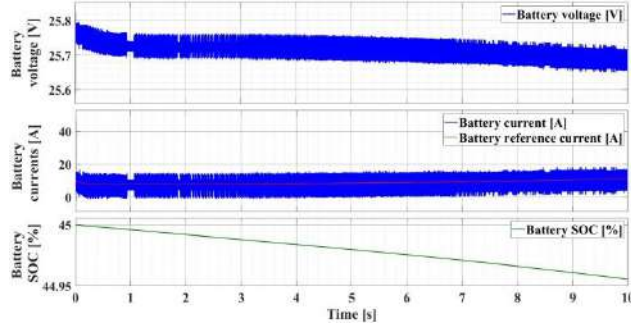


Fig. 6. Evolution of battery voltage, battery current, and battery SOC

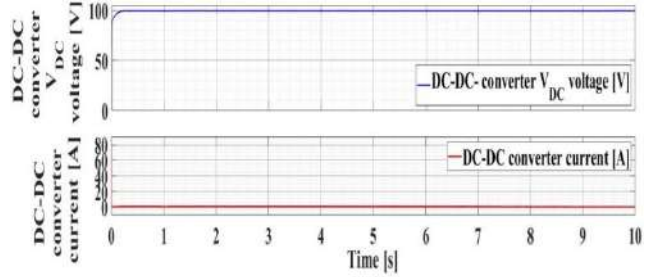


Fig. 7. Evolution of the voltage and current from the DC-DC converter

For the solar radiation profile presented in Fig. 5 and for the PI and PI-GWO controllers, Figs 8 and 9 show the time evolution of the V_{DC} voltage from DC intermediate circuit. The nominal load is 60Ω and each of the above figures shows the time evolution for V_{DC} voltage and for $\pm 25\%$ load variations.

The comparative time evolution of the V_{DC} voltage from DC intermediate circuit in case of using PI and PI-GWO controllers is presented in Fig. 10. By studying this figure, Table I presents the performance indicators, such as response time and V_{DC} voltage ripple for each of the control systems used.

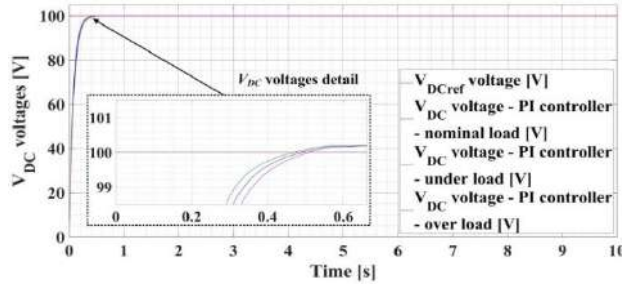


Fig. 8. Time evolution for the DC-DC converter control system governed by a PI controller at rated, under and over load conditions

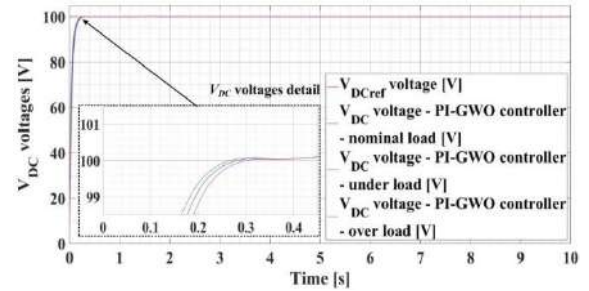


Fig. 9. Time evolution for the DC-DC converter control system governed by a PI-GWO controller at rated, under and over load conditions

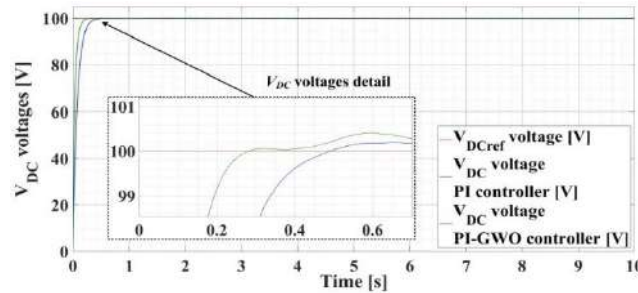


Fig. 10. Time evolution for the DC-DC converter control system governed by a PI and PI-GWO controllers at rated load

In Table 1, which presents the performance indicators like response time and V_{DC} voltage error ripple for the two types of controllers presented (PI and PI-GWO), it can be seen that the tuning of the parameters of PI controller according to the Ziegler-Nichols method can be improved by using the GWO algorithm. It can be

seen from Table I the superiority of the PI-GWO controller's performance in terms of response time and voltage signal ripple (under conditions of negligible overshoot and stationary error).

Table 1. Performances for the Proposed Controllers for DC-DC Converter V_{DC} Voltage Control

Controller	Response time [s]	V_{DC} voltage error ripple [V]
PI controller	0.39	1.82
PI-GWO controller	0.24	1.75

CONCLUSIONS

This article presents the overall structure of a benchmark, in which the main objective is to maintain the voltage in the intermediate DC circuit at a constant value under load variation conditions, and the primary energy is a PV array connected to a battery for storing surplus energy. The control systems presented are PI controller and PI controller tuned using GWO algorithm. The superior performance of the latter controller is demonstrated by the analysis of the performance indicators such as follows: response time and V_{DC} voltage error ripple, provided that the overshoot and stationary error are negligible. Future work will address combined multi-source power generation systems, as well as control systems with improved performance.

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DISTURBANCES CLASSIFICATION IN POWER QUALITY USING K-NEAREST NEIGHBORS AND DISCRETE WAVELET TRANSFORM ANALYSIS BASED ON LOW-COST HARDWARE

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ABSTRACT – IO4

Given that commercial analyzers are used to analyze power quality (PQ), which are highly accurate but very expensive, this article presents a system based on a smart meter plus application software that performs the main functions of a quality analyzer but at a lower cost. Based on the acquired signals, we present the main PQ disturbances and their total harmonic distortion (THD) characteristics, but also the characteristics based on the Discrete Wavelet Transform (DWT) analysis, such as: entropy and signal energy. It is presented the training, testing and validation of an automatic classifier based on support K-Nearest Neighbors (KNN) type algorithms that can be used for the automatic classification of PQ disturbances. The practical use of the data acquisition system and the automatic classification software application by recognizing as sag with harmonics, a PQ disturbance with harmonics, that occurs in the main electrical network is presented.

Keywords: Power Quality, Discrete Wavelet Transform, K-Nearest Neighbors

1. INTRODUCTION

The PQ refers to the extent to which the electricity supplied to the consumer approaches the ideal parameters: a constant voltage at the nominal value, a stable frequency, and a perfectly sinusoidal waveform without interruptions. Any deviation from these ideal parameters constitutes a disturbance in power quality [1-4]. The importance of PQ has increased exponentially with the proliferation of sensitive electronic equipment and nonlinear loads (e.g., frequency converters, LEDs, computers) in power grids. These devices are not only vulnerable to grid disturbances, but can also be a major source of them, creating a vicious cycle that further degrades PQ [5, 6]. Without advanced software tools for automatic disturbance classification and analysis, maintaining adequate PQ would be a major challenge, with negative implications for the economy and society as a whole. Therefore, the continuous development and refinement of these software solutions is a field of research and innovation of utmost importance [7, 8]. The WT is a powerful and versatile tool in the field of power quality, providing a detailed time-frequency perspective on disturbances and enabling more accurate analysis and more efficient management of power quality issues [9]. The ideal voltage signal in AC systems is a pure sine wave, at a constant frequency and amplitude. However, in reality, various phenomena lead to deviations from this ideal shape, called disturbances [10]. Based on these considerations, this article presents a PQ analysis method as an alternative to a PQ analyzer, which usually has high cost, by using a smart meter that performs the primary acquisition of the signals from a three-phase system and the software application implemented to perform the main functions of a PQ analyzer. Moreover, by properly using a DWT filtering which eliminates the disturbances below 0.1ms (which are considered beyond the scope of PQ analysis) [11] and the proper training of a classification learner like KNN algorithms, it is possible to automatically classify the main PQ disturbances [12, 13]. The rest of the article is structured as follows: Section II presents the low cost hardware and DWT implementation for PQ analysis. Section III presents the experimental test based on the KNN algorithms for PQ disturbances classification. The final section presents conclusions and proposals for future work.

2. MATERIALS AND METHODS

The general structure of the system for acquiring, processing and classifying disturbances in the power grid is presented in Fig. 1. Using voltage and current sensors in the appropriate range, the presence of a PM-3133-100 MTCP smart meter is noteworthy, which ensures high accuracy at a relatively low price, and acquires current and voltage signals which are then transmitted via the ModBUS TCP protocol to the application program running on a host PC. The application software that performs disturbance classification is implemented in LabVIEW, and uses KNN algorithms implemented in Matlab, in the form of the Classification Learner App from Machine Learning and Deep Learning toolbox.

Following what is presented in [12], the waveforms of the disturbances taken into account in the power quality classification are shown in Fig. 2. DWT is an advanced signal processing technique that has revolutionized the analysis of non-stationary signals, including those in the field of power quality. Unlike FT which uses sinusoidal basis functions, WT uses basis functions called wavelets. These wavelets have a crucial property: they are localized in both time and frequency. To eliminate the signals that are not subject to the PQ analysis of

disturbances, we apply the wavelet filtering. The sampling frequency used is of 12.8 kHz for a supply frequency of 50 Hz. By applying a db7 mother WT on 9 levels the DWT analysis for the disturbed sag waveform signal with harmonics using the facilities provided by the Wavelet Analyzer toolbox from Matlab (Fig. 3). By applying the inverse WT, Fig. 4 shows the initial signal recovered after filtering [12].

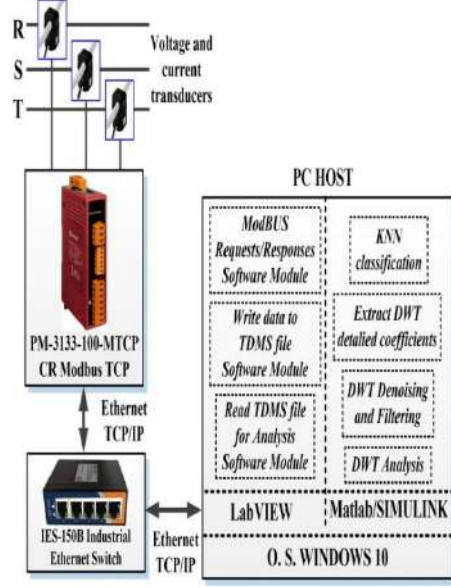


Fig. 1. Proposed software application structure

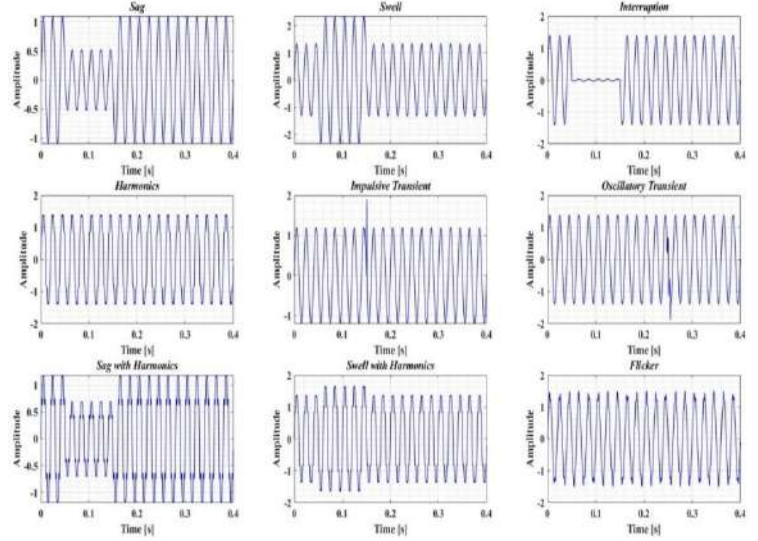


Fig. 2. Type of the waveform disturbances in PQ analysis

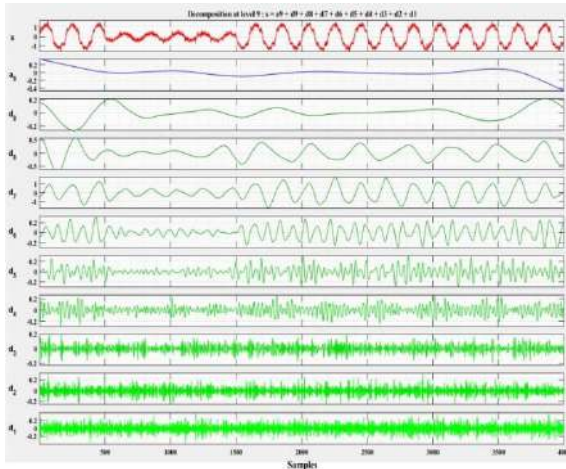


Fig. 1. Proposed software application structure

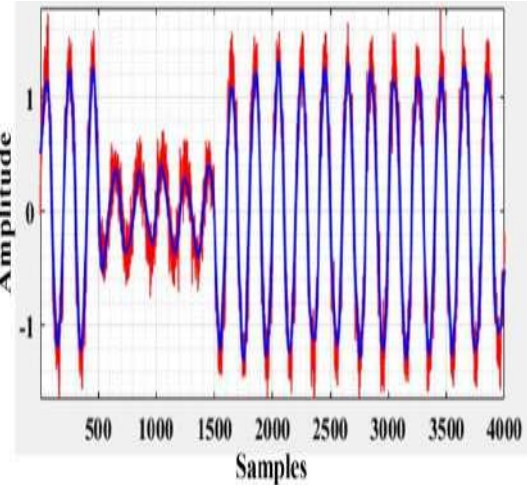


Fig. 2. Type of the waveform disturbances in PQ analysis

For the automatic classification of PQ disturbances, for each of the waveform disturbances presented above, a series of characteristics are extracted as is presented in [12, 13]. The entropy of the original signal, entropy of the approximate coefficients, and entropy of the detailed coefficients based on next relation:

$$E(s) = - \sum_{n=1}^N s_i^2 \log(s_i^2) \quad (1)$$

In relation (1), $E(s)$ is the Shannon entropy, s represents the signal and s_i is the coefficient of signal s in an orthonormal basis. Another characteristic is given by the energy of wavelet coefficients expressed by the next relation:

$$En(s) = - \sum_{n=1}^N |s_i|^2 \quad (2)$$

In relation (2), $E(s)$ is the energy, s is the signal and s_i is the coefficient of signal s in an orthonormal basis. Regarding the relation given in (11), we define the maximum percentage value of the detailed coefficients energy. The sixth characteristic used for the automatic classification is given by the THD and described as in follow expression:

$$THD(\%) = \frac{\sqrt{\sum_{n=1}^N U_n^2}}{U_{RMS}} \quad (3)$$

In relation (3), U_n is the RMS value of the harmonic n and U_{RMS} is the RMS value of the fundamental frequency. For normalization between values 0 and 1 of each of the six characteristics presented, it can be used the relation given in next form:

$$N = (x - \min(x)) / (\max(x) - \min(x)) \quad (4)$$

where: N is the normalized data, x is the original input data, $\max(x)$ and $\min(x)$ are maximal and minimal values between all inputs.

3. EXPERIMENTAL RESULTS

Fig. 5 shows the schematic diagram of the classification process performed using Classification Learner App from Machine Learning and Deep Learning toolbox of Matlab, based on KNN algorithms [14]. It can be noted that the classification system receives as input a data vector containing the normalized characteristics presented in the previous section, and based on the fact that the classification system has been properly trained, it will generate at the output PQ disturbances (one of the 10 types presented in the previous section). Training the classification system used 200 samples for each PQ perturbation, using the accuracy and training time for the KNN algorithms. It can be noted that the best accuracy is obtained for the Fine KNN classifier algorithm. Fig. 6 shows Scatter plot of the predictions (Mean energy versus THD) for Fine KNN classifier algorithm. Fig. 7 shows the confusion matrix of the Fine KNN classifier algorithm for PQ disturbance classification. Sag harmonic disturbance ROC curve using Fine KNN classifier algorithm is presented in Fig. 8. It can be observed that for sag harmonic disturbance ROC curve is 0.93.

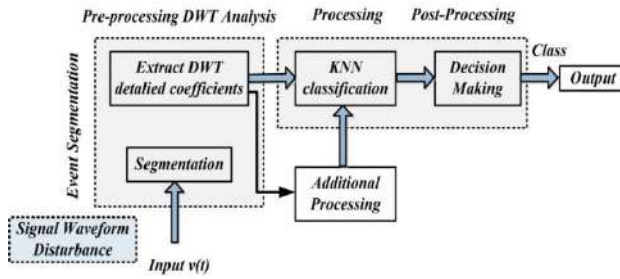


Fig. 5. Block diagram of the KNN type algorithms for PQ disturbances classification

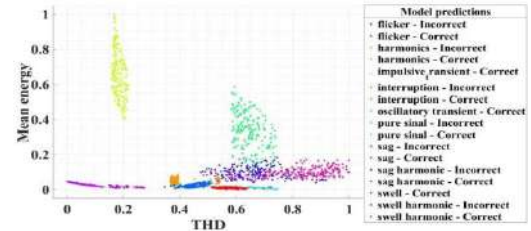


Fig. 6. Matlab/Simulink implementation for the DC-DC converter control system based on PI and PI-GWO controllers

flicker	192				8					
harmonics	1	198								1
impulsive_transient			200							
interruption				199		1				
oscillatory_transient				199			1			
pure_sinal					200					
sag							198			
sag_harmonic		2		2			176		22	
swell								200		
swell_harmonic		2					22		176	
	flicker	harmonics	impulsive_transient	interruption	oscillatory_transient	pure_sinal	sag	sag_harmonic	swell	swell_harmonic

Fig. 7. Evolution of battery voltage, battery current, and battery SOC

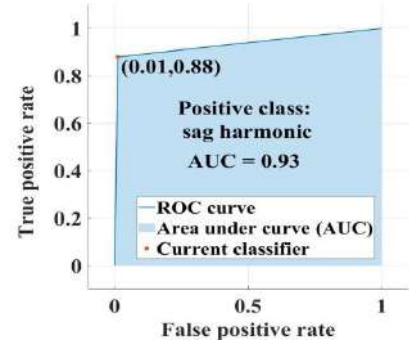


Fig. 8. Evolution of the voltage and current from the DC-DC converter

To improve the classification performance of the presented algorithm, the optimization facilities of the Classification Learner App are used. Thus, the optimization training of the Fine KNN classifier algorithm using Bayesian optimization is presented below. Thus, Fine KNN classifier algorithm with Bayesian optimization performance are the follows: accuracy 98.2%, prediction speed 21000 obs/sec, and training time 70.916 sec. Optimized hyperparameters used for this algorithm are the follows: Mahalanobis distance metric, squared inverse distance weighted, and 1000 number of neighbors. The minimum classification performance obtained for Fine KNN classifier algorithm with Bayesian optimization is presented in Fig. 9. By using the trained Fine KNN classifier algorithm with Bayesian optimization and by applying in the software application the following Matlab commands: `"PQ_Disturbance_Classification=trained_FKNNOB.predictFcn(Matrix2)"`, the normalized values of the signal are supplied at the input of the classifier algorithm, and at the output we obtain the PQ disturbance: *"sag with harmonics"* as in Fig. 10.

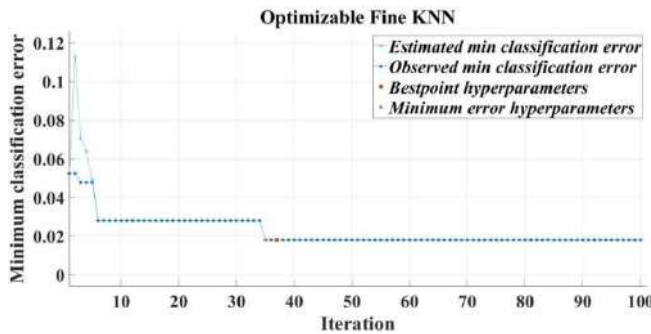


Fig. 9. Minimum classification performance for Fine KNN classifier algorithm with Bayesian optimization



Fig. 10. Result for Fine KNN classifier algorithm with Bayesian optimization using a sag harmonic disturbance signal on input

CONCLUSIONS

This article presents an application that, although it has the low-cost characteristic of a smart meter with an affordable price but with good accuracy, performs the classification and acquisition of current and voltage signals which it then transmits over the ModBUS TCP protocol to the application program running on a host PC. The system structure and experimental results are presented, which show the identification of a sag with harmonics disturbance occurring in the power grid. In future works, the study will continue with the implementation of other classification algorithms.

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HIGH POWER LABORATORY MODERNIZATION FOR LIMITING THE EFFECTS OF ELECTROMAGNETIC PERTURBATIONS

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ABSTRACT – IO5

Within paper there are analysed and synthesised main perturbations due to environment and to electromagnetic fields and are established measures and methods for limiting them within High Power Laboratory.

Keywords: electromagnetic fields, tests, standards, data acquisition and processing

1. INTRODUCTION

High Power Laboratory is designed for type tests of electric apparatus and equipment at high currents according to standards in vigour. Testing diagram uses electric circuits made from motor-generator groups, medium voltage circuit-breakers and switchgears, making switches, motors, power transformers, busbars, capacitors, resistors, measure transducers (shunts, current transformers, voltage dividers). [1,2,4]

Due to very strong stresses at high currents and high voltages, arises the problem of achieving such testing and measuring circuits which must contain environment-friendly materials and, on the other part, not to be affected by very intense electric and magnetic fields [1]. Thus, at initiation of high short-circuit currents and also at tests accompanied by high electric fields in secondary circuits, are induced currents and voltages which can affect the results of measurements if avoiding measures are not taken.

2. PARTICULARITIES REGARDING TESTING AND MEASURING CIRCUIT

Testing circuit from High Power Laboratory of ICMET Craiova uses a direct scheme. [2,3,4] As resulting from European Union requirements, main testing and measuring circuits were modernised with new apparatus, equipment, measuring and recording devices which avoid negative effects on environment and those of electromagnetic fields on staff. [3,4]

1.1. Testing circuits

Vacuum circuit-breakers (12 kV/1250 A, 12 kV/2500 A) were chosen to replace minimum-oil circuit-breakers which presented fire risks and pollution by explosion and also have negative environment impacts due to gas losses. [3]

Vacuum circuit-breakers have not any damaging influence on environment and no explosion risks. Reduced number of components and simplified construction made them more compact and with reduced dimensions which offer them better maintenance and longer life duration (over 25 years).

Medium voltage busbars system is passed by short-circuit currents up to 100 kA for 1-3 s duration. In order to reduce the strong electrodynamic stresses due to short-circuit currents was realised a special construction using screened aluminium busbars.

Reactance coils are of cylinder modular type and are realised from copper bands with special resin insulation. Their horizontal placement with frontal output diminishes the effect of mutual inductances and offers a good stability at electrodynamic stresses. [2,4]

The capacitors from load circuit are realised with modern technologies with ecologic dielectric replacing the old ones with oil dielectric which creates fire risk through explosion. [3]

1.2. Measuring circuits

The distortion of useful signal through interference with several perturbations occurs either at measuring transducer, either at connection cable between measuring transducer and recording system. Perturbations can occur due to electromagnetic fields penetration within measuring circuits, formation of closed current loop, multiple reflections, parasite capacitances, intrinsic inductances, too long measuring chain etc. [1,2,4]

As high currents transducers there are used compensated coaxial cage shunts (2 kA/2 V – 180 kA/1.8 V). For rapid variable (like making-breaking currents) are used compensated non-inductive shunts. For circuits with no earthing point are used Rogowski coils (2 kA – 180 kA).

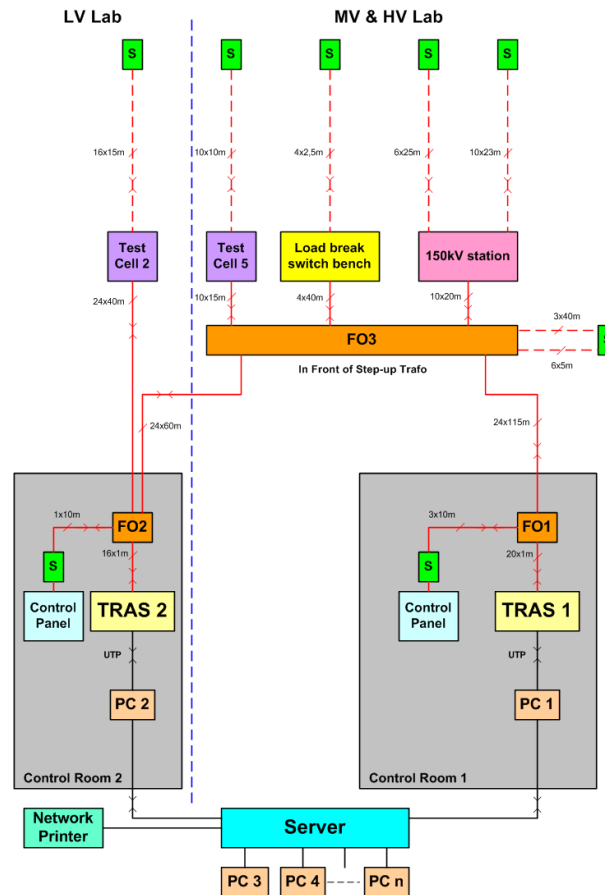
Other perturbation source is given by closed loop through earthing points. For a testing laboratory is not permitted to have two different grounding points which generate leak currents due to potential differences between these different points and due to voltages induced by rapid variable magnetic fields. So measuring devices (shunts, dividers, recording devices) are connected to same earthing point.

When TRV is measuring, perturbations appear from intrinsic inductances and parasite capacitances.

To avoid them there are used capacitive dividers with adapting resistances. Also perturbations can appear from too long measuring cables. In this case there are used coaxial double screened (screen earthed) cables. Some cases it is used differential measure schemes. [1]

Measuring circuits connected to recording devices (transient-recorders) are placed perpendicular to high current path and situated in a screened control room. The supply of transient-recorder is performed through galvanic insulated transformer or screened transformer.

These particular aspects were shown related to modernise of measuring circuits using fiber optic connections and transient-recorders with many channels for automatic data recording and processing (Fig. 1). [3]



TRAS1,2 – Transient-recorders
 FO1,2,3 – fiber optic concentrator and switches (patchfield)
 S – remote module (digitizer)
 PC1 ... PCn – local computers
 LV Lab – low voltage laboratory
 MV Lab – medium voltage laboratory
 HV Lab – high voltage laboratory

———— Fixed fiber optic (heavy duty)
 - - - - - Mobile fiber optic (heavy duty)
 ——— Ethernet fiber optic

Fig. 1. High Power Laboratory Measuring System

1.3. Particularities regarding professional staff

Laboratory staff are entering testing and measuring circuits only within test responsible witness. There are acoustic and optic warning systems during the tests. Staff is protected during tests within control rooms and is not exposed to electromagnetic fields or to possible explosions of tested apparatus.

However operative witness staff can feel the effects of electromagnetic fields.

In this aspect were established maximum values of exposure at short time electromagnetic fields. [1,5]

3. Experiments for verification of breaking capacity test on medium voltage circuit-breaker

In order to have the guarantee of safety operation in exploitation, the circuit-breaker is submitted to type tests according to the standard IEC 62271-100/2008 where the breaking capacity test is the most important.

According to the above standard, the circuit-breaker is tested at basic short-circuit test duties T10, T30, T60, T100s in operating sequence O-0.3s-CO-3min-CO and T100a in operating sequence O-3min-O-3min-O. Transient Recovery Voltage (TRV) parameters are specified in standard and are determined according to rated voltage of tested object [6] (see Table 1).

Breaking capacity tests were performed on 36 kV, 630 A, 16 kA SF6 Gas Circuit-Breaker. Test parameters of basic short-circuit tests were the following:

- rated voltage: 36 kV
- short-circuit current: 16 kA
- operating sequence O-0.3s-CO-3min-CO
- frequency: 50 Hz
- DC component: 31 %
- rated control pressure: 2 bar

Measuring circuit is presented in Fig. 1 for HV and MV Lab with recordign of phenomena from tests on TRAS_1. Data acquisition system is an transient-recorder characterised by parameters: number of channels: 24, sampling rate: 100 MS/s, on-board memory: 1 GB, precision: 16 bit.

Some of results obtained by oscillogram processing (presented in Fig. 4) are presented in Table 2. Using fiber optic Intranet and dedicated Server, recorded data and oscillograms are sent to customers room and test responsible office.

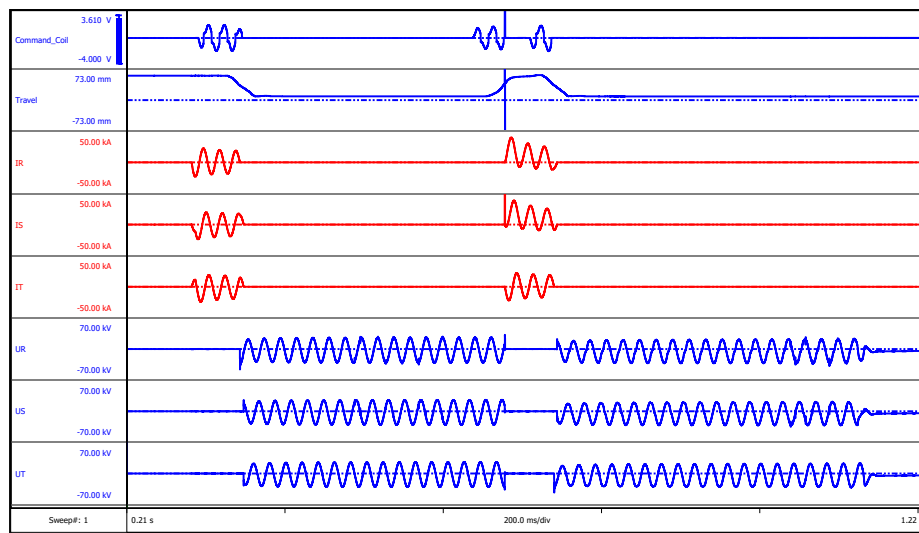


Fig. 3. Oscillogram from test duty T100s

CONCLUSIONS

By modernisation measures of High Power Laboratory on the basis of European funds [2] there were solved the problems related to screening both testing and measuring circuits. In this aspect the most important it is implementation of a new recording and measuring system by using – in measuring chain – new devices as fiber optic, optical emitters and receivers, transient recorders etc. which ensure both galvanic separation and electromagnetic perturbations immunity (as original contribution).

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EXPERIMENTAL STUDY ON THE BEHAVIOUR OF A 400 KV INSULATOR STRING WITH GLASS INSULATORS UNDER POWER ARC CONDITIONS

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ABSTRACT – IO6

This article examines the behavior of the power arc on insulator strings in high-voltage installations, focusing in particular on scenarios where the arc is initiated using a fusible wire, used as an experimental method to simulate real fault conditions in electrical networks, where atmospheric pressure affects the electrical performance of a contaminated insulator. The experiments help to understand the phenomenon of flashover, the length of the discharge path, the propagation of the electric arc, and the arc radius under different air pressures. The research results indicate that the position of the arc point is stochastic and that the phenomenon of multipoint arcing exists. The power arc levitates and transforms into an arc with air gaps under low air pressure. The length of the discharge path is related to the air pressure and the degree of pollution of the insulator and is always shorter than the creepage distance of the insulator. The shape and propagation speed of the arc are also related to the air pressure. The research results are important for the design of insulator strings and their behavior under the action of power arc.

Keywords: ac power arc, insulator strings, fusible wire, long rod, overvoltage

1. INTRODUCTION

This article analyzes the behavior of electric arcs generated on insulator strings used in high-voltage installations. The paper specifically analyzes situations in which an electric arc is initiated by a fuse wire. This method is used to simulate real fault conditions. The importance of maintaining symmetry in the supply and return circuits is emphasized because it is essential for obtaining reproducible and relevant experimental results. The symmetry of the electrical configuration helps to ensure a uniform distribution of voltages and currents during arc ignition. This directly influences the arc's shape, stability, and duration. This approach yields accurate results that represent the behavior of installations under real fault conditions [1], [2]. These results have significant implications for the design and sizing of insulator strings, as well as for protection strategies in electricity transmission and distribution networks.

2. CONTEXT

An electric arc is initiated using a fuse wire to simulate the most severe conditions that can be encountered during operation, such as when atmospheric pressure affects the electrical performance of a contaminated insulator. This paper examines the behavior of a double tensile insulator strings in a laboratory setting under high-power electric arc conditions. The experiments were conducted under installation conditions identical to those in operation and consisting of clamps, fittings, and insulators. These tensile insulator strings must withstand mechanical loads on the phases under normal and fault conditions, including wind, frost, and wind with frost. These strings are subject to dynamic stresses caused by conductor vibrations due to wind, as well as by shocks caused by gusts of wind, the discharge of ice from the conductors, or a subconductor breaking during opening operations. Electrical stress remains constant at power frequency, though atmospheric or switching surges may occasionally occur. Corona discharge may occur at the bottom of the live string, particularly in humid conditions [1], [3].

The continuous degradation of the atmosphere poses a significant threat to the stable and reliable operation of electrical networks due to the phenomenon of insulator pollution. In this context, the issue of creeping discharges on contaminated insulators remains a topic of interest in electrical engineering research. The development of a high-power arc in polluted conditions typically occurs in four distinct stages. First, contaminants accumulate on the surface of the insulator. Second, fog or rain wets these contaminants. Third, the arc appears in the dry band. Finally, the arc transitions to a high-power arc. To rigorously describe the initiation and propagation mechanisms of partial arcs, the literature presents a series of theoretical and experimental models that are designed to replicate the behavior of creeping discharges [4], [5]. Despite modeling efforts, however, there is still no scientific consensus on the fundamental mechanism that governs the propagation of partial arcs in the high-power arc stage. Current debates mainly focus on the dynamics of arc propagation, specifically the processes by which it reaches and develops along the wet surface of a contaminated insulator.

3. METHODOLOGY

Insulator strings are an essential component of any power supply system. Failure of insulators, particularly in the form of flashover, significantly contributes to total system failure. A number of efforts have been

made to improve the performance of insulator strings, such as using new materials and surface coatings to improve dielectric strength and improving insulator design. Improving insulator performance requires a systematic approach and an understanding of insulator behavior. This paper describes how to use an equivalent electrical circuit to analyze the behavior of a high-power arc and gain an understanding of an insulator string's behavior. High-power arcs affecting glass insulator strings are often seen in polluted areas, such as coastal regions and industrial zones. The interaction between polluting particles and the hydrophilic surfaces of insulators decreases their dielectric strength, reducing their ability to withstand electrical stress. This decrease in dielectric performance is especially problematic under transient overvoltage conditions, such as those caused by lightning strikes, because they can trigger the formation of high-power arcs on the insulator's surface. Another phenomenon often encountered in glass insulators is corrosion in the metal area of the fastening pin. This degradation is initiated by high-intensity currents and intense electric fields, such as those from corona discharge. It is also caused by the presence of pollutants containing electrolytic compounds in the baseline area of the pin. If the corrosion process continues for an extended period, the diameter of the metal pin will significantly decrease, leading to a substantial reduction in its mechanical strength. In critical situations, this structural weakening can lead to mechanical failure of the insulator [6], [7]. This can result in the collapse of the supported conductor and, consequently, an interruption in the electricity supply.

A flashover that occurs on contaminated insulator strings, either at rated voltage or as a result of switching surges, develops primarily on the insulator's surface. The electric arc consists of several distinct sections at the initial moment of formation. These sections are known as partial arcs and establish conductive connections between the metal elements of the insulator. For example, they connect the caps and pins in classic insulators. They are arranged in different spatial planes and are randomly oriented relative to each other. When adjacent partial arcs are positioned in diametrically opposite planes (approximately 180° apart), the base of the intermediate arcs can persist for a long time. This contributes to the complexity of the flashover process. In arc withstand testing, simulating a flashover under contaminated conditions is a standard method. This involves generating intermediate arc bases and measuring the voltage across the insulator string. This voltage exceeds the level recorded in the case of a simple arc, such as that produced by a lightning bridge. To perform high-power arc experiments, it is essential to precisely position the fuse wire in order to force the appearance of the necessary switching points for reproducibility of the tested phenomenon [8], [9]. The dynamics of power arcs that develop on insulator string used in high-voltage installations, as well as the voltages they induce on insulating elements, are significantly influenced by three major physical effects:

- a) The arc sections near the bases that are in direct contact with metal components are immobile and emit intense plasma, which is highly conductive. These bases are fixed in position and anchor nearby sections of the arc, causing them to follow the direction of the generated plasma flow. External forces, such as electrodynamic force, air currents, and buoyancy generated by thermal differences, do not significantly influence this proximal area.
- b) The mobility of distant sections of the arc is affected by their location. Those located farther away from the fixed bases are outside the direct influence of the plasma flow. Instead, they are subject to the action of electrodynamic forces, wind, and thermal buoyancy. These forces can significantly displace the arc, which affects its stability and trajectory on the insulator's surface.
- c) Reconfiguration of the electric arc path: Due to the action of these forces, certain sections of the arc may come into contact with other sections of the arc or with other metal components of the system. Under these conditions, potential differences can initiate a new electric arc channel. This causes the extinction of the initial path and the formation of new arc bases. This phenomenon suddenly reconfigures the position and shape of the arc.

The ionization process is accentuated due to the high intensity of the electric currents involved, which significantly increases the probability of failure of the insulator string. These aspects underscore the significance of dynamic arc analysis for studying the reliability of insulation systems in high-voltage installations [10].

The insulator string used in the experiments is a double tensile type with a nominal voltage of 400 kV and 23 glass insulator discs arranged in a 2x23 configuration, as shown in Fig. 1:

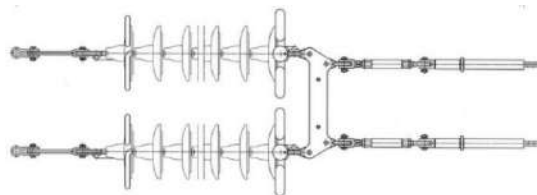


Fig. 1. The 400 kV insulator string used in experiments

The experiments were carried out in a single-phase AC circuit with an initial DC component of no more than 30%. Flashover on an insulator string generally occurs near a voltage peak during operation, resulting a

minimal DC component. Considering the most severe operating conditions, the power supply and return circuits were designed to create an unbalanced return circuit. This circuit simulates a situation in which the insulator string is located on an outer phase at the end of the line [11].

Fig. 2 shows the setup used for experiments involving a flashover caused by insulator contamination under the most severe possible operating conditions. The assembly was designed to recreate the electromagnetic field influencing the arc's movement. The dimensions in Fig. 2 represent an $L_B > 6\text{ m}$. The length of the L_S conductor is considered sufficient at 6 m. The distance between the conductor and the ground plane must be at least $L_B/2$. In order to comply with the electrodynamic forces, the length of the conductor on both sides of the insulator string had to be greater than 2.5 meters. A mechanical load of 5 kN was applied to avoid poor contact surfaces and ensure correct positioning. Arc initiation was performed according to Fig. 2, using a 1 mm² cross-section copper fusible wire. The position of the fuse wire was changed by 45 degrees for each experiment.

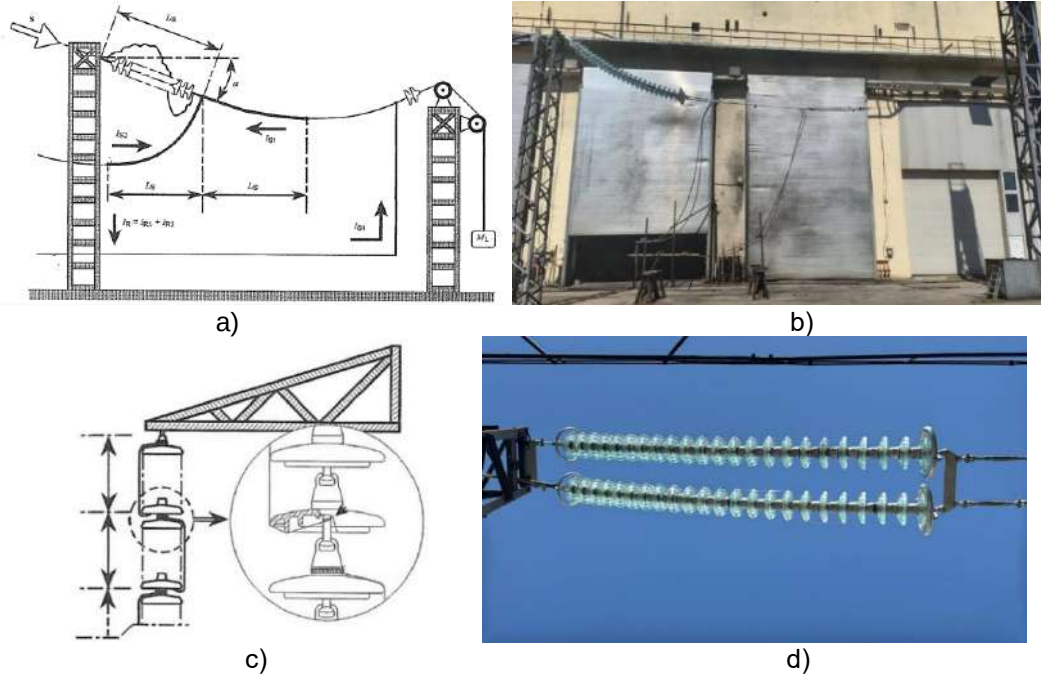


Fig. 2. Assembly diagrams and equipment used in the experiments:

a) assembly diagram; b) photo of assembly; c) arc initiation diagram; d) photo of arc initiation

4. EXPERIMENTATION

Three experiments were conducted using the unbalanced circuit variant under the same conditions presented in the previous chapter. The first two experiments lasted 200 ms, and the third experiment lasted 500 ms. The interval between experiments was more than 20 minutes, which was deemed sufficient time to address any potential issues that could arise during operation. The following are the assumed values for the experiments: the maximum short-circuit current I_{sys} is 40 kA, and the voltage is 24 kV, which is considered sufficient to maintain the arc throughout the experiments.

Fig. 3 shows the oscillograms the third experiment, which is considered representative because of its length.

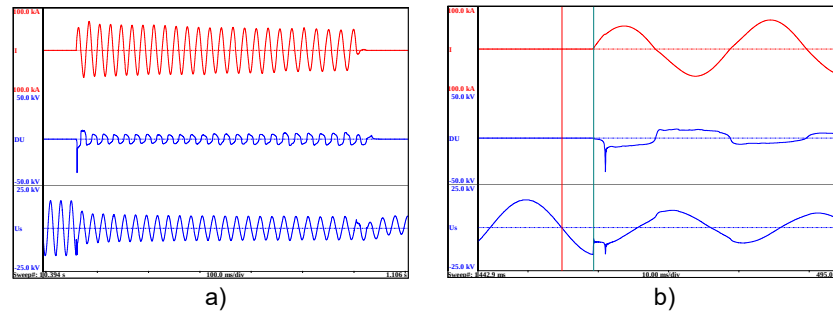


Fig. 3. Oscillograms of the third experiment: a) Complete recording; b) Detail of current occurrence

After evaluating the oscillograms, it was confirmed that the circuit could provide the necessary current and arc duration. Values obtained in the third experiment: $I_m = 63.5\text{ kA}$; $I_{RMS} = 38.8\text{ kA}$; $\Delta U = 4.56\text{ kV}$; $\Delta U_{peak} = 36.7\text{ kV}$; $DC\% = 16.1\%$.

Fig. 4 shows aspects from the experiments and the layout of the insulator string after the experiments.

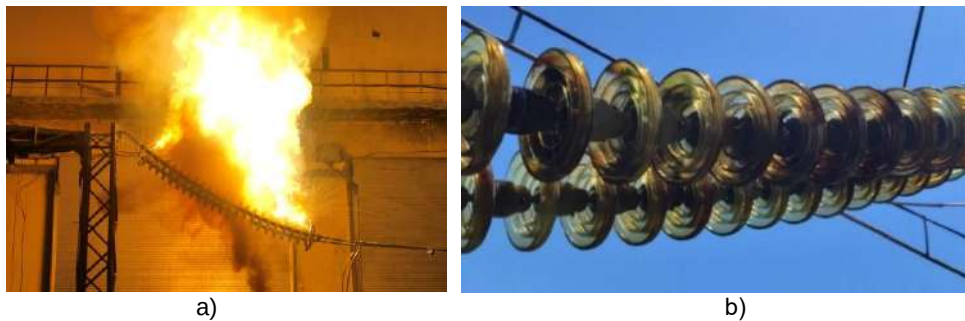


Fig. 4. Insulator string layout: a) During experiments; b) After experiments

5. RESULTS AND DISCUSSIONS

After the experiments, a visual inspection of the insulator string exposed to the high-power arc was performed. The inspection revealed no separation of the insulators or broken sheds, though melting of the galvanized surfaces was detected. A mechanical load test (70%) and an AC voltage test followed, both of which showed that the insulator string performed as expected. As the duration of the power arc increases, so does the length of the electric arc. However, it is always shorter than the creepage distance of any insulator. The experiments revealed that the arc tends to increase its column length over time. The experiments were conducted based on statistics showing that distribution lines have protective devices that operate within 0.2 seconds of a 15.75 kA current.

In conclusion, the results presented in this article demonstrate the effectiveness of the analyzed insulator strings in high-voltage electrical circuits of up to 400 kV. Analyzing their behavior under high-power arc conditions provides valuable insight into how they perform under intense dielectric and thermal stress. The article's main contribution is deepening our knowledge of the mechanisms that trigger and propagate electric arcs on insulator surfaces. This knowledge is essential for assessing the reliability and operational safety of these critical components in electricity transmission network infrastructure. Furthermore, the article's conclusions may be a useful starting point for developing applied research aimed at optimizing insulator string performance. This can be achieved by improving the materials and structural geometry or by developing advanced protection solutions against partial discharges and surface pollution. Thus, future research should focus on increasing arc withstand capacity, extending service life in harsh environmental conditions, and integrating these insulator strings into modern, real-time monitoring and diagnostic systems.

ACKNOWLEDGEMENTS

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EXPERIMENTAL STUDY ABOUT THE SWITCHING CAPACITY OF A CIRCUIT BREAKER IN OUT-OF-PHASE SITUATION

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ABSTRACT – IO7

In the experiment described in the article, the switching capacity of a 36 kV, 1250 A, 16 kA, SF₆ circuit breaker is analysed in the case of out-of-phase switching (coupling and decoupling of two non-synchronous systems). In interconnected systems, situations may occur in which the circuit breaker is closed by mistake, coupling two non-synchronous systems, which is equivalent to a short-circuit, and consequently, it is necessary to separate two generators or two sources whose voltages are in out-of-phase. The article contains a deep analysis of all situations that can occur, a description of a real life object, real life experiments in high-power circuits.

Keywords: circuit breaker, out-of-phase breaking, transient recovery voltage, high voltage, switchgear

1. INTRODUCTION

Electrical circuit breakers are essential devices that are strategically located within electrical power systems. They are designed to enable the controlled connection and disconnection of electrical circuits and equipment [1]. Advanced protection and control systems continuously monitor the network's operational parameters and control their operation [2]. Relay protection systems are essential for detecting abnormal operating conditions, especially major faults like short circuits [3], [4]. The protection system coordination is designed so that the circuit breaker or the closest circuit breaker to the fault location operates first. The principle of selectivity enables the most localized interruption of the fault current, thereby reducing its impact on the rest of the electrical network. This essential function requires that circuit breakers to be capable of interrupting high-intensity fault currents in a very short amount of time, ensuring the effective protection of the power system [5].

2. CONTEXT OF THE EXPERIMENTS

Fig. 1 shows the model used for the experiments: a circuit breaker with a rated voltage of 36 kV, a rated current of 1.250 A, and a rated short-circuit current of 16 kA. The circuit breaker presented is used in real life operation and is designed to close and break high-voltage electrical circuits in the presence of operating currents. It is also designed to automatically open these circuits when unacceptable overload currents occur, such as short-circuit currents. This article describes an experiment that tests the switching capacity of this type of circuit breaker during out-of-phase switching, which involves the coupling and uncoupling of two out-of-phase networks.

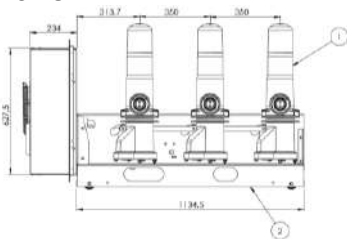


Fig. 1. The circuit breaker on which the experiments were performed 36 kV, 1250 A, 16 kA (item 1 - circuit breaker pole, item 2 - support)

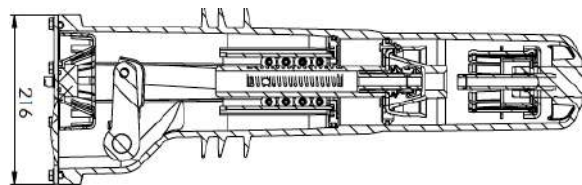


Fig. 2. Cross-sectional view of a circuit breaker pole

Fig. 2 shows a cross-section view of a circuit breaker pole and illustrates how it extinguishes the electric arc in the sulfur hexafluoride insulation medium. In the case of a neutral-grounded network, out-of-phase occurs differently than in an effectively neutral-grounded network. However, the stress during the arcing period is severe in both cases.

Although out-of-phase switching conditions rarely occur in practice, they are divided into two distinct cases: Case A: instability of a network in service due to overload, load rejection, or other major disturbances, such as those caused by a severe storm; Case B: faulty switching operation during synchronization.

Case A. Studies on energy system stability often take the network conditions illustrated above into account [1]. During such events, when parts of the network are disconnected, a phase shift occurs at a network impedance point where a strong load current can be assumed to exist. In the event of a phase shift, the protection system initiates a power interruption by detecting the difference in voltage phase angles on the

impedance and sending a trigger signal to the associated circuit breakers. The first circuit breaker to open will encounter the phase shift condition. This is the case that was studied. Studies indicate that, during such disturbances, the phase angles of individual generators scatter. This makes it unlikely that the two sections will have a uniform phase angle. Additionally, it is difficult to separate a densely connected part of a network and put it in out-of-phase with the rest of the network.

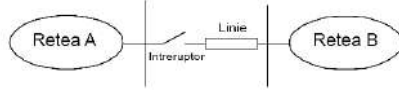


Fig. 3. Network configuration during out-of-phase current breaking in case A

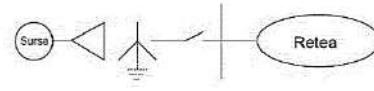


Fig. 4. Network configuration during out-of-phase current breaking in case B.

Fig. 3 shows two networks that are connected by a line containing a circuit breaker. The line—or impedance, such as a transformer—is the connection between the two networks. It is assumed that the networks in cases A and B each correspond to a network operating at the T30-T60 short-circuit level. Cases in which the short-circuit power of both networks corresponds to T100 in scenarios A and B can be considered exceptional.

Case B. Synchronization between high-power systems is a rare occurrence and is addressed in case A regarding transient recovery voltage.

Fig. 4 shows a typical configuration of the synchronization process in an electrical power system. In this system, a generator is connected to the grid via a step-up transformer. In this context, the short-circuit power of the system on the right can be approximated as a T60 level, which reflects a network with considerable rigidity and is equal to 60% of the nominal parameters. In such configurations, the synchronization operation is predominantly performed on the high-voltage side of the step-up transformer, even under asynchronous conditions. This is because the interaction between the generator and the system has the most significant impact on stability and switching currents in this area.

The technical parameters defined for this situation are as follows: subtransient reactance of the generator: 0.3 relative units (p.u.); equivalent reactance of the transformer: 0.1 p.u. These coefficients are essential for transient analysis of making currents and for estimating electromechanical stresses on equipment involved in synchronization. The nominal values of generator sets currently used in power systems are around 600 MVA for 245 kV and 1300 MVA for 550 kV. This reflects the trend of using high-power units in high-voltage networks. Considering the short-circuit reactance of the network, the out-of-phase breaking current—defined as the short-circuit current on the high-voltage side of the generator—varies from 0.5 kA to 8 kA depending on the application and equipment configuration. For the most commonly used configurations where the low-voltage winding of the transformer is connected in a delta (Δ) configuration and the high-voltage winding is connected in a Y configuration in firmly neutral-grounded systems, the generator-side reactance is considerably lower than the positive-sequence reactance, at approximately 25% of the latter. Once the fault current has been eliminated, the recovery voltage at the generator terminals exhibits strong damping, as indicated by an estimated damping coefficient of 0.8. This suggests that the transient component dissipates rapidly in the post-fault regime. These parameters are important for analyzing the transient behavior of generator sets during major system disturbances.

3. THEORETICAL SUPPORT

The experiments used a three-phase medium voltage circuit breaker with the following ratings: Voltage: 36 kV; Current: 1250 A; Short-circuit breaking current: 16 kA. The circuit breaker's insulation medium was SF_6 at a nominal pressure of 2 bar (absolute), reduced to 1.8 bar (absolute), representing the minimum operating pressure. The circuit breaker was operated by a mechanism that included 24 V DC coils and a 220 V AC motor. To obtain the minimum circuit breaker times, the voltage at the terminals of the operating coils was set to a maximum of 26.4 V DC for the purpose of experimentation. Thus, during the opening operation (0.3 s) of no-load operations, the times obtained were 46.9/48.1/49.6 ms and 66.9/66.1/66.4 ms for closing. These experiments examine out-of-phase disconnection faults in interconnected high-voltage networks that are supplied by at least two power plants. Disconnecting the circuit breaker, which ensures the parallel operation of the two power plants, can cause the power-frequency recovery voltage to reach values twice the combined voltage of the network. This phenomenon will be studied in a single-phase electrical circuit. Thus, based on the cases in Figs 3 and 4, we have two equivalent generators, G_1 and G_2 , which supply a consumer via inductance lines L_1 and L_2 , respectively. During normal operation, the voltages at the two generators' terminals are symmetrical.

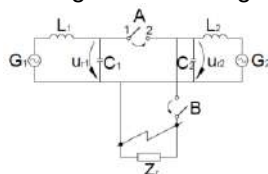


Fig. 5. Single-phase process study diagram

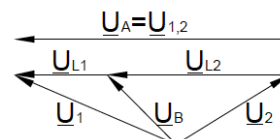


Fig. 6. Out-of-phase vector diagram

As shown in Fig. 5, when a short circuit occurs at the terminals of load Z_r , both generators contribute to the short circuit current value:

$$I_1 = \frac{U}{\omega} \left(\frac{1}{L_1} + \frac{1}{L_2} \right) \quad (1)$$

A short circuit causes the generators' active load to short circuited, resulting in the generators being out of synchronism. Opening circuit breaker B eliminates the short circuit and establishes a current flow between the two generators. The current flow is determined by the phase difference between the terminal voltages of the two generators. This current flow is similar to a short circuit. Its highest value occurs when the terminal voltages of the two generators are in phase opposition. If U is the terminal voltage of a generator, then this current is:

$$I_2 = \frac{2U}{\omega(L_1 + L_2)} \quad (2)$$

The ratio of the out-of-phase short-circuit current (I_2) to the normal short-circuit current (I_1):

$$k = \frac{I_2}{I_1} = \frac{\frac{2}{L_1 + L_2}}{\frac{1}{L_1} + \frac{1}{L_2}} \quad (3)$$

The k -ratio is highest when $L_1 = L_2$ ($k=0.5$). Opening circuit breaker A interrupts the short-circuit current I_2 , and the power-frequency recovery voltage is $U_{1,2}$, as shown in Fig. 6.

In short-circuit mode, voltage $U_{1,2}$ is applied to inductances L_1 and L_2 after circuit breaker B is disconnected.

The magnitude of the recovery voltage U_B of circuit breaker B is reduced, resulting in circuit breaker B disconnecting the short circuit under mild conditions. In the case of total out-of-phase, the recovery voltage $u_{1,2}$ of circuit breaker A results from the difference between the recovery voltages u_1 and u_2 at the terminals of capacitors C_1 and C_2 , respectively.

Out-of-phase in three-phase circuits. Circuit breaker requirements depend on the degree of opposition, grounding of the neutral, and other potential faults in the network. Fig. 7 assumes that the two sources have grounded neutrals.

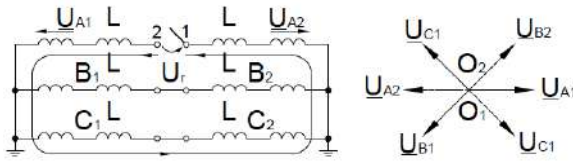


Fig. 7. Grounded neutral of both sources.

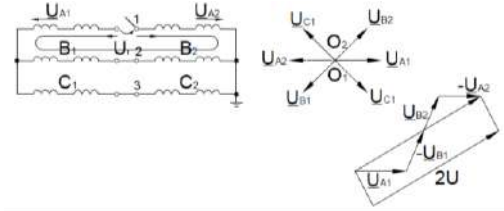


Fig. 8. Grounded neutral of a source.

In this case, the three poles of the circuit breaker interrupt equal currents in the module. The power-frequency recovery voltage is $2\bar{U}_1$, or twice the single phases voltage. Fig. 7 shows that:

$$U_r = U_{A1} - U_{A2} \quad (4)$$

Fig. 9 assumes that one of the two sources is neutral-grounded.

As shown in the diagram, when the first pole is disconnected, the power-frequency oscillating recovery voltage is:

$$U_r = U_{A1} - U_{B1} + U_{B2} - U_{A2} = 2U \quad (5)$$

Typically, this voltage is twice the voltage between phases.

4. EXPERIMENTATION

The experiments aimed to reproduce the situation depicted in Fig. 4. Note that they were performed on the middle pole of a two-phase circuit. The middle pole experiences the same stress as in a three-phase circuit under the same conditions. The experimental circuit was designed so that approximately half of the applied and recovery voltages were on each side of the circuit breaker. The following figures show a single acquisition channel because they represent the differential measure of voltages according to (4). Conducting the experiments in three-phase mode was not considered practical, but it could have been achieved with two identical voltages separated in phase by 120° rather than 180° .

The first experiment simulates the circuit in Fig. 8 under real conditions. The circuit breaker in this experiment is designed for circuits in which the neutral is not connected to ground. The first experiment involved closing and opening operations at the maximum operating voltage of 26.4 V for the drive mechanism coils, with a SF_6 pressure of 1.8 bar (absolute) in the circuit breaker. The assumed values for which the experimental circuit was designed are as follows: applied voltage $\frac{2,5 \cdot 36 \text{ kV}}{\sqrt{3}} = 52 \text{ kV}$, and current of 4000 A with a DC component of $\leq 20\%$.

The values obtained are as follows: voltage: $U = 52.3 \text{ kV}$, r.m.s. current: $I = 4.1 \text{ kA}$, peak current value: $I_p = 4.9 \text{ kA}$, breaking current: DC component = 1%, transient recovery voltage (TRV): 91.2 kV. The opening time was 35.8 ms and the closing time was 64.8 ms, with an arcing time of 4.5 ms.

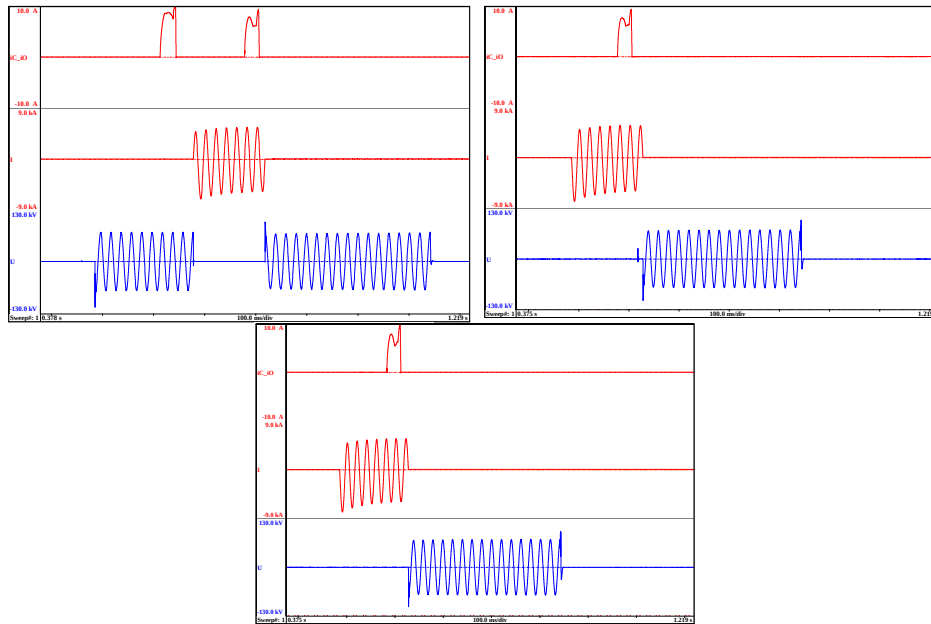


Fig. 9. Oscillograph recording of the first experiment

Fig. 10. Oscillograph recording of the second experiment

Fig. 11. Oscillograph recording of the third experiment

Fig. 10 shows the oscillograph recording from the second experiment, during which an opening operation was performed to obtain the maximum arcing time of the circuit breaker. The values obtained are as follows: voltage $U = 52$ kV; r.m.s. current $I = 4.1$ kA; breaking current: DC component = 2%; transient recovery voltage $TRV_p = 91.6$ kV. The opening time was 37.3 ms, and the arcing time was 13.2 ms.

Fig. 11 shows the oscillograph recording from the third experiment, during which an opening operation was performed to obtain the average arc time of the circuit breaker. The values obtained are as follows: assumed voltage $U = 52$ kV; r.m.s. current $I = 4.1$ kA; breaking current: DC component = 2%; transient recovery voltage $TRV = 91.4$ kV. The opening time was 37.2 ms, and the arcing time was 7.3 ms.

5. DISCUSSION

Circuit breakers are integrated into the structure of electrical networks, which consist of active components, such as rotating electrical machines, and passive components, such as cables and transformers. These components are also where magnetic and electric field energy accumulates in the corresponding inductances and capacitances. The dielectric, thermal, and electrodynamic stresses on the circuit breaker, as well as the stability of the electric arc, can be affected by the parameters of the electrical network. This article describes one such situation: out-of-phase disconnection, which can occur in high-voltage, interconnected networks powered by at least two power plants. In contrast to the preceding theoretical analysis, the experimental results obtained are appropriate.

Due to the high voltage level at the circuit breaker terminals, the lack of synchronization between the network elements on either side of the circuit breaker can have significant effects ($\max k_{pp}=2,5$ and $U = \frac{2,5 U_n}{\sqrt{3}}$). The out-of-phase fault current that may occur does not exceed 25% of the network's short-circuit capacity at the circuit breaker installation location, nor does it constitute a significant stress factor. In this mode, the transient recovery voltage that occurs after switching can reach $100 \text{ kV}_{\max}$ for $U_n = 36$ kV. Even if the circuit breaker can withstand this voltage, it still poses a serious dielectric stress to the other components of the installation because the voltage propagates to the terminals of the sources on either side of the circuit breaker. This overvoltage can lead to insulation breakdown and short circuits, which can have serious consequences because the fault current can reach the maximum short-circuit capacity.

The conducted experiments confirm the occurrence of high-level switching surges and relatively short arcing times. The voltage at the circuit breaker terminals is high in this mode, so the pre-arc times increase. This affects the making currents. When switching short-circuit currents at rated voltage, the pre-arc times are $1 \div 2$ ms. In out-of-phase, these times increase to values of up to 5 ms. The most unfavorable case occurs when the connection is made at a 90-degree angle to the phase voltage.

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RESEARCH ON ARTIFICIAL INTELLIGENCE ALGORITHM TO PREDICT THE BEHAVIOUR ON SHORT CIRCUIT SITUATION OF A CIRCUIT BREAKER

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ABSTRACT – IO8

The rapid integration of Artificial Intelligence (AI), Machine Learning (ML), and Internet of Things (IoT) technologies presents substantial potential for advancing the design, development, and operational optimization of electrical equipment. These emerging technologies facilitate enhanced capabilities in modeling, simulation, and analysis of equipment performance under real-world operating conditions. By enabling predictive diagnostics, intelligent control strategies, and adaptive system behavior, AI- and ML-driven tools contribute to greater efficiency, reliability, and sustainability in electrical engineering applications. The convergence of IoT with AI and ML further allows for real-time data acquisition and processing, thereby enabling continuous monitoring and dynamic decision-making throughout the equipment lifecycle. This article presents the development of an algorithm utilizing Artificial Intelligence (AI) techniques, aimed at simulating the dynamic behavior of electrical equipment under specific operating conditions. The performance of the proposed algorithm is evaluated by comparing its output with oscillographic data acquired during laboratory experiments conducted on actual equipment. This comparative analysis serves to validate the accuracy and reliability of the AI-based model, demonstrating its potential applicability for predictive analysis, diagnostic assessment, and real-time simulation in electrical engineering contexts.

Keywords: artificial intelligence, simulation, electrical circuit, predictive analysis, circuit breaker

1. INTRODUCTION

In the context of electrical circuit modeling and analysis, interpretability refers to the extent to which engineers and researchers can comprehend the internal mechanisms and decision-making processes of an AI system applied to circuit diagnostics, simulation, or optimization. Specifically, interpretability ensures that the underlying rationale behind the AI-generated outputs—such as fault detection, transient response prediction, or topology optimization—can be clearly understood in terms of circuit behavior and influencing parameters. When such transparency is lacking, the model becomes inexplicable, limiting its practical utility in critical engineering applications. This issue is particularly pronounced in deep learning-based models, which are often constructed with a primary focus on performance metrics, without due consideration for their explainability. As a result, these models function as "black boxes," where the reasoning behind a given prediction or output remains opaque to users. This lack of interpretability represents a significant drawback in the deployment of AI for electrical engineering applications, especially where reliability and safety are paramount. Therefore, enhancing the interpretability of AI systems is essential for building user trust and ensuring that decisions made by such models can be aligned with established circuit theory and engineering intuition. This requires the integration of explainable AI (XAI) frameworks, which facilitate the extraction of meaningful insights from complex models and promote the responsible adoption of AI in the field of electrical circuits [1].

2. CONTEXT

As automation and artificial intelligence (AI) advance at an accelerated pace, the scientific and research community perceives AI as a strategic component that can provide a competitive advantage by modernizing processes, differentiating products, and introducing a new level of performance. However, the effectiveness of AI depends on the availability and quality of data. In this context, data becomes a fundamental resource and a veritable currency, while AI is the essential mechanism for integrating, correlating, and leveraging this data to generate knowledge and applicable solutions. As more researchers and developers in electrical engineering turn their attention to AI's potential, critically analyzing this technology's real applicability becomes necessary. The intelligence process essentially involves three stages: collecting data, transforming the data into knowledge, and applying the knowledge in various contexts to support decisions or automated actions. This capacity for analysis and action becomes particularly relevant in technical fields.

As a subfield of machine learning, IA is predicted to become an integral part of engineering activities. Although some traditional data analysis and processing tools will continue to be used, AI has the potential to enhance their functionality. This can be achieved by optimizing data integrity assurance processes and automating repetitive or error-prone tasks. Over the last decade, the research and development process in electrical engineering has evolved significantly. In the past, creating a prototype involved going through complex and costly experimental stages. AI technologies currently enable the simulation of electrical circuit

behavior under realistic conditions, which significantly reduces the need for manual intervention by eliminating large amounts of code and minimizing the risk of human error [1], [2]. Of course, integrating AI into existing systems is not instant or automatic, nor does it guarantee spectacular results on its own. Success hinges on an iterative approach involving experimentation, adjustments, and continuous refinement. A systematic approach is necessary to achieve higher levels of customization, efficiency, and reliability in modern electrical engineering applications.

3. SIMULATION RESEARCH AND RESULTS ANALYSIS

This study developed a dedicated simulation platform and conducted a series of rigorous experiments, accompanied by extensive data analysis, to evaluate the effectiveness of the optimization method applied to the design of an electrical circuit containing a medium-voltage circuit breaker assisted by artificial intelligence. These experiments tested various algorithmic configurations and systematically compared system performance according to the implemented optimization variants. The comparative analysis revealed how each parameter influences the system's behavior, providing conclusive and representative results for validating the proposed methodology.

A dedicated simulation platform is essential for conducting simulation-based research. The main objective is to create a virtual experimental environment for testing and validating optimization algorithms applied to electrical circuits. There is a special focus on the dynamic behavior of medium voltage circuit breakers during connection and disconnection operations. This study used Micro-Cap software to develop a simulation platform that combines advanced simulation capabilities with high programming flexibility. This combination provides an efficient and robust framework for accurately modeling and optimizing electrical circuit configurations in different operational scenarios.

The simulation is based on the assumption that interrupting the electric arc of alternating current is easiest when the current naturally crosses zero and ionization in the arc column is minimal. The explanations provided to the artificial intelligence system were reformulated until the system could highlight the differences in the decision-making basis of black-box models trained for the same task. These models may use different rules to reach similar conclusions. An analytical framework, such as machine learning, must reflect this to the relevant parties. This feature is essential for a comparative understanding of the behavior of different electrical circuit models. A high degree of consistency in explanations was associated with situations in which the models provided justifications that were very close to the experimental results. However, consistency does not directly correlate with interpretability. For example, two models may have similar relationships between variables and, implicitly, coherent explanations, but if they use different sets of features to obtain similar predictions, the explanations must clearly reflect the lack of consistency [3]. Therefore, the most relevant explanations were those that highlighted the structural and functional differences between black box models, even when the models produced similar results for a given task. Specifically, in the present case, the switching device whose operation is to be simulated is considered to be in a network. The success or failure of interrupting the electric arc depends on the network's parameters, which are the arc voltage and the withstand voltage. These parameters signify the recovery of dielectric rigidity in the electric arc column.

During the preliminary modeling stage, the accuracy of the data was assessed intuitively, and its characteristics were described through visualization or exploration of data samples. Data quality assessment was essential in the building process. This included ensuring the accuracy of labels, the truthfulness and relevance of the datasets used for training, validation, and testing, and the balance and representativeness of these datasets. This analysis determined the data's suitability for the modeling process, the variables' degree of correlation, and the data's general characteristics. Analysis of variance, hypothesis testing, correlation analysis, regression, or factor analysis were used to describe trends and the degree of dispersion of the data. These analyses provided a solid foundation for selecting the appropriate modeling method and building an explainable, robust model. Based on the observations made during the initial discussion with AI, direct, indirect, and circumstantial explanations were provided [4]. These explanations generated rules and decision trees. The final circuit obtained with the AI-generated code is shown in Fig. 1.

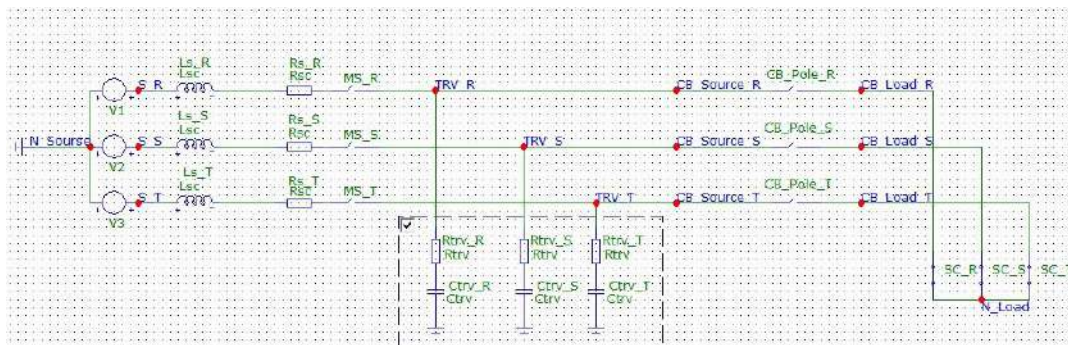


Fig. 1. The AI-generated circuit used in simulation

The circuit block elements in Fig. 1 were conditioned using values obtained from real experiments, such as the opening and closing times of the circuit breaker. This was done so that the results could be compared. Fig. 2 shows the oscilloscope recording obtained with transient analysis.

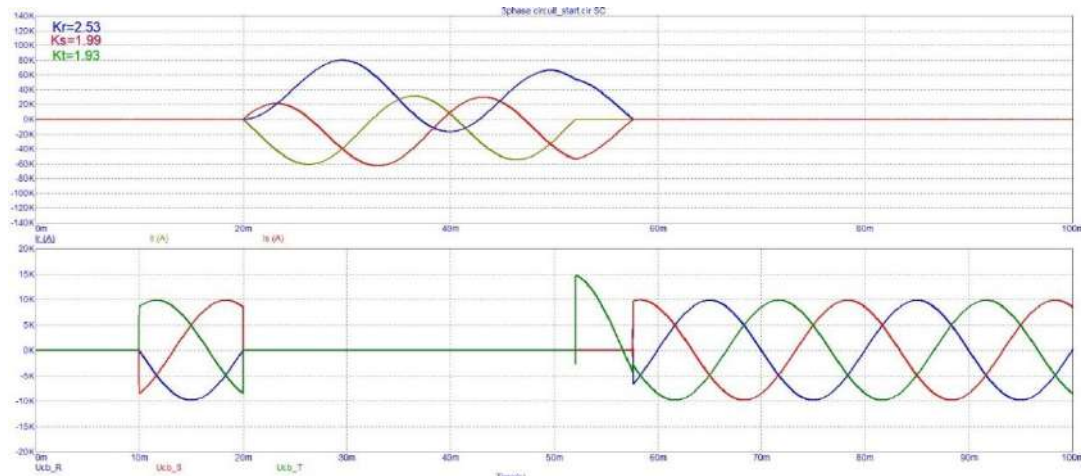


Fig. 2. Oscilloscope recording obtained with the AI-generated circuit

This model uses accuracy and error detection rates, as well as other indicators, to evaluate its performance. However, these indicators do not clearly explain how the model works. Therefore, additional interpretation methods are needed to make the "black box" more transparent. Methods such as partial dependence plots (PDP), individual conditional expectation (ICE), accumulated local effects (ALE), feature interactions (FI), and permutation feature importance (PFI) can currently provide explanations for the model. These methods are not dependent on a specific model, making them highly flexible [5].

4. EXPERIMENTS

The electric arc generated in switching devices is a manifestation of an electrical discharge in a gaseous environment. This arc is profoundly influenced by the local conditions in the extinguishing chamber. Its behavior is determined by several essential parameters, including the length of the arc, heat transfer mechanisms, electric current intensity, and the type of current (i.e., alternating or direct). These factors influence both the efficiency of the extinguishing process and the overall performance of the switching device.

The interruption technique aims to minimize the duration of the electric arc to reduce the thermal effects on the device and the impact of short-circuit currents on installations protected by the device. In these situations, it is important to extinguish the electric arc when the current crosses zero for alternating current (AC) or by creating combustion instability for direct current (DC).

Fig. 3 shows oscilloscope recordings obtained during experiments conducted in a high-power electrical circuit at the High Power Laboratory of ICMET Craiova. The electrical circuit was designed so that, when calibrated without a circuit breaker (as this adds transient phenomena), the expected parameters would be obtained, similar to those obtained in the AI simulation.

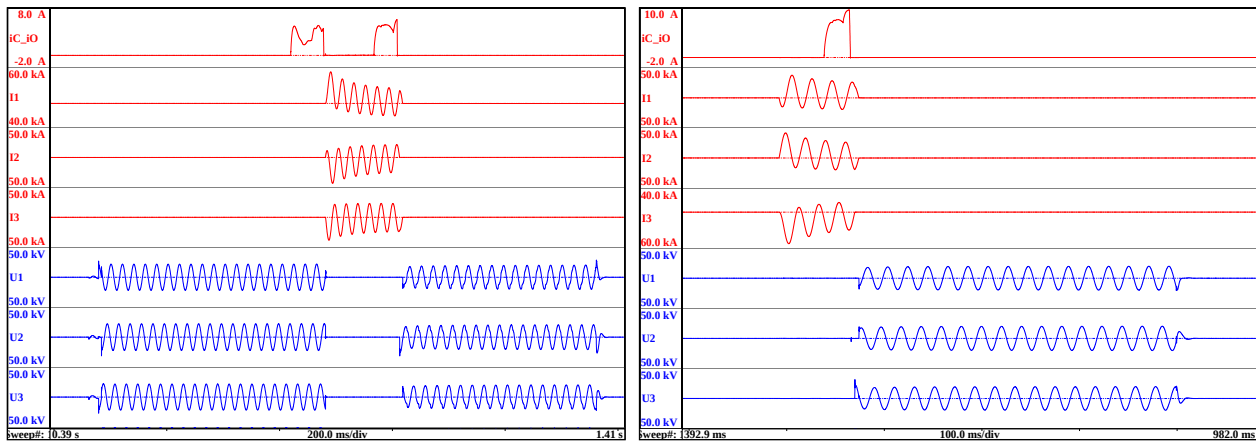


Fig. 3. Oscilloscope recordings obtained during experiments conducted on the actual object

The circuit breaker used for experiments was practically new, with new contacts so, it was very close to its ideal state. Since it was a spring-operated circuit breaker, operations were performed with the closing solenoid reaching 100% and 85% of the rated closing supply voltage.

Although the short-circuit breaking current is measured at the instant of contact separation, the circuit breaker's breaking capacity is determined by the final interrupting current in the last arcing loop. This is a key factor that must be emphasized in the simulated AI results. Therefore, it is very important to reduce the AC component of the short-circuit current, especially for circuit breakers that arc for several current loops. The instant of contact separation was determined by testing the circuit breaker under no load conditions.

5. RESULTS AND DISCUSSIONS

The purpose of this research is to compare oscilloscope recordings obtained using an AI-generated model with those obtained during real experiments involving the connection and disconnection of a short circuit in an AC network. The current and voltage waveforms were analyzed before and after separating the contact elements. In both experiments, the electric arc is extinguished and the recovery voltage is generated at the terminals of the device when the current first crosses zero. In both situations, the simulation condition to prevent the arc from reigniting is that the withstand voltage (the voltage required to restore dielectric strength after an electric arc has been extinguished) must be higher than the recovery voltage.

Regarding the AI-generated model, it must be reliable and characterized by robustness. The explainability methods used to interpret it must also demonstrate this property. An interpretation method with a high degree of stability must be resistant to minor changes in input data that do not significantly influence the model's decision. The value of this property is directly proportional to its interpretability. High stability of explanations increases persuasiveness and trust in the system. It is difficult to accept unstable explanations because there is insufficient evidence to confirm that they are not the result of coincidences. Therefore, it is crucial that the explanations produced by artificial intelligence models are highly stable. Any product that integrates these methods must include a way to quantify this property. One method is to use cosine similarity to evaluate interpretability by comparing the explanation provided for an input instance with the explanations provided for its neighbors.

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EXPERIMENTAL STUDY ABOUT THE SWITCHING CAPACITY OF A SF₆ FREE SWITCH DISCONNECTOR

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ABSTRACT – IO9

In the context of replacing sulfur hexafluoride (SF₆) in switching devices, current research directions focus on the development of alternative gases with low global warming potential, such as synthetic air, low-impact fluorinated gas mixtures, or hybrid solutions, as well as the optimization of solid-state switching technologies. Integrating these solutions into power grids requires a reassessment of equipment architecture, design specifications, and testing protocols to ensure a sustainable transition without compromising system reliability. This article presents the behaviour of an SF₆-free switch disconnecter during the making and breaking of capacitive and resistive electrical circuits.

Keywords: switch disconnecter, mainly active load, cable charging, sulfur hexafluoride

1. INTRODUCTION

Designing gas-insulated switchgear with environmentally sustainable alternative gases presents new challenges. As one of the non-fluorinated gases, synthetic air is a viable option for use in switch disconnectors. However, due to its lower switching capacity than sulfur hexafluoride (SF₆), synthetic air requires operation at higher pressures or the use of additional methods to extinguish electric arcs. This paper examines the behavior of synthetic air when interrupting predominantly active and capacitive loads, as well as the characteristics of this process. To this end, a switch disconnecter with a configuration similar to those commonly found in SF₆ disconnectors was used. The shift away from using sulfur hexafluoride (SF₆) in gas-insulated switchgear in favor of alternatives that have a smaller environmental footprint is prompting a reevaluation of using synthetic air for insulation and arc extinguishing. Synthetic air has certain technical limitations compared to SF₆ and other alternative gases or gas mixtures used in similar applications. These limitations include lower dielectric strength, a higher arc time constant, and reduced interrupting (arc extinction) capacity. Despite these disadvantages, synthetic air remains a viable option for use in switchgear, especially in gas-insulated switchgear (GIS) designed for high-voltage installations [1]. In this context, synthetic air's ecological nature provides a significant advantage, making it one of the most sustainable options for future electrical switching technologies.

2. CONTEXT OF THE EXPERIMENTS

Fluorinated greenhouse gases are man-made chemicals that are extremely potent greenhouse gases, often thousands of times more potent than carbon dioxide (CO₂). Along with CO₂, methane, and nitrous oxide, fluorinated greenhouse gases are among the emissions covered by the Paris Agreement, which was adopted under the United Nations Framework Convention on Climate Change (UNFCCC). Currently, fluorinated greenhouse gases account for 2.5% of total greenhouse gas emissions in the Union. Unlike other greenhouse gases, which have decreased, fluorinated greenhouse gases doubled between 1990 and 2014. In its December 11, 2019 communication, the Commission presented the European Green Deal, a new growth strategy for the Union that aims to transform it into a fair and prosperous society with a modern, competitive, and resource-efficient economy [2]. The strategy reemphasizes the Commission's commitment to making Europe the first climate-neutral, zero-pollution continent by 2050. Air-insulated load break switches used in high-voltage installations must be able to switch low currents at the rated operating voltage [3]. This ability is a fundamental requirement of the design standards for high-voltage substations in which this equipment is used. In practice, however, this minimum requirement is often surpassed due to the additional requirements imposed by the specific configuration of substations and the particular operational applications in which disconnectors are used. Therefore, this equipment's design must consider not only compliance with basic technical standards, but also the operating and reliability requirements specific to each installation's context.

EQUIPMENT USED IN EXPERIMENTS

Fig. 1 shows the equipment used in the experiments: a 24 kV, 630 A, 16 kA three-way load break switch that uses synthetic air as the extinguishing medium. For experimental purposes, synthetic air (O₂ 21% ± N₂ 1%) was used as the extinguishing medium. It had a purity of 99.9995%, a ppmv of H₂O < 2, C_nH_m < 0.1, CO < 1, and CO₂ < 0.2. Its molecular weight was 29 g/mol, and its absolute density was 1.204 g/L. Three media are highlighted in the literature on the electric arc extinguishing technique: nitrogen, hydrogen resulting from oil

decomposition under the action of the electric arc, and sulfur hexafluoride. Although hydrogen has the highest diffusivity and sulfur hexafluoride (SF_6) has the lowest, SF_6 performed the best during operation.

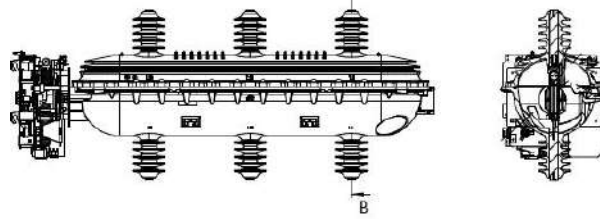


Fig. 1. The 24 kV, 630 A, 16 kA load break switch on which the tests were performed

A gaseous medium is considered effective at extinguishing an electric arc if its conductivity decreases rapidly when the electric current crosses zero. In other words, a gas's ability to interrupt an electric arc is directly associated with the arc time constant, which reflects the deionization rate of the arc column [4]. Therefore, a gas with a low time constant promotes rapid arc extinction. This reduces the risk of re-ignition and contributes to the safety and reliability of electrical circuit interruption. From this point of view, the conditions that must be met for an electric arc to ignite in a gas are:

- to optimize the process of extinguishing an electric arc in a gaseous environment, the binding energy between the gas's constituent atoms should be as low as possible. This energy directly affects the temperature associated with the recombination phenomena that occur in the arc column's peripheral region. Therefore, low binding energy allows for the more efficient recombination of ionized particles. This contributes to the rapid dissipation of thermal energy and reduction of electric arc duration. This aspect is essential when designing and selecting gases for use in medium-voltage switchgear;
- the temperature at which the gas molecule dissociates should be as low as possible, preferably below the extinguishing temperature. The extinction temperature is the temperature at which the electron concentration drops below 109cm^{-3} , the threshold at which an electric arc will no longer ignite in the presence of excitation, such as recovery voltage.

From this perspective, SF_6 and S_2F_2 are good gases for extinguishing electric arcs because dissociation processes occur in them below 3000 K. However, although hydrogen has high diffusivity, its dissociation temperature is 4500 K. In terms of the gas used, synthetic air (consisting mainly of 78% nitrogen and 21% oxygen) begins to dissociate significantly at temperatures between 2,700 and 3,800 Kelvin (K), with complete dissociation occurring above 5,200 and 6,200 K. Significant bonding energies are found between nitrogen molecules (N-N), at 708 kWs/mol.

The electric arc that occurs during the disconnection operation is not cylindrical due to various influences, such as electrodynamic forces, the path forced by the equipment's shape, and the Lorentz force, which is significant at high values. Additionally, the arc base is located inside the equipment on a conductive material where the current density is high ($>107\text{ A/cm}^2$). The arc column develops in synthetic air, a less conductive medium.) Because of the physical properties of synthetic air used as an extinguishing medium, the electric arc column's diameter tends to be significantly larger than the cathode spot's diameter [5]. The expansion of the arc column in its central area creates a variation in the cross section. This generates an asymmetry in the distribution of the magnetic field and electric current density. This asymmetry is reflected by the altered distribution of Lorentz forces along the arc column. These imbalances directly result in plasma currents flowing toward the electric arc's transverse axis of symmetry. In this central region, plasma flows collide from opposite directions of the two electrodes, generating an intense plasma ejection oriented in the system's transverse symmetry plane. This phenomenon significantly impacts the stability and dynamics of the arc. It influences the arc's thermodynamic behavior and the efficiency of the extinguishing process in high-voltage switching equipment. The AC arc interruption is facilitated by the natural zero-crossing of the current [1], [6]. At this point, ionization in the arc column is minimal. Since the load break switch will be placed in a network, the success of interrupting the electric arc depends on network parameters such as the short-circuit current and recovery voltage etc. Thus, the experiments simulated both a capacitive circuit, in which SF_6 -free switchgear encounters difficulties, and a resistive circuit.

3. EXPERIMENTS

The experiments focused on the load break switch's ability to interrupt capacitive currents because these devices are sensitive to this type of switching in SF_6 -free constructions. First, we verified that the load break switch could perform closed-open operations without voltage or current, and it successfully completed the operations. Then, a circuit was created to simulate the opening of a no load (capacitive) cable circuit. The equipment was installed under the same conditions as in operation, with the casing grounded via a current indicator device. The device consisted of a 0.1-mm-diameter, 5-cm-long copper fuse wire. It was determined that no significant current flowed through the wire because it remained intact after the experiment. Additionally, the Joule integral of this current did not exceed $5\text{A}^2\text{s}$ for a duration greater than 100 ms. The experiments simulating the disconnection of cables under no load proceeded normally. The load break switch was capable of performing these operations [5]. Fig. 2 shows the oscilloscope recording from the experiment:

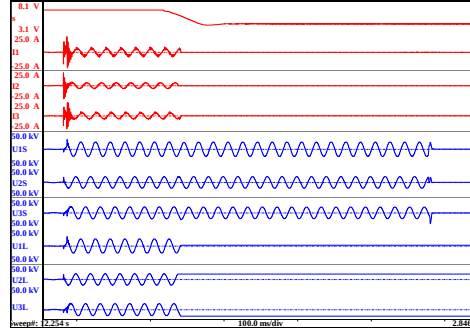


Fig. 2. Oscilloscope recording of no-load cable opening operation

The experiments were conducted at a nominal voltage of 24 kV. This voltage was measured before the contacts were opened, at the point closest to the separator terminals. Since these were three-phase experiments, the voltage was evaluated on a per-phase basis. The current that had to be interrupted was sinusoidal in shape with insignificant distortion. The values were considered satisfactory, as the ratio of the rms value of the total current to the rms value of the fundamental component did not exceed 1.2. The interrupted current did not cross zero more than once per half-cycle of the operating frequency. Capacitors were used to simulate sheathed cables (used in circuits with voltages up to 15 kV) and shielded cables. Because the tests were three-phase with a grounded source represented by three-core sheathed cables, the capacitive circuit's positive sequence capacity was about three times greater than its zero-sequence capacity. A non-inductive resistance that did not exceed 5% of the capacitance impedance was placed in series with the capacitors. The values obtained in the last experiment are as follows: Breaking current: 3.7 A, 3.5 A, and 3.6 A; Maximum voltage value after disconnecting the circuit on the supply side: 23.4 kV; Maximum voltage after disconnecting the circuit on the load side: -22.1 kV; Arc duration: 3.9 ms, 0.5 ms, and 3.9 ms; Total opening time: 1352 ms; Breaking time: 1355.9 ms, 1352.5 ms, and 1355.9 ms.

In the presented experiment, the electric arc ensures electrical conduction after the separating the contact elements. First, an electrical interruption occurs at the pole where the current crosses zero for the first time (pole L2). An interruption is achieved simultaneously in poles L1 and L3 when the phase is out of phase by an angle $\pi/2$ and there is a delay. Even after an interruption on phase L2, the capacitor on pole L2 remains loaded at voltage $\hat{E}$. During the quarter cycle—from the moment of interruption on phase L2 to the moment of interruption on phases L1 and L3, as shown in the vector diagram in Fig. 3b - the potential of point O increases from zero to $\frac{\hat{E}}{2}$.

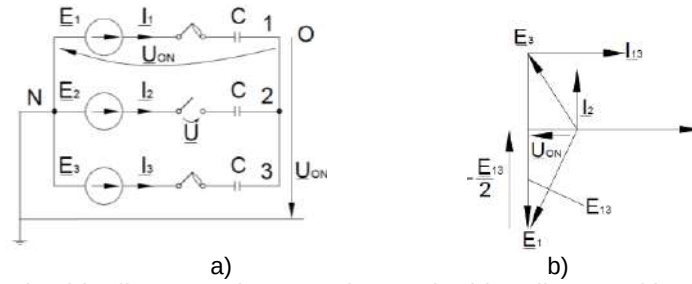


Fig. 3. No-load cable disconnection experiment a) wiring diagram; b) vector diagram

The following relationship can be written based on Fig. 3a): $\underline{E}_2 = \underline{Z} \underline{I}_{13} + \underline{U}_{ON}$, where $\underline{U}_{ON}$ is the voltage of point O relative to ground, and $\underline{I}_{13} = \underline{E}_{13} / 2\underline{Z}$, therefore $\underline{U}_{ON} = 0,5\underline{E}_1$.

The recovery voltage on pole L2 is obtained by adding the voltage at point O relative to ground to a normal single-phase recovery voltage of $2\hat{E}$, amplitude, resulting in an amplitude of $2,5\hat{E}$. After electrical disconnection on phase L2, it follows that the capacitor bank used in the experiments is subjected to a voltage of $\sqrt{3}\hat{E}$ for poles L1 and L3. The interruption occurs when the i_{13n} current crosses zero with a phase shift of $\pi/2$ relative to the L2 zero crossing. The interruption occurs simultaneously at poles L1 and L3. The same current (i_{13}) flows through both. The recovery voltages u_1 and u_3 reach a maximum value $\sqrt{3}\hat{E}$, because the maximum value applied to these poles is $2\sqrt{3}\hat{E}$. The duration of the electric arc in poles L1 and L3 is greater by a time of $t = \pi/2\omega$ compared to the arc's duration in pole L2. The current in phase L1 leads by an angle of $\pi/6$ relative to the current in three-phase mode. The current through pole L3 crosses zero with a delay of an angle of $\pi/6$ relative to normal operating mode. Experiments were conducted in a resistive circuit with a predominantly active load, considering the corresponding capacitive circuit operation. A power factor of ≤ 0.2 was achieved by connecting reactances and resistances in parallel in the power supply circuit. The power supply circuit's impedance accounted for $15 \pm 3\%$ of the experimental circuit's total impedance. The first

experiment involved performing an opening operation at the nominal current of 630 A for the disconnecter. The experiment also includes a closed-loop experiment in which elements were added to the circuit to create more severe transient recovery voltage parameters. The transient recovery voltage parameters were adjusted by increasing the amplitude factor. The source impedance is 15%.

Fig. 4 shows the oscilloscope recording of the experiment:

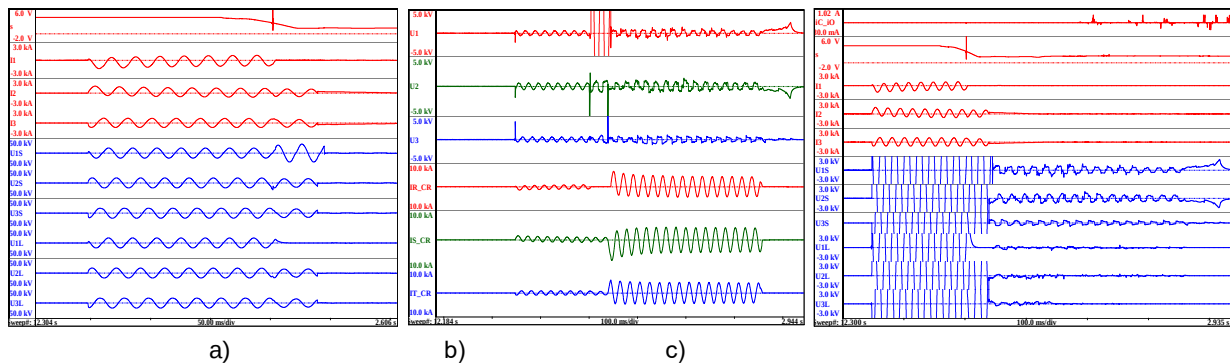


Fig. 4. Oscilloscope recording of an experiment involving a predominantly active load: (a) View of the entire experiment (b) A detailed view of the fault currents (c) Detailed view of arc voltages.

The load break switch could not interrupt the expected 630 A current flowing through the predominantly resistive circuit. The values obtained are as follows: current (I): 648/647/650 A, transient recovery voltage (U): 21/10.2/10.2 kV, arc duration: 2.81/38.2/38.2 ms.

CONCLUSIONS

Although it performed adequately when connecting and disconnecting capacitive loads, the SF₆-free load break switch solution proved to be unsuitable for disconnecting electrical circuits with predominantly active loads. Sulfur hexafluoride (SF₆) remains an essential component of high-voltage switchgear, especially disconnectors, thanks to its exceptional dielectric insulation and arc-quenching properties. This gas's electrical and thermal properties enable the safe and efficient operation of equipment under extreme conditions and ensure the stability of complex electrical networks.

However, sulfur hexafluoride (SF₆) is a gas with a high global warming potential (GWP), raising significant concerns in the context of international regulations aimed at reducing greenhouse gas emissions. Consequently, the scientific community and the energy industry have made sustained efforts to identify and implement environmentally friendly alternatives that maintain operational performance while minimizing environmental impact. In this context, research efforts focus on developing alternative gases with a low global warming potential. These gases include synthetic air, low-impact fluorinated gas blends, and hybrid solutions. Research also focuses on optimizing solid-state switching technologies. Integrating these solutions into electrical networks requires reassessing equipment architecture, design requirements, and testing protocols. This ensures a sustainable transition without compromising system reliability. Therefore, the current challenge is to harmonize technical performance with sustainability requirements to establish a sustainable and reliable energy future compatible with environmental protection policies.

ACKNOWLEDGEMENT

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ELECTRICAL EQUIPMENT FOR MEDIUM AND HIGH VOLTAGE IMPLEMENTED IN MONITORING SYSTEMS

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ABSTRACT – IP2

In order to manufacture modern electrical equipment that ensures and guarantees operational safety, protective adapters for isolated passages, implemented in monitoring systems, are important. Protective adapters for isolated passages manufactured by ICMET are presented, offering a wide variety of applications for high-voltage electrical equipment in power stations throughout the country, these are important components used to ensure safety and reliability in operation. This work is intended for those interested in purchasing protective adapters for isolated crossings, manufactured at ICMET Craiova, based on the execution documentation and with specialized support for performing all certification tests in accordance with the international standards in force.

Keywords: adapter, system, monitoring, protection, electrical

1. INTRODUCTION

By implementing protective adapters in isolated crossing monitoring systems, the proper functioning of medium- or high-voltage electrical equipment in electrical stations can be monitored remotely.

ICMET Craiova has a tradition in designing and manufacturing medium and high voltage electrical equipment, as well as testing finished products in its own laboratories, according to market requirements. Thus, based on the execution documentation, we manufacture a wide range of protective adapters for insulated bushings, which are compatible with the type of insulated bushing, the rated voltage of the transformer, and the relevant standards (e.g., SR EN 60137:2018-Insulated bushings for alternating voltages above 1000 V). In the actual manufacture of insulated crossing protection adapters, high-quality materials are used from domestic and foreign suppliers that comply with the applicable norms and standards set out in the execution documentation. Both the materials and components purchased are accompanied by quality certificates, warranties, and declarations of conformity attesting to their quality.

We present some of the adapters made at ICMET Craiova:

1. Capacitive adapter for measuring terminals of capacitor-type insulated bushings;
2. Box-type capacitive adapter for online measurement of insulated capacitor-type crossings;
3. Isolated signal conditioning module (MCS);
4. Protective adapter for insulated crossings.

These are manufactured in several designs and are used for continuous monitoring of electrical quantities in high-voltage capacitor-type insulated bushings that equip transformer units in electrical substations.

2. TYPES OF PROTECTIVE ADAPTERS

2.1. Capacitive adapter for measuring terminals of capacitor-type insulated bushings

Initially, we started by developing capacitive adapters for insulated measuring terminals designed to measure and monitor the capacitive current of high-voltage insulated passages. The adapter output contains two overlapping signals, one signal being proportional to the leakage current through the insulated passage and the other being pulses resulting from partial discharges. The insulated passage measuring electrode is connected to an electronic circuit consisting of two gas discharge tubes, which provide surge protection, connected in parallel with four 0.47 μ F/310V capacitors. These, together with the isolated pass capability, achieve the capacitive divider. The output signal passes through the ferrite coil, which eliminates high-frequency noise, and is connected via a shielded coaxial cable to the electrical equipment that performs the monitoring. During normal operation, the leakage current is picked up by the sensor, filtered by the high-frequency components, and then conducted into the acquisition board.

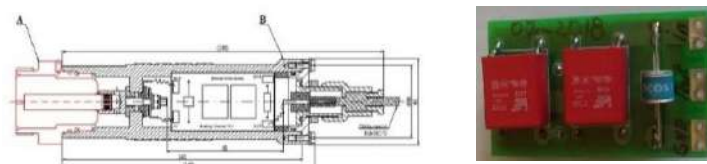


Fig. 1. Capacitive adapter for measuring terminals of capacitor-type insulated bushings: (a)Overview; (b) Electronic Board

The capacitive adapter for isolated measurement terminals in Fig.1a, respectively B, consists of: adapter body, contact tulip, insulating spacer, electronic board (Fig.1b), and 50Ω female/male connector assembly for RG-58 C/U coaxial cable. A represents the terminal on the transformer insulator to which the B adapter is connected. Depending on the type of terminal A, the size of the thread and the bolt that makes direct contact with the socket, adapters are also manufactured.

2.2. Box-type capacitive adapter for online measurement of insulated capacitor-type crossings

For efficiency and modernization purposes, box-type capacitive adapters were designed and manufactured for online measurement of capacitor-type insulated bushings with the same purpose, to measure and monitor the capacitive current of high-voltage insulated bushings with which the transformer units are equipped. They can be equipped with two types of electronic boards: with or without partial dischargers (DP).

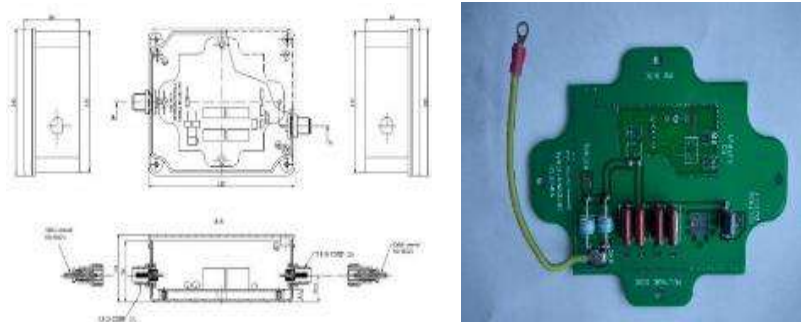


Fig. 2. Box-type capacitive adapter for online measurement of insulated capacitor-type crossing without DP: (a) Overview; (b) Electronic board without DP

This adapter contains an electronic circuit protection box, an electronic board (Fig.2b). The initial capacity of the adapter was $2.72 \mu\text{F} \pm 10\%$, depending on the type and manufacturer of the isolated passages. Working range: 0÷200 mA, 50 Hz. The adapter's protection rating is IP66, according to SR EN 60529:1995/A1:2003.

3. Isolated signal conditioning module (MCS)

Subsequently, the electronic board in Fig.2b was improved by equipping it with 470 nF capacitors (1.88μF in total), mounted for isolated passages with voltages lower than or equal to 220 kV, and with 680 nF capacitors (2.72μF in total) for isolated passages with a voltage of 400 kV. This unit, enclosed in an IP65-rated box and mounted on a metal mounting plate, constitutes the isolated signal conditioning module (MCS) for continuous monitoring of the status of isolated crossings:

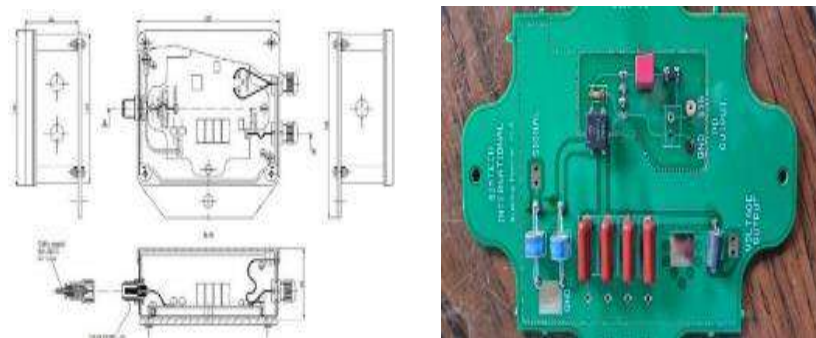


Fig. 3. Isolated signal conditioning module (MCS) with DP: (a) Overview; (b) Electronic board with DP

The product obtained is an improved version of the box-type capacitive adapter for online measurement of insulated capacitor-type crossings. The output of the conditioning module provides a signal proportional to the leakage current through the isolated passage. The isolated passage measurement terminal is connected through a protective adapter (equipped with arresters for protecting the isolated passage) and the coaxial cable equipped with N-type connectors to the electronic circuit located in the module box. MCS consists of two gas discharge tubes, which provide surge protection, connected in parallel with 4÷6 capacitors of 0.68 μF/310V which, together with the isolated passage capacity, form the capacitive divider. The output signal passes through the ferrite coil, which eliminates high-frequency noise, and connects to the monitoring equipment through a coaxial cable. The coaxial cable shield is connected to the product ground. In normal operating conditions, the leakage current is picked up by MCS, filtered by the high-frequency components using ferrite, and then sent to the acquisition, processing, and monitoring equipment. The electrical diagram of the measuring circuit is shown in Fig.4:

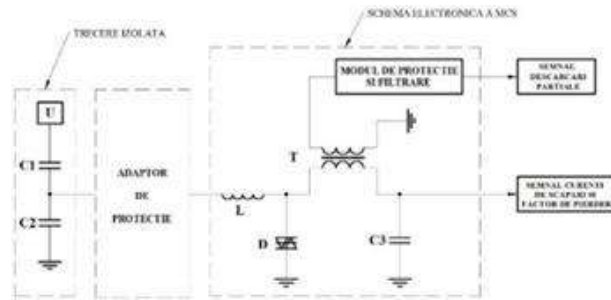


Fig. 4. Electrical diagram for MCS

The circuit uses a D surge arrester for protection in case of signal cable breakage; an L ferrite filter for filtering high-frequency components and a C3 capacitive divider. C1 and C2 are the capacitances of the isolated junction. The partial discharge pulses are captured by the T transformer. After the transformer, two stages are used: one for protection and one for filtering disturbances. MCS is connected to an isolated crossover protection adapter, through the coaxial cable.

4. Protective adapter for insulated crossings

At ICMET Craiova, a diverse range of protective adapters for insulated bushings is manufactured, based on the same principle, which are compatible with MCS, for continuous monitoring of the condition of insulated bushings in order to measure and monitor the operation of transformers in power stations.

Some examples of protective adapters made at ICMET are:

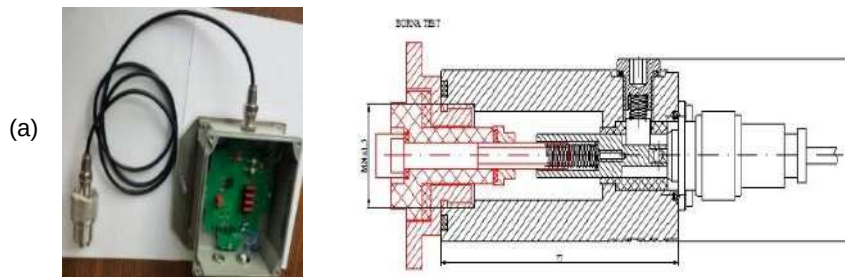


Fig. 5. (a) MCS with DP together with protective adapter for isolated passages, type ECTA 145; (b) Example: BRDLW type isolated crossing protective adapter

The insulated bushing protection adapters allow the electrical quantities to be taken from the insulated bushing measuring terminal with which the transformer units are equipped. They are composed of: adapter body, tulip, insulating sheath, N-type panel connector, female connector, EPCOS 600YYO (600V) gas discharge tube, and plug. The isolated passage measurement terminal is connected through the adapter body and patch cord to the electronic circuit of MCS.

The output of the protective adapter for insulated crossings is the input for MCS, and two signals are provided at its output: one signal is proportional to the leakage current through the isolated passage, and the other represents pulses resulting from partial discharges.

3. TESTING ADAPTERS

The conditioning modules together with the isolated passage protection adapters operate in the range (0÷60) mA and 50 Hz; the measured resistance within the ground circuit is (0.1-0.2) Ω ; the degree of protection of the products is IP 65, according to SR EN 60529:1995/A1:2003. If the adapter cable is interrupted, MCS limits the output voltage to $(90 \pm -10\%)V_{c.a.}$ as peak voltage. After the adapter has been manufactured, in accordance with the execution documentation, is subject to type, individual, and special tests. Type tests are performed both during product assimilation into manufacturing and during manufacturing, whenever materials or manufacturing technology are changed, and are performed in the following sequence:

- a. Checking the materials;
- b. Checking the shape, dimensions and weight;
- c. Checking the equivalent capacity;
- d. Checking the measurement range;
- e. Checking the continuity of the measurement circuit;
- f. Checking the degree of protection;
- g. Checking the electrical circuit for partial discharge acquisition;
- h. Checking the level of protection against overvoltages.

The quality of purchased and used materials and equipment shall be verified **(a)** by checking the quality certificates issued by the supplier of materials and equipment. The verification of shape, dimensions, and weight **(b)**, according to the execution documentation, is performed by visual inspection and with the help of adequate means of measurement. The verification of the equivalent capacity of MCS **(c)**, according to the electrical diagram in Fig.4 , is performed by measuring the electrical capacity on each electronic board, between the input terminal and ground. When the measured capacity is equal to the equivalent capacity of the installed capacitors $\pm 10\%$, the condition is considered fulfilled. The measurement range **(d)** is checked using the electrical diagram shown in Fig.6:

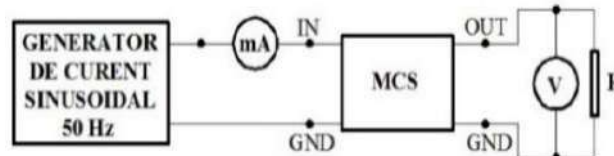


Fig. 6. Electrical diagram

With the sinusoidal current generator, a current of $(10\div 60)$ mA is injected at a frequency of 50Hz, in increments of 10 mA, noting the values indicated by the milliammeter (mA) and the voltmeter (V). The resistance value is used to calculate the current: $R=(5.6\pm 1\%)\Omega$. The verification condition is met if the calculated current is equal to the injected current $\pm 2\%$. The continuity of the measuring circuit **(e)** is checked by measuring the resistance between the ground of the input connector and the ground of the output connector using a digital multimeter. The condition is considered fulfilled if the measured resistance value is $(0.1\div 0.2)\Omega$. The degree of protection **(f)** is checked in accordance with SR EN 60529:1995/A1:2003 and must be IP 65.

The verification of the electrical circuit for acquiring partial discharges **(g)** is performed by assembling the circuit shown in Fig.7:

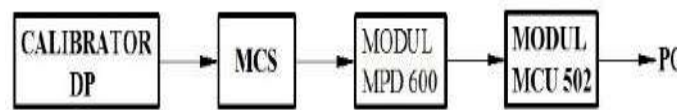


Fig. 7. Block diagram for DP verification

After completion, using the partial discharge calibrator, pulses in the range (100 ± 1900) pC are applied to the MCS input as follows: $(100-500-1000-1900)$ pC. For each of the four input values (pC), the values displayed for the output signal are read from the desktop on the acquisition interface. The surge protection level **(h)** is checked using the setup shown in Fig.8. A current in the range (0 ± 60) mA is injected into the input terminal at a frequency of 50 Hz; note the value of the limiting voltage. The condition is considered fulfilled if the limiting voltage value is $(90\pm 10\%)V_{c.a.}$. If one technical condition isn't met, measures are taken to eliminate the causes, after which the tests are repeated.

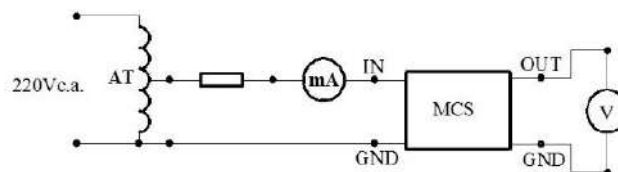


Fig. 8. Electrical diagram for checking the level of protection against overvoltage

These verifications are carried out in the ICMET Craiova laboratories.

The performance of the adapters was demonstrated during operations at the beneficiaries premises, where their efficient implementation in the monitoring systems was observed.

CONCLUSIONS

All types of adapters presented in this paper represent new technical solutions developed by ICMET Craiova based on its experience in the field and as a result of collaborations with interested companies (SC SIMTECH International SRL in particular) in the implementation of adapters in monitoring systems.

ICMET Craiova began manufacturing these products in 2016 and since a significant number were installed and put into operation by beneficiaries in electrical stations across the country.

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SOLUTIONS FOR REVITALIZING/REGENERATING USED INDUSTRIAL OILS

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ABSTRACT – IP3

This paper presents a study that highlights the importance of regenerating/treating/revitalizing used oils in order to identify an optimal solution for regenerating used oils from electrical equipment, bringing their parameters in line with those of new oil. In this study, a paraffin-based mineral oil without additives, with a high degree of degradation/aging, and three adsorbents were used to determine each one's ability to improve the physical and chemical properties of used oils. The experiments showed that all the adsorbents used significantly reduced the moisture concentration and removed a significant portion of the oil acid degradation products (polar elements), thus significantly improving the properties of the oil undergoing treatment.

Keywords: used oil, regenerating, revitalizing, molecular sieve

1. INTRODUCTION

The revitalization/regeneration of used industrial oils is a process of processing them to restore them to a state as close as possible to their original condition. This process consists of removing impurities, degraded additives, and contaminants accumulated during use. Regeneration/treatment is an essential component of the circular economy and has major benefits for both the environment and the economy.

The regeneration of used oils is of major importance in:

- ↳ environmental protection - used oils are a source of contamination of soil, water, and ecosystems. Through the revitalization/regeneration/treatment process, illegal dumping into the environment can be prevented.
 - ↳ resource conservation - industrial oils are obtained from petroleum, which is a non-renewable resource. The revitalization/regeneration/treatment process makes it possible to reuse these oils, thus reducing dependence on crude oil and conserving natural resources.
 - ↳ economy - the activities necessary to carry out the revitalization/regeneration/treatment process of industrial oils generate economic effects such as the creation of new jobs in the waste collection and processing industry, reducing the costs of maintenance and operation of electrical equipment.
- regenerating used oil is less expensive and consumes less energy than refining crude oil.

In Romania, the management of waste oils is strictly regulated by legislation, which prioritizes regeneration. The process of revitalizing/regenerating/treating waste oils, also known as electrical insulating oils, is an essential technical process for maintaining the performance and safety of electrical equipment.

These oils perform critical electrical insulation and cooling functions in transformers. As they age, their properties deteriorate due to contaminants (water, gases, solid particles) and oxidation products. Revitalization aims to restore these properties, thereby extending the life of the equipment and preventing malfunctions.

This paper aims to highlight the importance of treating/regenerating/revitalizing used oil in electrical equipment in use, as well as oil considered waste. Treatment/revitalization/regeneration methods have a strong economic impact, but also an important positive component on the environment. This paper presents a study on the treatment of used oil using adsorbent media.

REVITALIZATION/REGENERATION/TREATMENT METHODS

The regeneration of used transformer oil is an essential process for maintaining the performance and safety of electrical systems. There are several technological solutions, ranging from simple physical methods to complex chemical processes, aimed at restoring the basic properties of the oil.

Physical methods of revitalization/regeneration/treatment

These methods are the first stages of treatment and aim to remove physical contaminants such as water, gases, and solid particles. They are often performed with mobile equipment, directly at the transformer installation site, without taking the equipment out of service.

Filtration is performed using special filters designed to remove solid impurities such as cellulose particles, dust, and fine metal residues, which can affect insulation and cause short circuits.

Vacuum degassing: this method involves pumping the oil into a vacuum chamber where, at reduced pressure, dissolved gases, particularly oxygen, nitrogen, and carbon dioxide, as well as water vapor, are extracted. This method plays a major role in maintaining the dielectric strength of the oil within the parameters required by standards, by removing dissolved gases.

Drying consists of removing water vapour from the oil, as water is one of the most dangerous contaminants. Water affects both the insulating properties of the oil and those of the transformer's paper insulation.

Chemical revitalization/regeneration/treatment methods

These methods go beyond simple filtration and degassing, aiming to completely restore the chemical and physical properties of the oil by removing aging products (acids and corrosive sulfur).

Treatment with adsorbents: this stage involves passing the oil through a solid medium, called an adsorbent (such as special clay/activated alumina, etc.), which neutralizes corrosive compounds and removes acids and other oxidation products. This method is efficient and economical, thanks to regeneration systems that can reactivate the adsorbent, allowing it to be reused hundreds of times, thus reducing costs and waste.

Catalytic hydrogenation: in this case, the used oil is treated with hydrogen under pressure, in the presence of a catalyst. The chemical reaction breaks down and removes pollutants, sulfur compounds, and nitrogen, resulting in a high-purity base oil with properties almost identical to those of new oil. This method is considered one of the most complex and effective treatment/regeneration methods.

2. CASE STUDY

The oil used in the experiments is an unmodified paraffinic transformer oil (type TR30). To measure and determine the characteristics of the oils both in the initial phase (before treatment) and after treatment with adsorbents, the testing procedures required by the standards were followed.

For easy interpretation of the results, the oil states and oil samples tested were marked as follows:

- ↪ State i (I) is the notation for the initial state, the phase before the treatment process I–U1.
- ↪ State t1 (T1) is the notation for the state after the activated alumina treatment process (T1–U1);
- ↪ State t2 (T2) is the notation for the state after the zeolite molecular sieve treatment process, type 4A (T2–U1);
- ↪ State t3 (T3) is the notation for the state after treatment with zeolite molecular sieve, type 13X (T3–U1).



Fig. 1. Adsorbent materials used: a) zeolite 4A, b) activated alumina, c) zeolite 13X

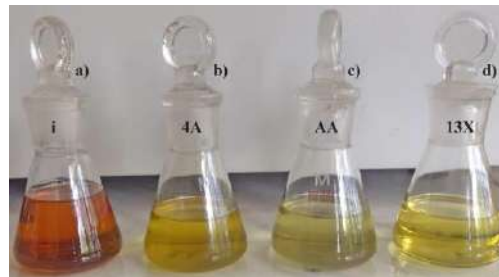


Fig. 2. Oil in: a) state i; b) state t2, c) state t1, d) state t3



Fig. 3. Initial reactions between oil and adsorbents

Table 1. Parameters measured before and after the revitalization process

No.	Measured parameter	Oil I-U1	Oil T1-U1	Oil T2-U1	Oil T3-U1	Limits according to IEC 60296
1	Breakdown voltage [kV] / Dielectric strength [kV/cm]	17,1/ 68,8	34,2/ 136,8	75,5/ 302	76,7/ 306,8	min. 30 kV/ 70 kV
2	Tan δ 90°C, 1a 50 Hz	0,0206	0,0014	0,0034	0,0055	max.0,005
3	Water content at 20°C [ppm]	14,87	12,75	9,14	5,76	max. 30/40
4	Interfacial tension [dyne/cm]	24,78	50,74	46,82	47,12	min. 40
5	Neutralization index [mgKOH/g]	0,223	0,089	0,056	0,044	max. 0,01
6	No. of particles with $\phi \geq 5\mu\text{m}/100\text{ ml}$	90930	2335470	318160	131980	< 5000
7	Density [g/cm ³]	0,868	0,863	0,862	0,861	max 895 kg/cm ³
8	Kinematic viscosity ν [cSt] 1a 40°C	9,83	9,506	9,227	9,827	max. 12
9	Dynamic viscosity μ [mPa*s] at 40°C	8,53	8,185	7,954	8,481	max.12
10	Corrosive sulfur on copper foil	shows no signs of corrosion				

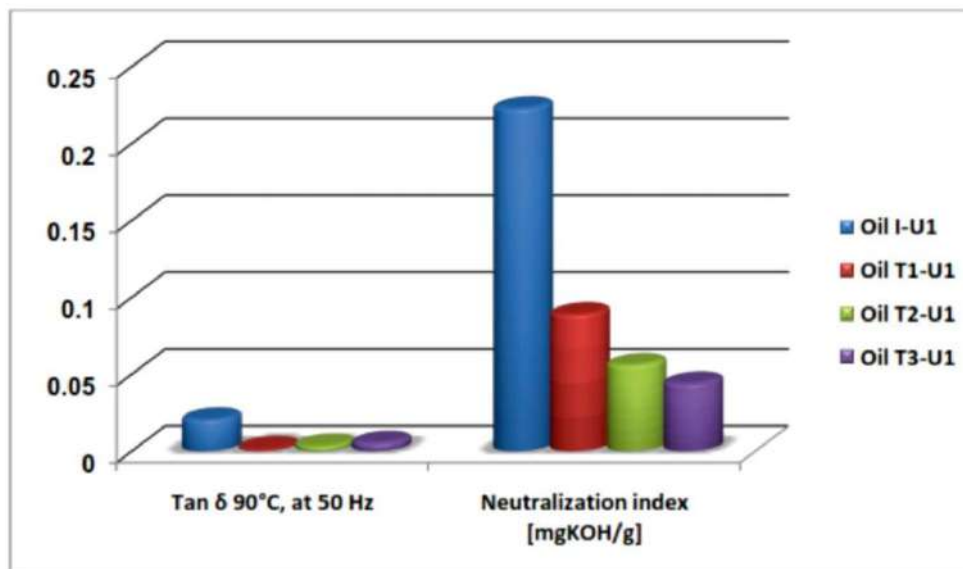
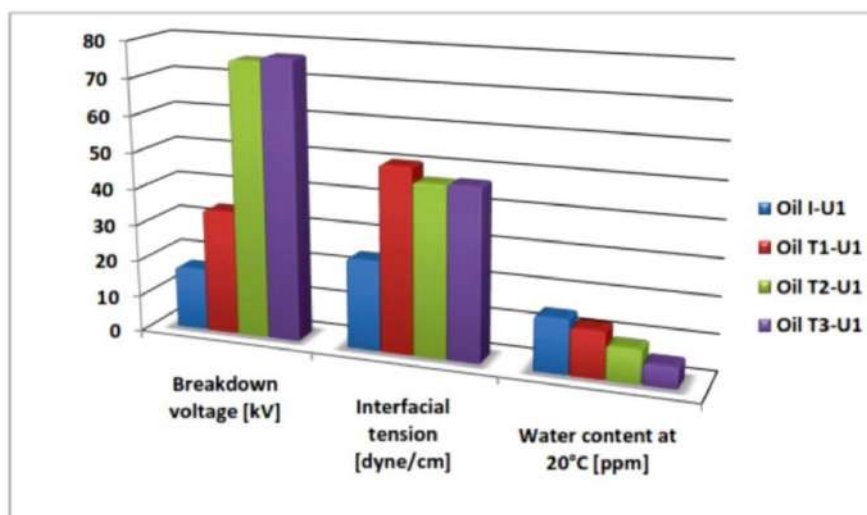

 Fig. 4.Variation of neutralization index and dielectric losses (tan δ) before and after treatment with alumină, 13X, 4A.


Fig. 5.Variation of the breakdown voltage, interfacial tension and water content before and after treatment with alumină, 13X, 4A

CONCLUSIONS

The results obtained following the treatment process based on Activated Alumina, molecular sieves type 4A and 13X, emphasize the fact that each adsorbent contributes significantly to improving the quality parameters of used oils. The nature of paraffinic oil, naphthenic oil, with or without inhibitors and passivators, plays an important role in the treatment/regeneration process of used oil, which led us to perform experimental tests on several types of oil.

Category of paraffinic oils tested within the project U1 - influence of adsorbent materials on its quality:

- ↳ AA produces an increase of the oil quality index from 4% to 22%, respectively moving from class D to class B;
- ↳ 4A produces an increase of the oil quality index from 4% to 32%, moving from class D to class A;
- ↳ 13X produces an increase of the oil quality index from 4% to 42%, moving from class D to class A.

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SECURITY OF PERSONNEL IN THE MAINTENANCE ACTIVITY OF THE NATIONAL ENERGY SYSTEM BY USING CERTIFIED EQUIPMENT

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ABSTRACT – IP4

Maintaining the National Energy System (SEN) in permanent operating condition involves revisions, repairs and maintenance works of all its components. Instructions, maneuvers and procedures ensure the correct framework in which each operation must be carried out within maximum personnel safety limits.

The use of safety equipment, short-circuit protection devices, protection clothing (coveralls) resistant to electric arc action certified in accredited laboratories that meet the requirements of SR EN ISO/IEC 17025:2018 and are competent to carry out testing activities, should be a constant concern.

The paper presents conditions, rules and methods for verifying the behavior of this equipment in extreme conditions at short-circuit currents and electric arcs accidentally occurring in SEN installations.

Keywords: electric arc, short-circuit protection devices, protection clothing, accredited laboratory

1. INTRODUCTION

Standardization and safety in the maintenance activities of the National Power System are two notions that, at first glance, have nothing in common. However, upon closer inspection, we can see they are closely interconnected.

Maintenance activities and interventions for accidental events in the Electric Power Transmission Grid (RET) involve human intervention for the periodic checking of equipment and the remediation of potential faults.

In an increasingly technological world, we easily forget that people are the foundation of any action within the power system; they cannot be replaced by robots, and it is important that they are protected as much as possible from accidents that may occur in their daily work.

This paper aims, from among many elements of electrical safety, to address two of major importance: short-circuiting devices, or so-called "Portable grounding and short-circuiting equipment," and thermal protective clothing for electric arc flash protection.

2. PORTABLE GROUNDING AND SHORT-CIRCUITING EQUIPMENT

Portable grounding and short-circuiting equipment (commonly referred to as "short-circuiting devices") are protective devices used to temporarily ground and short-circuit the conductors of an electrical installation, thereby protecting working personnel against the reappearance of voltage (accidental re-energization) and induced voltages.

Portable grounding and short-circuiting equipment are used on overhead high-voltage and medium-voltage cable lines, and in medium-voltage switchgear cells with a busbar system.

The main purpose of the short-circuiting device is to prevent accidents by ensuring a safe and efficient connection to earth or short-circuit, reducing the risk of electrocution and fire during maintenance or repair operations.

Quality certification involves testing the devices in accredited laboratories to verify their capability to withstand the short-circuit currents that occur during an improper switching operation. During the short-circuit event, the short-circuiting device must not interrupt the circuit until the short-circuit protection operates.

The use of these devices is strictly regulated by national and international standards, such as:

- IEC 61230:2008, and respectively SR EN 61230:2009 - Live working. Portable equipment for earthing or earthing and short-circuiting.

- The norms and regulations issued by ANRE (The Romanian National Energy Regulatory Authority).

- The internal rules of the energy supply company or the operator.

The SR EN 61230 standard specifies the requirements and test methods, procedures, and assembly for each piece of portable equipment used for earthing or earthing and short-circuiting, to ensure safety during work on de-energized or isolated electrical installations, in both alternating current (AC) and direct current (DC) networks, for distribution and transmission.

The high-power laboratory within ICMET Craiova is accredited for short-circuit testing and possesses 3x2500 MVA sources, both single-phase and three-phase circuits, and a measurement, data acquisition, and processing system for short-circuit testing.

The test setup in the figure below allows for short-circuit testing up to a current of 50 kA and for a duration of up to 1 second.

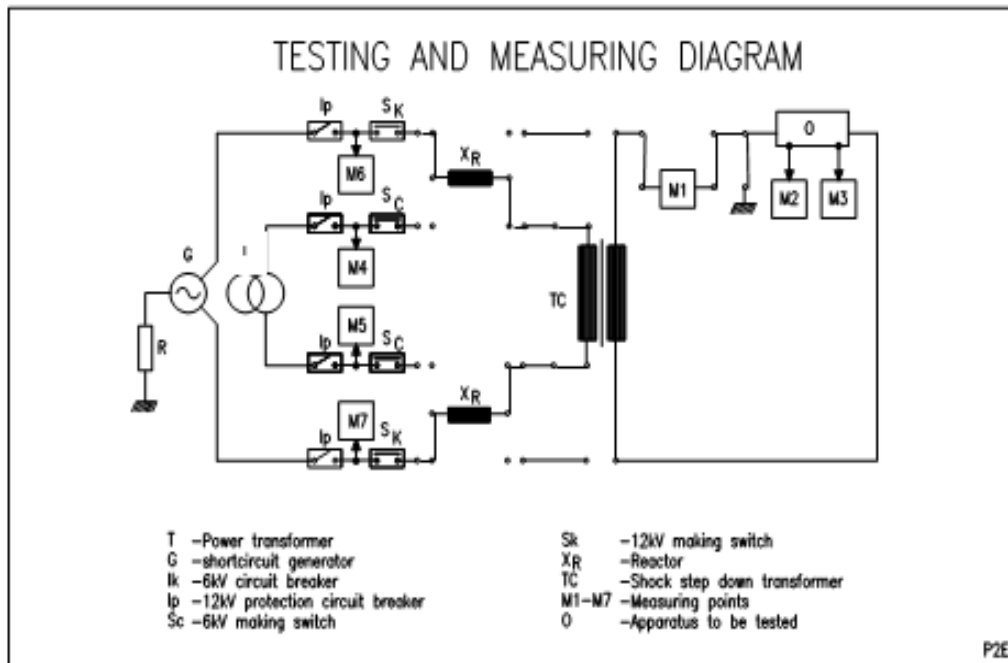


Fig. 1 – (Single-phase) Data of testing and measuring circuit

The selection of devices appropriate to the intervention site is made based on the maximum accidental energization current.

The ability of these short-circuiting devices to withstand short-circuit currents without breaking is verified in laboratories capable of supplying short-circuit currents with values, durations, and configurations conforming to IEC 61230.

The testing of the devices must replicate the demands, parameters (current, time), single-phase or polyphase setups, and their behavior must be of a nature that protects the users.

For illustration, we will present the short-circuit test of a short-circuiting device for a medium-voltage (MV) overhead power line (OHPL) at a current of 9 kA for 1 second.

Along with the imposed test current of 9 kA / 1 s, the voltage drops across the short-circuiting device during the short-circuit are also recorded. These drops reach values of 240 V – 360 V between the endpoints (phase clamp - grounding clamp).

Therefore, when the short-circuiting device is carrying 9 kA, a voltage of approximately 360 V appears between the clamps. This could be dangerous for an operator if they were to touch both clamps (the phase conductor and the grounding stake) simultaneously. However, considering the considerable length of the conductor (on the order of meters), this is quite improbable.

When IEC 61230 was implemented, this voltage was initially intended to be limited to non-dangerous values: 50 V – 60 V. However, it was found to be impossible to achieve with a long short-circuiting device (over 2-3 m), and it was no longer imposed as a technical condition to be obtained during short-circuit current testing .



Photo 1 – 2. Different types of pieces in testing circuit and after tests

Portable grounding and short-circuiting devices are the last line of defense for the worker against electrocution. They are not an optional accessory but an absolute necessity. Their correct use, in strict accordance with established procedures and with verified devices, is what makes the difference between a safe job and a serious, potentially fatal accident.

Protective clothing resistant to the thermal effects of the electric arc

Apparently unimportant, the coverall used in electrical installations can save the operator's life in the event of an electric arc occurring in the installation where work is being performed.

Rarely, but inevitably, due to incorrect switching operations, an electric arc can appear in front of personnel working in medium and low-voltage installations.

The thermal effects of the electric arc on the operator can be extremely dangerous because it is accompanied by particles of molten metal and boiling gases that appear in front of the operator at very close distances.

The coverall must protect the operator by meeting the requirements of the IEC 61482-1 standard, verified through testing in accredited laboratories.

To eliminate the hazard and to test the coverall under the most severe conditions of electric arc effects, the IEC 61482-1 standard introduces the notion of a ****directed electric arc**** using a specially constructed box with precise dimensions that directs the electric arc towards the operator's chest, where the human body's sensitivity to arc effects is greatest.

The effects of the electric arc on the operator can be: contact with molten and vaporized metal; intense light; extreme acoustic pressure; electrocution; fire risk.

Thermal protective clothing is divided into two classes: Class 1 and Class 2, based on a short-circuit current of 4 kARMS and 7 kA RMS respectively, at a voltage of 400 V for 0.5 seconds.

In an electrical circuit capable of supplying the short-circuit current, in specialized laboratories accredited according to SR EN ISO / IEC 17025:2018, an electric arc is triggered within the enclosure shown in Fig. 2 of IEC 61482-1-2. A mannequin wearing the tested coverall is placed 300 mm in front of it (Photo 3).

The electric arc with the parameters: $U=400\text{ V}$, $I=7\text{ kA}$, $t=0.5\text{ s}$ generates thermal effects through boiling gases and molten metal particles that affect the coverall material (photos 4, 5) and the fastening system.

To highlight the thermal effects on the mannequin wearing the coverall, a polyethylene film is applied.

The visual inspection of the mannequin, the material, and the fastening system (buttons, zipper, fly flap) must reveal:

- burning of the material;
- holes made by the molten material;
- the condition of the fastening system;
- embrittlement of the material.

The appearance of the coverall after testing is presented below.



Photo 3 – The appearance of the suit before testing against the restricted and directed electric arc



Foto 4 – 5. The appearance of the suit after testing against the restricted and directed electric arc

The coveralls used by operators in electrical installations must be resistant to the effects of the electric arc.

CONCLUSIONS

It is very important that manufacturers of portable equipment for earthing or earthing and short-circuiting, as well as coverall suits, test their prototypes in accredited testing laboratories to ensure the safety of operational personnel.

The research and experimental development activity within the laboratory allows for the resolution of major problems before they cause accidents or financial losses. It is an integral part of the development process, offering the opportunity to test, validate, and refine the concept before final production.

By testing equipment in accredited laboratories, the manufacturer obtains all the information regarding the product's behavior in advance, prior to the product entering production. This is a preferable method compared to the principle of „forging ahead, implementing on the go, and improving along the way” [2]

Following these research and experimental development activities, the manufacturer identifies and remedies problems at an early stage, saving significant time and resources.

Testing conducted in accredited laboratories constitutes the ultimate and most critical validation phase prior to certifying electrical safety equipment as safe for operational use. These research and experimental development activities provide the crucial empirical evidence that theoretical designs and material selections will perform as intended under real-world fault conditions. This rigorous process is the fundamental barrier that ultimately safeguards human lives and critical infrastructure.

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DISTRIBUTED SENSOR SYSTEM FOR REAL-TIME MONITORING OF OVERHEAD POWER LINES

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ABSTRACT – IP5

This article presents a system for the real-time monitoring and evaluation of status parameters in two major components of overhead power line structures (OPL): the cable and the pillar. It is described the general architecture of this system, which is designed to measure the main operating parameters of overhead power lines (current through the OPL cable, cable temperature, cable tilt, cable oscillations, cable mechanical force, pillar tilt/vibration), and environmental parameters (ambient temperature, wind speed and direction, relative humidity, barometric pressure, rainfall, hail and ice) in the overhead power line corridor. These parameters are considered to be basic for the safe application of the dynamic load rating of power lines. The main characteristics of the sensors and communication equipment used, are also presented along with the main software application modules, used for monitoring the status of the cable and pillar, components in the overhead power line structure. The software applications are designed to monitor the main power line parameters and display the results both on the electricity supplier's intranet, using a web server and a MySQL database, and on the internet, using an IoT (Internet of Things) server for authorized users.

Keywords: real-time monitoring, sensors, web server, IoT

1. INTRODUCTION

The National Power System represents the facilities that ensure the production, transmission, distribution, and consumption of electricity and is organized as an interconnected structure of power systems, distributed throughout the territory and owned by a multitude of economic agents. Through overhead power lines (OPL), electricity is transported at high voltages of 110, 220, and 400 kV to the proximity of consumers, where the voltage is reduced again in substations to 6 and 20 kV.

The most modern solution for controlling and optimizing the operation of overhead power lines requires the use of smart grids based on real-time monitoring systems for operating parameters and conditions [1,2]. In order to achieve effective operation planning of the overhead power lines and coordination of electricity transmission needs in relation to the technical condition of the power lines and electrical equipment in high-voltage substations, as well as environmental conditions [3,4], a smart electricity transmission network should have, in addition to energy-efficient power lines, real-time monitoring and evaluation systems.

Among the specific elements presented in the scientific literature, we can mention: monitoring based on a wireless sensor network [5,6], the creation of a data communication system based on Long Range (LoRa) [7], monitoring of power lines using a chirped fiber Bragg grating [8,9], and the development of a power line monitoring system based on the Differential Global Positioning System (DGPS) [10].

This article is grounded on the research described in the paper [11] and the results achieved in the Project SMIS code156460, funded by European Regional Development Fund Competitiveness Operational Programme. The purpose of the paper is to introduce a distributed sensor system for real-time monitoring of overhead power lines. The hardware and software architecture of the proposed system is intended to be a viable solution for accurately assessing the technical and operational status of OPLs. The article is structured as follows: the first Section presents the general architecture of the distributed sensor system for real-time monitoring of the overhead power line condition, and the main modules of the software application used for reading/calculating/ transmitting/information are covered in the second Section. The final section presents some conclusions and suggestions for further development.

2. GENERAL ARCHITECTURE OF THE DISTRIBUTED SENSOR SYSTEM FOR REAL-TIME MONITORING OF OVERHEAD POWER LINES

The solution for controlling and optimizing the operation of high-voltage overhead power lines requires the use of smart grids based on real-time monitoring systems for operating and status parameters. At the same time, real-time knowledge of the health status of the components of the National Power System is a desideratum, being an essential element in the development of strategies and forecasts, correlated with a correct estimation and planning of costs, activities, and resources [12].

The proposed general architecture for the distributed sensor system for real-time monitoring of overhead power lines, presented in Fig. 1, was designed with a view to minimizing errors in the evaluation of overhead power line operating parameters.

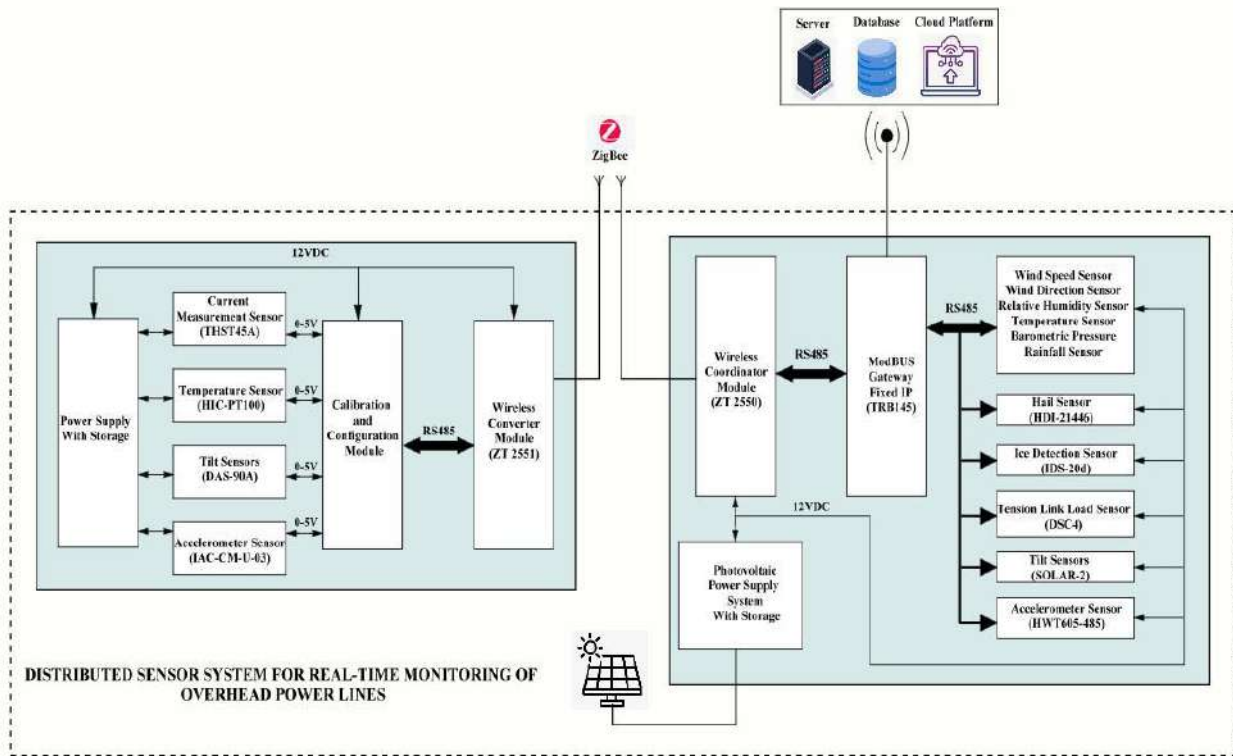


Fig. 5. General Architecture of the Distributed Sensor System for Real-Time Monitoring of Overhead Power Lines

The implementation of the proposed hardware system and software applications for data acquisition and transmission for the real-time monitoring system of OPL is based on the ModBUS and ZigBee protocols. The software applications developed for the OPL real-time monitoring system involve writing software functions for each sensor to set minimum and maximum values, various thresholds, and status values. According to Fig. 1, the data acquired by the sensor network is collected in a unified manner on the ModBUS protocol in a local gateway, which will transmit it to the application server of the OPL monitoring system on the 3G/4G protocol. The sensors used in the real-time monitoring system proposed configuration are shown in Fig. 2.



Fig. 6. The sensors used in Distributed Sensor System for Real-Time Monitoring of Overhead Power Lines Configuration

The Fig. 2 includes the following elements: (a) Inclinator sensor for measuring cable angles; (b) Cable temperature sensor; (c) Accelerometer for measuring cable vibrations; (d) Hall-effect sensor for measuring cable current; (e) Cable mechanical tension sensor; (f) Accelerometer for measuring pole vibrations; (g) Tilt sensor for measuring pole angles; (h) Meteorological sensor for ambient temperature, wind speed and direction, relative humidity, barometric pressure, and rainfall; (i) Hail detection sensor; (j) Ice detection sensor.

The following is a brief description of the distributed sensor system for real-time monitoring of overhead power lines, specifying its main components:

- The power supply system is represented by two split core current transformers. SCT045B-type PowerUC Electronics, Piastów, Poland, which transform the energy radiated by the electric cable on which it is mounted (up to 1000 A and 400 kV), at the output of the transformer obtaining a power of 10 VA.
- To measure the current through OPL cables, a Hall split-core current transducer type THST45A [Fig. 2d] is used, which provides a measuring range of up to 1,200 A. The analogue output of this type of transducer is $0 \div 5$ V.
- For cable temperature is used a PT100 sensor [Fig. 2b] within the range $-50 \div 400$ °C, an accuracy of 0.2% and a drift of less than 0.04%.
- The inclinometers [Fig. 2a] used to measure the pitch and roll angles of the OPL cables are the DAS-90-A from Level Developments [13]. They use a micro-electro-mechanical systems (MEMS) sensor in a rugged, sealed aluminum structure with a shielded polyurethane (PUR) cable.
- The Recovib IAC-CM-U-03 sensor [Fig. 2c] from Micromega Dynamics [14] is used to measure OPL cable vibration. It has a measurement sensitivity of 40 mV/g over a range of -50 g to $+50$ g and a drift offset of ± 50 mg/°C.
- The sensor that measures the inclination of the pillar is of the SOLAR-2 type [Fig. 2g] from Level Developments. The sensor is powered in the range $9 \div 30$ VDC, and the measured angle is in the range -45° to 45° .
- The accelerometer-type sensor [Fig. 2f] used to measure the vibration of the OPL pillars is the HWT605-485 from WIT Motion [15].
- A versatile load cell [Fig. 2e], the DCL10 Central Load Cell [16], is used to measure mechanical stress in the cable.
- Based on the fact that reliable estimates of the power line's capacity are only possible when weather conditions are known, the real-time monitoring system has the following sensors in its configuration: HD52.3DT147 [Fig. 2h] from Delta OHM [17] which sends real-time data about ambient temperature, wind speed and direction, relative humidity, barometric pressure and rainfall; HDI-21446 [Fig. 2i] for hail and IDS-20 [Fig. 2j] to measure icing and freezing rain, both from SOMMER Messtschienik [18,19].
- Data transmission between the two cabinets located, one on the cable, one the pillar, is achieved using the ZT-2550 and ZT-2551 series modules, which are small, wireless ZigBee converters based on the IEEE802.15.4 standard, which allows the RS-232 and RS-485 interfaces to be converted into a ZigBee Personal Area Networks network (PAN) [20,21].
- The wireless coordinator hardware module ZT-2550 will be connected to a GSM hardware module (gateway) Teltonika TRB145 type [22] that enables the following communications: SIM card and SMS communication. This gateway collects all measurements from the sensors, and their transmission must be encrypted to a server/cloud. The GSM hardware module (gateway) must also have a built-in GPS that can be used to locate the installation site and to mark the measurement time.

3. SOFTWARE APPLICATIONS OF THE DISTRIBUTED SENSOR SYSTEM FOR REAL-TIME MONITORING OF OVERHEAD POWER LINES

This section presents the architecture of the software application which, based on the measurements provided by sensors, allows the processing of data along with the storage of monitored parameter values in a database to create a history, as well as the presentation of data on the intranet via a web server or on the internet via an IoT.

The software application modules of the OPL cable and pillar condition monitoring process implemented on the server computer are shown in Fig. 3, and are as follows:

- The LabVIEW software module application client for reading values from the sensor network via a ModBUS I/O server;
- Matlab and LabVIEW software module application for real-time calculation of the OPL cable sag;
- LabVIEW software module client application for writing to and reading from the MySQL (My Structured Query Language) database;
- LabVIEW software module client application to send automatic e-mails with warnings and alarms about OPL cable sag limits and sensor faults;
- LabVIEW software module client application for data transmission on the electricity wholesaler's intranet via a web server;

➤ LabVIEW software module client application for viewing data by authorized users, based on username and password, through an IoT server.

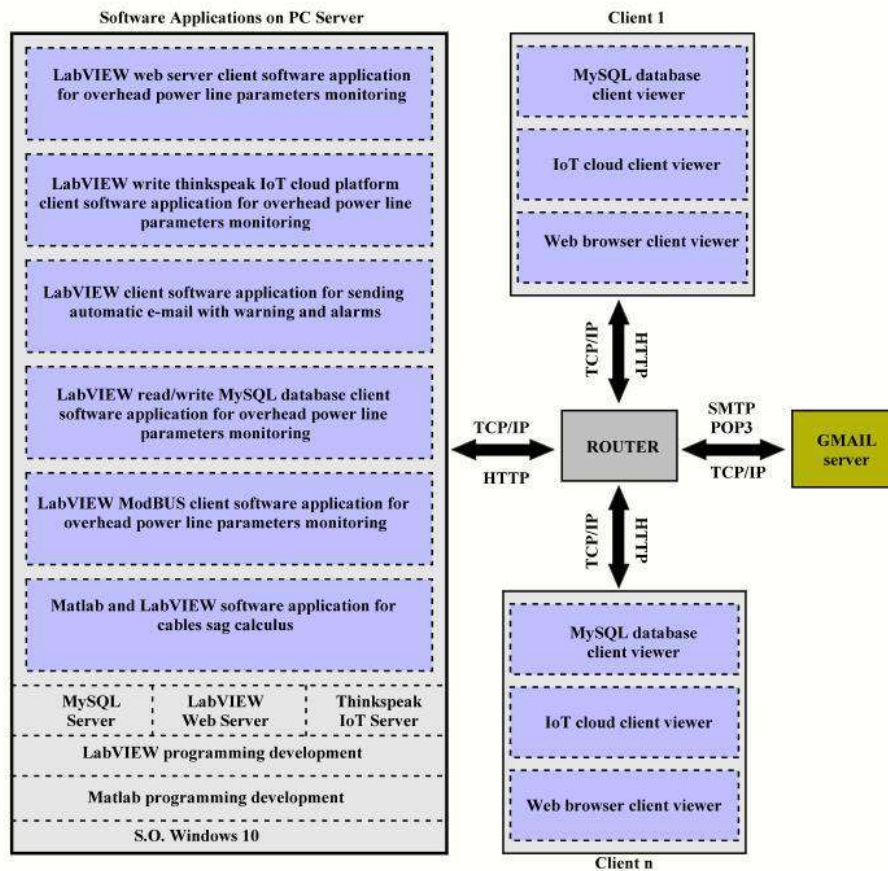


Fig. 7. Software Architecture of the Distributed Sensor System for Real-Time Monitoring of Overhead Power Lines

The software application is based on an NI-OPC server provided by National Instruments, which can be integrated into a SCADA-type system, and performs the following functions: the process of monitoring the state of the OPL (cable&pillar) and the management of client-server communication of quantities through online viewing and creation of records using TDMS (Technical Data Management Streaming) type files. A MySQL database server is used with data write/read applications from the OPL monitoring process. The data from the OPL cable and pillar condition monitoring process is displayed over the intranet/internet network via a web server embedded in the application, along with the presentation of a software application that transmits the data to an IoT-type cloud platform.

The software application for the OPL cable and pillar condition monitoring process is developed in the LabVIEW graphical programming environment, a programming environment that incorporates all the concepts mentioned above and the most common industrial process control techniques.

CONCLUSIONS

The presented distributed sensor system for real-time monitoring of overhead power lines provides an accurate database, which supports the safe operation of OPL at the maximum permissible load. Also, the presented monitoring system allows the monitoring and diagnostic structures to be optimized in terms of efficiency and cost. The overall aim of the optimization is to achieve the following objectives: monitoring and identification of the condition of OPL; loading related to the condition of OPL, identification of sub-assemblies with vulnerabilities and location of evolving faults; identification of critical wear thresholds and the dynamics of fault evolution; identification of causes generating excessive stresses; carrying out maintenance processes and durations between major interventions resulting in temporary equipment shutdowns; estimation of equipment lifetime for efficient maintenance.

In future developments of the presented monitoring system, as a result of collaboration with users, data collected both from the presented application and from direct measurements in extreme weather conditions (wind, hail and ice) will be used to make the necessary corrections to the cable sag calculation algorithm using machine learning software.

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CONTRIBUTIONS TO THE DIGITALIZATION OF ASSETS WITHIN THE NATIONAL ENERGY SYSTEM (SEN)

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ABSTRACT – IP6

The digitalization of assets in the National Energy System (SEN) is a strategic process through which the energy infrastructure is modernized using advanced digital technologies. Its main goal is to transform the grid into a smart, flexible, and secure system, capable of meeting consumption demands, integrating renewable sources, and supporting Romania's energy transition. Transformer substations are critical nodes of the SEN, where electricity is transferred between different voltage levels. These technologies turn substations into intelligent hubs that enhance system stability. Transmission and distribution networks are the backbone of the SEN. The contributions to the digitalization of SEN assets, presented in this paper, refer to: electrical power transformers and their accessories, overhead power lines, backup power supply batteries in power stations and transformer stations.

Keywords: digitalization, assets, energy system

1. INTRODUCTION

The digitalization of transformer substations and power grids is a key step in modernizing the SEN. It not only increases efficiency and resilience but also contributes decisively to energy security and Romania's green transition.

The digitalization of transformer substations involves: Real-time monitoring using sensors and smart devices (IED, PMU, RTU); Advanced automation through SCADA systems; Virtual modeling of the substation for simulations, predictive analysis, and maintenance optimization; Predictive maintenance – applying artificial intelligence to detect failures before they impact operation. The digitalization of transmission and distribution networks supposes shifting from a static system to a smart grid, with the following features: Smart meters for consumers and prosumers; Advanced Distribution Management Systems (ADMS) for efficient grid operation; Bidirectional monitoring and control – integrating decentralized generation (solar, wind, storage); Big Data and AI analytics for load balancing and incident management; Interoperability and standardization, ensuring compatibility across digital platforms and equipment.

The importance of energy system digitalization is presented and argued in currently existing specific literature [1..7]. [1] describes the "Digital Twin" concept application in intelligent networks, covering asset modelling, fault diagnosis, operational optimization, and business modelling; [2] explores blockchain technology applicability in intelligent electrical networks; [3] further analysis the "Digital Twin" concept application for modern electrical stations; [4] presents a study (via ResearchGate) which analysis the digitalization contribution in the energy transition, while including applications, digital architectures and development perspectives; [5] overviews a study regarding solid state transformers as new generation digital equipment for electrical stations; [6] shows a report regarding the digitalization of the national energy system, while [7] represents an international reference document for overhead power line digitalization.

Regarding the electric power activity domain, implementing data acquisition systems able to solve real practical issues in specific installations has represented a constant scientific concern. The research in designing and implementing various monitoring and control equipment, whose features and performance are constantly improved, has been materialized.

The digitalization of assets within the national energy system allows the following: real-time monitoring of machinery, fast fault detection and disconnecting time minimization, easy integration of sensors and predictive maintenance algorithms, increasing safety and decreasing operational costs, smart metering, massive integration of prosumers and electrical vehicles, the use of Digital Twin and artificial intelligence for the optimization of electric power flow, the insurance of cybersecurity and increasing resilience to attacks and extreme phenomena.

2. SYSTEMS DESCRIPTION

Monitoring System for Power Transformer Windings Hot Spot Temperature Using Fiber Optic Sensors

This paper presents a monitoring system based on fiber optic sensors for measuring the transformer windings hot spot temperature. The fiber optic temperature monitoring technology is based on the dependence between the temperature and the GaAs crystal property of light absorption. The GaAs has a band deviation of certain energy, which is a fundamental characteristic of all semiconductor materials. The proposed solution for the windings hot spot temperature monitoring system using fiber optic sensors is

presented in Fig. 1. The block diagram of the hardware configuration of the data acquisition and remote transmission system is presented in Fig. 2.

Describe the problem/system being studied and methodology applied. Avoid footnotes at the bottom of the page within the frame.

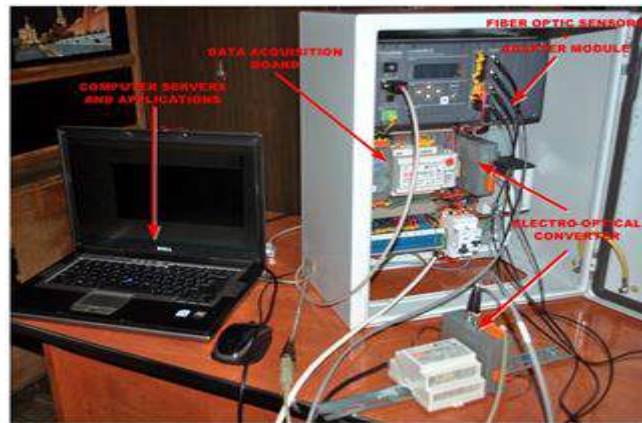
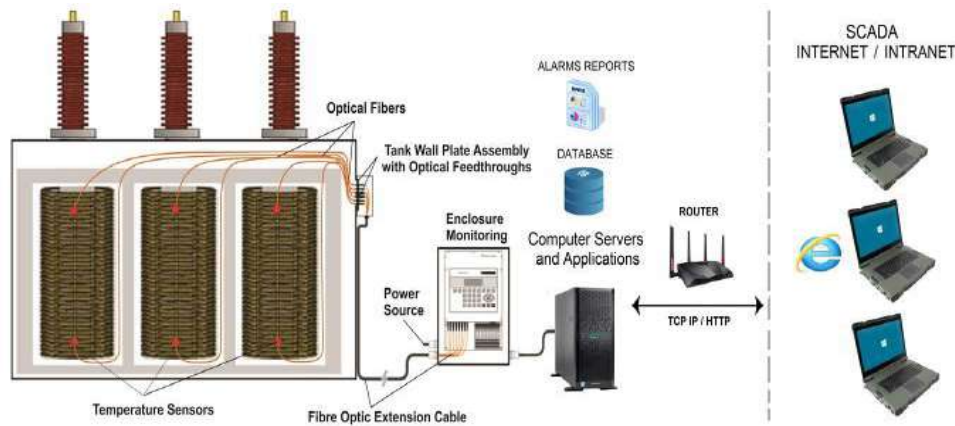


Fig. 1. The block diagram of the monitoring system

Fig. 2. Picture of the monitoring system

For the direct method of monitoring the transformer winding hot spot temperature, a monitoring system, using fiber optic sensors in direct contact with the high voltage windings was achieved, tested, and integrated into the complex system for operating parameter monitoring in power transformers.

Modular system for continuous monitoring and diagnosis of transformer unit functioning

Condition monitoring and technical diagnosis based on the results of transformer units monitoring represents an important component of the electric substations monitoring in the context of their integration into SMART GRIDS.

The monitoring system presented in this paper is a modular system with components distributed according to the beneficiary request and the substation configuration. The configuration of the monitoring system can be chosen depending on the best monitoring requirements and the transformer fitting out level.

Data acquisition and transfer through optical fiber ensures their immunity to electromagnetic disturbances specific to electric power stations and an important decrease of classical copper cable usage. The monitored quantities for SCADA integration are as follows: computed oil temperature for phase S windings (for IT and JT), ambient environment temperature, core temperature (3 values of temperature), the amount of H_2 in oil, the amount of CO in oil, the amount of C_2H_2 in oil, the amount of C_2H_4 in oil, the amount of gas in Buchholz relay, the capacitive current for the bushings [R, S, T, r, s, t], the $Tan\delta$ for the bushins [R, S, T, r, s, t], IT an JT, voltages and currents on phases [R, S, T], the oil level in the transformer tank, oil level of the tap changer, the operation time, the lifespan consumed, the current consumed by the drive engine of the tap changer operation. The resulting system is depicted in Fig.3. The extent of state parameter monitoring at an electric power station level highlights the perspective of electric power station control without the presence of its own staff.



Fig. 3. Image of the system

Digitalization of transformer stations

The system has a distributed type of architecture, developed with data acquisition equipment; each equipment module performs a well-defined system function, all of them being connected through a MODBUS RTU serial communication bus, which also connects the GSM server. All centralized data will be collected at the transformer substation level, from where it will be transmitted through a gateway at a central database of the electric power distribution company.

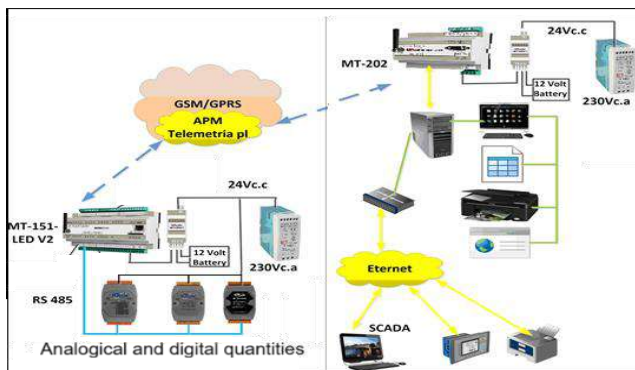


Fig. 4. The block diagram of the monitoring system

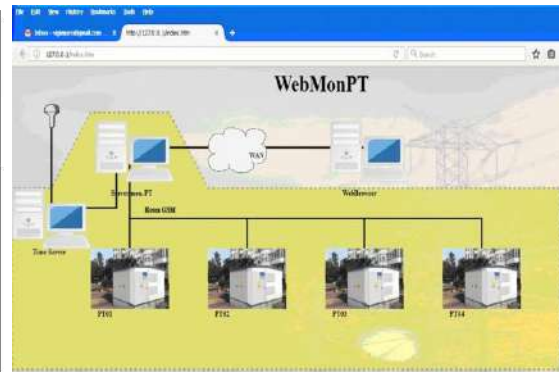


Fig. 5. Main window

The achieved version uses GSM communication and includes data acquisition, transmission and reception modules. The equipment includes the related sensors and transducers.

The screenshot shows the iMConnect application window. On the left, there are several buttons for selecting data views: "Digital I/M (1-1)", "Analog I/M (1-5)", "Temperature I/M (3-15)", "Temperature I/M (7-17)", "Name FACH 1", "Name FACH 2", "Name FACH 3", and a "Global" button at the bottom. The main area displays a table of data with the following columns: INSTANCE, SYMBOL, DESCRIPTION, VALUE, UH, and TIME. The table contains 18 rows of data, including parameters like V_avg, I_avg, L_avg, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, I_act_tot, and I_act_tot. The values are numerical, and the units are listed in the UH column. The time column shows dates from 10.12.2012 to 10.12.2012.

INSTANCE	SYMBOL	DESCRIPTION	VALUE	UH	TIME
V_avg	V_avg	Terminals media	223.30	V	10.12.2012 09:45:19:00Z
I_avg	I_avg	Current media	2.80	A	10.12.2012 09:45:19:00Z
I_act_tot	I_act_tot	Active media	1.30	W	10.12.2012 09:45:19:00Z
I_act_tot	I_act_tot	P reactive media	1.40	W	10.12.2012 09:45:19:00Z
I_act_tot	I_act_tot	P apparent media	1.50	kVA	10.12.2012 09:45:19:00Z
I_act_tot	I_act_tot	Factor power media	0.69		10.12.2012 09:45:19:00Z
I_act_tot	I_act_tot	Energy active media	4.40	kWh	10.12.2012 09:45:19:00Z
I_act_tot	I_act_tot	Energy reactive media	4.80	kVarh	10.12.2012 09:45:19:00Z
I_act_tot	I_act_tot	Energy apparent media	7.20	kVAh	10.12.2012 09:45:19:00Z
Proc_1	Proc_1	Percentage flow 1	49.00	%	10.12.2012 09:45:19:00Z
Proc_2	Proc_2	Percentage flow 2	49.00	%	10.12.2012 09:45:19:00Z
Proc_3	Proc_3	Percentage flow 3	49.00	%	10.12.2012 09:45:19:00Z
Proc_4	Proc_4	Percentage flow 4	49.00	%	10.12.2012 09:45:19:00Z
Proc_5	Proc_5	Percentage flow 5	49.00	%	10.12.2012 09:45:19:00Z
Unit	Unit	Unit data	62.70	Hz	10.12.2012 09:45:19:00Z
Temp	Temp	Temperature	38.38	gradC	10.12.2012 09:45:19:00Z
Q1	Q1	Q1	972.00	gpm	10.12.2012 09:45:19:00Z



Fig. 6. Interface for monitoring quantities

Fig. 7. Data acquisition

Fig. 8. Data reception unit processing

Integrated system for monitoring, analyzing, and diagnosing overhead power lines (OPL)

The system, consists of two acquisition modules (100) located on a T-section of the high voltage overhead power line conductor, which include the tilt sensors of the line conductor, power supply sources, a WiFi module for communication with a local data acquisition and remote transmission unit (120), powered by an independent source (121), a communication module (130) and a system (131) for calculating the sag of the electric conductor.

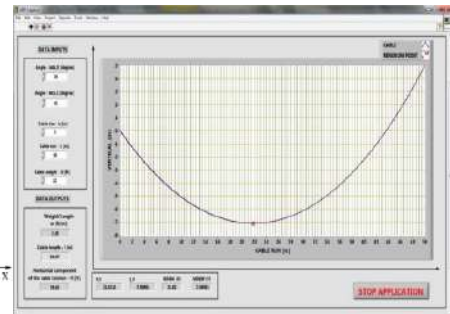
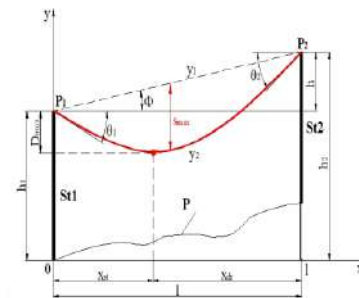
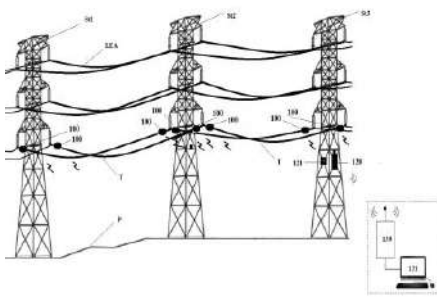


Fig. 9. Schematic representation

Fig. 10. Representation of the operands

Fig. 11. Software interface for a section of the power line

The integrated system configuration is modular and can be adapted to the needs and requirements of the beneficiary. The result will be an integrated system of hardware and software components that provides real-time monitoring of overhead power lines.

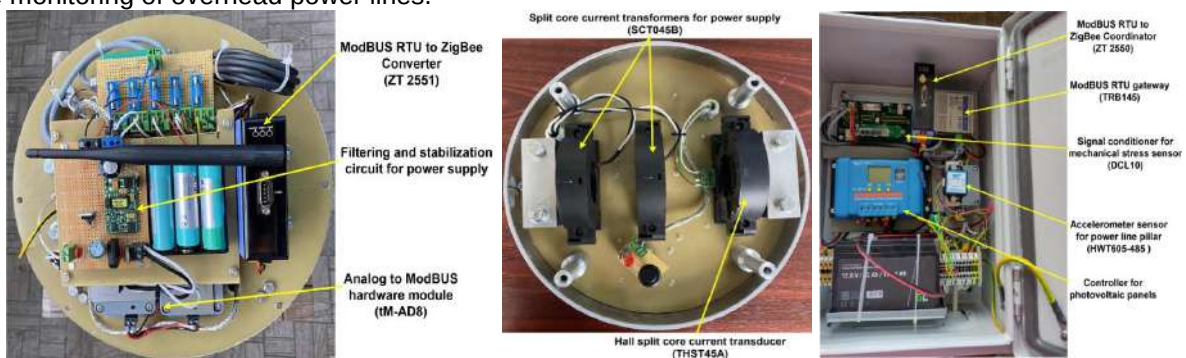


Fig. 12. Device board: view from lower housing (left)

Fig. 13. Inside of the cabinet for the on-line pylon monitoring hardware module view from upper housing (right)

Continuous monitoring and diagnostics system for the 220 V.d.c. stationary battery from transformer stations

The analyzed system computes the battery quantity with typical cell voltage measurements, the package current, the package voltage, and the package temperature, while using these measurements for estimating the state of loading (SOC), the state of health (SOH), and the unloading depth. The importance of implementing a battery monitoring system must be evaluated in relation to the amount of data that can be lost and the equipment that can be damaged in the event of a backup system failure.

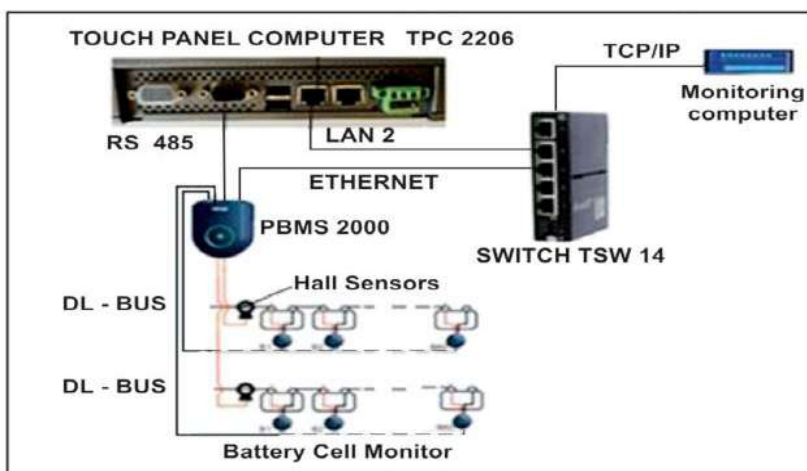


Fig. 14. The block diagram of the monitoring system



Fig. 15. Picture of the system

CONCLUSIONS

- The digitalization of assets within SEN is not only a technology option, but also a strategical requirement for Romania as well as for European Union. It supports the efficiency, sustainability and security goals to transform the electric power infrastructure in an intelligent, flexible and resilient system.
- The digitalization of transformer substations and power grids is a key step in modernizing the SEN. It not only increases efficiency and resilience but also contributes decisively to energy security and Romania's green transition.
- Smart grids enable the large-scale integration of renewable energy, active consumer participation in energy markets, and reduced technical losses.

ACKNOWLEDGEMENTS

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AN EXPERIMENTAL STUDY ON THE BEHAVIOR OF SPECIALLY DESIGNED BUSBARS IN LOW-VOLTAGE ASSEMBLIES UNDER CONTINUOUS CURRENT

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Abstract – IP11

This article presents an analysis of the operational behavior of specially designed busbars intended to safely conduct electrical current while minimizing energy loss. The busbar configurations under investigation are non-insulated to enhance convective cooling and provide convenient access for additional connections.

A series of experimental verifications involving multiple design variants were conducted, including the configuration that was the most demanding in terms of thermal and electrical stress. This study aims to evaluate the effectiveness, efficiency, and practical applicability of these busbar systems in real-world distribution scenarios.

Keywords: continuous current, busbars, temperature rise, contacts, short-circuit

1. INTRODUCTION

This article focuses on analyzing the operational behavior of specially designed busbars used in low-voltage electrical assemblies. These busbars are designed to handle current ratings ranging from 25 to 2,000 amperes. Their key characteristics include mechanical robustness, long-term durability, and high adaptability to various installation and operational requirements. Regarding their behavior under steady-state operating conditions (either continuous or intermittent), a thermal equilibrium is established between the amount of heat generated and the amount dissipated to the surrounding environment. The upper limit of temperature rise—and thus the maximum temperature a busbar can reach at any given point—is determined by two key factors: the preservation of its physical and mechanical properties, and the integrity of its joints and support points. These temperature limits are defined by international standards for both rated current operation and for short-circuit current conditions.

When designing and selecting equipment for low-voltage electrical installations, it is important to consider how all components behave under fault conditions along the current path. High short-circuit currents can cause severe electrodynamic and thermal stress, which can lead to equipment failure. Although individual devices may be able to withstand such stresses, doing so often requires substantial oversizing, which is not always practical or feasible. Therefore, equipment protection typically depends on the proper functioning of upstream overcurrent protective devices. In this context, verifying the coordination between these devices is essential. Furthermore, lower-magnitude faults, such as overloads or certain types of earth faults, can lead to system disturbances. These disturbances can trigger unnecessary tripping and power outages, which can affect larger sections of the installation than initially anticipated.

2. GENERAL REQUIREMENTS FOR SWITCHGEAR CONSTRUCTION

Materials used in low-voltage switchgear must be capable of withstanding mechanical, thermal, electrical, and environmental stresses under various conditions of use. Depending on functional requirements and specific applications, the external dimensions of this equipment may vary.

Components made of insulating materials, which are frequently subjected to thermal energy generated by internal electrical phenomena, must not be adversely affected by excessive heat and fire risk. The degradation or melting of busbar insulators due to high temperatures can result in a short circuit that compromises the entire switching equipment assembly. For this reason, the insulating materials used to construct equipment must be heat- and fire-resistant. This property is verified using the glow-wire method in accordance with the IEC 60695-2-11 standard. These mechanical strength requirements apply to both the outer casing and all internal components, including partition, supports, hinges, and locking systems. These components must be strong enough to withstand normal operating stresses, as well as those arising from faults, including short circuits.

When it comes to the construction and design of low-voltage switchgear, special care is taken to ensure the proper insulation distances are maintained, both in the air and on the surface. The IEC 60664-1 standard details these requirements. The installation of devices and other equipment within the switchgear must not adversely affect the specified values, so insulation distances must be maintained. When separate circuits are provided, impulse voltages must be considered when determining the air and surface insulation distances between them. For busbars and connections between devices and cable terminals (i.e., all non insulated elements), the insulation distance must be at least equal to that specified for the connected equipment. It is assumed that a short circuit between the bars will not permanently affect the insulation distances. Convex grooves are often used in insulating elements to increase insulation distances in the air and on the surface.

Only the surface insulation distance is affected in the case of concave grooves.

The dielectric properties of low-voltage equipment structures are verified in accordance with the PN-EN 61439-1 requirements, which precisely specify how to perform dielectric strength measurements. The enclosure and structural elements undergo testing at industrial frequency mains voltage. Meanwhile, the main, control, and auxiliary circuits undergo testing at the specified test voltage values, depending on the rated insulation voltage.

Electrodynamic forces are generated when electric current flows through the current paths and cables of switching equipment. These forces induce stresses on the support insulators of the current paths, cable fasteners, supports, and other associated components. Electrodynamic forces occur between: current paths; power cables; ferromagnetic and conductive materials, such as busbars and conductors; and surfaces that separate materials with different magnetic permeabilities.

The electrodynamic moments and forces acting on the current paths are determined using the Biot-Savart, Lorentz, and Maxwell equations. Maxwell's equations are specifically used to calculate electrodynamic forces in current path systems for which the inductance can be expressed analytically. The Lorentz and Biot-Savart equations are generally used to estimate electrodynamic moments and forces acting on straight portions of current paths.

3. THEORETICAL CONSIDERATIONS

Considering the equipment shown in Fig. 1a and the specially constructed general bars shown in Fig. 1b, the temperature is not constant across the cross-sectional area in an environment with a heat source because heat is produced by the Joule effect of the current.

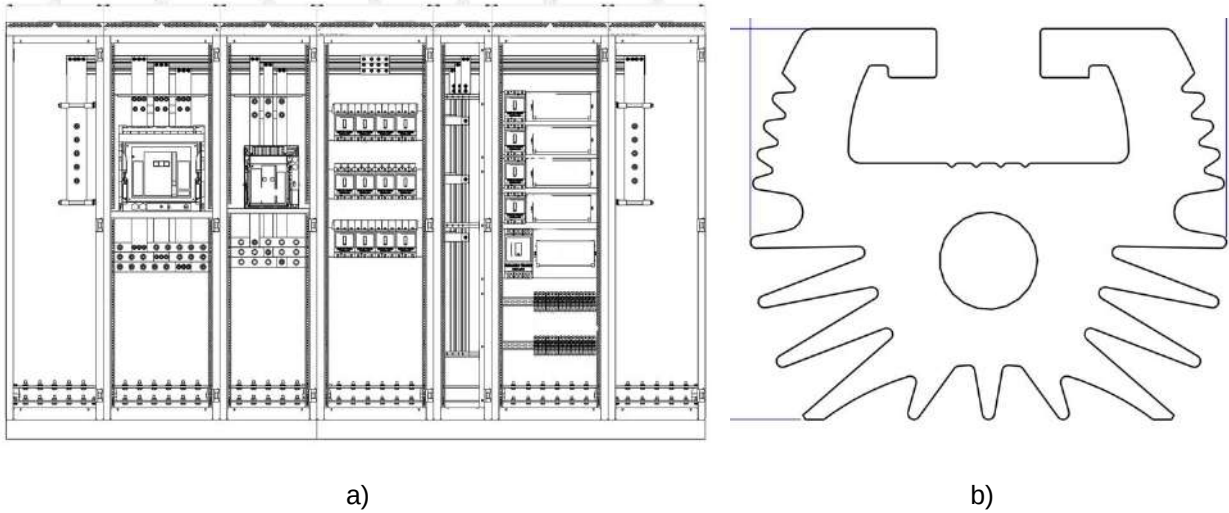


Fig. 1a) – Low-voltage switchgear equipped with specially designed general bars b) Specially designed general bar cross-section

The temperature field for the conductor in Fig. 1b) is obtained by integrating the Laplace equation for heat transfer:

$$\frac{\delta \theta}{\delta t} = \frac{p_1}{c_1} + \frac{\lambda}{c_1} \Delta \theta \text{ in } \frac{d^2 \theta}{dx^2} = -\frac{p_1}{\lambda} \quad (1)$$

assuming that heat transfer from the specially designed bar to the external environment only occurs in the x-direction due to the radiator's shape at the bottom. By integrating each element successively, we arrive at the following equation:

$$\frac{d\theta}{dx} = -\frac{p_1}{\lambda} x + C_1 \text{ where } \theta = -\frac{p_1}{2\lambda} x^2 + C_1 x + C_2 \quad (2)$$

Given the boundary conditions $x=0$; $\theta=\theta_0$ and $x=d$; $\theta=\theta_d$, $C_1=\theta_0$ is the resultant integration constant. In order to determine the constant C_2 , an assumption must be made about the specific power discharged by area A of a lateral surface. This can be done through the following balance:

$$Adp_1 = A(v_1 + v_2) \quad (3)$$

where $v_1 \left[\frac{W}{m^2} \right]$ and $v_2 \left[\frac{W}{m^2} \right]$ X and Y are the dissipation powers in the x and -x directions, respectively. If we set $a = \frac{v_1}{v_1 + v_2}$ then from (3), we get:

$$p_1 d = \frac{v_1}{a} \quad (4)$$

The temperature gradient at the surface, $x = 0$, is expressed in successive forms according to (2):

$$\left(\frac{d\theta}{dx}\right)_{x=0} = C_1 \text{ and based on Fourier's law: } -\lambda A \left(\frac{d\theta}{dx}\right)_{x=0} = -v_1 A \quad (5)$$

$$\text{The result is as follows: } C_1 = \frac{p_1 da}{\lambda} \quad (6)$$

$$\text{and the final equation is: } \theta = -\frac{p_1}{2\lambda} x^2 + \frac{p_1 da}{\lambda} x + \theta_0 \quad (7)$$

4. EXPERIMENTS

For these specially designed bars, the operating temperature $\theta_{\max}$ is reached after more than eight hours. To reduce experimentation time, a straight line ($\theta = f(\Delta\theta)$) was constructed, as shown in Fig. 2a.

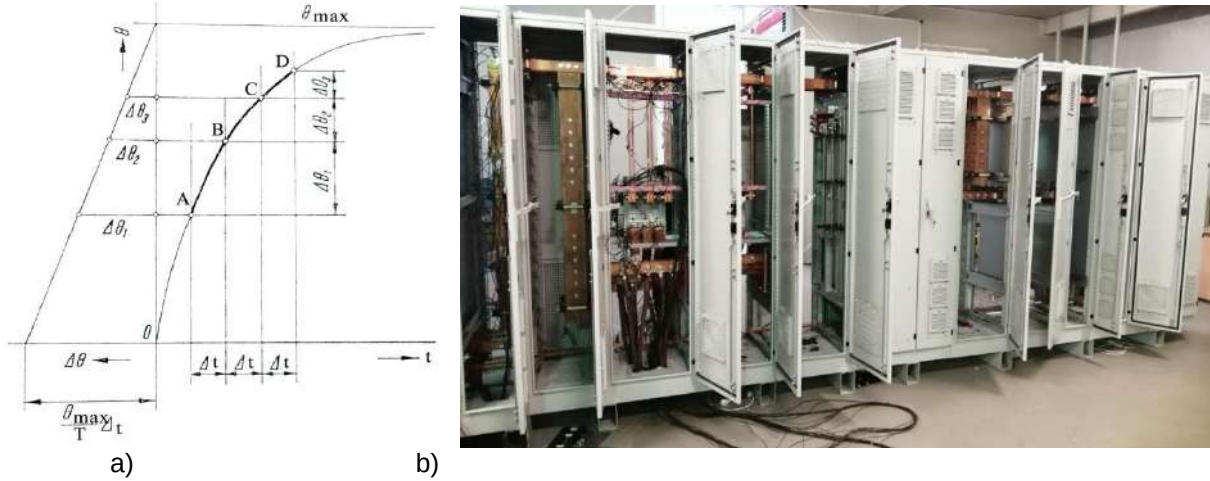


Fig. 2 – a) Experimental determination of the thermal conditions b) Low-voltage switchgear equipped with specially designed general bars during experiments

The intersection of this line with the y-axis defines the value of $\theta_{\max}$. The temperature rise values $\Delta\theta_1$, $\Delta\theta_2$, and $\Delta\theta_3$ correspond to equal time intervals, Δt . To obtain the result, it is only necessary to measure the temperature of the bars corresponding to the heating curve at points A, B, C, and D. The justification is as follows. From the heating equation:

$$\theta = \theta_{\max} \left(1 - e^{-\frac{t}{T}}\right) \quad (8)$$

where θ is the temperature rise of the bar in degrees, we derive the following:

$$\frac{d\theta}{dt} = \frac{1}{T} \theta_{\max} e^{-\frac{t}{T}} \quad (9)$$

We also obtain the expression $e^{-\frac{t}{T}} = 1 - \frac{\theta}{\theta_{\max}}$ from relation (8). When this expression is inserted into relation (9), the following result is obtained:

$$\frac{d\theta}{dt} = \frac{1}{T} (\theta_{\max} - \theta) \quad (10)$$

In finite quantities, this relationship (10) is written as:

$$\theta = \theta_{\max} - T \frac{\Delta\theta}{\Delta t} \quad (11)$$

where $\Delta\theta$ is the temperature rise during the time interval Δt .

As shown in relation (11), when Δt is constant, the temperature rise is represented by a straight line on a graph. This line intersects the x-axis (i.e., temperature rise $\theta=0$) at

$$\Delta\theta = \frac{\theta_{\max}}{T} \Delta t \quad (12)$$

The Y-axis is intersected if $\Delta\theta=0$ at $\theta=\theta_{\max}$.

Experimental checks were also carried out to verify that the temperature rise in the general bars, subassemblies, and entire assembly did not exceed the limits imposed by international standards. According to international standards, the temperature rise in a low-voltage assembly can be verified using three methods: current crossing, derivation from similar variants, or calculation. The experimental option was chosen because it was the most conclusive. Experiments were conducted using subassemblies that could operate independently and were fully equipped with general and distribution bars.

For general busbar systems consisting of one or more rectangular conductor sections whose variants differ only in the reduction of the height, thickness, or quality of the associated conductor bars, but which retain the same busbar configuration and spacing, as well as the same type of coating and busbar compartment, the configuration with the largest conductor cross-sectional area shall be selected as the representative variant. The critical configuration was chosen for the experiments, corresponding to the most demanding conditions of the compartment and casing. This configuration took into account the shape, dimensions, and structure of

the partition walls, as well as the ventilation characteristics of the assembly. The maximum permissible current was determined for each functional unit variant. Then, the power losses corresponding to the maximum current were calculated for each functional unit, including the losses of the devices themselves and the associated conductors. Because this is a functional unit with currents above 630 A, the critical unit in each range is the one with the highest rated current. This ensures that the additional thermal effects related to eddy currents and current displacement are taken into consideration.

Thermocouples and thermometers were used to measure temperature. These instruments were protected against air currents and heat radiation. Particular attention was given to the joints within the main circuit. Several devices were arranged in convenient places to measure the temperature inside the assembly.

The temperature rise at the end of the experiment did not exceed the values specified in the international standards. The apparatus operates satisfactorily within the specified voltage limits at the temperature inside the assembly. The tests were performed on aluminum bars according to Fig. 1b). The established ratings are also valid for copper bars with the same design and cross-sectional dimensions and configurations. The ratings of the variants that were not the subject of the experiments can be determined by multiplying their cross-section by the current density of a larger busbar cross-section.

5. RESULTS AND DISCUSSION

This article presents a new configuration of busbars designed for low-voltage electrical assemblies. It focuses on the busbars' thermal behavior under standard operating conditions. Since all electrical assemblies generate heat during operation, they reach a state of thermal equilibrium when the rate of heat dissipation matches the amount of heat generated. Under these conditions, the system's internal temperature stabilizes at a value that exceeds the surrounding ambient air temperature.

The objective of the experimental investigations was to ensure that the stabilized temperature does not result in any of the following: (1) significant degradation or accelerated aging of the assembly components, (2) excessive heat transfer to external conductors that could compromise the performance of connected equipment or the conductors themselves, and (3) safety hazards for personnel, operators, or animals in the vicinity of the assembly during normal operation.

During testing, multiple current ratings were validated, which are critical for the end user. In practical applications, most primary circuits within an assembly operate under load conditions, resulting in thermal interaction between adjacent circuits. This typically results in a reduction of the system's effective current-carrying capacity compared to that of individual circuits in isolation.

The experimental procedure was designed to enable the extrapolation of performance ratings from verified variants to similar untested configurations under clearly defined conditions. Although the established design guidelines allow for the replacement of components with similar characteristics, all tests in this study were conducted using the original configuration without any deviations.

The main busbars were tested independently and mounted inside the assembly enclosure in the normal operational setup. All covers and internal partitions were in place to replicate actual service conditions. There were no joints present in the main busbars during testing. To minimize the thermal influence of external conductors, a continuous current was applied along the entire two-meter length of the busbars.

Similarly, the distribution busbars were evaluated independently of the outgoing units. They were connected to the main busbars and mounted inside the enclosure according to the standard operational configuration. No functional units or additional conductors were connected during the tests. To simulate the most demanding thermal conditions, tests were performed at the rated current across the entire length of the distribution busbar.

ACKNOWLEDGEMENTS

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RESEARCH ON SOIL TEMPERATURE DYNAMICS WITH RELEVANCE TO SHALLOW GEOTHERMAL SYSTEMS

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ABSTRACT – IP12

The efficiency of ground-coupled geothermal systems depends on soil temperature at shallow depths. This study examines the thermal behavior of soil at a depth of 1.5 meters using continuous in situ measurements over a defined monitoring period. The analysis focuses on temperature variation amplitude, evolution by season, and its relationship with surface climatic conditions. The results show that thermal fluctuations are significantly reduced at this depth compared to the temperature of the air at the surface, which confirms the soil's natural buffering capacity. These findings offer practical insights into the design and optimization of shallow geothermal heat exchangers, especially with regard to operational stability and long-term performance in renewable energy applications.

Keywords: soil temperature, heat transfer, surface geothermal systems, thermal conductivity, monitoring

1. INTRODUCTION

This article aims to provide a scientific summary of soil temperature dynamics and its applicability in designing and operating geothermal heat exchangers.

Geothermal energy, also known as earth energy, is a renewable energy source available in abundance and without interruption, regardless of the season or region [1], [2].

Surface geothermal heat exchangers, such as vertical or horizontal loops and ground collectors, are efficient solutions for small-scale heating and cooling in residential and commercial buildings and photovoltaic panel systems. These installations' performance depends heavily on how thermal energy is stored and transported in bulk by the soil adjacent to the heat exchangers. Soil temperature is a local thermodynamic state that varies over time and space due to solar radiation, heat exchange with the air, precipitation, evapotranspiration, and human activities such as irrigation and construction [3], [4].

The thermal properties of the soil, such as conductivity, diffusivity, and heat capacity, as well as the presence of free or frozen water, significantly impact the heat transfer process. Understanding these phenomena is essential to designing geothermal heat exchangers, selecting loop depth and density, predicting seasonal efficiency, and ensuring the sustainability of local thermal resources [5], [6].

The heat diffusion equation describes heat transfer in soil:

$$\frac{\partial T(z,t)}{\partial t} = \alpha \frac{\partial^2 T}{\partial z^2} + \frac{Q(z,t)}{\rho c} \quad (1)$$

where: $T(z,t)$ is the soil temperature at depth “ z ” and time “ t ”; $\alpha = \frac{\lambda}{\rho c}$ is the thermal diffusivity; λ is the thermal conductivity; ρ — is the density; c — is the specific heat.

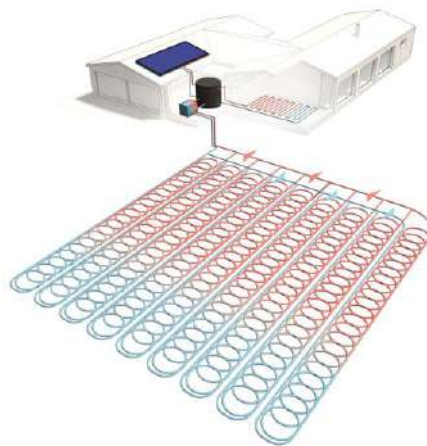


Fig. 1. Household heating system using a geothermal heat exchanger

The weather station plays a key role in establishing optimal operating conditions, both through its location and by providing essential real-time parameters (global and reflected solar radiation, soil temperature at one-meter depths, wind speed and direction, humidity, etc.) [1].

The weather station consists of:

- ✓ A *datalogger* that allows multiple types of sensors to be connected to its four configurable analog inputs;
- ✓ An *albedometer* for measuring solar radiation consisting of two Class C pyranometers with spectral flatness;
- ✓ A *two-axis ultrasonic anemometer*, which measures wind speed, direction, temperature, and relative humidity.

A *soil temperature probe* equipped with seven PT100 temperature sensors for measuring soil temperature at seven different levels: +5 cm, 0 cm, -5 cm, -10 cm, -20 cm, -50 cm, and -1 m.



Fig. 2. Weather station equipped with a probe that measures the soil temperature at a given depth

2. DIURNAL EXPERIMENTAL DATA OBTAINED USING THE WEATHER STATION AT ICMET CRAIOVA

To validate the data, information from an experimental site in a temperate zone was analyzed. At this site, a weather station monitored solar radiation, temperature, humidity, wind speed, dew point, and soil temperatures at depths of 0.1–1.5 meters hourly throughout the day.

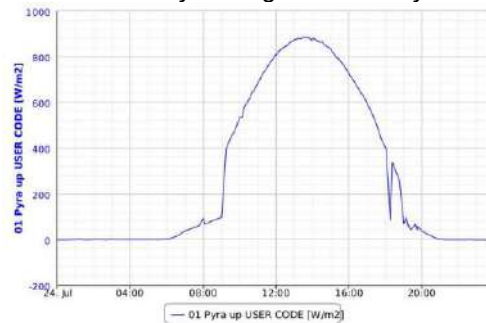


Fig. 3. Direct solar radiation on a sunny day

Fig. 3 shows that the variation in solar radiation during the day is parabolic, reaching a maximum of 887 W/m².

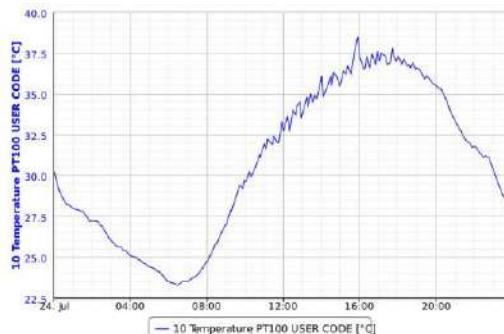


Fig. 4. Ambient temperature on a sunny day during the heat wave period

As shown in Fig. 4, the ambient temperature reaches a maximum of 38.5 °C around 4 p.m. during the day.

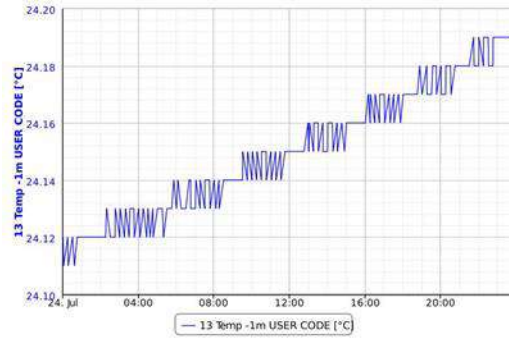


Fig. 5. Temperature measured in the soil at a depth of 1.5 meters on a sunny day during heat wave

Figures 5 and 6 show that although the ambient temperature has a strong diurnal oscillation, ranging from a minimum of 23.3°C at 06:30 to a maximum of 38.5°C at 16:00, the temperature in the soil at a depth of 1.5 meters remains constant at 24°C throughout the day.

EXPERIMENTAL DATA OBTAINED BY SEASON USING THE WEATHER STATION AT ICMET CRAIOVA Experimental data obtained using the weather station during the cold season

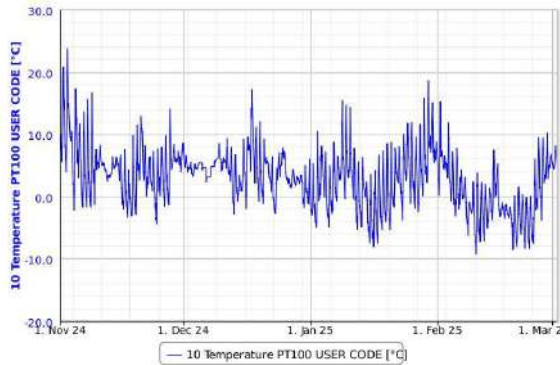


Fig. 6. Ambient temperature during the cold season

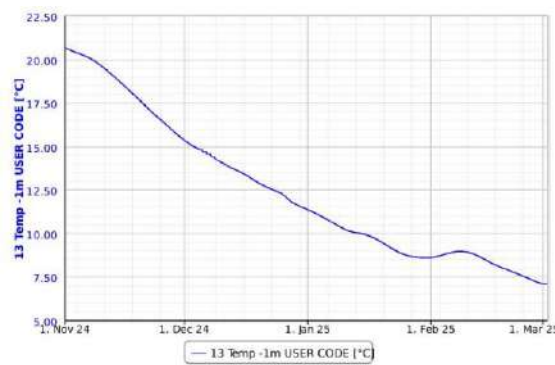


Fig. 7. Temperature measured in the soil at a depth of 1.5 meters during the cold season

Fig. 6 shows that, during the cold season (November 2024 to March 2025), the ambient temperature reached a maximum of 23.6°C on November 2, 2025, and a minimum of -8.6°C on February 10, 2025.

Fig. 7 shows that, during the cold season (November 2024 to March 2025), the maximum temperature measured in the soil at a depth of 1.5 meters was 20.6°C on November 2, 2025, and the minimum temperature was 7.4°C on March 1, 2025.

Experimental data obtained using the weather station during the warm season

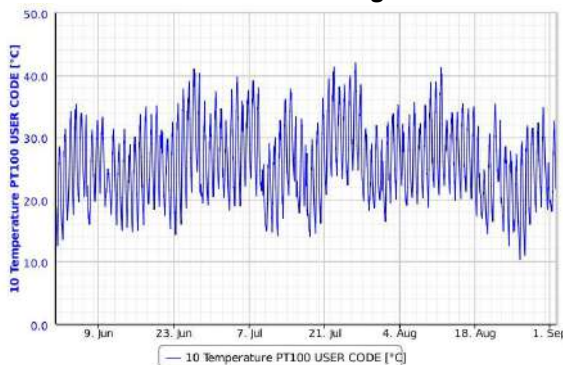


Fig. 8. Ambient temperature during the warm season

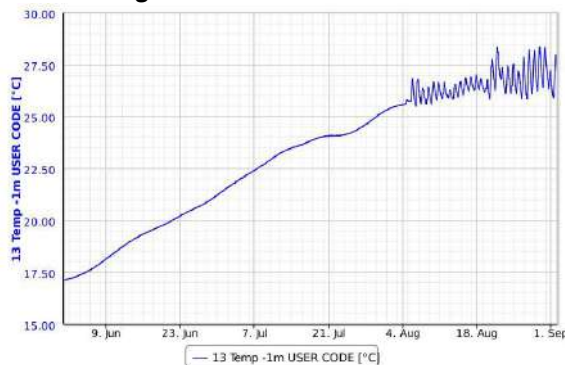


Fig. 9. Temperature measured in the soil at a depth of 1.5 meters during the warm season

Fig. 8 shows that, during the warm season (June–September 2025), the ambient temperature reached a maximum of 42 °C on July 26 and a minimum of 10.3 °C on August 26.

Fig. 9 shows that, during the warm season (June–September 2025), the minimum temperature measured in the soil at a depth of 1.5 m was 17.1°C on June 1, 2025, and the maximum temperature was 28.31°C on August 30, 2025.

CONCLUSIONS

A study of soil temperature dynamics at a depth of 1.5 meters, conducted via continuous monitoring with the weather station at ICMET Craiova, revealed several important points for designing and operating shallow geothermal systems:

Amortization of daily temperature variations - Experimental data show that diurnal oscillations are practically non-existent at a depth of 1.5 m. In hot summer conditions, the soil temperature remains constant at ~24 °C, while the air temperature varies between 23.3 °C and 38.5 °C.

Thermal stability by season - During the cold season (November–March), the soil temperature ranged from 7.4 to 20.6 °C. During the warm season (June–September), the temperature ranged from 17.1 to 28.3 °C. The reduced amplitude of these variations compared to the ambient air demonstrates that the soil provides a stable heat source throughout the year at the analyzed depth.

Phase shift from air to ground - Due to high thermal inertia, temperature variations in the soil lag behind those in the ambient environment, with a delay in thermal response. This phenomenon must be considered in the sizing and dynamic control processes for geothermal heat exchangers.

The influence of seasonality on SGMA performance - An average soil temperature between 15 and 25 °C during most of the year is optimal for the operation of groundwater heat pumps, ensuring a high coefficient of performance (COP) and consistent energy efficiency.

Practical relevance for design - The results confirm that a depth of 1.5 meters strikes a favorable balance between thermal stability and installation costs. Additionally, reduced temperature variations minimize thermal stress on the heat exchangers, thereby increasing the system's durability.

Sustainability and integration potential - Geothermal systems are effective for local energy strategies based on renewable sources due to their thermal stability and independence from daily weather conditions. They can be used in combination with photovoltaic panels to power heat pumps.

In conclusion, the experimental analysis confirms that the soil at depths of 1–2 meters constitutes a stable, natural thermal reservoir that is ideal for shallow geothermal exploitation. Implementing geothermal systems at these depths can significantly reduce conventional energy consumption, increase building energy efficiency, and promote environmental sustainability. Future research may focus on correlating temperature data with soil physical properties, such as texture, moisture, and thermal conductivity. Additionally, multi-year numerical simulations may be used to optimize the performance of hybrid systems, such as geothermal-photovoltaic systems.

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RESEARCH ON THE BEHAVIOUR OF BIFACIAL PHOTOVOLTAIC MODULES (BPV) DEPENDING ON TYPE INSTALLATION

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ABSTRACT – IP13

As the global demand for clean energy accelerates, renewable energy technologies are continuously evolving to enhance efficiency and reduce costs. Of these innovations, bifacial photovoltaic modules have emerged as a promising alternative to conventional monofacial systems. Bifacial photovoltaic technology offers a compelling solution for increasing solar energy yield due to its ability to capture radiation on both the front and back, utilizing not only direct sunlight but also reflected and diffuse light. Depending on factors such as ground reflectivity (albedo), installation height, tilt angle, and environmental conditions, this dual-side absorption can lead to a significant increase in total energy production. This study provides a comparative assessment of the performance of bifacial photovoltaic systems installed in two distinct scenarios: ground-mounted and residential rooftop installations.

Keywords: photovoltaics, bifacial panels, solar energy, residential, rooftop

1. INTRODUCTION

Concerns about climate change, fossil fuel depletion, and pollution from burning fossil fuels are growing. These concerns have spurred global efforts to reduce greenhouse gas emissions and accelerate the energy transition. In 2024, fossil fuels still dominated global electricity production, accounting for around 59% of the total. Meanwhile, low-carbon sources, including hydro, nuclear, solar, wind, and bioenergy, accounted for the remaining 41%. However, the trend is clearly toward decarbonization. Renewables are experiencing record growth, and photovoltaic and wind power systems are reaching record production levels. Projections from the International Energy Agency (IEA) indicate that, amid growing demand and investment in clean energy, renewables are set to overtake coal as the main source in 2025–2026 [1]. From 2024 to 2030, this technology is expected to account for 80% of the growth in global renewable energy capacity, fueled by the construction of new, large-scale solar power plants and an increase in rooftop solar installations for businesses and households [2].

The Energy Performance of Buildings Directive (EU/2024/1275) took effect on May 28, 2024. It provides substantial support for developing photovoltaic systems in Europe. It establishes minimum standards for non-residential buildings and renovation plans for residential buildings. At the same time, it introduces the obligation to install solar panels. Initially, this obligation applies to new commercial and public buildings. Starting in 2029, this obligation will also apply to residential buildings.

2. BIFACIAL PANEL TECHNOLOGY

In recent years, bifacial photovoltaic panel technology has received more recognition in the energy sector because of its ability to efficiently convert solar radiation into electricity. Unlike monofacial photovoltaic panels, which only absorb solar radiation on their front side, bifacial panels harness light from both sides, including radiation reflected from surfaces such as the ground or built infrastructure. This feature significantly increases energy production per unit of installed power, improving the efficiency of the photovoltaic system. According to the International Technology Roadmap for Photovoltaics (ITRPVs), the market and applications for bifacial panels are growing rapidly, and global market share is projected to reach 60% by 2029. Thanks to innovations in bifacial cell and panel technologies, the cost of photovoltaic systems is decreasing, which keeps solar power competitive in the multi-terawatt era. These advances include improvements in cell design and manufacturing processes, as well as optimization of reflected light capture [3], [4].

Table 1. Technologies and Efficiency Characteristics of Bifacial Photovoltaic Panels

Technology	Bifacial factor (%)	Main features
PERC (Passivated Emitter and Rear Contact)	~ 70 %	Relatively low-cost partial rear contact cells.
TOPCon (Tunnel Oxide Passivated Contact)	~ 80 %	Greater efficiency, reduced recombination losses, long service life.
SHJ (Heterojunction)	~ 87 %	They are highly efficient and excellent at capturing diffuse light. They also perform well at high temperatures.
IBC (Interdigitated Back Contact)	~ 70 %	Full rear contact cells are more expensive but aesthetically pleasing.

Bifacial panels are made up of solar cells enclosed between transparent layers. This structure allows for the efficient capture of reflected light and optimizes energy performance. They are typically mounted on adjustable structures that allow the inclination angle to be adjusted for optimal solar radiation capture. Recent studies indicate that bifacial photovoltaic panels can generate up to 30% more energy than monofacial panels. This strengthens their position as an effective solution for optimizing photovoltaic system investments in the residential and commercial sectors. The bifacial factor is the ratio of the energy generated by the back side of the module to the energy generated by the front side. Higher values indicate a more efficient capture of reflected light [4]. Advantages of bifacial technology include increased energy efficiency, adaptability to various surfaces, a longer service life due to its double-glass construction, and a reduced levelized cost of energy (LCOE) [5].

Key factors influencing the performance of bifacial photovoltaic panels:

➤ **Solar radiation**

❖ *Direct radiation captured on the front side:* If the panel is optimally oriented, the front side of the bifacial panel will capture almost all direct incident radiation; The angle of incidence affects the amount of energy captured. The greater the perpendicularity of the panel to the sun, the greater the efficiency of direct radiation [6], [7].

The simplified formula for the amount of energy captured by the front side is: $E_{\text{front}} = G_{\text{direct}} \cdot \cos(\theta) \cdot A \cdot \eta$, where: G_{direct} = direct radiation [W/m^2]; θ = angle between the direction of the sun's rays and the panel; A = panel surface area [m^2]; η = panel efficiency.

❖ *Radiation captured on the back side:* The back of the bifacial panel receives radiation reflected from the ground and diffuse radiation; Depending on the albedo and height of the panel, the additional energy can be between 5 and 30% of the energy generated on the front side. The approximate formula for the back side is as follows:

$E_{\text{back}} = G_{\text{diffuse}} + \text{albedo} \cdot R_{\text{bifacial}} \cdot A$, where: R_{bifacial} is the bifacial efficiency factor (usually 70-90% compared to the front side).

➤ **Albedo-** High-albedo surfaces, such as white gravel, reflect more light onto the back of solar panels, thereby improving their performance.

➤ **The tilt angle and mounting height** - Optimizing these parameters can improve light capture and reduce shading, thereby increasing energy efficiency.

➤ **Type of installation-** The type of installation is very important with bifacial photovoltaic panels in order to benefit from both direct solar radiation (on the front of the panel) and reflected/diffuse radiation (on the back). Types of bifacial panel installation: Ground-mounted; Rooftop (building roofs); Carport (photovoltaic carports); Facade/building (BIPV – Building Integrated PV); Installation with solar trackers (1-axis or 2-axis) [8].

➤ **Temperature-** The efficiency of photovoltaic cells is reduced by high operating temperatures. Ground-mounted bifacial panels are more efficient because they benefit from better ventilation and lower temperatures.

➤ **Shading-** Reducing the amount of shading at the front or rear reduces production. Bifacial panels are more susceptible to rear shading than monofacial panels, particularly in conditions of low albedo.

Challenges of ground-mounted bifacial systems:

- Additional land costs are incurred due to the requirement for large areas, which can be expensive or controversial in terms of agriculture and biodiversity.

- Additional infrastructure – they require cabling, transformers, and sometimes dedicated access roads.

Challenges of bifacial systems mounted on residential buildings (rooftop):

- Reduced bifacial gain: on many rooftops, the back receives little reflected light, resulting in actual gains of only 3÷10% in the absence of reflective surfaces (e.g. a white rooftop or snow).

- Structural limitations: the weight and orientation of the roof may prevent the installation from being carried out optimally.

- Shadowing: reduced production due to trees, antennas and neighboring buildings [6], [8].

3. CONFIGURATION OF THE SYSTEMS TESTED

The study examined two bifacial photovoltaic systems mounted outdoors and installed in southwestern Romania (44.32° N, 23.80° E). The two bifacial photovoltaic systems were analyzed simultaneously: one was mounted on the ground, while the other was installed on the rooftop of a residential building. They both used standard mounting systems.

The ground-mounted photovoltaic system is equipped with bifacial photovoltaic panels and has an installed capacity of 5.34 kW. The height of the ground-mounted photovoltaic system is 2,810 mm at the rear and 1,110 mm at the front, when measured from the natural ground level. This ensures an inclination angle of 28°, which is optimal for capturing solar radiation (Fig. 1).

The ground-mounted bifacial photovoltaic system comprises 12 SOLARWATT 445 Wp panels with TOPCon technology, which have the following technical characteristics: Cell type: Monocrystalline n-type (TOPCon, HJT); Cell design: Half-cut/dual cell (HPDC); Nominal power: $P_{\text{max}} = 445 \text{ W}$; Panel efficiency: 22.3 %; No-load voltage: $V_{\text{oc}} = 39.6 \text{ V}$; Maximum power point voltage: $V_{\text{mpp}} = 33 \text{ V}$; Short circuit current: $I_{\text{sc}} = 14 \text{ A}$; Current at maximum power point: $I_{\text{mpp}} = 13.5 \text{ A}$; Temperature coefficient: $P_{\text{max}} = -0.25 \% / ^\circ\text{K}$; Panel operating temperature: 42 °C; Dimensions: 1762x1134x35mm; Weight: 24.8 kg. This ground-mounted photovoltaic

system is supported by a metal structure and comprises 12 bifacial photovoltaic panels, a 5 kW Huawei inverter, a backup box, a smart meter and a 5 kW storage unit.



Fig. 1. Ground-mounted, bifacial photovoltaic panel system.



Fig. 2. Bifacial photovoltaic panel system installed on the rooftop of a residential building.

The bifacial photovoltaic system installed on the rooftop of the residential building has an installed capacity of 7.12 kW and is equipped with bifacial photovoltaic panels. The bifacial photovoltaic system installed on the rooftop of the building comprises 16 Longi 445 Wp bifacial panels with TOPCon technology, with the following technical specifications: Cell type: Monocrystalline n-type (TOPCon, HJT); Cell design: Half-cut/dual cell (HPDC); Nominal power: $P_{max} = 445 \text{ W}$; Panel efficiency: 22.3 %; No-load voltage: $V_{oc} = 35.19 \text{ V}$; Maximum power point voltage: $V_{mpp} = 29.48 \text{ V}$; Short circuit current: $I_{sc} = 16.01 \text{ A}$; Current at maximum power point: $I_{mpp} = 15.1 \text{ A}$; Temperature coefficient: $P_{max} = -0.28 \% / ^\circ\text{K}$; Panel operating temperature: $45 ^\circ\text{C}$; Dimensions: $1762 \times 1134 \times 30 \text{ mm}$; Weight: 23 kg. The system installed on the rooftop of the residential building comprises 16 bifacial photovoltaic panels, a 6 kW Huawei inverter, a backup box, a smart meter and a 5 kW storage unit.

4. EXPERIMENTAL RESULTS

Table 2. The initial data for the two systems

System	Installed power (kW)	Energy produced in one day (kWh)
1- ground-mounted	5,34	36,71
2 - rooftop	7,12	39,18

The experimental data was analyzed on a sunny day (8 August 2025), when energy production was high. The two systems (a ground-mounted bifacial photovoltaic system and a rooftop bifacial photovoltaic system installed on the rooftop of a residential building) were analyzed in the same climatic conditions, which included direct and indirect solar radiation, albedo, wind speed and ambient temperature. The climatic conditions were analyzed using the DeltaOhm Cloud online platform, the FusionSolar application was used to obtain experimental data for each type of system.

Ground-mounted bifacial photovoltaic system

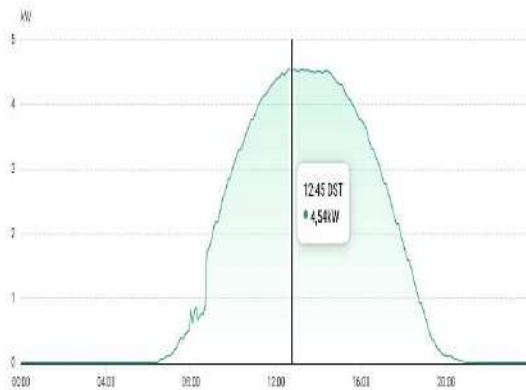


Fig. 3. Real-time evolution of power production throughout the day

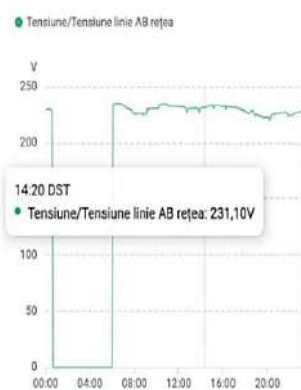


Fig. 4. Network voltage

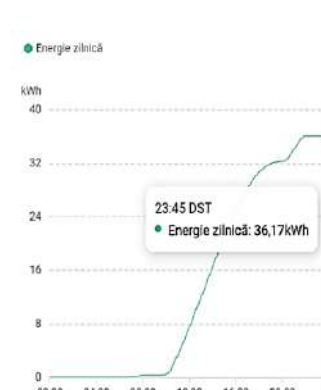


Fig. 5. Electricity generated by the ground-mounted bifacial photovoltaic system

Bifacial photovoltaic system installed on the rooftop of a residential building

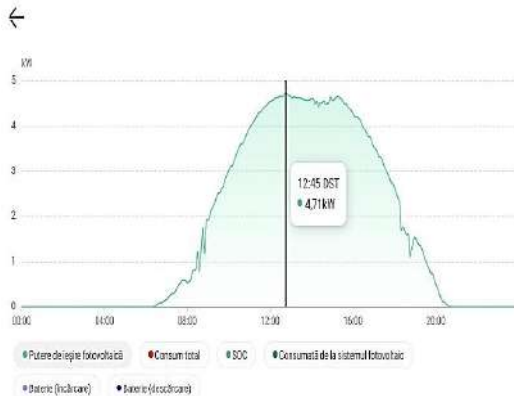


Fig. 6. Real-time evolution of power production throughout the day.

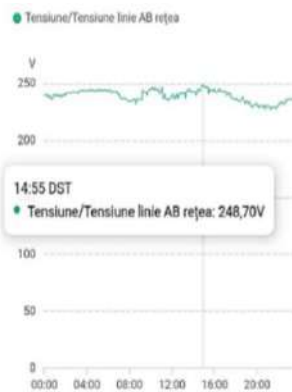


Fig. 7. Network voltage.



Fig.8. Electricity generated by the bifacial system installed on the rooftop of a residential building.

Calculation of specific production (kWh/kWp):

$$Y = \frac{E}{P} \quad (1)$$

System no. 1 (ground-mounted bifacial photovoltaic system):

$$Y_{S1} = \frac{36,71}{5,34} \approx 6,88 \text{ kW/kWp} \quad (2)$$

System no. 2 (bifacial photovoltaic system installed on the rooftop of a residential building):

$$Y_{S2} = \frac{39,18}{7,12} \approx 5,50 \text{ kW/kWp} \quad (3)$$

CONCLUSIONS AND DISCUSSION

Absolute production: The rooftop photovoltaic system produces more energy than the ground-mounted system, reaching 39.18 kWh compared to 36.71 kWh. This is because it has a higher installed capacity.

Specific production: The ground-mounted bifacial photovoltaic system has a higher output per unit of installed power than the roof-mounted system. It reaches 6.88 kWh/kWp compared to 5.50 kWh/kWp.

Percentage difference in efficiency:

$$\Delta = \frac{6,88 - 5,50}{5,50} \times 100 \approx 25,1 \% \quad (4)$$

A ground-mounted system produces around 25% more electricity than a roof-mounted system. In terms of total production, the 7.12 kW rooftop-mounted system has an advantage; however, this is only because of its higher installed power. When we analyze efficiency per unit of power, the ground-mounted system (5.34 kW) performs significantly better, with a +25% increase in specific production.

This study compared the performance of two photovoltaic systems with different installation methods: one ground-mounted and one rooftop-mounted. The results show that the rooftop system produced more energy (39.18 kWh compared to 36.71 kWh) due to its higher installed power (7.12 kWp compared to 5.34 kWp). However, the ground-mounted system demonstrated a significantly higher specific yield of 6.88 kWh/kWp, which is approximately 25% higher than the value of 5.50 kWh/kWp recorded by the rooftop-mounted system. These results highlight that performance is directly influenced by the type of installation: ground-mounted systems benefit from better ventilation, an optimized tilt angle and greater albedo contribution, whereas rooftop-mounted systems are more exposed to high temperatures and potential shading.

Overall, while rooftop installations can provide a higher total output when space is available, ground-mounted systems are more efficient per unit of installed power. This makes them better suited to applications where specific yield is a priority. This confirms that, when it comes to bifacial panels, well-optimized ground mounting is more effective than residential rooftop mounting.

Acknowledgements

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CONSIDERATIONS ON THE PERFORMANCE OF INSTRUMENT TRANSFORMERS UNDER INTERNAL ARC FAULT TESTING CONDITIONS

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ABSTRACT – IP14

This paper analyzes the behavior of instrument transformers under internal arc fault conditions. The goal is to ensure the safe operation of the transformers and the power system to which they belong. The study evaluates transformers' ability to withstand an internal arc between high- and low-voltage windings without endangering personnel or nearby equipment. It presents the test conditions, methodology, measurement setup, and parameters applied during internal arc fault testing, as well as the results obtained from various instrument transformers. To better understand the findings, recordings of the electrical phenomena observed during the tests are included.

Keywords: instrument transformers, peak current, windings, internal arc, safety

1. INTRODUCTION

This paper presents an internal arc experiment that is a destructive evaluation method designed to verify a measuring transformer's compliance with the specified internal arc protection class. This experiment does not guarantee that the effects will be retained in all possible short-circuit scenarios. However, it does demonstrate compliance with a pre-established, standardized safety level. It is important to note that the internal arc test does not extend to, nor does it guarantee, the performance of the transformer in situations where the arc forms outside the tested area. This includes the insulation area of insulated bushings and any other location that was not reproduced during the testing procedure. Because insulation behavior is inherently probabilistic, the "technically most probable" location of the defect should be interpreted strictly literally, without implying guaranteed behavior. Therefore, implementing an internal arc protection system does not definitively guarantee that the measuring transformer will function as expected under actual internal arc conditions. These protective measures should be understood as strategies for reducing risk, not as absolute safety measures.

2. GENERAL ASPECTS ABOUT INSTRUMENTS TRANSFORMERS

In recent years, increasing operational safety has become one of the most important aspects of high-voltage equipment performance. Fires and explosions are classified as major defects and are among the most serious defects that can affect measuring transformers. According to specialized sources, such events account for about 3% of all reported faults in measuring transformers. Approximately 80% of these faults are caused by internal insulation issues, especially in the main insulation. The main insulation is responsible for about 70% of these cases. While the distribution of faults may differ slightly for other types of transformers, existing data indicates that 70 to 80 percent of faults are caused by short circuits between windings. These statistics come from different data sets and are therefore considered complementary and relevant to this paper's analytical framework.

Fire or explosion defects in measuring transformers are usually caused by internal electric arcs, which produce high-power discharges in an extremely short amount of time. These discharges release a significant amount of energy, which is sufficient to compromise the mechanical integrity of the transformer casing. This includes both the active part casing and the external insulation part (bushing). In the 2000s, internal arc testing was introduced into the relevant international standards applicable to measuring transformers to address the need for increased operational safety in the face of such critical events. However, the internal arc test is still one of the most controversial topics in transformer measurement. Testing requirements and associated evaluation criteria are subjects of ongoing debate and continuous improvement. This reflects the industry's efforts to align safety standards with evolving technological and operational requirements, as well as its constant concern for increasing operational reliability and ensuring a standardized level of safety.

The internal arc experiment is based on the assumption of a high-energy fault scenario in which the impedance of the main insulation system is disregarded. Therefore, the test only evaluates the casing's structural strength and the efficiency of its pressure relief mechanisms. However, this testing methodology only applies to internal defects originating in the measuring transformer tank. It does not include the insulated bushings component in the evaluation. Furthermore, the test fails to consider several critical factors known to significantly contribute to fires and explosions. These factors include short circuits between windings, aging materials, quality control deficiencies, and design vulnerabilities. Consequently, while the internal arc experiment is valuable for assessing energy withstand performance in the event of a fault, it is not applicable

to the broader spectrum of fault modes in instrument transformers.

In general, current transformers can be categorized by their construction into two types:

- Current transformers with normal construction, where the active part (the magnetic core and windings) is located at the top;
- Current transformers with a clip have the active part (the high-voltage winding shaped like a hair clip) in the lower area.

Although each of the two design variants has its advantages and disadvantages, they differ significantly in terms of behavior during internal electric arc testing. In the event of an electric arc fault, enormous pressure—tens of atmospheres—develops in the area of the arc within the first few milliseconds. This pressure can cause mechanical damage, such as breaking the insulator or detaching metal parts, membranes, covers, etc.

These reasons explain why the two types of construction behave very differently when exposed to an electric arc. In the first milliseconds, the pressure instantly causes the valve (membrane) to open, releasing oil into the atmosphere. This results in serious mechanical effects that throw structural parts over a large area, which is necessary to pass the test according to international standards.

The active part of clip-on current transformers is located in the lower area. The volume of oil, ranging from tens to hundreds of liters, creates additional static pressure on the electric arc. This static pressure overlaps the arc's extremely dynamic pressure.

For current transformers with the active part in the upper area, the pressure created is released almost instantly (within a few milliseconds) into the atmosphere. Even if clip-on transformers have a pressure release device (diaphragm) at the top, it takes several tens of milliseconds for the operating time to elapse after the electric arc is generated. During this time, the insulator breaks or is dismantled from the lower flange.

3. THEORETICAL CONSIDERATIONS

The experiment applies to the new design of instrument transformers intended for use in applications where the voltage is higher than 1 kV AC. These transformers have an analog or digital secondary signal for measuring, protection, and control purposes, and have rated frequencies ranging from 15 Hz to 400 Hz. The instrument transformers are intended for use under normal environmental conditions at their rated characteristics. If the actual environmental conditions differ from these, the transformers shall be designed to comply with the requested environmental conditions. The ratings of instrument transformers and their auxiliary equipment, if applicable, are selected from international standards. For exposed installations subject to overvoltage of atmospheric origin, the highest coordinated insulation level is recommended. The maximum voltage for equipment U_m must be equal to or greater than the maximum voltage of the system U_{sys} .

This experimental framework applies to newly designed measuring transformers intended for use in applications where the operating voltage exceeds 1 kV AC. These transformers provide analog or digital secondary signals for measurement, protection, and control purposes. These transformers are designed to operate within the nominal frequency range of 15 to 400 Hz. They must operate under normal environmental conditions that correspond to their rated performance characteristics. If the actual environmental conditions differ from the standard conditions, the transformers must be designed to meet the specific environmental requirements. The selection of nominal parameters for measuring transformers and auxiliary equipment, when applicable, must be in accordance with relevant international standards. It is recommended that the highest level of insulation available be chosen for installations exposed to atmospheric overvoltages, especially those located outdoors. To ensure compliance with insulation coordination principles and operational safety requirements, the maximum permissible voltage for equipment (U_m) must be at least equal to the maximum system voltage (U_{sys}).

An electric arc occurring inside the active part may be due to damage to the insulation between the turns of the high-voltage winding, or between the high-voltage winding and the magnetic core.

From the perspective of the arc's location for the experiment, the manufacturer of measuring transformers studies the electric field in the active area. Where the electric potential gradient is highest, a short circuit is created and fed with a current proportional to the network's short-circuit power at the transformer's installation site.

If required, the manufacturer must explicitly declare the value of the rated internal arc fault current (I_{arc}). In the absence of specific requirements, a level of internal arc fault current equal to 60% of the short-time rated current permitted by the switching equipment is generally considered adequate for most applications. Empirical data shows that setting the internal fault current value at 100% of the system's fault current usually results in the measuring transformer being oversized unnecessarily, since actual phase-to-ground fault current levels are considerably lower. However, depending on the results of detailed calculations of the phase-to-ground fault current at the specific location, values higher than 60% of the system fault current may be justified in certain installation contexts.

4. EXPERIMENTS

Transformers with a maximum operating voltage of $U_m \geq 72.5$ kV for which the purchaser specifies a protection class for internal arc faults must undergo and successfully pass an internal arc test. This test is destructive in nature and is intended to verify the transformer's compliance with the declared protection class. The following are the classifications for internal arc protection:

- Class 1A1: Casing cracking and fire are permitted; however, all fragments and ejected parts must remain within the designated reference area. In this context, materials such as insulating paper and non-flammable fluids are not considered hazardous.
- Class 1A2: The insulator or casing must not crack, except when an appropriate pressure relief device is in operation. Additionally, the emission of flammable or combustible liquids is prohibited.

These classifications establish minimum safety and damage limitation requirements for internal arc faults, thereby increasing the operational reliability and safety of high-voltage instrument transformers.

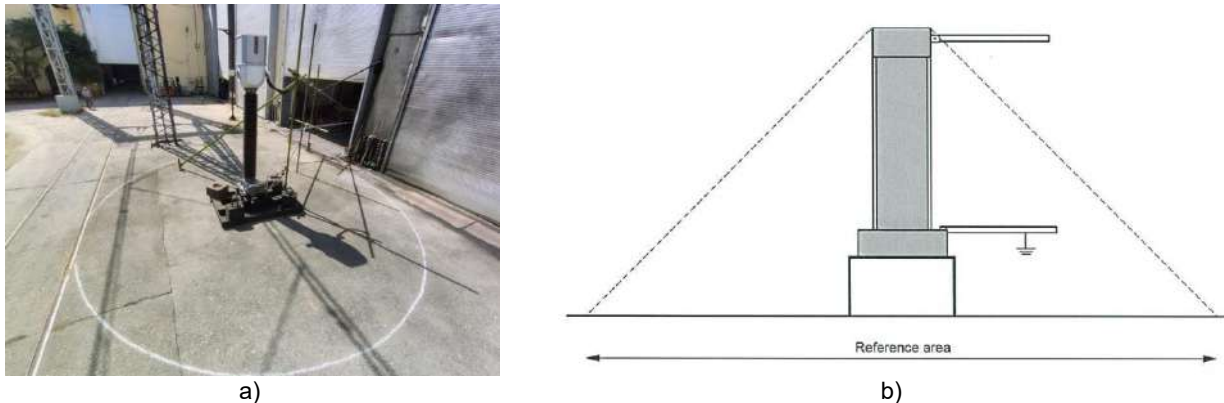


Fig. 1. a) View of the instrument transformer within the prescribed area b) Configuration for an internal arc experiment

As shown in Fig.1, the 145 kV measuring transformer used in the experiment was installed in a configuration that accurately reproduced actual operating conditions. Similar to its standard operating conditions, the equipment was filled with organic insulating oil and mounted on a 500-mm-high pedestal to simulate typical installation conditions.

A reference area was defined around the transformer to establish the permissible limit for the dispersion of fragments resulting from an internal electric arc fault. The diameter of the reference area was determined by adding the transformer's maximum lateral dimension to twice its total height, including the base.

The internal arc test was performed at ambient temperature to ensure that the evaluation reflected real operating scenarios and did not include additional thermal influences.



Fig. 2. View of the instrument transformer during the experiment

Fig. 2 shows the images obtained from the experiment. An internal arc test was performed using an asymmetrical fault current with an effective value (RMS) equal to the nominal internal arc current (I_{arc}) for 800 ms. As expected for such faults, the peak value of the first half-cycle of the current was 1.7 times greater than the RMS value. According to international standards, there is a $\pm 5\%$ tolerance for both the RMS value of the current and the duration of the fault.

The testing laboratory measured the fault current separately from the measuring transformer being tested. A

2,500 MVA short-circuit generator provided the power supply, delivering a virtually sine wave fault current throughout the entire experiment. Fig. 3 illustrates the corresponding oscilloscope recordings. The arc formed between the high-voltage winding and the magnetic core in the active area, specifically at the junction of the insulator and the tank. Power was supplied from terminal P₂ to ground via two 240-mm² copper cables.

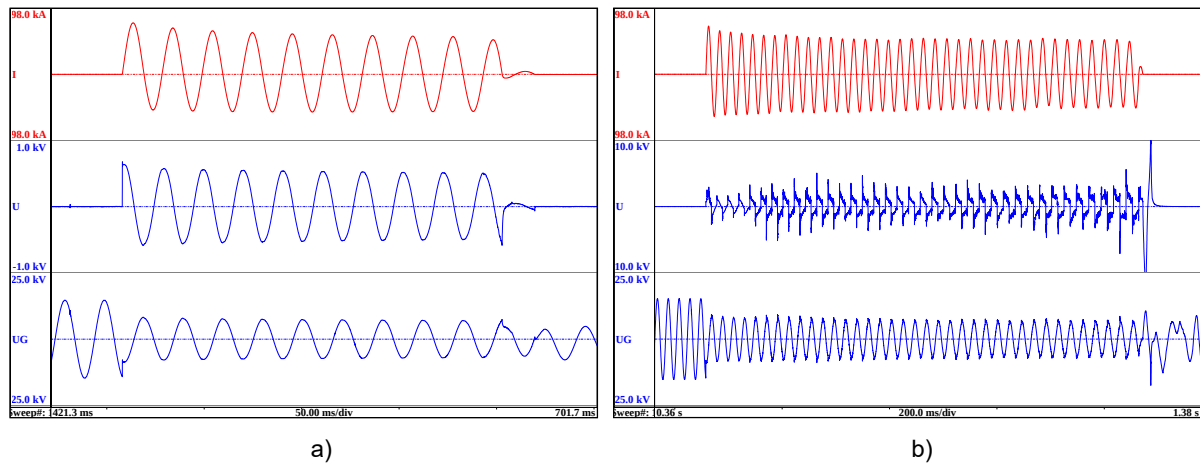


Fig. 3. a) Oscilloscope recording of the calibration of the experimental circuit. b) Oscilloscope recording of the experiment

The following data was obtained for the calibration: applied voltage of 6 kV; equivalent rms value of short-circuit current; and phase value of 41.1 kA. The experiment involved applying a voltage of 6 kV, which is the equivalent rms value of the short-circuit current. The phase value was 38.5 kA, and the voltage drop on the arc was 1.3 kV for duration of 810 ms.

5. RESULTS AND DISCUSSION

This paper presents an analysis of the performance of measuring transformers under internal arc conditions. This analysis is based on an experiment that was conducted under real operating conditions and used actual short-circuit currents. During the experiment, the transformer structure did not break apart. Only the pressure release device activated as designed. The experiment was considered a success because all of the expected test parameter values were achieved within the specified tolerance limits.

Although the experiment focuses on one product, the authors have experience with dozens of similar tests involving all types of measuring transformers. The high-power laboratory at ICMET Craiova tests high-voltage and current transformers of all designs with the following insulation media: oil, sulfur hexafluoride (SF₆), nitrogen, and dry air under pressure. The laboratory tests transformers at short-circuit currents ranging from 20 kA to 80 kA and durations ranging from 200 ms to 800 ms. These tests validate the chosen design solution in terms of internal electric arc behavior, according to IEC 61869. These extremely "harsh" tests are destructive, and 50% of the measuring transformers do not pass them successfully. However, careful analysis of the effects provides manufacturers with valuable information for improving the design.

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TRENDS AND OUTLOOK FOR COMPOSITE INSULATOR CRIMPING PROCESS

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ABSTRACT – IP16

Due to their superior mechanical strength, lightweight structure, and excellent resistance to environmental stresses, composite insulators have become increasingly important in modern power transmission and distribution systems in recent decades. These insulators are made up of a fiberglass-reinforced polymer (FRP) rod, silicone rubber housing, and metal end fittings. One critical step in manufacturing composite insulators is crimping metal end fittings onto the central rod. This process ensures the insulator's mechanical stability and electrical performance throughout its lifetime. The crimping process involves mechanically deforming a metal sleeve over an FRP rod with a predefined force and displacement. The quality of this joint is crucial because it directly affects the tensile strength and environmental stress resistance of the insulator. However, ensuring joint integrity without destructive testing poses a significant manufacturing challenge due to the composite nature of the materials involved. Traditionally, quality assurance in insulator crimping has relied on operator experience, periodic destructive testing, and post-processing inspections. While these methods can identify major defects, they often fail to detect deviations in process parameters, which can result in latent defects. These limitations can be addressed by implementing a real-time crimping process monitoring system. Thanks to advancements in sensor technology and data acquisition systems, important process parameters such as crimping force, displacement, and acoustic emissions can now be continuously monitored. In recent years, acoustic emission (AE) technology has evolved into a real-time, non-destructive monitoring tool that can detect defects occurring during the manufacturing process. AE offers a promising approach for dynamic monitoring of the crimping process quality by capturing and analyzing high-frequency sound waves produced by the material under stress.

Keywords: Crimping Process, Acoustic Emissions, Monitoring System

1. INTRODUCTION

A composite insulator consists of glass reinforced polymer (GRP) rod, two metal end fittings attached to the rod during assembly and a series of electrically insulating rubber sheds (Fig. 1). The insulator assembly must be able to withstand tensile force as per particular specification of insulator [1], [2], [3], [4]. The primary function of the end fittings is to provide a mechanical link and to transfer loads from the high voltage conductor to the GRP-rod (at the line end), and from the GRP rod to the tower (at the tower end). Modern GRP demonstrate a number of advantages compared to conventional materials. Due to reliability, low cost and reproducibility, compression type joints become state-of-art in composite insulators technology.

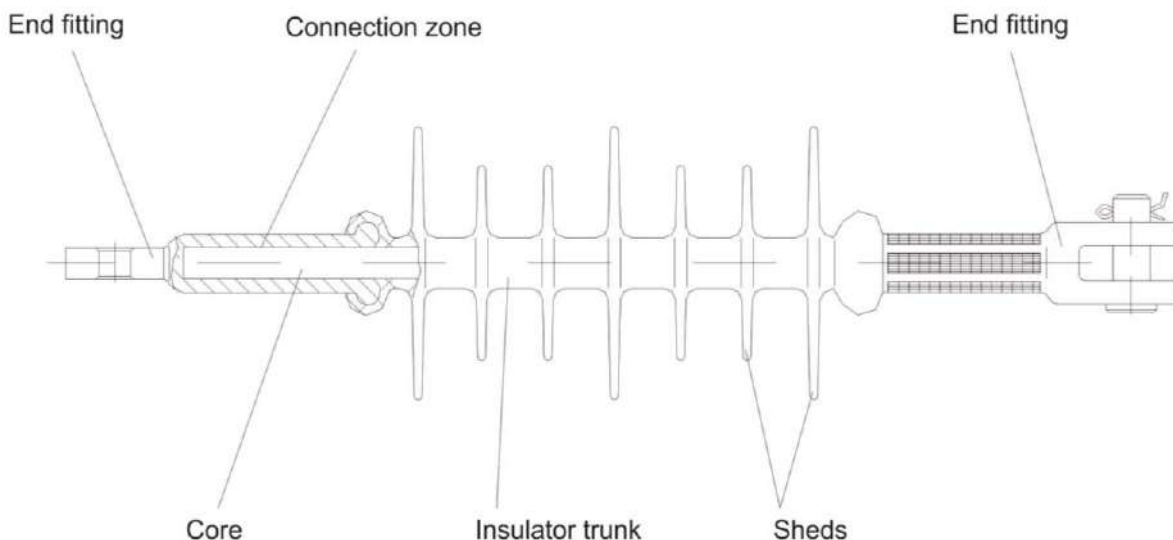


Fig. 1. Composite insulator

The bonding between the GRP rod and the metal end fitting in the insulators is strongly dependent on the magnitude of compression applied during crimping and the friction coefficient between the fitting and the rod. The excessive crimping deformation may result in fracture of the core. The cracks might gradually grow in service due to complex mechanical (static and cyclic) stress as well as the chemical and electrical

environment associated with high voltage applications. Humidity and corona discharges could have a severe effect on the in-service performance of over crimped composite insulators.

The combined effect of the mechanical, electrical and environmental stress can cause brittle fracture failures of high voltage composite suspension insulators in-service [2]. On the other hand, low crimping deformation will provide a too weak joint. The mechanical strength of a composite insulator with crimped end-fittings can be determined by pulling the GRP rod out of the end-fittings.

A hydraulic press is used to drive the die set in the radial direction, towards the end fitting. The standard crimping process is achieved in three steps. In the first step, the crimping pressure increases up to set value. In the second step, the pressure is held at this value until the set holding time is finished. In the third step the pressure is discharged.

Two main factors [4] affect the crimping process, for the same forming load and for the same joint. These are material properties and tolerances of the components.

The composite insulators producers use the acoustic emissions technology for monitoring the crimping process of the end fittings. An acoustic emission may be definite as a transient elastic wave by the rapid release of energy within a material. With AE equipment we can "listen" to the sounds of fiber glass breaking and cracks growing. This method of AE monitoring indicates only if the cracks occurred.

2. CRIMPING CONDITION AND INSULATOR FAILURE

The insulators were crimped [3] with the following four crimping conditions: standard stress condition, constant high stress condition, high stress condition and reversed stress condition.

Three insulators, from each group were tested to establish relationships between the type of compression profile and the type of insulator failure (Fig. 2).

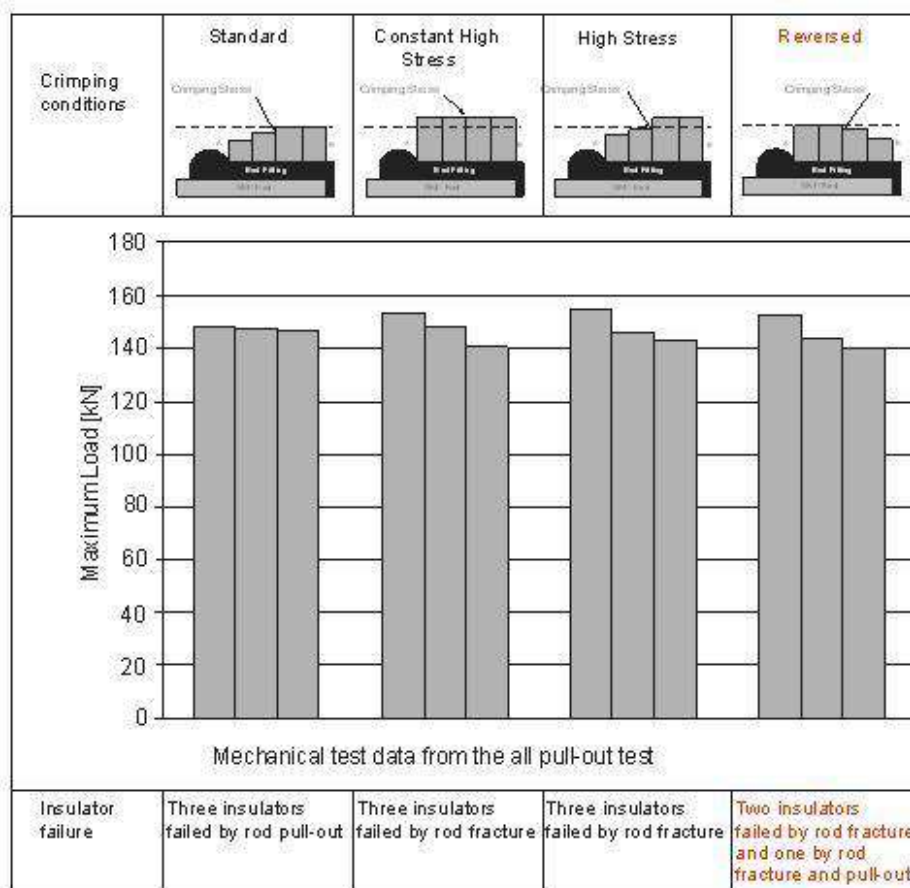


Fig. 2. Mechanical test results [3]

The insulators with the standard stress conditions failed by the insulator rod simply being pulling out of the end-fitting. No visible damage to the rod was observed. However, traces of white powder inside the fitting and on the rod surface inside the fittings were detected.

The failure of the insulators crimped with the high stress conditions was characterized by a large crack in the rod inside the fittings, with considerable splitting in the rod.

The reversed stress crimping was also characterized by cracks in the rod well down in the end grip. However, the cracks were smaller and much more splitting and pull-out was observed. The constant high stress conditions gave

by far the most splitting and pullout of the four samples. The mechanical tests result obtained from the pull-out tests clearly show that the failure process of insulators is strongly dependent on the crimping process. The insulator with the standard stress condition of crimping failed by pull-out. The other crimping conditions resulted in the mechanical failure of the rods. Very little scatter has been observed in the loads at failure for all the insulators investigated. It was also shown that the failures by pull-out or by rod fracture occurred almost at the same load level.

3. METHOD FOR CRIMPING THE END-FITTINGS ON THE COMPOSITE INSULATOR ROD USING ACOUSTIC EMISSION AND CRIMPING PRESSURE MONITORING [4], [5]

I - Zone of linear increase of the crimping pressure, from p_i value up to p_v value.

The pressure p_i , value set by software, represents the pressure initiating the data acquisition. The pressure p_v , value set by software, represents the pressure from which the acoustic emissions are validated. The removal of acoustic emissions within the pressure interval p_i - p_v is necessary because they have high values at the initial contact between fittings and rod. The acoustic emissions are also determined by the local crushing caused by rod unevenness and fittings roughness and do not affect the crimping quality.

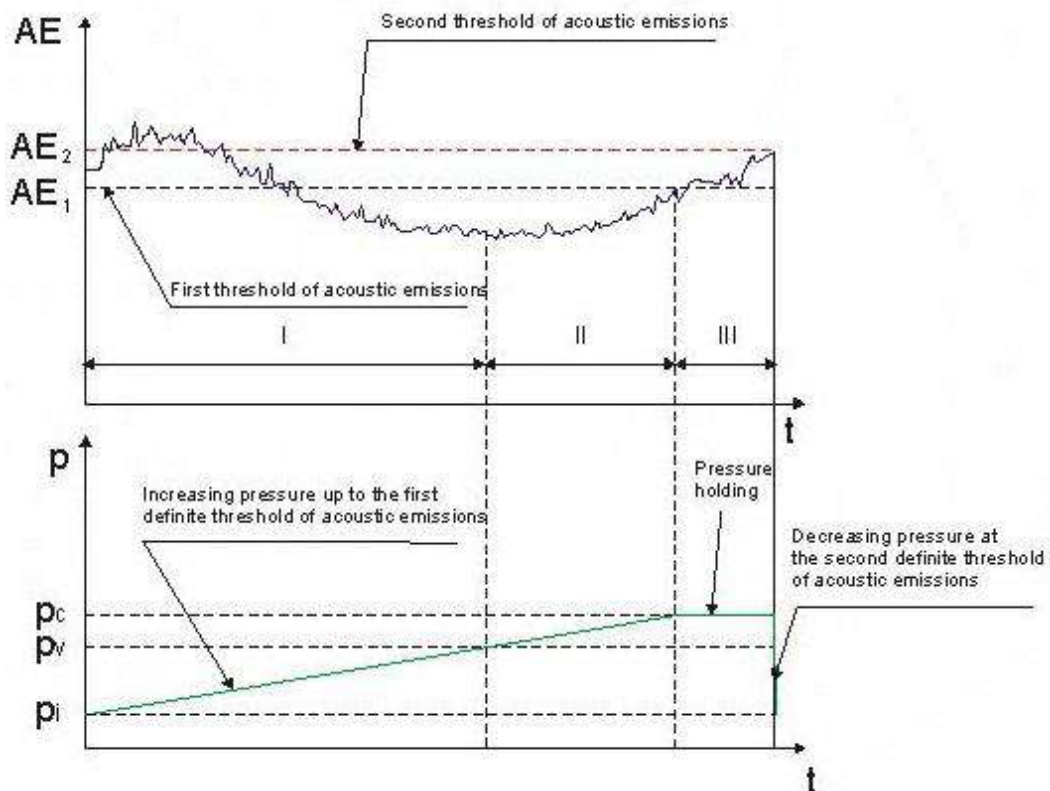


Fig. 3. Acoustic emissions signature for crimping process

II - Zone of linear increase of the crimping pressure from p_v value up to p_c value, with the same slope as in zone I. The p_c pressure represents the crimping pressure and is determined by the reaching of AE_1 value by the acoustic emissions. The threshold value AE_1 is set by software and determines the stopping of the crimping pressure increase and maintaining it constant.

III - Zone for compressing the fittings and rod at the constant crimping pressure p_c until reaching the second level of acoustic emissions AE_2 . The threshold value AE_2 is set by software and determines the sudden release of the crimping pressure. The pressure decrease below the value p_i finalizes the data acquisition.

4. EQUIPMENT FOR CRIMPING COMPOSITE INSULATORS

The acoustic sensor mounted on the die of the crimping press (Fig. 4) detects acoustic emissions appearing in the crimping process of the fittings on the rod of the composite insulator. The electrical signal is filtered and amplified [4]. The equipment for acoustic emission monitoring and for crimping pressure control (Fig. 4) receives the AE signal and an electric signal of pressure from the hydraulic installation of the crimping press by means of pressure transducer. The equipment communicates with the computer on which the software is installed. The monitoring equipment also limits the crimping pressure achieved by the hydraulic installation.

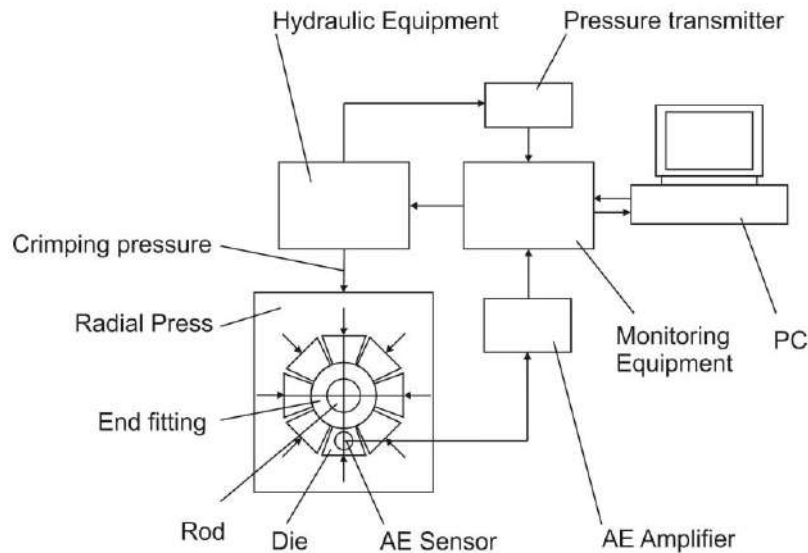


Fig. 4. Equipment for crimping composite insulators

The acoustic sensor mounted on the die of the crimping press detects acoustic emissions appearing in the crimping process of the fittings on the rod of the composite insulator. The electrical signal is filtered and amplified. The equipment for acoustic emission monitoring and for crimping pressure control receives the AE signal and an electric signal of pressure from the hydraulic installation of the crimping press by means of pressure transducer. The equipment communicates with the computer on which the software is installed. The monitoring equipment also limits the crimping pressure achieved by the hydraulic installation.

5. EXPERIMENTAL RESULTS

To examine the method for crimping composite electrical insulators, six insulators with reversed stress conditions were tested up to pull-out (over Specified Mechanical Load). All of these insulators with SML 120 kN failure by rod pull-out.

The maximum load was between 158 and 160 kN.

No damage to the rod was found, except traces of white powder indicating that the crimping method did not create any damage. No transverse surface cracks in the GRP rod was found.

CONCLUSIONS

The method for crimping the fitting on the composite insulator rod using acoustic emission and crimping pressure monitoring provides:

- Insulators free from any intralaminar damage due to optimal crimping of the fittings on the insulator rod;
- The rods are pulled-out without fracture or cracks because the stress is not exceeded;
- Metallic end-fittings with different hardnesses can be used because the system automatically controls the crimping pressure depending on acoustic emissions;
- Crimpings when the differences in the diameters of the rod and end-fittings are within the allowed tolerance field.

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MOISTURE IN TRANSFORMER UNITS: A COMPLEX AND EVER-PRESENT PROBLEM

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Abstract – IP19

Transformer units are complex, critical, and among the most expensive components of electricity transmission and distribution systems. The general aging of the transformer fleet, the continuous extension of operating times, ever-increasing electricity demand, and the use of renewable energy sources have put additional pressure on energy systems, leading to an increased risk of failure, unscheduled outages, and significant costs. Moisture, known as the number one enemy of transformers' paper-oil insulation systems, has always been a critical parameter for monitoring and diagnostic practices because it plays an important role in degrading these systems, leading to various failures that affect transformers' lifespans. This paper briefly presents the impact of moisture on the decrease in dielectric strength of oil-paper insulation and the development of partial discharges. Operating transformers with high moisture content can lead to dangerous scenarios, such as free water developing in the transformer oil or bubbles forming at the oil-paper interface. These events pose a threat to the integrity of the equipment. It also provides straightforward, practical solutions that improve the quality and reliability of transformers and their accessories, reducing costs over the transformers' lifetime.

Keywords: transformers, moisture content, monitoring, maintenance

1. INTRODUCTION

Today, electricity is the most widely used energy source, and energy transmission and distribution systems face challenges due to high load rates and the intermittent integration of new energy sources, such as photovoltaic and wind power [1]. Transformers are vitally important in energy systems, whether the energy is traditional or the new energy that has developed rapidly in recent years. They are also the most expensive type of equipment in energy systems. The reliable operation of an energy system hinges on the health of its transformers. No matter how small, transformer failures reduce the reliability of the energy system. These failures often lead to electricity supply interruptions for consumers, resulting in significant economic losses and sometimes environmental impacts. Thus, to ensure sustainability, manufacturers of transformer units must consider the long-term environmental, social, and human impacts of their products [2]. Using digitization for condition-based life cycle management improves transformer reliability and extends its service life. Advanced maintenance approaches based on accurate condition data optimize maintenance while reducing risks and costs [3]. Additionally, effective assessment techniques are necessary for managing transformer units. This allows operators to closely monitor the most critical components of the transformer and plan their maintenance expenses accordingly.

According to CIGRE researchers, monitoring transformers with effective techniques can reduce the risk of fatal failure by half. Studies have shown that early diagnosis of problems can reduce repair costs by 75% and revenue loss by 60%. Additionally, annual cost reductions of up to 2% of the price of a new transformer are possible, resulting in substantial savings for electricity companies and services. The development and use of renewable energy sources has put additional pressure on energy systems, increasing the likelihood of transformer failure. These sources have been found to significantly impact the interior of transformers through temperature, fluid dynamics, and micro-moisture dispersion [1].

Therefore, it is becoming increasingly important for utility companies and other organizations to invest in proactive maintenance and modernization strategies. These strategies mitigate the risk of failure and minimize the financial impact of any failures that may occur [7]. Thus, proactive measures have been taken globally to protect and secure transformer units. These measures include modifying and establishing rigorous standards and issuing technical guidelines that lead to the implementation of practices and approaches for monitoring, evaluating, and maintaining transformer units [3-5] and [8-11].

The reliability, efficiency, and service life of transformer units largely depend on their paper-oil insulation systems, which protect the units' internal components against electrical and thermal stresses [12]. In preventive diagnostics, it is important to understand the physical phenomena that can lead to transformer failure, such as partial discharges, lightning impulses, and the bubble formation effect. It is also important to understand the factors that cause unexpected transformer failure. The most significant failure factor is moisture in the paper-oil insulation system, which has also been shown to be an important catalyst in the aging process of transformer units [13-14]. Therefore, reducing this aging factor or avoiding its influence from the beginning ensures a longer reliable service life for transformer units.

2. MOISTURE IN THE PAPER-OIL INSULATION SYSTEM

A transformer's most important quality is its insulation, which ensures reliability, efficiency, and longevity. As is well known, transformer insulation consists of two main components: liquid insulation, or insulating oil, and solid, cellulose-based insulation, also known as "paper" or "insulating paper."

Oil plays a significant role in the transformer's insulation system. In addition to being an insulator and a cooling agent, oil carries information about its quality and the condition of the paper. This information determines the transformer's operating state and service life. The oil must also meet strict requirements, including high dielectric strength, chemical stability, and good thermal conductivity, even when subjected to large temperature fluctuations caused by the operating conditions of transformers [13]. Cellulose paper acts as a dielectric, storing electrical charge when the transformer is powered. It also improves the transformer's thermal health by creating conduits for cooling oil.

Selecting suitable insulating materials is essential for transformers' performance and longevity because each material has unique properties that affect its thermal stability and resistance to degradation. The most commonly used materials are mineral oil and Kraft paper. However, due to new environmental concerns and the challenge of high load rates, alternative oils, such as silicone oil and natural and synthetic esters, as well as insulating materials, such as thermally enhanced Kraft paper and aramid paper, which have good dielectric properties and high thermal and mechanical resistance, are also being used.

The degradation of the insulation system in liquid-filled power transformers is a serious concern for electric power companies. The aging mechanisms of the paper-oil insulation system are known to be complex and closely interconnected. They are also highly temperature-dependent. Moisture, acids, oxidation products, and other decomposition particles (both soluble and colloidal) accelerate the insulation system's degradation. During transformer operation, moisture gradually penetrates the oil and dissolves in it. Then, the hygroscopic solid cellulose insulation absorbs the water molecules in the oil because it can absorb approximately 400 times its weight in water at any given temperature [15].

As shown in Table 1 [7], water can exist in three states of aggregation in insulating oil. Because oil does not dissolve well in water, the concentration of water in oil is measured in micrograms per gram ($\mu\text{g/g}$), where one microgram of oil in one gram of water is equal to one part per million (ppm). In insulating paper, water can exist in four states. It can be adsorbed onto surfaces, exist as vapor, or exist as free water in capillaries or as droplets. The water content of paper is typically expressed as a percentage, which is the weight of the water divided by the weight of dry paper.

Table 1. Types of water in insulating oil and their properties [7]

Types of water	Dissolved water	Emulsified water	Free water
Characteristics	Individual water molecules dispersed in oil.	Supersaturated in solution, but not yet completely separated from the oil.	It is supersaturated in solution, but in a concentration high enough to form water droplets and separate from the oil.
Appearance	No visible indication.	Milky or cloudy.	Visually apparent as a layer.
Sources	Absorption when the transformer is open for maintenance.	Usually occurs due to temperature changes and once the oil is aged.	Formed from emulsified water when a large drop of water enters the oil directly.
Effects	Low impact on the dielectric strength of the oil.	Potential hazard to dielectric strength.	The harmful effect that damages the transformer.

During transformer operation, water migrates between the paper and oil as the temperature changes. When the temperature is high, water migrates from the paper to the oil. Conversely, when the temperature drops, water migrates in the opposite direction. The diffusion of water between oil and paper depends on temperature, the thickness of the solid insulation, the contact area between the circulating oil and the paper, the type of insulating liquid, and the diffusion time constants. The temperature and type of liquid significantly impact solubility due to differences in water solubility in various dielectric liquids at different temperatures [8].

Sources and pathways of moisture ingress in transformer units

The main sources of moisture in oil-filled transformer units are as follows:

- **residual moisture** – in the cellulose insulation, that was not removed during drying at the factory, but new oil may also contain traces of water;
- **moisture absorbed by the paper-oil insulation system throughout the transformer's lifetime** – this is moisture absorbed from the atmosphere for various reasons, such as an unprotected breather or saturated silica gel, aged and porous gaskets, a pressure difference between the inside of the tank and the environment, microcracks and corrosion (on the radiator, tank walls, or imperfect welds), and during maintenance (when the transformer is opened or the oil is changed under inappropriate conditions);
- **moisture produced by the degradation of the insulation system itself** - during the aging process of oil and paper, primarily through pyrolysis and oxidation, resulting in the production of water, carbon oxides, alcohols, and furan compounds.

It should be noted that dry-type transformers are susceptible to moisture, too. Moisture penetrates these transformers through [16]: **ventilation** - the air in the rooms where they are installed may contain high levels of moisture that can penetrate directly into the winding; **temperature variations** - when the temperature around the transformer is low, air condenses on surfaces, which promotes water penetration into the insulation; **micro-cracks in the insulation or defects in the resin layer** (in transformers cast in epoxy resin) - thermal or mechanical stresses can cause micro-cracks or cracks, allowing water vapor to diffuse into the insulating layer or resin.

3. METHODS FOR DETERMINING MOISTURE CONTENT IN OPERATING TRANSFORMER UNITS

Since most of the water (approximately 99%) is contained within the solid insulation, it is crucial to determine the water content in the paper in order to maintain stable operation and prevent damage to the transformer. Many case studies and research projects have been conducted over time to develop an accurate method for determining the water content in paper. Because access to the solid insulation is not possible during transformer operation, accurate determination of the moisture content in the paper can only be performed on transformers undergoing major repairs, refurbishment, or scrapping. In conclusion, determining the water content in the dielectric fluid first and then estimating the water content in the solid insulation is easier and cheaper.

There are several ways to indirectly assess the moisture content in paper:

- the Karl Fischer titration method used together with well-known standard equilibrium curves, such as the Oommen, Griffin, and Fabre-Pichon curves [4, 7];
- the use of mathematical formulas such as Fessler's equation, ABB's equation, and Serena's equation [7];
- Fourier transform infrared (FTIR) spectrometry [8, 16];
- dielectric response methods include time-domain methods based on polarization/depolarization current (PDC) and frequency-domain methods such as spectroscopy (FDS) and the return voltage method (RVM) [8, 16];
- the DIRANA method combines time and frequency domain measurements, which substantially shortens measurement time and improves reliability in determining moisture content in solid insulation [8, 16];
- the use of thin-film capacitive sensors and sensors with fiber Bragg grating (FBG) technology [8, 16].

Due to uneven moisture levels in cellulose insulation and mineral oil or other alternative oils in use, characterizing the moisture content of insulation systems in operating transformers is an ongoing challenge.

4. THE EFFECTS OF MOISTURE AND PREVENTION AND REMEDIATION MEASURES

The negative effects of moisture on transformer units

The presence of moisture in power transformers significantly impacts the performance, reliability, service life, and safety of the equipment in a negative way. Excessive moisture in the oil-paper insulation system can lead to the following:

- **a decrease in the dielectric strength of oil and paper** - increases the risk of partial discharges, electric arcing, and punctures (insulation breakdowns);
- **increased risk of electrical failure** - increased electrical conductivity leading to sudden electrical failures, especially under overvoltage conditions;
- **accelerated aging and degradation of insulation** - in the presence of moisture and high temperatures, cellulose insulation degrades more quickly, leading to a decrease in the degree of polymerization and, consequently, in the service life of the transformer;
- **Decreased thermal efficiency and local heating** (hot spots): Water reacts with oxygen and other impurities in the oil, forming acids and sludge that can block oil circulation paths. This reduces cooling efficiency and causes hot spots that accelerate degradation;
- **degradation of metal components** - moisture causes corrosion on metal parts such as the transformer tank, windings and connections, conservator, insulating bushings, gaskets, compromising their mechanical integrity and leading to structural damage and additional leaks. The presence of corrosion products can increase the risk of electrical problems and even short circuits, which can pose a significant safety hazard;
- **risk of vapor bubble formation** - increased moisture in solid insulation can generate vapor bubbles when heated, increasing internal pressure and risking structural damage or tripping of protective relays.

Prevention and remediation measures

Avoiding major failures and extending the life of power transformers requires preventing and fixing moisture. Additionally, moisture reduction solutions enable cost-effective restoration and enhanced transformer reliability. Therefore, some preventive and repair measures include the following:

- drying the insulation before commissioning;
- repairing leaks and sealing systems - checking and replacing worn gaskets;
- sealing the cover, flanges, level indicators, etc., to prevent moisture from entering the system from the atmosphere;
- installing a rubber membrane or bag in the conservator to prevent contact with humid air;

- using smart filters with silica gel or self-regenerating silica gel breathers, which require no maintenance and ensure significant drying of the atmospheric air;
- continuous monitoring of humidity by installing online sensors for oil humidity and temperature, internal temperature sensors, and online dissolved gas analyzers (DGA) that measure water content, allowing early defects to be correlated with humidity levels;
- revitalizing the oil-paper insulation system by regenerating the oil and drying and purifying the cellulose insulation using equipment with adsorbers or molecular sieves. This equipment can be connected online and automated to start when the sensor detects moisture above the limit.

CONCLUSIONS

Moisture is indeed a serious adversary of transformers, causing deterioration of the insulation, corrosion, formation of sludge, reduced cooling efficiency, and internal structural damage. To ensure reliability and longevity, it is essential to perform preventive maintenance, including sealing, oil analysis, and drying. Prevention is also the most economical way to maintain normal levels of moisture and its effects. Monitoring the moisture content of cellulose insulation is essential for the early detection of moisture in transformers, which helps avoid catastrophic and costly failures.

As previously mentioned, moisture in the insulation system of an operating transformer is a constant concern because hybrid insulation systems, which use new materials such as thermally enhanced or aramid paper and alternative oils, are becoming more common. Therefore, further research on the impact of moisture and its dynamics in these hybrid insulation systems is necessary in order to use them effectively.

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NUMERICAL EVALUATION OF HIGH-VOLTAGE IMPULSES PARAMETERS

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ABSTRACT – IP23

Modern measurement systems in high-voltage impulse testing/calibration laboratories use software for graphical representation, waveform analysis and parameter evaluation. Characteristic parameters of the waveforms that are measured in a high-voltage dielectric testing laboratory are defined in the IEC 60060-1 standard. The waveforms are lightning impulses (LI), lightning chopped impulses (LIC) and switching impulses (SI). The numerical method for parameter evaluation must be done according to the IEC 60060-1:2025 standard and meet the requirements of the IEC 61083-2:2013 standard which establishes the limit values of the deviations of the parameters calculated for reference waveforms obtained with the software called IEC 61083-2 Test Data Generator (TDG). The paper presents how the algorithm for evaluating high-voltage impulse parameters was implemented in dedicated software and the results of the evaluation of the reference curves necessary for validation.

Keywords: numerical method; high-voltage impulses; measurement; parameters

1. INTRODUCTION

The numerical measurement method of high-voltages consists of calculating the characteristic parameters from the series of sampled points corresponding to the recorded waveforms, based on the definitions imposed by the IEC 60060-1:2025 standard [1].

If for some waveforms, such as AC and DC, the measurement of parameters can be done easily, for the impulse voltages LI, LIC and SI there has been a continuous concern to use a unitary method at the level of different laboratories. The standard [1] introduced a method for evaluating the parameters of impulse voltages using a mathematical model. The algorithm consists in determining the mean curve $u(t)$ of the real signal which is defined by the double-exponential function (DE):

$$u(t) = U_p \cdot \left(e^{-\frac{t-t_0}{\tau_1}} - e^{-\frac{t-t_0}{\tau_2}} \right) \quad (1)$$

In relation (1) the unknown parameters are: U_p the peak voltage value, T_1 the front time, T_2 the tail time and t_0 is the zero crossing time (delay).

The problem to be solved is to identify the four parameters so that the analytical function (1) best approximates the experimental data set.

The evaluation of waveform parameters must be done within the limits accepted by IEC 61083-2. This standard introduced the software called TDG which is used to obtain waveforms in numerical format. The waveforms presented are of the LI, LIC, SI type and are those commonly used in high voltage impulse dielectric testing laboratories.

The standardized verification method [2] of software consists of evaluating the parameters of the waveforms obtained with the TDG and comparing them with the permissible limits for deviations. If the parameter deviations are smaller than the limits, then the software is valid and can be used for high voltage impulse measurement.

2. HIGH-VOLTAGE IMPULSE EVALUATION

A. The Levenberg-Marquardt algorithm

The standard [1] indicates the Levenberg-Marquardt algorithm for the numerical evaluation of high-voltage impulses. Measuring the impulse parameters involves identifying the parameters of the DE function that "best" approximate the set of "n" experimental values $\{t_i, y_i\}$, $i = 1 \dots n$ recorded at a constant sampling rate.

The DE function can be written in the form:

$$f(t, \mathbf{p}) = p_1 \cdot \left(e^{-(t-p_2) \cdot p_3} - e^{-(t-p_2) \cdot p_4} \right) \quad (2)$$

where: t – the time;

$\mathbf{p}$ – the vector of parameters to be identified.

In the general case $\mathbf{p} = [p_1, p_2, \dots, p_m]$ and for the DE function of the standard [1] and the vector $\mathbf{p}$ contains only four components $\mathbf{p} = [p_1, p_2, p_3, p_4]$.

For the set of experimental values $\{t_i, y_i\}$, $i = 1 \dots n$, it is assumed that there is a solution $\mathbf{p}' = [p'_1, p'_2, p'_3, p'_4]$ such that the approximation error is minimal:

$$y_i = f(t_i, \mathbf{p}') + e_i, i = 1 \dots n$$

where: e_i is the calculation error at point $\{t_i, y_i\}$.

The identification of the parameters $\mathbf{p}'$ is done by determining the minimum of the function [3, 4, 5]:

$$F(\mathbf{p}) = \sum_{i=1}^n (y_i - f(t_i, \mathbf{p}))^2 \quad (3)$$

B Algorithm implementation

The algorithm for determining the average DE curve was implemented in software running in Windows 10 operating system. For high-voltage impulses evaluation, the Levenberg-Marquardt algorithm was implemented to determine the mean curve that was used to represent the test voltage.

C Software for evaluating high-voltage impulse parameters

The numerical method for evaluating the parameters of lightning or switching voltage impulses, with normal or chopped waveform, has been implemented in software.

When implementing the software, it was required that the series $\{t_i, y_i\}$ have a maximum of 131072 points, so that the evaluation time would be as short as possible at a maximum data segment length.

For example, a graphical representation of a TDG signal obtained for an amplitude resolution of 10 bits is in Fig. 1. For evaluation, the curve of the signal without offset, the curve of the test voltage, the curves of the residual and the filtered residual are also plotted in the TDG signal graph. The curves were determined numerically according to the method presented in [1, 5], between the points corresponding to the levels 20 % on the front and 40 % on the tail of impulse.

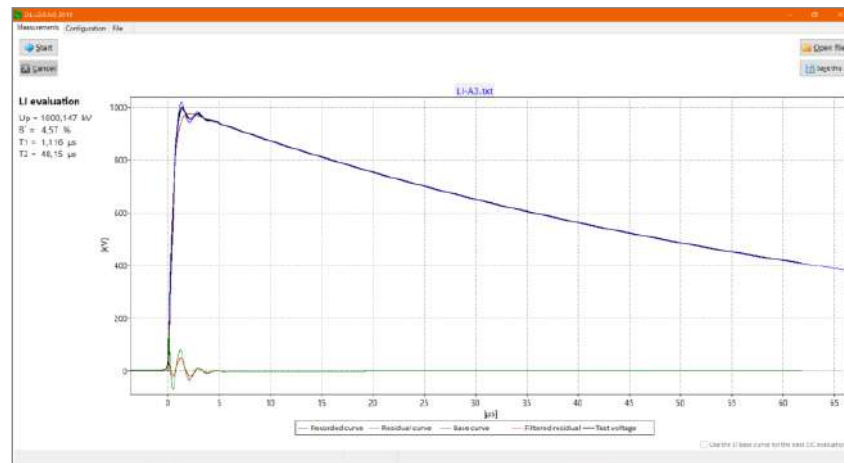
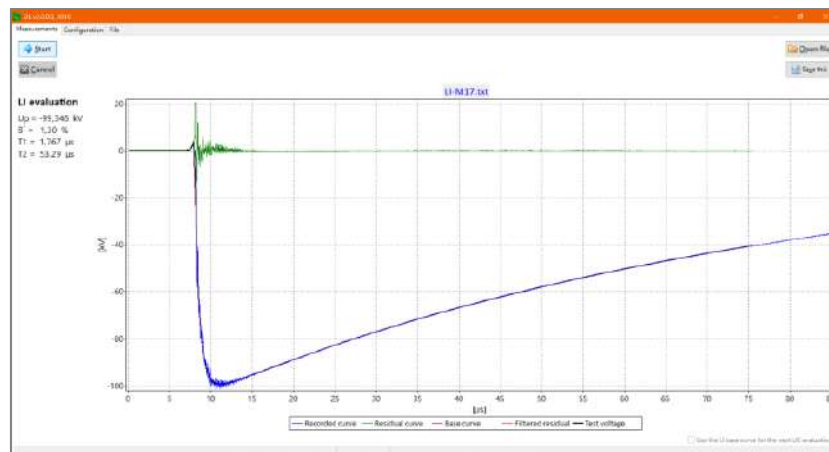


Fig. 1. Graphical representation of the LI-A3 voltage impulse from the standard [2] and calculated parameters

The software allows numerical evaluation of the parameters of smooth analytical pulses, but also of impulses measured under real conditions when recorded with noise.

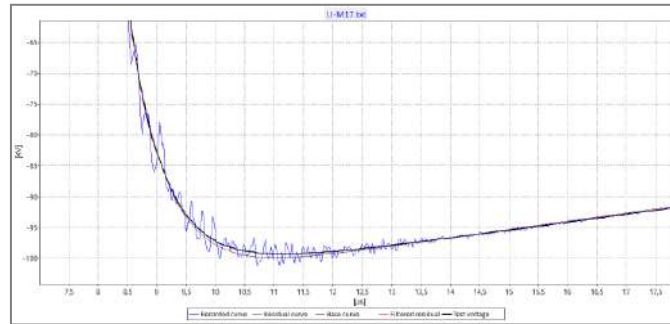
The calculated values for the impulse simulating a impulse measured with a transient-recorder with 10-bit amplitude resolution is shown in Fig. 2.

The evaluation with the developed software has deviations of 0 % for amplitude and less than 0.46 % for time parameters. The standardized permissible limits for deviations are 1 % for amplitude and 2 % for time parameters. The obtained results show that the calculation procedure was implemented correctly.



Parameters evaluation for voltage impulse recorded with a 0.1 % measurement noise (LI-M17 impulse from [2]).

In Fig. 3 a detail of the peak area for the impulse in Fig. 2 is shown to see how the noise is removed from the signal curve. The recorded signal curve is in blue, the test voltage curve is represented in black and the base curve (DE) is in brown.



Detail in the peak area of the voltage impulse in Fig. 2

It is observed in Fig. 3 that there is no noise or oscillations on the test voltage curve.

Parameters are automatically calculated after recording and plotting a signal, depending on the signal type LI, SI or LIC. The software automatically identifies the waveform. The software developed runs on 32-bit or 64-bit Windows operating systems.

3. SOFTWARE VALIDATION RESULTS

Analytical and measured waveforms are defined in the standard [2]. Waveforms can be generated with the desired amplitude resolution according to the transient-recorder used to record the waveforms. The results obtained for an amplitude resolution of 10 bits are presented below. For LI there are 12 analytical waveforms (LI-A1,..., LI-A12) and 17 measured waveforms (LI-M1, ..., LI-M17). The results of the evaluation of lightning impulse parameters showed negligible deviations from the reference values, both for analytical and measured impulses. The developed software is not affected by measurement noise, polarity or impulse offset.

For SI impulses, there are 3 analytical waveforms (SI-A1, SI-A2, SI-A3) and two waveforms for measured signals (SI-M1, SI-M2). For measured signals, the reference value limits are defined higher. In Fig. 4 is the result of the evaluation of the SI-M2 impulse which presents a measurement noise specific to electromagnetic disturbances and the digital recording device.

The LIC waveforms are evaluated according to the recommendations of the standard [1]. There are requirements for the LIC evaluation for one analytical waveform (LIC-A1) and five measured waveforms (LIC-M1, LIC-M2,... LIC-M5). In Fig. 5, the calculated parameters for the LIC-M4 tail chopped voltage impulse are presented. The numerical evaluation of the parameters of tail chopped impulses recommended in [1] is done in two stages: evaluation of a full reference impulse and evaluation of the chopped impulse. The full reference impulse can be applied to the tested object at a lower voltage level so as not to produce too high a dielectric stress.

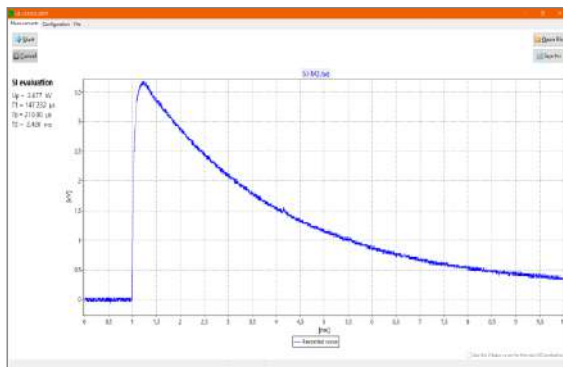


Fig. 4. Evaluation of the measured switching voltage impulse (SI-M2 impulse from [2]).

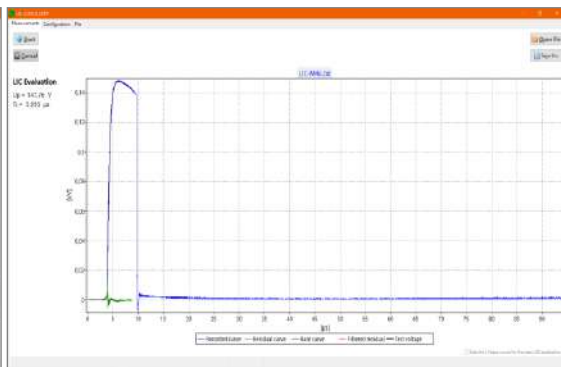


Fig. 5. Evaluation of the measured tail chopped lightning voltage impulse (LIC-M4 impulse from [2]).

The results obtained show that the deviations of the calculated parameters are smaller than the limits presented in the standard [2] for numerical evaluation. In this way, the developed software is validated and can be used for high-voltage impulse measurement.

CONCLUSIONS

The paper presents the implementation of the numerical method for evaluating the parameters of high-voltages impulse, of type LI, SI or LIC.

For the measurement of the impulse parameters, the Levenberg-Marquardt algorithm indicated in [1] was implemented to determine the mean curve and the procedure to obtain the test voltage.

The developed software complies with IEC 60060-1:2025, IEC 61083-2:2013 standards and can run on the Windows operating system.

From the experiments carried out, it was found that the numerical evaluation is not affected by the noise specific to numerical recording systems, offset or polarity.

Parameters were calculated within standardized limits for all reference curves in [2], both for smooth impulses obtained analytically and for impulses measured under real conditions of a high-voltage test where noise is present in the recordings. This means that the developed software can be used for measuring high-voltage parameters.

By introducing in [1] a standard method for measuring high-voltage impulse parameters and establishing maximum deviation limits in [2], the conditions were created for the validation of any software developed in a laboratory.

The developed software can be updated in the future to communicate with a digital waveform recording system or to periodic updates of standards [1, 2].

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PERFORMANCE EVALUATION OF METAL-OXIDE SURGE ARRESTERS IN HIGH-VOLTAGE POWER SYSTEMS

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ABSTRACT – IP24

In high-voltage (HV) power systems, ensuring reliable and continuous service depends critically on protecting equipment from transient overvoltages. which are often caused by lightning strikes, switching operations, or insulation failures, pose a significant threat to the integrity of transmission lines, substations, power transformers, circuit breakers, and other valuable assets. Without adequate protection, such overvoltages can lead to insulation breakdown, equipment failure, costly outages, and serious safety hazards. Consequently, surge arresters have become an indispensable component of high-voltage networks, providing the first and most direct line of defense against these potentially damaging events. Surge arresters designed for high-voltage applications are built to withstand extreme electrical and environmental conditions. They operate by limiting transient overvoltages to acceptable levels through their highly nonlinear voltage-current characteristics. They typically use metal-oxide varistors (MOVs), which are made of zinc oxide (ZnO). In the event of a surge, the arrester directs the excess energy to the ground. This protects the equipment downstream from voltage levels that exceed its insulation's ability to withstand. Once the surge has subsided, the arrester returns to its non-conductive state, enabling normal operation to resume. Designing, selecting, placing, and maintaining surge arresters in high-voltage environments involves complex engineering considerations. These include energy handling capacity, residual voltage characteristics, thermal stability, aging mechanisms, pollution performance, and coordination with insulation levels (insulation coordination). This paper provides a thorough analysis of surge arresters used in high-voltage applications.

Keywords: surge arrester, metal oxide varistor, ZnO, overvoltage protection

1. INTRODUCTION

Transient overvoltages caused by switching operations, internal faults, or electromagnetic coupling often affect autotransformers. These overvoltages can cause high dielectric stress in the transformer's insulation system.

A surge arrester is a non-linear, voltage-limiting device that conducts current when the system voltage exceeds a threshold. It diverts energy safely to ground and returns to a high-impedance state after the event. They protect transformer insulation from lightning and overvoltages induced internally.

Modern surge arresters primarily use metal-oxide varistor (MOV) technology. This technology offers superior energy-handling capability, nonlinear voltage-current characteristics, and faster response times than older silicon carbide-based designs. Fig. 1 shows a surge arrester DPRTU ZE 64 G23 (12 ZnO blocks).



Fig. 1. Surge arrester DPRTU ZE 64 G23

Table 1. DPRTU ZE 64 G23 main technical characteristics

Nominal Voltage	36 kV _{rms}
Maximum Operating Voltage on TTU-250 MVA	15,13 kV _{rms}
Maximum Permissible Continuous Operating Voltage (U _c) at 70 °C	19,2 kV _{rms}
Residual Voltage at Rated Current of 10 kA	86,76 ÷ 97,8 kV _{peak}
Reference Voltage at a Current of 1 mA (DC)	51,36 ÷ 57,84 kV
Lightning Impulse Test Voltage	67 ÷ 97,5 kV _{peak}
Test Voltage Corresponding to the Induced Voltage Test on TTU-250 MVA	25,42 kV _{rms}
DP Level at 1.05U _c	≤ 10 pC

2. TESTING THE AC VOLTAGE OF SURGE ARRESTERS CORRESPONDING TO THE INDUCED VOLTAGE OF AUTOTRANSFORMERS

Metal-oxide surge arresters (ZnO type) are installed to prevent insulation failure by clamping overvoltages. To ensure proper functionality, these arresters must pass various type and routine tests, including AC voltage testing, which verifies the device's dielectric strength before it is put into service.

Induced voltages in autotransformers may be caused by:

- Electromagnetic coupling between windings;
- Switching transients and resonance phenomena;
- Abnormal operating conditions or faults.

These voltages can exceed the level of insulation that can be withstood, especially in low-impedance transformer configurations.

Surge arresters are nonlinear voltage-limiting devices that:

- conduct current when the system voltage exceeds a threshold
- divert energy safely to ground
- return to a high-impedance state after the event.

2.1. PURPOSE OF THE AC VOLTAGE TEST

- Verify the dielectric strength of the surge arrester between its terminals and ground;
- Detect any internal or surface insulation deterioration;
- Confirm the mechanical and electrical integrity of the surge arrester before installation.

2.2. TEST DIAGRAM (FIG. 2)

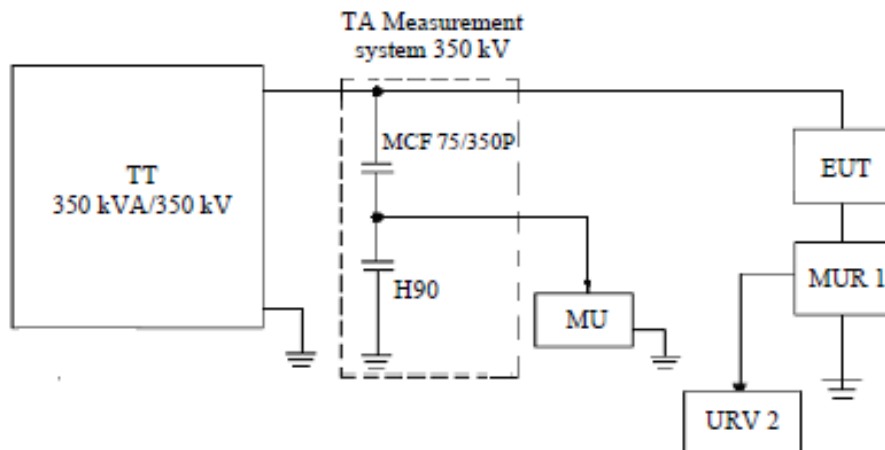


Fig. 2. Test diagram

where:

TI-350 kVA/350 kV Test Transformer

TA-350 kV Measurement System Consisting of High-Voltage Divider

MU-Digital Peak Voltmeter

MUR-1 Adjustable Shunt

URV-2 Electronic Voltmeter

EUT—Equipment Under Test

2.3. TEST SETUP

- The arrester is installed in a test configuration that replicates field conditions.
- A sinusoidal AC voltage is applied between the line terminal and the grounded housing.
- The voltage is gradually increased to the test level (e.g., 1.5 times the continuous operating voltage, or U_c).

2.4. TESTING STEPS

- a. Visual inspection before testing.
- b. Application of test voltage for a standard duration (typically 60 seconds).

- c. Monitor leakage current. Analyze capacitive and resistive components.
- d. Observe audible or visual effects (corona, noise, sparks, ozone smell).
- e. Post-test inspection for physical or thermal changes.

The test was performed by immersing the EUT in transformer oil at a temperature of $75 \pm 5^\circ\text{C}$ in a specially designed insulating tank (see Fig. 3).



Fig. 3. Insulated tank arrester

2.5. Experimental Results

Table 2. Experimental Results

Test Voltage (kVrms)	Frequency Hz]	Duration [kV _{rms}]	I ₀ [mA _{rms}]
25,42	50	60	0,7 stable

CONCLUSIONS

- A leakage current of less than 1 mA is typical for well-insulated devices;
- There are no visual or acoustic discharges that confirm the integrity of the internal insulation;
- The arrester is fit for service if it operates stably under AC test voltage;
- It is essential to perform AC voltage testing on surge arresters before using them in high-voltage systems, especially those involving autotransformers;
- The test confirms that the arrester can withstand the same type of dielectric stress it will encounter during operation;
- It is recommended that regular dielectric testing be performed for preventive maintenance and asset management purposes.

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THE ROLE OF STANDARDIZATION IN THE FIELD ENERGY AND ENVIRONMENT

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ABSTRACT – IP28

Standardization in the field of energy and environment plays a crucial role in establishing common norms, principles and technologies that promote energy efficiency, reduce environmental impact, facilitate international trade and ensure public safety and health, contributing to a sustainable and balanced future.

Keywords: standardization, energy efficiency, environmental protection

1. INTRODUCTION

National standardization in the field of energy and environment, in recent years and currently, has focused on the adoption of all European standards as national standards, as well as on the activity of participating in the European standardization activity (where Romania has the status of permanent member with full rights) and international standardization (where Romania has the status of participating member).

2. CONSIDERATIONS REGARDING THE BENEFITS OF STANDARDIZATION IN THE FIELD OF ENERGY AND THE ENVIRONMENT

It is well known that specific standards in the field of energy and the environment offer a number of key benefits, including:

- **Energy efficiency:** the standards impose minimum requirements for the energy performance of products, buildings and processes, helping to reduce energy consumption and losses.
- **Environmental protection:** the standards set limits on pollutant emissions, manage waste and promote the use of renewable resources, contributing to better air and water quality.
- **Safety and health:** standards ensure that products and systems are safe to use, protecting consumers and workers from risks.
- **International trade:** common standards simplify trade by removing technical barriers, facilitating market access and ensuring global consistency.
- **Innovation:** standardization stimulates innovation, providing a clear framework for the development of new technologies and more sustainable solutions.
- **Consistency and trust:** by adopting accepted standards, a more predictable framework is created and public and investor confidence in sustainable practices is increased.

Concrete examples:

- Standards for solar panels and wind turbines (Fig. 1) ensure their performance and safety.
- Standards for energy labeling of household appliances inform consumers about the efficiency of products.
- Standards for energy and environmental management, such as ISO 14001, help companies manage and improve their environmental performance.



Fig. 8. Solar Panels and Wind Turbines

In essence, standardization provides a common language and a roadmap for the transition to a green economy and sustainable development.

Wind energy is confirmed as the cheapest energy obtained from renewable sources and the development of wind turbines is now promoted in many national programs for the introduction or expansion of renewable energy sources (Fig. 2).



Fig. 2. Renewable Energy Applications

The widespread use of renewable energy has the effect of eliminating dependence on fossil fuels, combating global warming and increasing living standards in developing countries. The Kyoto Protocol commits signatory states to reduce greenhouse gas emissions. This agreement has led to the adoption of national development policies. Climate change, marine ecology, biodiversity and economic growth based on the use of renewable energies will be the priorities of the coming period, knowing that in the next quarter of a century electricity production is expected to double, and renewable energy is expected to increase by 57%. The main objective is to maintain electricity at a low cost and at a high quality from wind turbines and other sources that do not emit carbon dioxide. Renewable energy sources (RES) protect the climate and are inexhaustible, wind energy, solar energy, hydropower, bioenergy.

The mission of standardization is to establish technical and security performance standards in the field of renewable sources and to establish certification schemes to establish the level of quality and to protect consumers and the environment.

At the international and european level, there are several standardization activities involving:

- achieving a European standard in the field of energy auditing;
- defining a harmonised EU measurement system to improve energy efficiency;
- development of European standards for certification schemes for heating and power plants and for the certification of management personnel in plants.

By definition, standards are a way of facilitating communication in the technical field, by introducing a degree of order and a language, which ensures the promotion of technology and public welfare across international borders. Standards establish conditions for quality, interoperability, health and safety for products, processes and services.

In order to develop renewable energy sources, CEI cooperates with ISO and regional standardization bodies. Regarding product standards, technical committees must continuously evaluate and improve existing standards and also develop new standards, which aim to reduce the negative impact on the environment throughout the entire life cycle.

CONCLUSIONS

Standardization substantially supports these new unconventional energy technologies to become competitive, by providing documentation and certification systems, by promoting international trade in high-quality products, and by supporting the transition from traditional energy system technologies to unconventional ones.

Users of existing and future standards are found within national and local government authorities, as well as testing bodies and industry in general.

As the wind turbine industry is already a mature industry, demand from interest groups and trade has grown, and this is reflected in the increased demand for standards.

Wind energy is confirmed as the cheapest energy obtained from renewable sources and the development of wind turbines is now promoted in many national programs for the introduction or expansion of renewable energy sources. National standardization in this field, in recent years and currently, has focused on adopting all European standards as national standards, as well as on participating in European standardization activity (where Romania has the status of permanent member with full rights) and international standardization (Romania has the status of participating member).

In this context, the use of renewable energy sources and the application of technologies that protect the environment represent considerable contributions to sustainable development that contribute to ensuring well-being and a superior quality of life for future generations.

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DEVELOPMENT OF A HIGH-GAIN CONVERTER FOR HYDROGEN, BATTERY AND GRID INTEGRATED ELECTRIC VEHICLES

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ABSTRACT

DC-DC power converters are essential parts of power electronics circuits. These converters play a vital role, especially when renewable energy sources (RESs), charging and discharging of the electric vehicles (EVs) and grid integration are the issue. For many types of photovoltaic (PV) arrays, hydrogen fuel cells (FCs), or battery packs on the EVs, the generated voltage is in direct current (DC) form, while the majority of the loads need to be fed by alternating current (AC) type voltages. On the other hand, the generated voltage level of these sources is not sufficient to be converted and used in grid, high voltage batteries in EVs or micro-grid systems. Therefore, DC-DC converters are used to enhance the voltage and make it ready for conversion to AC voltages if the load is in the state of AC loads.

This study presents a hydrogen–PV–battery-based bidirectional power converter to transfer power from the low-voltage fuel cell and EV battery to the high-voltage battery or AC voltage side and from the high-voltage to the low-voltage side using the same topology. The configuration includes the minimum number of semiconductor devices and passive elements such as inductors and capacitors, and presents features like minimum voltage and current stresses on key elements that guarantee the feasibility and longevity of the converters and these RES-type sources. The suggested topology presents a decreased current stress at the input side, where the converter is connected to the RES sources. This topic is essential to enhance the lifespan of the RESs and provide a longer lifetime for the overall system.

Keywords: Hydrogen powered electric vehicles, Bidirectional DC-DC converter, long-life and longevity, Grid to vehicle, Vehicle to grid

1. INTRODUCTION

Bidirectional DC-DC converters are capable of transferring power in DC form from the low-voltage side to the high-voltage side or vice versa [1]. By applying these types of converters in connection with the grid, the grid AC power can easily be converted to DC and then used for battery charging systems. These types of converters normally use fully bidirectional energy transfer semiconductor devices, including the new generation of metal-oxide field-effect transistors (MOSFETs) with body diodes. Thanks to this diode, the topology is designed to transfer current during the time intervals when the gate-source pins of the transistor do not receive a pulse-width modulation (PWM) signal, and the reverse energy transfer is performed. This energy conversion is essential for grid-to-vehicle (G2V) and vehicle-to-grid (V2G) applications of EVs in battery or fuel cell hydrogen-powered systems [2]. Different types of isolated [3] and non-isolated [4] bidirectional converters have been presented, especially in recent years, considering the widespread adoption of EV technology worldwide. While isolated converters are normally used for fast charging processes due to the use of transformers in the converter topology, non-isolated converters are widely used in lower-power-rate residential home EV chargers.

The main advantages and features of an acceptable converter topology include the use of the minimum number of active semiconductor devices and passive inductors and capacitors in the converter circuit. Since efficiency is the ultimate goal of energy transfer, using a smaller number of elements can guarantee lower dynamic and switching power losses in the components and therefore higher efficiency. On the other hand, the designed topology should benefit from controlled voltage and current stress levels to ensure a longer lifetime for the RES-based fuel cells, PV arrays, and batteries as input power sources, along with the converter circuit components. This can be achieved by generating voltages and currents with minimal ripple levels and without sudden or instantaneous overshoots or undershoots.

The suggested bidirectional circuit in this study includes a total of four transistors, two inductors, and two capacitors with a non-isolated and single-grounded topology that can boost or buck a 24/500 V DC input source to more than 500/24 V DC at 80 percent duty ratios of the switches. Both boost and buck operational modes are analyzed separately, and the results are presented. In the boost mode, only one of the transistors is switched, and two body diodes conduct in this state, resulting in minimum complexity in the control process and a desirable lifespan for the components. In the buck operational mode, a total of three transistors and one body diode conduct. The control process in the buck state is also simple, since two transistors receive the same PWM signal, while the third one receives the complementary signal, which can easily be generated by a NOT logic gate. The mathematical analysis for gain calculations and the corresponding simulation results are reported.

2. MATERIALS AND METHODS

Fig. 1a presents the suggested bidirectional power converter, which includes four transistors, two inductors, and two diodes, integrated with a low-voltage fuel cell, battery pack, or PV array and a high-voltage DC grid or EV battery pack. As the converter topology indicates, the proposed design offers a single-grounded configuration to simplify the control process. Also the suggested topology minimizes the number of components for higher efficiency.

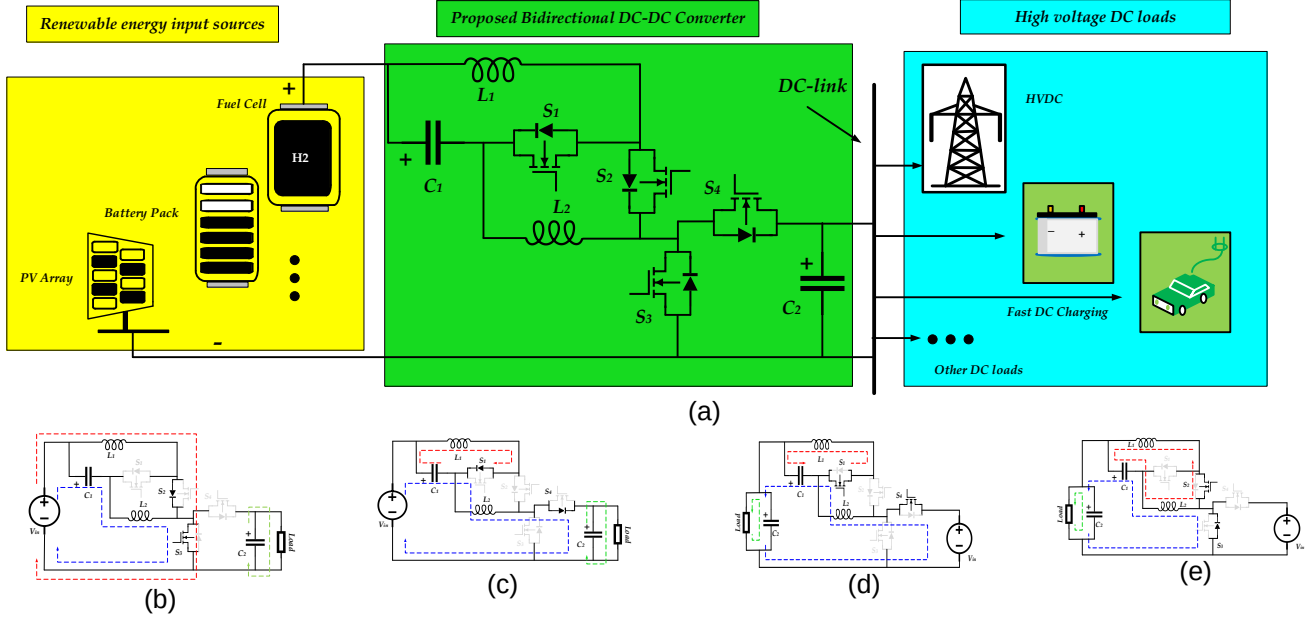


Fig. 1. (a) The proposed bidirectional converter, Buck operational mode, (b) for d and (c) $1-d$ time intervals, Boost operational mode, (b) for d and (c) $1-d$ time intervals.

Boost operational mode:

Fig. 1b shows the state of the converter during the time interval when switch S_3 is on. As can be seen, both inductors L_1 and L_2 start to charge through the input voltage source and receive positive voltages. Inductor L_1 is charged through a current loop that includes the input power source, inductor L_2 , the body diode of transistor S_2 , and the drain–source pins of transistor S_3 . At the same time, inductor L_2 is charged through the current conducted via the input power source, capacitor C_1 , and transistor S_3 . During this time interval, capacitor C_1 conducts a positive current and is being charged. Since switch S_4 does not receive a PWM signal, it remains off, and capacitor C_2 feeds the load. The following equations can be considered for this period in boost operational mode:

$$V_{L1} = L_1 \cdot \frac{di_{L1}}{dt} = V_{in} \quad (1)$$

$$V_{L2} = L_2 \cdot \frac{di_{L2}}{dt} = V_{in} - V_{C1} \quad (2)$$

$$V_{C2} = V_O \quad (3)$$

The state of the converter for the net time interval, is shown in Fig. 1c. Fig. shows that the inductor L_1 and capacitor C_1 are discharged by forming a current loop through the body diode of the switch S_1 . Inductor L_2 discharges the stored energy on the capacitor C_2 through the body diode of the transistor S_4 . The related equations can be summarized as following:

$$V_{L1} - V_{C1} = 0 \rightarrow V_{L1} = V_{C1} \quad (4)$$

$$V_{in} = V_{C1} + V_{L2} + V_{C2} \rightarrow V_{L2} = V_{in} - V_{C1} - V_O \quad (5)$$

According to the voltage balance rule for the inductor in a switching circuit, the average voltage of an inductor for a time period is equal to zero. Then:

$$V_{L1}D + V_{L1}(1-D) = 0 \rightarrow V_{in} \cdot D + V_{C1} \cdot (1-D) = 0 \rightarrow V_{C1} = V_{in} \cdot \frac{D}{1-D} \quad (6)$$

$$V_{L2}D + V_{L2}(1-D) = 0 \rightarrow (V_{in} - V_{C1})D + (V_{in} - V_{C1} - V_O)(1-D) = 0 \rightarrow V_O = \frac{V_{in}}{(1-D)^2} \rightarrow G_{Boost} = \frac{V_O}{V_{in}} = \frac{V_{in}}{(1-D)^2} \quad (7)$$

Buck operational mode:

Figures 1d and 1e present the state of the proposed circuit for the time intervals when transistors S_1 and S_4 are switched simultaneously, then turned off, and transistor S_2 is switched. The first state is demonstrated with d , and the next time interval is shown by $1-d$, respectively.

The following equations for inductors and capacitors voltages can be written for d time interval:

$$V_{L1} + V_{C1} = 0 \rightarrow V_{L1} = -V_{C1} \quad (8)$$

$$V_{in} = V_{L2} + V_{C1} + V_O \rightarrow V_{L2} = V_{in} - V_{C1} - V_O \quad (9)$$

$$V_{in} = V_{L1} + V_{L2} + V_O \quad (10)$$

These equations indicate that while inductor L1 is being discharged in this time interval by getting a negative voltage through the capacitor C1, inductor L2 starts to be charged through the high voltage input source, transistor S4 and capacitor C1. In this time duration, the output capacitor is connected to the input voltage source and is charged. For the next time interval, the following equations can be written according Fig. 1e:

$$V_{L1} + V_{C1} - V_{L2} = 0 \rightarrow V_{L1} = V_{L2} - V_{C1} \quad (11)$$

$$V_{L2} - V_{C1} + V_O = 0 \rightarrow V_{L2} = V_{C1} - V_O \quad (12)$$

By applying the voltage balance rule for both inductors respectively:

$$V_{L1}D + V_{L1}(1-D) = 0 \rightarrow (-V_{C1}) \cdot D + (V_{L2} - V_{C1}) \cdot (1-D) = 0 \rightarrow V_{C1} = V_{L2} \cdot (1-D) \quad (13)$$

$$V_{L2}D + V_{L2}(1-D) = 0 \rightarrow (V_{in} - V_{C1} - V_O)D + (V_{C1} - V_O)(1-D) = 0 \rightarrow D \cdot V_{in} + V_{C1}(1-2D) = V_O \quad (14)$$

Using the recent equations and doing some simplifications, the voltage on the capacitor Co can be calculated as following:

$$V_{C2} = V_O = V_{in} \cdot \frac{D^2-D+1}{2D^2-4D+3} \rightarrow G_{Buck} = \frac{V_O}{V_{in}} = \frac{D^2-D+1}{2D^2-4D+3} \quad (15)$$

Fig.s 2a and 2b compare the voltage gain for the proposed and conventional buck and boost converters. The boost state is shown in Fig. 4a. This figure clearly indicates that the proposed topology has very good performance; for example, for $D=0.8$, this converter can theoretically boost the input voltage up to 25 times, while the classic converter can increase the input source only up to 5 times. For the buck state, the proposed converter performs better for duty ratios greater than 0.5.

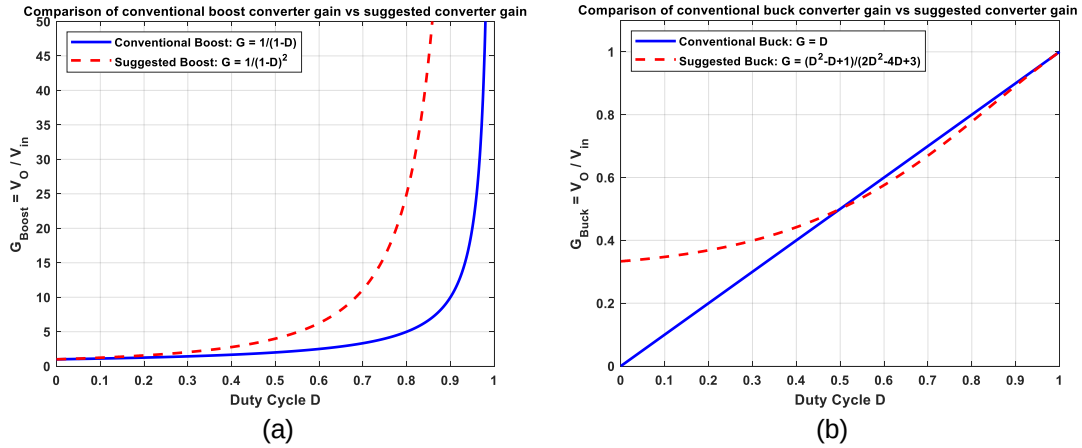


Fig. 2. Gain comparison for the suggested and conventional converters in (a) Boost and (b) Buck operational modes

3. RESULTS AND DISCUSSION

The suggested topology has been tested using the MATLAB program, and different voltage and current waveforms have been measured. To confirm the theoretical analysis, in the first stage, the state of the semiconductor devices should be observed to determine the condition of the switches at different time intervals. For the boost operational mode, based on the mathematical analysis, during the time intervals when switch S3 is in the on state, switch S1 is turned off, and the body diode of transistor S2 conducts. Figures 3a and 3b present the voltage waveforms for this operating mode under transient and steady-state conditions. According to the results, while switch S3 is turned on, a positive voltage drop appears across the drain–source pins of switch S1, causing it to turn off, and switch S2 conducts. Since this switch does not receive any PWM signal, it means that its body diode conducts.

For the buck state, as shown in Figures 4a and 4b for the transient and steady-state conditions, as estimated, during the time interval when switches S2 and S3 are turned off, switch S1 conducts. When the body diode of transistor S3 is activated and the gate–source pins of transistor S2 receive a positive PWM signal, transistor S1 is turned off. All these results indicate that the theoretical estimations and analytical calculations have been correctly considered.

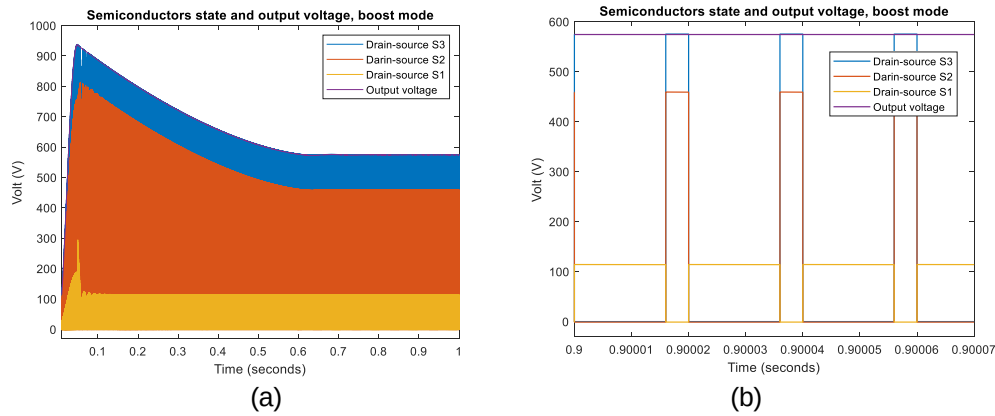


Fig. 3. Semiconductors and output voltage for boost operational mode under (a) transition and (b) steady state mode.

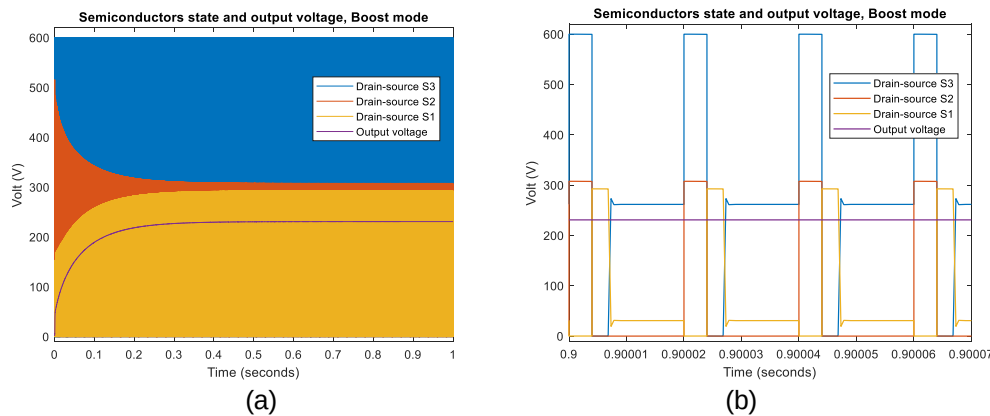


Fig. 4. Semiconductors and output voltage for buck operational mode under (a) transition and (b) steady state mode.

CONCLUSIONS

A simple and practical bidirectional DC-DC power converter is designed and introduced in this study. It utilizes four semiconductor switches with a simple switching pattern, while providing high voltage gains in both buck and boost operational modes. For RESs such as fuel cells or batteries, since the voltage level is normally lower than the required values, this converter can easily boost the generated voltage and prepare the system for integration into high-voltage battery packs or DC grids applications. Conversely, a high-voltage source can be connected to this topology to achieve a high-current and low-voltage output for G2V charging applications or other similar utilities. The results confirm the mathematical and theoretical analyses.

The proposed topology benefits from using a single circuit configuration instead of two separate buck and boost circuits, making it both cost-effective and feasible.

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ADAPTIVE SMALL SIGNAL-BASED ANALYSIS OF A BIDIRECTIONAL POWER CONVERTER FOR HYBRID HYDROGEN ELECTRIC VEHICLES

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ABSTRACT

For hydrogen-powered (HPVs) or electric vehicles (EVs), a central DC-DC power converter is used to transfer energy from the hydrogen tank or battery pack to various sections such as the heating and cooling systems, acoustic circuits, lighting, wipers, and other components depending on the required DC level. In addition to these elements, seat heating systems are also widely used in the automotive industry. Therefore, a stable and ripple-free DC voltage is essential for these systems to provide a pure DC output with minimal variations over a wide range of input DC voltages. The proposed design in this study provides accurate small-signal, state-space matrix calculations and a sixth-order transfer function for the electromagnetic interference (EMC) filter elements integrated with an industrial DC-DC buck–boost converter for seat heater system in EVs. Another EMC filter is implemented at the output side of this converter. Since the mentioned buck–boost converter supplies fundamental components in the system such as voltage regulators, the microcontroller unit (MCU), occupancy sensors, and switching circuits, the application of EMC filters is crucial. The laboratory test bench, and experimental results are presented, demonstrating that the designed and manufactured system operates properly. All semiconductor devices have been selected in accordance with the Automotive Electronics Council – Qualification Specification (AEC-Q)100 and AEC-Q200 standards for automotive applications.

Keywords: Hydrogen Powered Vehicles, Electric Vehicles, Seat Heater, State Space Vector, Small Signal Analysis, DC-DC Converters

1. INTRODUCTION

Longevity of fuel cells in HPVs and battery packs in EVs is crucial for extending the lifespan of these systems. Therefore, providing voltage and current waveforms with minimal ripples can ensure higher reliability and longer life for these energy sources and circuit components. For that, the application of an EMC filter on both input and output sides of the converter is crucial [1]. These filters should also operate at frequencies lower than the DC–DC converter's switching frequency, known as the corner frequency, to ensure undamped voltage and current signals for the heater system. These filters are generally formed from passive elements such as inductors and capacitors and generate a corner frequency that inversely depends on the values of these elements [2]. This means that for larger inductor or capacitor values, the corner frequency will be lower, and vice versa. The most important requirement for an undamped operational mode is that the generated corner frequency should be much smaller than the switching frequency of the driving circuit in the power electronics–based converter topology. Otherwise, the EMC filter will operate incorrectly and impose undesired damping at the input and output sides of the converter, decreasing the quality and performance of the designed system. These filters form the input and output sides of the DC–DC converter. This converter is a vital power electronics–based device used to regulate a variable battery voltage [3]. In the automotive industry, different input battery systems are used. Nowadays, voltages from 9 to 32 VDC are required by automotive companies, and all converters must be capable of operating across this wide input voltage range. The reason is that the designed board can be used in any vehicle and will automatically detect the input voltage, regulating it to the required output voltage, which is normally 24 VDC and, in some cases, 12 VDC. According to the input and required output voltages, a buck–boost type converter should be used. This converter is capable of increasing or decreasing the input voltage when the battery voltage is lower or higher than the output voltage, respectively [4]. This study presents an optimal design for seat heater systems, presenting a sixth-order small-signal-based state-space vector transfer function for input and output EMC filter design for the heating system by considering all inductors' internal resistance to model an accurate calculation to fix the output voltage at the input and output of the MPQ8875A converter and controller board. Calculations show that these filters generate a non-minimum phase system by presenting a new group of zeros and poles in the right half-plane, which is simply compensated by the mentioned controller that is a product of MPS company.

2. MATERIALS AND METHODS

The proposed Control Unit is a product designed to manage and control various functions in passenger seats. It monitors features such as heating, ventilation, seat belts, and seat occupancy. Fig. 1 shows the block diagram of the hydrogen-battery integrated buck boost power converter with control unit of the system. The system operates within a 9–32 V input voltage range. In commercial vehicles, the product is powered by

a 24 V battery, and in passenger cars, by a 12 V battery. For the product to operate that is, to provide the necessary current to the heating pads, someone must be seated that means the occupancy sensor should detect the presence of a passenger, and the user should press the button. When both conditions are met, the heating function begins. The three-stage heating is achieved by controlling the current. However, in these three stages, only the duration during which the switch is in the on-state is adjusted; there is no current-limiting circuit.

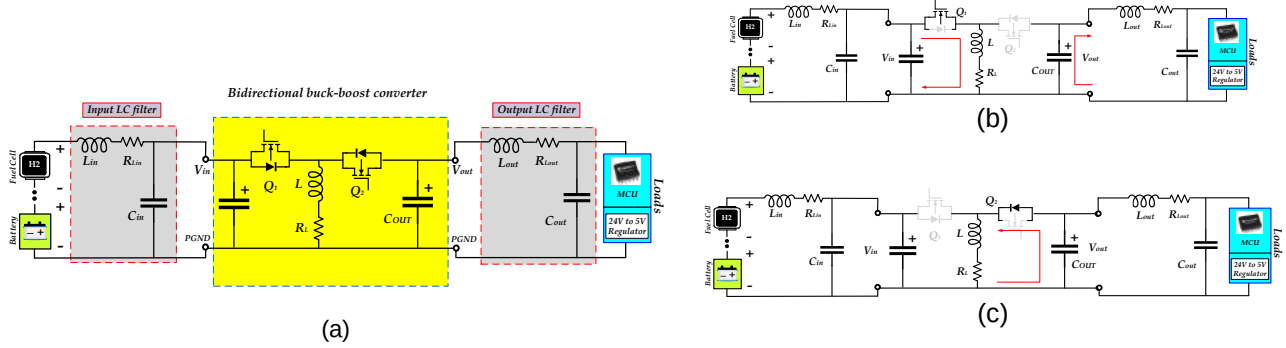


Fig 1. Integration of the hydrogen-battery system with seat heater circuit via 6th order EMC filters

The input and output EMC filter structure of the DC-DC converter used is shown in Fig. 1. An LC filter structure has been added to both the input and output of the converter, increasing its immunity to EMC. The schematic design of the used DC-DC converter is shown in this Figure. For the proposed EMC-filtered circuit topology, considering an equivalent capacitor and inductor at the input side of the converter and the same elements at the output of the DC-DC converter, and regarding the circuit topology of the used DC-DC converter, which includes one capacitor and one inductor, the system will have a total of three independent inductors and three independent capacitors, meaning it will represent a sixth-order system. The state of the converter for the times that transistor Q_1 conducts (d time interval) and internal diode of Q_2 conducts ($(1-d)$ time interval) is presented in Figures 1b and 21c respectively. This system will generate 6×6 order matrices for evaluating the current derivatives of the inductors and the voltage derivatives of the capacitors. It should be noted that the state of the system in a switching circuit must be evaluated over two different time intervals, during which the switch in the converter is in the on and off modes separately.

These time durations are directly related to the duty cycle of the pulse that drives the switch. For the turn-on time, the duty ratio is equal to d , and for the turn-off time, it is equal to $1 - d$. For the d time interval, the voltage derivative equations for the capacitors and the current derivative equations for the inductors can be expressed through the following equations:

$$V_{in} = L_{in} \frac{di_{L_{in}}}{dt} + R_{L_{in}} \cdot i_{L_{in}} + V_{C_{in}} \rightarrow \frac{di_{L_{in}}}{dt} = \frac{V_{in} - V_{C_{in}} - R_{L_{in}} \cdot i_{L_{in}}}{L_{in}} \quad (1)$$

$$V_{C_{in}} = L \frac{di_L}{dt} + R_{L_{in}} \cdot i_L \rightarrow \frac{di_L}{dt} = \frac{V_{C_{in}} - R_{L_{in}} \cdot i_L}{L} \quad (2)$$

$$V_C = L_{out} \cdot \frac{di_{L_{out}}}{dt} + R_{L_{out}} \cdot i_{L_{out}} + V_{out} \rightarrow \frac{di_{L_{out}}}{dt} = \frac{V_C - R_{L_{out}} \cdot i_{L_{out}} - V_{out}}{L_{out}} \quad (3)$$

$$i_{L_{in}} = C_{in} \frac{dv_{C_{in}}}{dt} + i_L \rightarrow \frac{dv_{C_{in}}}{dt} = \frac{i_{L_{in}} - i_L}{C_{in}} \quad (4)$$

$$-C \frac{dv_C}{dt} = i_{L_{out}} \rightarrow \frac{dv_C}{dt} = -\frac{i_{L_{out}}}{C} \quad (5)$$

$$i_{L_{out}} = C_{out} \frac{dv_{C_{out}}}{dt} + \frac{V_{out}}{R} \rightarrow \frac{dv_{C_{out}}}{dt} = \frac{i_{L_{out}} - \frac{V_{out}}{R}}{C_{out}} = \frac{i_{L_{out}}}{C_{out}} - \frac{V_{out}}{RC_{out}} \quad (6)$$

In the presented equations, V_{in} represents the battery pack voltage that is normally equal to 12VDC or 24 VDC. L_{in} indicates the input side filter inductor and to present an accurate calculations, $R_{L_{in}}$ shows the internal resistance of L_{in} and $i_{L_{in}}$ presents the current for this inductor. i_L , $\frac{di_L}{dt}$, and $R_{L_{in}}$ show the current of the inductor in the body of DC-DC converter, its derivation and its internal resistor. For the output side filter inductor, $i_{L_{out}}$, $\frac{di_{L_{out}}}{dt}$, and $R_{L_{out}}$ are introduced to show the same parameters respectively.

For the input side capacitor filter, $V_{C_{in}}$, $\frac{dv_{C_{in}}}{dt}$ are presented and show the voltage on the filter capacitor and its derivation. The internal resistance of the filter and body capacitors have been ignored since they have a very small and ignorable values. V_C and $\frac{dv_C}{dt}$ shows the voltage on capacitor inside the DC-DC converter and its derivation while C , v_C and $\frac{dv_C}{dt}$ stands for output filter capacitor, its voltage and its voltage derivations respectively. Similarly, C_{out} , V_{out} , and $\frac{dv_{C_{out}}}{dt}$ indicate the output filter capacitor, its voltage and voltage derivation. R models the seat-heater internal resistor. It will have a variable value since the seat-heater will

be capable to work under different levels of heat. R is operating with three different values of 3, 4 and 4.5 A under a fixed 24VDC voltage supplied by the DC-DC converter. For the $1-d$ time interval, the following equations can be written:

$$V_{in} = L_{in} \frac{di_{Lin}}{dt} + R_{Lin} \cdot i_{Lin} + V_{Cin} \rightarrow \frac{di_{Lin}}{dt} = \frac{V_{in} - V_{Cin} - R_{Lin} \cdot i_{Lin}}{L_{in}} \quad (7)$$

$$L \frac{di_L}{dt} + R_{Lin} \cdot i_L = V_C \rightarrow \frac{di_L}{dt} = \frac{V_C - R_{Lin} \cdot i_L}{L} \quad (8)$$

$$V_C = L_{out} \frac{di_{Lout}}{dt} + R_{Lout} \cdot i_{Lout} + V_{out} \rightarrow \frac{di_{Lout}}{dt} = \frac{V_C - V_{out} - R_{Lout} \cdot i_{Lout}}{L_{out}} \quad (9)$$

$$i_{Lin} = C_{in} \frac{dv_{Cin}}{dt} \rightarrow \frac{dv_{Cin}}{dt} = \frac{i_{Lin}}{C_{in}} \quad (10)$$

$$-C \frac{dv_C}{dt} = i_L + i_{Lout} \rightarrow \frac{dv_C}{dt} = -\frac{i_L}{C} - \frac{i_{Lout}}{C} \quad (11)$$

$$i_{Lout} = C_{out} \frac{dv_{Cout}}{dt} + \frac{V_{out}}{R} \rightarrow \frac{dv_{Cout}}{dt} = \frac{i_{Lout} - \frac{V_{out}}{R}}{C_{out}} = \frac{i_{Lout}}{C_{out}} - \frac{V_{out}}{R \cdot C_{out}}$$

(The relation between the output voltage and duty ratio can be presented by $\widehat{V_O}(S) = C[SI - A]^{-1}[A_1 - A_2]X \rightarrow \frac{\widehat{V_O}(S)}{\widehat{d}(S)} = C[SI - A]^{-1}[(A_1 - A_2)X]$. A_1 and A_2 indicate the state matrix for d and $1-d$ time intervals, A is equal to $A_1 d + A_2(1-d)$ and C represents the output coefficients matrix. By simplifying the obtained matrices to calculate the $\frac{\widehat{V_O}(S)}{\widehat{d}(S)}$, below steps can be taken:

$$\frac{\widehat{V_O}(S)}{\widehat{d}(S)} = [0 \ 0 \ 0 \ 0 \ 0 \ 1] \left[\begin{pmatrix} S + \frac{R_{Lin}}{L_{in}} & 0 & 0 & \frac{1}{L_{in}} & 0 & 0 \\ 0 & S + \frac{R_{Lin}d}{L} + \frac{R_{Lin}(1-d)}{L} & 0 & -\frac{d}{L} & \frac{d-1}{L} & 0 \\ 0 & 0 & S + \frac{R_{Lout}}{L_{out}} & 0 & -\frac{1}{L_{out}} & \frac{1}{L_{out}} \\ -\frac{1}{C_{in}} & \frac{d}{C_{in}} & 0 & S & 0 & 0 \\ 0 & \frac{1-d}{C} & \frac{1}{C} & 0 & S & 0 \\ 0 & 0 & -\frac{1}{C_{out}} & 0 & 0 & S + \frac{1}{R \cdot C_{out}} \end{pmatrix}^{-1} \times \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{1}{C_{in}} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{C} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_{Lin} \\ i_L \\ i_{Lout} \\ v_{Cin} \\ v_C \\ v_{Cout} \end{bmatrix} \quad (13)$$

Using Matlab program, the transfer function for this system can be obtained as below equation:

$$\frac{\widehat{V_O}(S)}{\widehat{d}(S)} = \frac{1.15e^{17}S^3 + 1.26e^{17}S^2 + 2.87e^{27}S + 4.10e^{34}}{S^6 + 1439S^5 + 1.03e^{13}S^4 + 16S^3 + 2.53e^{23}S^2 + 3.59e^{26}S + 6.84e^{32}} \quad (14)$$

The plot for zero-poles of the system is shown in Fig. 2a. The bode results presented in Fig. 2b illustrate that an attenuation for gain can be occurred and around 90 degrees for phase margin can be obtained. The Nyquist diagram and its details, used to confirm the results in Figures 2a and 2b, are presented in Fig. 2c. The mentioned system will reach to -270 degrees for high frequencies. When a controller designed and eliminated the poles of RHP, the gain margin automatically will be enhanced and the phase graphics will reach to -90 degrees for high frequencies.

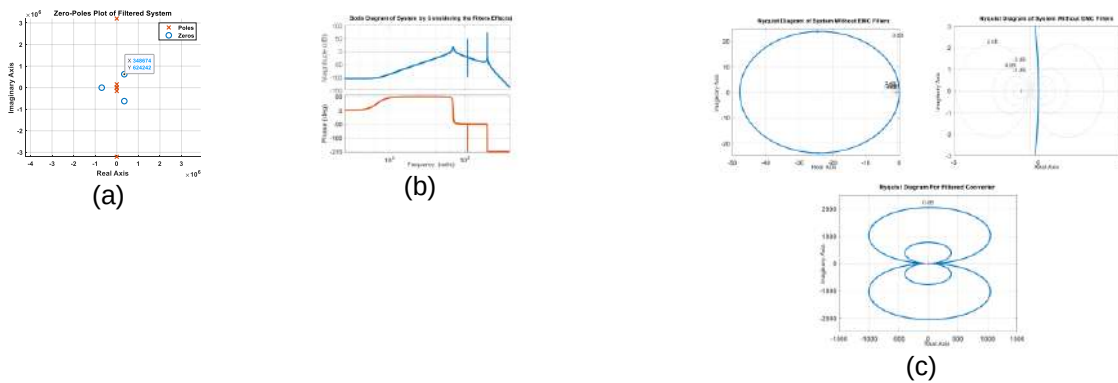


Fig. 2. (a): Zero-pole plot and (b): phase-gain margin for DC-link filters-based topology and its(c) Nyquist plot

3. RESULTS AND DISCUSSION

The integration of the design with the test setup in a laboratory environment is shown in Fig. 3a. The designed PCB was tested under three different input DC voltages that simulate the battery voltages. Since a buck-boost type power converter is tested in the prototype circuit, both lower and higher voltages than the desired 24 V DC output are considered. The tested input DC voltages are 10 V DC, 16 V DC, and 28 V DC, and the performance of the converter in stabilizing at 24 V DC, as well as the designed EMC filter's ability to

maintain undamped input and output voltages, are evaluated. Fig. 3b presents the output voltage of the PCB under 10V, 16V and 24V of input respectively. Channel 1 shows the input voltage, and Channel 2 demonstrates the generated voltage of the proposed DC–DC converter. As can be seen, despite the large difference between the input and output voltages, the proposed circuit successfully generates an undamped 24 V DC output voltage.

The results of the performance analysis of the designed EMC filter for different input voltages, on both the input and output sides, are presented in Fig. 3c. This Figure shows the state of the input and output voltages under a 10V, 16V and 28V of battery voltage respectively. As can be seen, for all battery voltages, undamped input and output voltages are maintained for the proposed DC–DC converter thanks to the application of the designed EMC filters. These figures confirm that the generated corner frequencies on both the input and output sides are much smaller than the switching frequency of the converter.

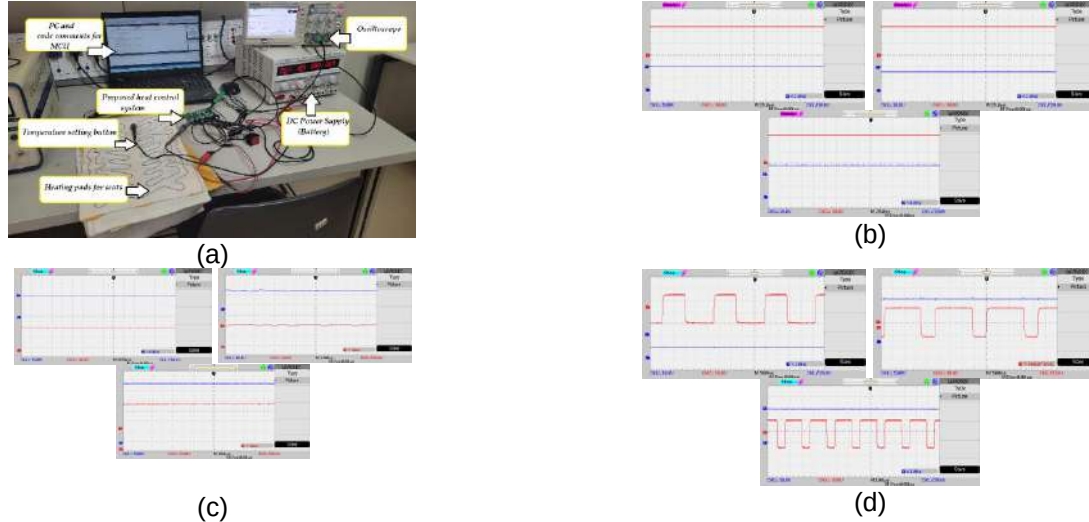


Fig 3. (a) laboratory work-bench, (b) Generated a fixed 24 VDC output voltage for 10VDC, 16VDC and 28VDC as the input battery DC voltages respectively. (c) The quality of the input and output DC voltages and performance analysis for the designed EMC filters for 10VDC, 16VDC and 28VDC as the input battery DC voltages respectively. (d) The generated rectangular switching voltages for the inductor of the DC-DC buck boost converter under 10VDC, 18VDC and 30VDC as the input battery DC voltages respectively.

The internal switching frequency for the mentioned converter is set at 460 kHz. Fig. 3d shows the voltage across the inductor in the DC–DC converter. As is known, rectangular positive and negative voltages are observed across the inductor in switching circuits. Subfigures in 3d respectively show the state of the inductor voltage for 10 V DC, 18 V DC, and 30 V DC input battery voltages. These figures confirm that the inductor experiences both negative and positive voltages, and the peak-to-peak voltage equals the output voltage, 24 V DC. Another observation is that, as the input battery voltage increases, the duty ratio required to generate the output voltage also increases.

CONCLUSIONS

A novel and practical seat heater circuit is presented in this study for application in hydrogen powered or electric vehicles in automotive industry. Since it is important to design a system for use in the real-world automotive sector, all components especially the semiconductor devices have been selected according to the Automotive Electronics Council (AEC) qualification specifications AEC-Q100 and AEC-Q200 standards. The design introduces a sixth-order accurate state-space matrix analysis for the input and output EMC filters, taking into account the internal resistance of the passive inductors. The presented model shows that the generated corner frequencies for both input and output EMC filters are much smaller than the switching frequency of the DC–DC converter, which guarantees undamped voltages at the converter's input and output. This results in pure DC voltage signals and low ripple currents on the PCB, enhancing the reliability of the designed board and increasing the longevity and lifespan of the overall system.

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THE RELATIONSHIP BETWEEN NATIONAL POLICIES AND THERMODYNAMICS: A THEORETICAL AND APPLIED STUDY ON ENERGY, EXERGY, ENTROPY, AND POLITICAL SYSTEM DYNAMICS

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ABSTRACT

This study analyzes the sustainability and institutional dynamics of modern political systems by examining the fundamental concepts of thermodynamics energy, entropy, equilibrium, open systems, and irreversibility from the perspective of social sciences and political science, and by exploring their structural analogies with national policies. Modern political systems exhibit significant parallels with thermodynamic systems in terms of energy flow, information exchange, resource management, and the preservation of institutional order. Within this framework, thermodynamic principles are interpreted along the axes of energy inputs, available energy (exergy), and disorder (entropy) in political systems.

Keywords: Political Systems, Political Science, Democratic Regression, Energy, Exergy, Entropy

1. INTRODUCTION

Political science has historically focused on the analysis of **power, authority, institutions, governance, decision-making processes, and social interactions**. However, the complex nature of contemporary political systems has necessitated conceptual support from disciplines such as **physics, biology, systems theory, and information science**. In particular, within the contexts of **system continuity, equilibrium-seeking behavior, and crisis management**, thermodynamic principles offer more than a mere metaphor in the social sciences they present a **potential analytical framework**.

Thermodynamics is the science that studies **energy transformations and processes through which systems reach equilibrium**. Similarly, political systems are sustained by continuous inflows of **energy** (resources, information, motivation), experience the accumulation of **entropy** (disorder, inefficiency), and engage in an ongoing search for **dynamic balance**. **Exergy**, in this context, represents the *maximum potential efficiency* that can be achieved in the utilization of available political or institutional energy. While **energy** expresses the *quantitative dimension* of political capacity, **exergy** reflects its *qualitative dimension* the degree to which resources can be effectively converted into outcomes. **Entropy**, on the other hand, represents the *deficiencies and negative interactions* within and between the internal and external structures of the system. Therefore, the **sustainability of a state**, much like that of a thermodynamic system, depends on the **efficient management of energy flows** and the **control of entropy** within its political and institutional framework [1,2].

The significance of energy as a fundamental component of economic growth and as a cornerstone in strategies aimed at improving human well-being is well established. In physical terms, energy is defined as the capacity of a system to perform work. However, this definition captures only its thermophysical essence. From a broader socio-political perspective particularly within the framework of energy efficiency and governance capacity energy may also be interpreted as the enabling medium of functionality, symbolically comparable to money [3] or even cash [4,5]. Within political systems, this analogy highlights that the availability and management of energy-like resources determine the operational and developmental potential of the state. Wall and Gong [6] traced the historical evolution of the exergy concept, while Çengel [13,14] expanded its interpretation into daily human experience. He noted that Exergy can be viewed as the opportunities that we have, and exergy destruction as the opportunities wasted. The exergy of a person in daily life can be considered the best performance that a person can achieve under specific conditions. The difference between a person's exergy and their actual performance represents the irreversibility or exergy destruction. In this study, an interdisciplinary analysis will be conducted by considering the concepts of energy and entropy along with these politically determinant parameters, using Germany, Turkey, and China as case examples. Within this framework, energy and exergy efficiency, together with entropy management, are treated as critical indicators for sustainable governance and policy formulation.

2. MATERIAL- METHODS

The Thermodynamic Model of Political Systems (TMPS) offers a novel theoretical framework to analyze governance from a systemic and energetic perspective. By redefining energy, exergy, and entropy in political terms, the model provides analytical tools for assessing sustainability, adaptability, and institutional resilience [7,8].

2.1. Theoretical Framework

Thermodynamics and System Theory

Thermodynamics explains how systems exchange energy and evolve toward equilibrium or disorder [9]. When applied to social sciences, this framework supports the understanding of political structures as non-equilibrium open systems that rely on continuous inflows of information and legitimacy to maintain order [10]. The Second Law of Thermodynamics states that entropy tends to increase in isolated systems. However, open systems like political entities can sustain low entropy states through external energy inputs and adaptive restructuring [11]. Thus, political systems must balance energy acquisition, transformation, and dissipation to avoid systemic stagnation.

Conceptual Variables

➤ **Energy (E):** Aggregate political and socioeconomic capacity (e.g., GDP, public trust, institutional legitimacy).

➤ **Exergy (Ex):** Effective, usable political energy that contributes to decision-making and reform processes.

➤ **Entropy (S):** A measure of institutional inefficiency, corruption, polarization, and information distortion.

In TMPS, high-exergy systems demonstrate efficient governance and innovation, whereas high-entropy systems experience rigidity and democratic regression.

Table 1. Thermodynamic variable and Political analogue

Thermodynamic Variable	Political Analogue	Conceptual Meaning
Energy (E)	Total political-economic capacity	Aggregate societal resources (economic output, institutional strength)
Exergy (Ex)	Usable political capacity	Efficiency of transforming resources into effective policy outcomes
Entropy (S)	Institutional disorder	Loss of coherence via corruption, distrust, or polarization

2.2. The Thermodynamic Model of Political Systems (TMPS)

Model Definition

The sustainability of a political system is possible only when energy inputs exceed entropy production. The following equation metaphorically summarizes this condition:

System Equilibrium = Energy Input (Economy + Knowledge + Societal Trust) – Entropy (Corruption + Uncertainty + Repression) (1)

When system equilibrium is positive, the state's capacity for reform increases; when it is negative, the system enters a cycle of collapse, polarization, or crisis.

The model conceptualizes political systems as open systems in which the energy balance of inputs and outputs determines systemic stability and can be stated as below formula [9,12]:

$$E_{in} - E_{out} = \Delta E_{sys} \quad (2)$$

where E_{in} represents external inflows (economic resources, legitimacy, social engagement), E_{out} refers to policy outcomes and administrative outputs, and ΔE_{sys} signifies internal energy change, or political transformation capacity. However, the Model conceptualizes political systems as open systems in which the exergy balance between inputs and outputs determines the efficiency and usability of converting systemic resources into functional governance outputs, and it is defined by the following formula [12];

Exergy input - Exergy output - Exergy consumption = Exergy accumulation

$$Ex_{in} - Ex_{out} - Ex_{con} = \Delta E_{sys} \quad (3)$$

where Ex_{in} represents external exergy inflows (Efficiency of transforming resources into effective policy inputs), Ex_{out} refers to Efficiency of transforming resources into effective policy outcomes, Ex_{con} consumption of exergy and ΔE_{sys} signifies internal exergy change, or political transformation capacity

Entropy, which is a measure of systemic disorder, institutional inefficiency, corruption, polarization, or loss of coherence, is calculated for a steady-state, steady-flow process as follows [13,14];

$$S_{in} - S_{out} + S_{gen} = 0 \quad (4)$$

where S_{in} represents external inflows (disorder, institutional inefficiency, corruption, polarization, or loss of coherence), S_{out} refers to disorder outcomes and corruption outputs, and S_{gen} signifies generation of disorder, institutional inefficiency, corruption, polarization.

Normalization Procedure

Each variable X_i was normalized using min–max scaling to eliminate unit inconsistencies[26]:

$$X_{norm,i} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (5)$$

This approach ensures that “0” corresponds to the lowest global value observed (maximum entropy) and “1” corresponds to the highest efficiency or order.

2.3 Construction of Thermodynamic Variables

(1) Energy (E)

The composite index “E” used in this study integrates economic capacity, human development, and educational indicators into a single normalized measure. Represents total societal resource capacity and the index is defined as follows:

$$E = \frac{1}{3}(GDP_{norm} + HDI_{norm} + Education_{norm}) \quad (6)$$

A composite indicator capturing economic, human, and knowledge-based energy inputs; GDP_{norm} denotes the normalized (0–1 scaled) value of Gross Domestic Product per capita. Normalization eliminates the influence of absolute magnitude differences across countries and enhances cross-national comparability [15,16]. HDI_{norm} represents the normalized Human Development Index, which incorporates life expectancy, health, education, and living standards. It reflects the broader social and developmental environment of each country [17,18]. $Education_{norm}$ corresponds to the normalized education indicator derived from expected years of schooling, mean years of schooling, or enrollment-based metrics. It provides a quantitative measure of human capital formation [19,20].

All three indicators are assigned equal weights (1/3) to avoid overweighting any single dimension. Equal weighting is consistent with the methodology used in prominent composite indices, including the Human Development Index [17] and the OECD Better Life Index [21]. This approach supports the development of a balanced and multidimensional measure of national development [22].

Higher values of “E” indicate stronger combined performance in economic capability, human development, and educational advancement. Consequently, the composite index functions as a robust proxy for assessing a country’s sustainable development potential and institutional resilience [23,24].

(2) Exergy (Ex)

Represents effective political work capacity:

$$Ex = \frac{1}{3}(GovEff_{norm} + PolicyResp_{norm} + InnovEff_{norm}) \quad (7)$$

(3) Entropy (S)

Represents systemic disorder and institutional inefficiency:

$$S = 1 - \frac{1}{3}(CPI_{norm} + PolStab_{norm} + Freedom_{norm}) \quad (8)$$

3. RESULT AND DISCUSSION

The concepts of energy, exergy, and entropy provide powerful tools for analyzing political systems from a social sciences perspective. These concepts offer not only a means to understand physical systems but also a metaphorical and analytical framework to explain complex political and institutional structures. Modern states can strengthen political decision-making processes, enhance crisis management, and maintain social stability by optimizing internal and external energy flows.

Within this context, three countries—Germany, Turkey, and China—will be comparatively examined using normalized data from 2022

Table 2. Illustrative Example (2022, Normalized Data),

Country	E	Ex	S	EER	SI	TGC
Germany	0.88	0.77	0.24	0.88	0.24	0.71
Türkiye	0.64	0.45	0.51	0.70	0.51	0.46
China	0.73	0.49	0.60	0.67	0.60	0.42

These preliminary results demonstrate the model’s discriminative capacity: systems with higher exergy efficiency and lower entropy (Germany) achieve superior TGC scores, indicating sustainable systemic equilibrium.

3.1. Germany: High Energy Efficiency and Institutional Negentropy

Germany represents a political system characterized by high energy transformation efficiency from a thermodynamic perspective. Its robust institutional framework, adherence to the rule of law, transparent governance, and knowledge-based decision-making mechanisms collectively constrain systemic entropy production. The country’s energy resources are strongly anchored in technology and knowledge. Furthermore, the quality of the education system, substantial investments in research and development, and

sustainable energy policies contribute to maintaining dynamic equilibrium. Potential sources of entropy include demographic aging, immigrant integration challenges, and the economic costs associated with energy transition. Nevertheless, through ongoing institutional reforms and active civil society participation, Germany is able to maintain entropy at manageable levels.

3.2. Turkey: High Energy Potential and Rising Entropy Risk

Turkey represents a political system with substantial energy potential, reflected in its young population, strategic geographical location, regional influence capacity, and economic diversity. Nevertheless, the country occasionally experiences elevated levels of political entropy. Factors such as social polarization, institutional weakening, economic instability, and limitations in information circulation reduce the efficiency of energy transformation within the system. From a thermodynamic perspective, Turkey can be characterized as a system with high energy potential but limited entropy control.

polarization, the performance of democratic mechanisms, and corruption have the potential to increase entropy, thereby negatively impacting the stability of the political system.

3.3. China: Controlled Open System and Entropy Management

China exemplifies a political system with a highly efficient energy transformation mechanism underpinned by centralized planning. The state's long-term strategic plans and economic growth policies ensure sustained high energy inflows. However, this approach simultaneously constrains information flows, particularly in areas such as freedom of expression and media independence, introducing potential entropy risks. In thermodynamic terms, the Chinese model can be described as an open system with substantial energy input but tightly controlled information flows. While entropy levels are maintained at relatively low levels, the system's flexibility is inherently limited. Over the long term, environmental challenges, demographic aging, and international pressures may exert additional stress on systemic equilibrium.

CONCLUSION

Thermodynamic concepts—energy, exergy, and entropy—offer a robust analytical framework for assessing the sustainability of political systems. These concepts not only provide a lens for understanding physical systems but also serve as a metaphorical and methodological tool to examine complex political and institutional structures. Based on this framework, several strategies emerge for promoting sustainable governance:

- Strengthening institutional reforms and transparency mechanisms to mitigate entropy and enhance systemic stability.
- Enhancing exergy through effective information flow and participatory democratic mechanisms, which enable efficient energy transformation within political systems.
- Reducing social inequality and polarization to support entropy management and foster cohesive governance.
- To improve overall energy and exergy efficiency.

The application of energy and exergy concepts in political system analysis represents a significant methodological contribution, offering insights into sustainable governance and policy-making. Efficient entropy management and exergy optimization not only increase political stability but also enhance reform capacity, thereby supporting long-term social and economic development.

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HYDROGEN PRODUCTION FROM WASTE-ACTIVATED SLUDGE USING A MEMBRANELESS BIOELECTROCHEMICAL REACTOR

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ABSTRACT – OH23

This work examines the performance of a membraneless microbial electrolysis cell (MEC) using raw sludge and waste-activated sludge as substrates. The experimental design analyses the effect of applied voltage (0.8-1.1 V), sludge ratio (RS:WAS), electrode spacing (1.5-6.5 cm), electrode area (16-28 cm²), stirring (0-400 rpm), temperature (20–50 °C), and electrode material (aluminum, graphite, other carbon). Among these, electrode spacing and electrode material had the strongest effect on performance. An intermediate spacing of 2.5 cm gave the highest gas output (584 ppm), exceeding 1.5 cm (521 ppm), 4.5 cm (370 ppm), and 6.5 cm (291 ppm). Aluminum achieves the best overall conversion, with 13.39% energy efficiency, 15.46% exergy efficiency, and 51.93% COD removal. Graphite was the stronger carbon electrode, achieving 11.53% versus 11.19% in energy efficiency, 13.32% versus 12.93% in exergy efficiency, and 43.73% versus 38.45% in COD removal.

Keywords: Microbial electrolysis, Biohydrogen, Wastewater, Efficiency

1. INTRODUCTION

Globalization has increased economic activity and connectivity, but it has also increased pollution and energy use through more industry and fossil fuel consumption, harming climate, ecosystems, and health [1]. Reaching net-zero demands comprehensive changes across energy production, transport, and use. With conventional fuels in retreat and their environmental costs mounting, nations are increasingly pivoting to cleaner renewables [2]. In this shift, Hydrogen (H₂) is an important energy carrier with its high energy content. H₂ can be produced from various energy sources, including solar, nuclear, biomass, and wind. When derived from biomass, it can be generated through three main methods which are electrolysis, thermochemical processes, and biological processes. Bio electrochemical systems (BES) provide one such biological methods by using electroactive microbes to treat waste while recovering energy. Microbial electrolysis cells (MECs) apply a small external voltage (typically >0.2 V) to drive H₂ production from organic matter [3]. The MEC systems are divided into two configuration which are membrane and membraneless configurations. MEC systems can use many wastes (industrial or domestic wastewater, food waste) as substrates [4]. This study places particular emphasis on raw sludge (RS) and waste-activated sludge (WAS) due to their high organic content and ready availability. Using RS and WAS serves a dual purpose: they provide feedstock for bioenergy production while simultaneously supporting wastewater-derived waste management. Unlike conventional MEC systems that typically rely on membranes to separate chambers, the suggested system eliminates membranes, hence markedly decreasing costs and operating complexities while maintaining competitive bioH₂ production efficiency. This strategic elimination of membranes also mitigates fouling and resistance losses, optimizing substrate utilization and enhancing overall system performance. This study investigates how operating parameters affect biohydrogen production and COD removal to identify optimal conditions.

2. MATERIALS AND METHODS

In this study, RS and WAS are used as substrate and inoculum for bioH₂ production. Fig. 1 illustrates the schematic representation of the experimental setup and the laboratory-scale system. A membraneless MEC utilizes for experiments. The MEC consists of a cylindrical glass reactor with dimensions of 10 cm in length and 9 cm in diameter, providing a total operational volume of 572 mL. In each test, 300 mL of solution is used. The entire membraneless MEC system is sealed to preserve anaerobic conditions. Electrical connections between the electrodes are established using copper cables linked to a direct current (DC) power source. The experiment investigates seven main parameters:

- Applied voltage: 0.8, 0.9, 1.0, and 1.1 V
- Raw sludge (RS) to waste activated sludge (WAS) ratio: 3:0, 2:1, 1.5:1.5, 1:2, and 0:3
- Electrode spacing: 1.5, 2.5, 4.5, and 6.5 cm
- Electrode surface area: 16, 20, 24, and 28 cm²
- Stirring speed: 0, 100, 200, 300, and 400 rpm
- Temperature: 20, 30, 40, and 50 °C
- Electrode material: aluminum, graphite, and carbon

At the start of the experiments, average values are selected for each parameter as the baseline: an applied voltage of 0.9 V, an RS:WAS ratio of 1.5:1.5, an electrode spacing of 2.5 cm, an electrode surface area of 20

cm² (4 cm x 5 cm), a stirring speed of 0 rpm, and a temperature of 20 °C, with aluminum electrodes. These initial conditions are chosen as representative averages among the test ranges.

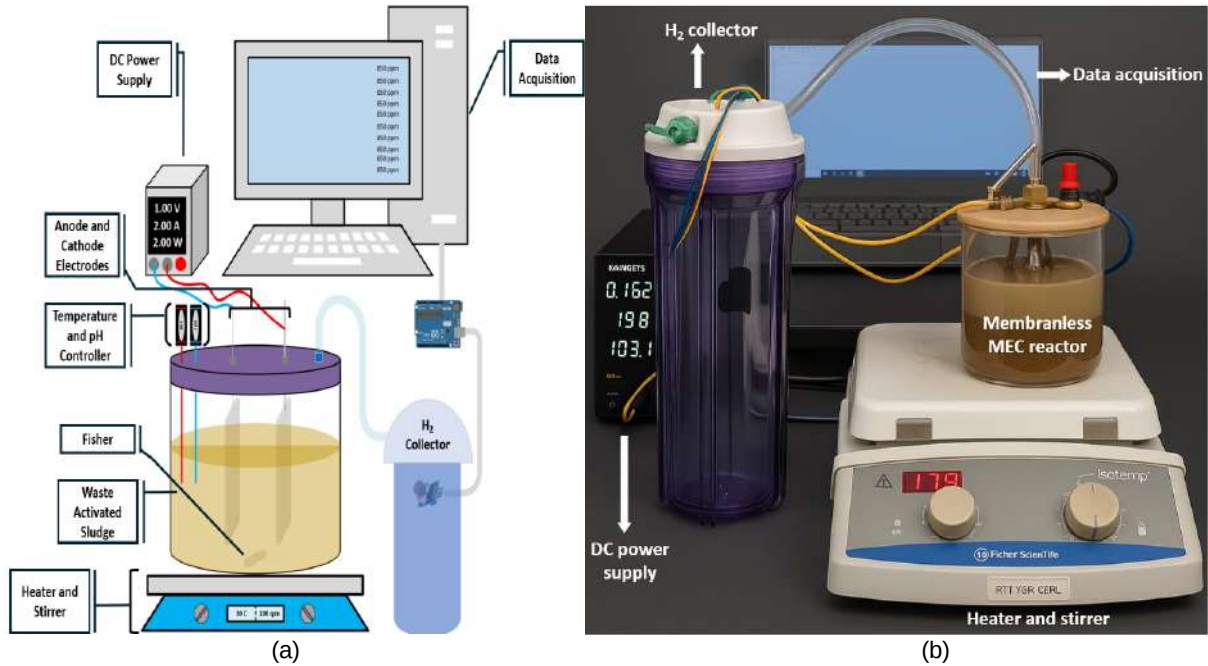


Fig. 1. (a) A schematic illustration of the experimental setup and (b) A photograph of laboratory scale the experimental setup of membraneless MEC system

3. ANALYSIS

To find the overall cumulative H₂ production, the following equation was used accordingly:

$$V_{H_2,t} = C_{H_2,t} \times V_{BG,t} + V_{HS} \times (C_{H_2,t} - C_{H_2,t-1}) \quad (1)$$

Here, $C_{H_2,t}$ and $C_{H_2,t-1}$ represent the H₂ concentrations measured at time points t and $t-1$ respectively. $V_{BG,t}$ denotes the volume of H₂ generated between these time points, and V_{HS} refers to the headspace volume of the reactor. The cumulative H₂ production $V_{H_2,cumulative}$ was calculated by summing the individual H₂ volumes produced between each pair of consecutive measurements throughout the duration of the experiment.

The $COD_{Removal}(\%)$ efficiency can be calculated as follows

$$COD_{Removal}(\%) = \frac{(COD_{Bt} - COD_{At})}{COD_{Bt}} \times 100 \quad (2)$$

where COD_{Bt} denotes for measured COD before treatment and COD_{At} stands for measured COD after treatment.

4. RESULTS AND DISCUSSION

Fig. 2a presents the effects of electrode spacing on bioH₂ production in the membraneless MEC system. It plays a key role in controlling internal resistance, mass transfer, and the effective surface available for microbial electron exchange.

Reducing the electrode spacing significantly increased H₂ production. The highest bioH₂ yield, about 584 ppm, was obtained at a spacing of 2.5 cm, followed by 1.5 cm with 521 ppm after 180 minutes of operation. When the gap widened to 4.5 cm and 6.5 cm, the total yield dropped to 370 ppm and 291 ppm, respectively. The decline at larger distances can be explained by the increased ohmic resistance and slower proton diffusion between the anode and cathode compartments, which effect charge transfer and delay H₂ production at the cathode. Conversely, smaller electrode gaps enhance ionic conductivity and electron transport, reducing potential losses. However, extremely narrow spacing (1.5 cm) can cause localized gas accumulation and turbulence near the electrodes, slightly lowering the efficiency compared with the 2.5 cm configuration. Therefore, an intermediate spacing of around 2.5 cm provides the most favorable balance between low internal resistance and adequate mass transport in the membraneless MEC system. Fig. 2b presents the comparative performance of different electrode materials on the energy, exergy, and COD efficiencies of the membraneless MEC system. Aluminum demonstrates the highest overall performance, with an energy efficiency of 13.39%, exergy efficiency of 15.46%, and COD removal efficiency of 51.93%, confirming its strong catalytic and electrical properties. Between the two carbon-based electrodes, graphite outperforms carbon in all evaluated parameters.

The graphite electrode achieved energy and exergy efficiencies of 11.53% and 13.32%, respectively, compared to 11.19% and 12.93% for the carbon electrode. Similarly, the COD removal efficiency was higher for graphite (43.73%) than for carbon (38.45%). The superior performance of graphite can be linked to its higher electrical conductivity and smoother surface morphology, which reduce internal resistance and improve charge transfer across the electrode biofilm interface. Additionally, the crystalline structure of the graphite enhances the adhesion of electroactive biofilms, supporting more stable anodic oxidation of organic compounds.

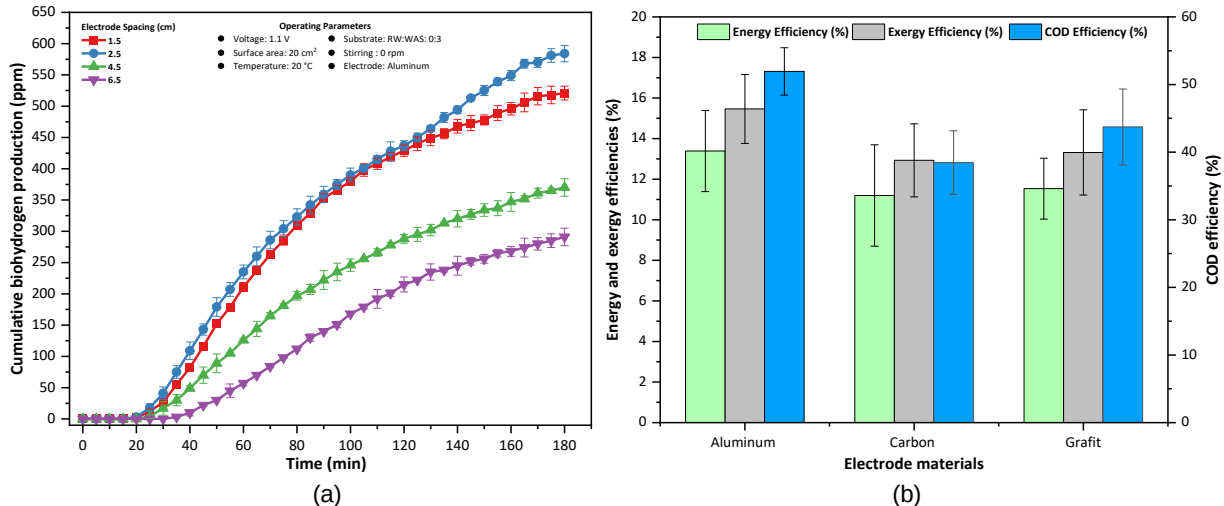


Fig. 2. (a) Cumulative bioH₂ production shows the effect electrode spacing (b) Energy, exergy and COD efficiencies of membranless MEC system under different electrode material

CONCLUSIONS

This study demonstrates that operating parameters strongly influence MEC performance. An intermediate electrode spacing about 2.5 cm gives the highest gas output by limiting internal resistance, whereas smaller or larger gaps performs worse. Electrode material was also one of the important parameters. Aluminum achieves the best overall conversion. Among the carbon options, graphite performs better than the other carbon electrode, mainly because aluminum and graphite offer lower internal and charge transfer resistance, better electrical conductivity and contact with the current collector, in contrast, the other carbon surface has higher resistance and fewer active sites, which slows electron transfer and reduces gas production and efficiencies. These results define an intermediate range spacing with a high activity electrode improves energy, exergy and COD removal efficiencies of the MEC systems.

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ECONOMIC EVALUATION OF SOLAR-BASED LIQUID HYDROGEN UTILIZATION FOR HYDROGEN PEROXIDE PRODUCTION

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ABSTRACT – OH25

In this investigation, the techno-economic analysis (TEA) for the solar-based hydrogen production and conversion process integrated with solar electricity production, electrolysis, hydrogen liquefaction, the transportation process in the cryogenic form of hydrogen, and hydrogen peroxide production via H_2O_2 production processes was carried out. This process chain analysis was carried out using the hydrogen delivery scenario analysis model, HDSAM. The solar electricity fuels the electrolysis process for gaseous hydrogen production, which undergoes liquefaction and subsequent transportation via fuel cell heavy-duty cryogenic trucks to an integrated H_2O_2 production plant. Using the HDSAM scheme, the hydrogen cost for the liquid-based hydrogen fuel station was computed to be approximately 6.29 \$/kg H_2 at an investment cost of 2.43 million USD and a payback period of approximately 6.73 years. Through the integration of solar hydrogen production and the hydrogen peroxide production process, the economic feasibility for the conversion of renewable hydrogen into a high-value chemical compound enhances the cost-effectiveness of clean hydrogen technologies.

Keywords: Hydrogen, liquid hydrogen, techno-economic analysis, HDSAM

1. INTRODUCTION

Hydrogen is recognized as the critical player in the global transition for clean/sustainable energy resources, besides being used as an energy carrier as well as an industrial feedstock. Among the variants, Liquid Hydrogen (LH_2), on one hand, finds preference for having high volumetric energy density and the ability for mass transportation and storage; however, the high fixed cost for the production process restricts their economic viability [1]. To counter this, the combination of hydrogen from renewable sources and high-value chemical processes such as the production of hydrogen peroxide (H_2O_2) may improve the economic feasibility of hydrogen-based technologies in general. H_2O_2 is a common oxidizing agent used in chemical synthesis, the treatment of water and air, and other energy conversion processes. Production of H_2O_2 from hydrogen obtained from non-carbon based sources may therefore improve the economic and sustainable aspects of hydrogen-based technologies [2]. In the context of the proposed paper, for the purposes of carrying out the techno-economic analysis without the consideration given to the environmental aspects, the cost composition of the solar hydrogen process combined with hydrogen peroxide production will be analyzed. To achieve this objective, the HDSAM process analysis tool will be used for the modeling of the process in order to estimate the Levelized Cost of Hydrogen (LCOH) [3].

2. METHODOLOGY

The techno-economic analysis was carried out utilizing the Hydrogen Delivery Scenario Analysis Model (HDSAM) for the cost analysis of solar-based hydrogen production integrated with hydrogen peroxide production. The scheme level description, depicted in Fig. 1, entails six process chain elements in sequence: solar photovoltaic electric power production, electric power transmission and distribution, hydrogen production from solar electrolysis, hydrogen liquefaction, transportation of the liquefied hydrogen via a heavy-duty truck, and the conversion process for the production of hydrogen peroxide (H_2O_2) from the received liquid hydrogen (LH_2). All cost estimations are based in 2022 USD and financial inputs considered for the analysis are received from HDSAM and comprise an additional discount rate of 10 % after-tax real value, debt ratio of 38.5 % for the cost of the analysis period of 15 years, and nominal interest rate of 7%. However, for the mid-scaled hydrogen fuel station modeling based on the hydrogen station, the resultant capital requirement stands at 2.43 million USD, the Levelized Cost of production comes to be around 6.29 \$/kg H_2 , and the break-even point takes around 6.73 years for the given economic feasibility conditions without consideration for the added environmental effects. Every step of the process, from electricity production to electrolysis, liquefaction, transportation, and the synthesis of H_2O_2 , was implemented as an economic module in HDSAM. The process for the synthesis of H_2O_2 uses the direct catalytic conversion of LH_2 and O_2 , relating the cost of the supplied hydrogen to the reactor and catalyst needs for the subsequent calculation of the cost of H_2O_2 production. The above modeling approach fully reveals the economic interaction between the production costs of renewable electricity, hydrogen, and the chemical production process.

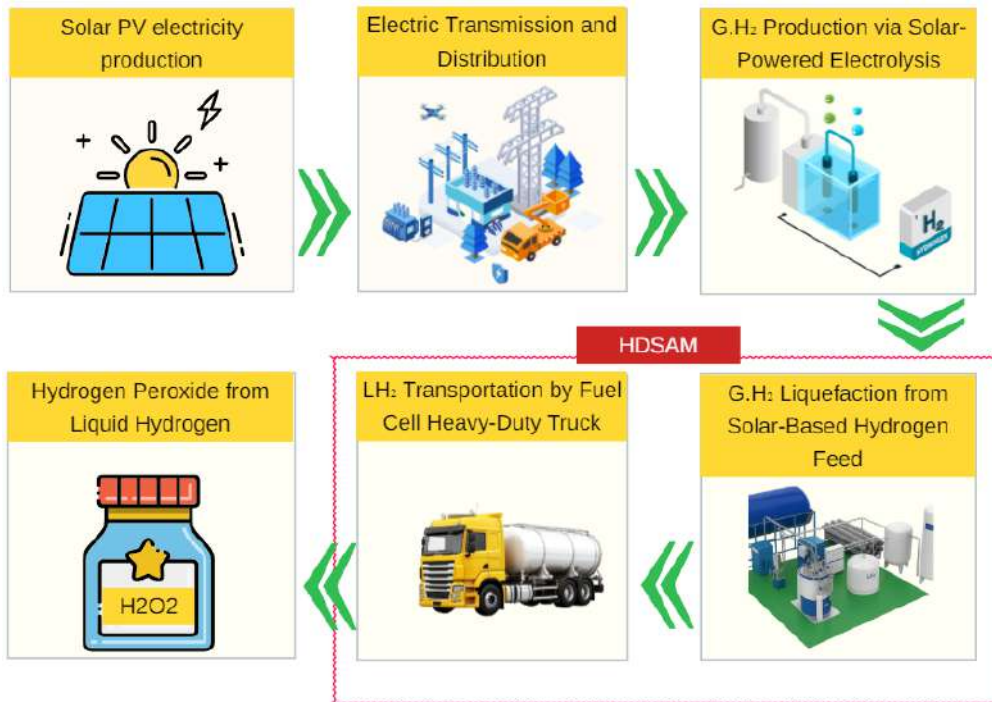


Fig. 1. Techno-economic process flow of solar-powered hydrogen production, liquefaction, transportation, and hydrogen peroxide synthesis modeled in HDSAM

3. RESULTS AND DISCUSSION

Fig. 2 presents the overall cost breakdown of the liquid hydrogen refueling station per kilogram of hydrogen delivered. The capital cost constitutes the largest portion, equal to 3.23 \$/kg H₂, followed closely by O&M (operation and maintenance) costs excluding energy, at 2.99 \$/kg H₂. The energy/fuel cost contributes only 0.07 \$/kg H₂, representing a minimal share of the total cost. This indicates that the economic performance of the station is primarily driven by capital and maintenance expenses rather than energy consumption.

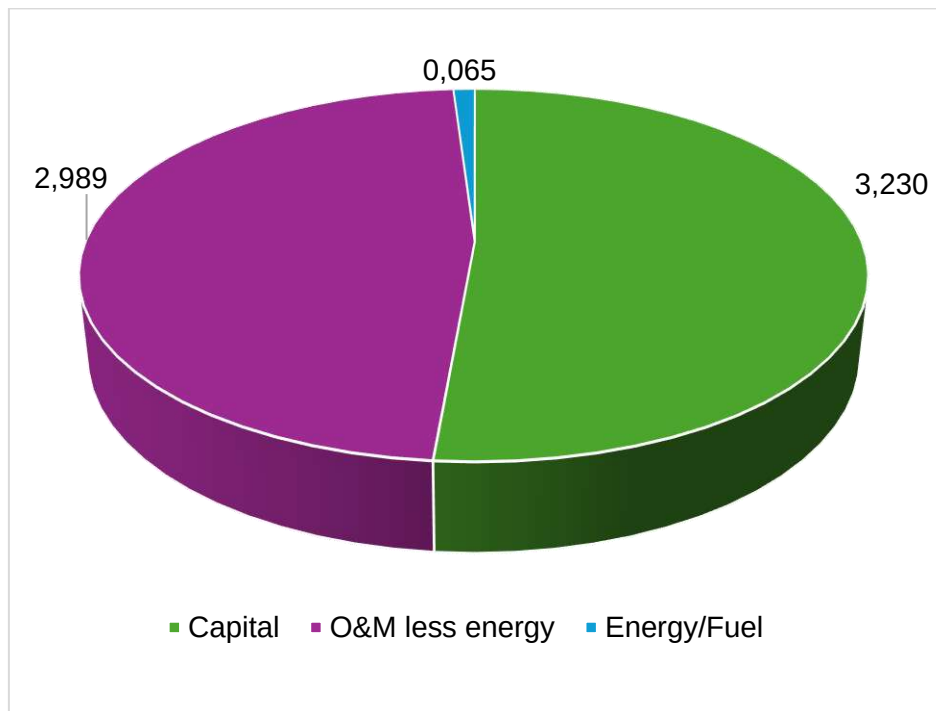


Fig. 2. Cost breakdown of the liquid hydrogen refueling station

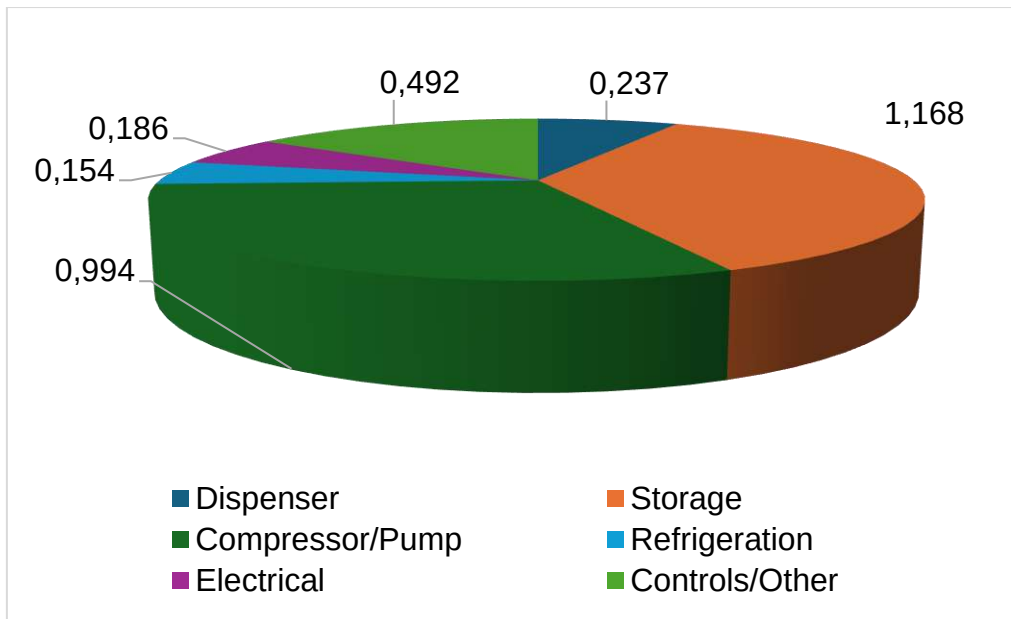


Fig. 3. Capital cost distribution of subsystems in the liquid hydrogen refueling station

Fig. 3 shows the capital cost distribution of the liquid hydrogen refueling station. The storage (1.168 \$/kg H₂) and compressor/pump (0.994 \$/kg H₂) units dominate the total cost, followed by controls/other (0.492 \$/kg H₂). Minor contributions come from the dispenser (0.237 \$/kg H₂), electrical (0.186 \$/kg H₂), and refrigeration (0.154 \$/kg H₂) systems. This indicates that storage and compression are the main cost drivers of the station.

CONCLUSIONS

In this analysis, a cost-oriented techno-economic assessment of a solar-based liquid hydrogen process integrated with hydrogen peroxide production is proposed. By avoiding the analysis of the other aspects, the tool focuses only on an economic feasibility analysis. From HDSAM, the results shown are that:

- The cost of hydrogen production at the LCOH is given 6.29 \$/kg H₂,
- The liquefaction and capital are the major cost determinants,
- The contribution to energy is fairly small ($\approx 1\%$),
- Including H₂O₂ production capability enhances the value chain and increases the effectiveness of the reactive hydrogen from renewable sources.

The results have justified the fact that solar hydrogen conversion into hydrogen peroxide could be used as an economic approach for increasing the financial transformation and feasibility of clean hydrogen technologies for industrial applications.

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GREEN HYDROGEN PRODUCTION USING ULTRASONICALLY ENHANCED GA-DOPED ZNO PHOTOELECTRODES

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ABSTRACT – OH2O

This study investigates hydrogen production by combining the photoelectrochemical (PEC) and ultrasonic techniques using 1% Ga-doped ZnO/ZnO electrodes. ZnO substrates are coated with Ga-doped ZnO thin films prepared by the dip-coating method, and their performance is evaluated under illumination with and without ultrasonic excitation. The application of ultrasonic waves significantly enhances the system performance, increasing the hydrogen generation rate from 0.20 to 0.50 mL cm⁻², the energy efficiency from 0.132% to 0.352%, and the Faradaic efficiency from 0.56% to 1.82%. These results demonstrate the synergistic effect of the ultrasonic field, which improves charge separation and bubble detachment, thereby enhancing overall photoelectrochemical hydrogen production efficiency.

Keywords: Hydrogen production, PEC, ultrasonic waves, Ga-doped ZnO, dip-coating

1. INTRODUCTION

The combination of photoelectrochemical (PEC) and ultrasonic methods has recently attracted great attention to enhance the production capacity of hydrogen, a clean and reliable energy carrier [1]. This hybrid approach, based on renewable and sustainable energy conversion, is considered a promising method to improve hydrogen generation efficiency. In PEC systems, electrode material and doping ratio play a crucial role in determining light absorption and charge separation performance. Ahn et al. [2] report that Ga-doped ZnO films exhibit higher photo response in photoelectrochemical water-splitting systems, thereby significantly improving hydrogen production performance. Zhao et al. [3] state that 1% Ga-doped ZnO nanosheets provide the highest photo response and that an appropriate doping ratio enhances the electrical conductivity and band gap characteristics of ZnO, leading to a marked improvement in its optoelectronic performance. In this study, hydrogen production is investigated in a system combining the PEC method and ultrasonic effects using 1% Ga-doped ZnO/ZnO substrate electrodes.

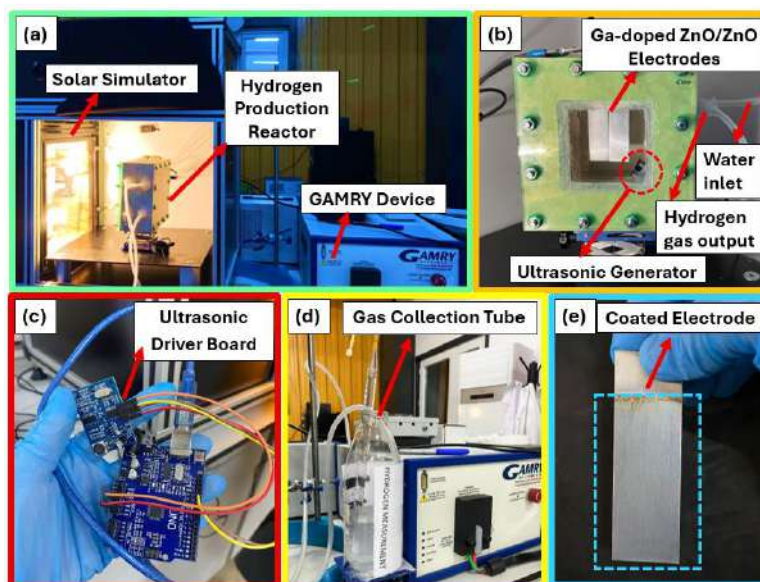


Fig. 1. Overall setup of the system (a) Photoelectrochemical hydrogen production setup with solar simulator, reactor, and GAMRY device; (b) Ultrasonic-assisted reactor with Ga-doped ZnO/ZnO electrodes; (c) Ultrasonic driver board; (d) Gas collection tube; (e) Coated electrode surface

2. MATERIALS AND METHODS

In this study, hydrogen production is carried out by combining the photoelectrochemical (PEC) method with the effect of ultrasonic waves. ZnO plates are used as substrates, and 1% Ga-doped ZnO films are coated on these substrates to prepare the working electrodes. The coating process is performed using the dip-coating method, and the electrode dimensions are 4 x 6 cm². During the electrochemical measurements, LSV (Linear Sweep Voltammetry) and CA (Chronoamperometry) tests are conducted using a GAMRY device.

Measurements are taken both in the dark and under illumination to evaluate the photo response. When the illumination is on, the ultrasonic device is activated, and the influence of ultrasonic waves on hydrogen production is analyzed. The experiments are conducted in 0.1 M Na₂CO₃ electrolytes to prevent ZnO surface etching and maintain electrode stability. Although the use of Na₂CO₃ results in slightly lower photocurrent compared to strong alkaline media such as KOH, it provides a stable and chemically safe environment for long-term operation. The overall setup of the photoelectrochemical hydrogen production system is presented in Fig. 1. The system consists of a solar simulator, a hydrogen production reactor, and a GAMRY potentiostat (Fig. 1a). The ultrasonic-assisted reactor includes Ga-doped ZnO/ZnO electrodes, a water inlet, a hydrogen gas outlet, and an ultrasonic generator (Fig. 1b). The ultrasonic driver board used for signal control is shown in Fig. 1c, while Fig. 1d illustrates the gas collection tube for hydrogen measurement. The surface morphology of the coated electrode is presented in Fig. 1e.

3. RESULTS AND DISCUSSION

Fig. 2 compares the hydrogen production rate and related efficiencies of the Ga-doped ZnO/ZnO electrodes under conventional PEC and ultrasonic-assisted PEC conditions. The hydrogen generation rate increases from 0.20 to 0.50 mL cm⁻², indicating that the application of ultrasonic waves significantly enhances gas evolution activity (Fig. 2a). Correspondingly, the energy efficiency rises from 0.132% to 0.352% and the exergy efficiency from 0.133% to 0.357% (Figs. 2b–c). Moreover, the Faradaic efficiency exhibits a remarkable increase from 0.56% to 1.82% (Fig. 2d), confirming that the generated current is more effectively utilized for hydrogen production. These improvements clearly demonstrate the synergistic effect of the ultrasonic field, which promotes charge separation and accelerates bubble detachment from the electrode surface, thereby enhancing the overall photoelectrochemical hydrogen generation performance.

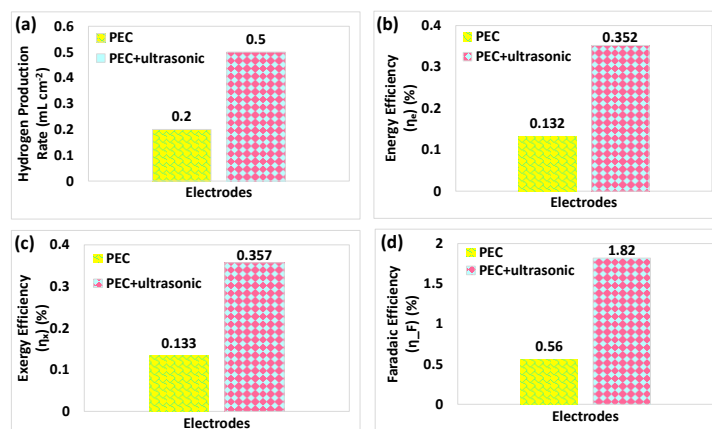


Fig. 2. Comparison of PEC and ultrasonic-assisted PEC performances for 1% Ga-doped ZnO/ZnO electrodes: (a) hydrogen production rate, (b) energy efficiency, (c) exergy efficiency, and (d) Faradaic efficiency

CONCLUSIONS

In this study, 1% Ga-doped ZnO/ZnO electrodes are used to investigate the effect of ultrasonic waves on photoelectrochemical hydrogen production. With the application of ultrasonic excitation, the hydrogen generation rate increases from 0.20 to 0.50 mL cm⁻², the energy efficiency rises from 0.132% to 0.352%, and the Faradaic efficiency improves from 0.56% to 1.82%. These findings indicate that ultrasonic waves accelerate charge separation and bubble detachment, significantly enhancing system performance. The combination of photoelectrochemical and ultrasonic effects provides a synergistic improvement in sustainable hydrogen production.

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EXPERIMENTAL INVESTIGATION OF LAYERED COPPER OXIDE MESH ELECTRODES FOR PHOTOELECTROCHEMICAL HYDROGEN PRODUCTION

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ABSTRACT – OH24

In this work copper oxide mesh photoelectrodes with different layers are developed and electrochemically assessed. The copper oxide mesh photoelectrodes consist of 2, 3, or 4 layers, respectively, with varying thicknesses. Electrochemical tests are conducted under both light and dark conditions. As the number of layers increases the light response of the photoelectrodes increase; however, the onset potential slightly decreases due to the increased overall resistance of the photoelectrodes with higher thicknesses. Linear sweep voltammetry shows that the 4-layered photoelectrode bears a current density of 2.77 mA/cm² under light conditions, and 2.61 mA/cm² for the 3-layered permutation.

Keywords: Hydrogen; Hydrogen production; Photoelectrode; Solar Energy

1. INTRODUCTION

Photoelectrochemical hydrogen production refers to the utilization of photoactive materials as electrodes in conventional electrochemical cell configurations [1]. This approach allows photoactive materials to contribute positively to the operation of electrochemical cells by absorbing light, which is then converted to electrons that take part of the catalytic (redox) reactions happening within the cell. Once a photon with energy higher than the photoactive material's bandgap is incident on it, it excites electrons from the valence band of the material to its conduction band, where they can be collected. Electron collection in this context can refer to the transport of electrons through the external circuit of an electrochemical cell to the counter electrode (or cathode [2]) leading to a higher hydrogen generation rate compared to their absence. Transition metals have been widely used as photoactive materials for different applications including photoelectrochemical hydrogen generation. Their properties fit the requirements of the photoelectrochemical hydrogen generation well, which includes having a bandgap that fits the visible spectrum such as that of copper oxide, having good electrical properties and direct synthesis approaches, as well as being economically viable.

In this work, layered copper oxide mesh photoelectrodes are developed and electrochemically assessed to study the effect of having multiple layers within the same electrode area (varying the electrode thickness) on the current density produced as well as the photo-response of the photoelectrode.

2. MATERIALS AND METHODS

Various materials are used for the synthesis of the copper oxide mesh photoelectrode and the testing of the electrochemical cell. Sodium hydroxide (NaOH) (Fisher Bioreagents®, Fisher Scientific, USA) Potassium Chloride (KCl) (Powder, ≥ 99.0 %, Sigma Aldrich, USA) is used to make the solution for the Ag/AgCl reference electrode. The copper mesh is initially treated with hydrochloric acid (HCl) (Fisher Scientific, USA) in a chemical bath and sonicated for 15 minutes. Then it is rinsed off with deionized water and sonicated for 15 minutes. Three different copper mesh configurations are used, such as shown in Fig. 1, with dimensions of 2 cm × 2.5 cm and varying thicknesses to constitute the different number of layers. Copper mesh is then annealed at 500°C of 30 minutes to obtain copper oxide mesh, which is later used for photoelectrochemical assessment. The electrolyte used within the photoelectrochemical cell is 0.1 M NaOH, and the counter electrode used is stainless steel with similar dimensions to the copper oxide mesh. Cyclic voltammetry tests are conducted under dark and light conditions using GAMRY Reference 3000 potentiostat, with a voltage scan range of -1.048 to 0.182 V with a scan rate of 10 mV/s. Linear sweep voltammetry is conducted under the same voltage scan range and rate.

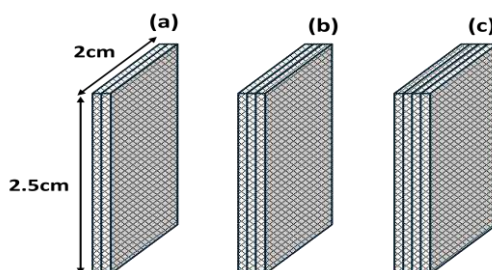


Fig. 1. Schematic of the three developed copper oxide mesh electrodes with (a) 2 layers (b) 3 layers and (c) 4 layers

3. RESULTS AND DISCUSSION

Cyclic voltammetry results for the developed photoelectrodes are shown in Fig. 2. Fig. 2 (a) shows the results for the 2-layer photoelectrode under dark and light conditions. In the mid-scan range the performance under light conditions is higher relative to that under dark conditions. Although in the low voltage range the dark condition shows a higher current density, it is neglected as it is in a non-desirable voltage operational region. As the number of layers increases to 3 and 4, shown in Fig. 2 (b) and (c) the light conditions show more deviation with respect to their dark counterparts especially at the voltage point of -0.6 V vs Ag/AgCl, which is later used to conduct chronoamperometric results. Moreover, for the 4-layered electrode, the onset potential enhancement due to light exposure is more prominent compared to the other two permutations.

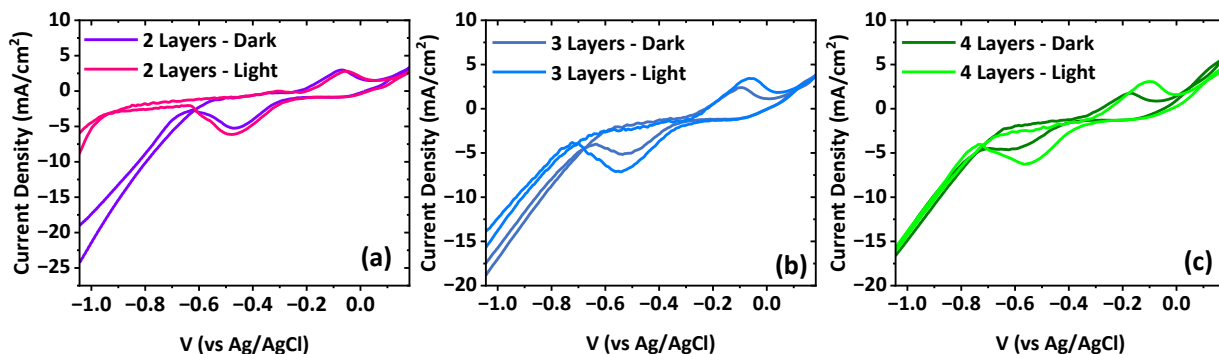


Fig. 2. Current density variation under LSV conditions for copper oxide mesh electrodes with (a) 2 layers (b) 3 layers and (c) 4 layers

The linear sweep voltammetry (LSV) results for the different electrode permutations and under different light conditions are shown in Fig. 3. The highest current density is obtained for the 4-layered photoelectrode considering -0.6 V vs Ag/AgCl voltage point, at -2.77 mA/cm² under light conditions followed by the 3-layered photoelectrode at -2.61 mA/cm² under light conditions. These are 0.46 mA/cm² and 0.1 mA/cm² enhancements for the 4-layered and 3-layered photoelectrodes compared to their dark condition operations. However, the onset potential of the photoelectrode worsens with the increased number of layers, this can be correlated with the increased overall resistance of the electrode and electrolyte interaction with the increased thickness.

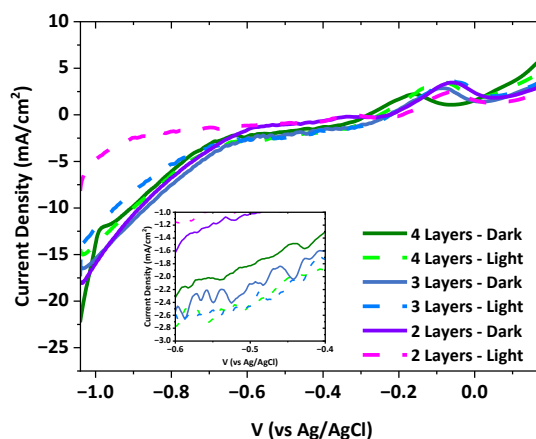


Fig. 3. Current density variation with voltage under LSV conditions for copper oxide mesh electrodes with 2, 3 and 4 layers.

CONCLUSIONS

In conclusion, this work showcases the development and assessment of layered copper oxide mesh photoelectrodes for hydrogen production. The main findings of this work are as follows: (i) under light conditions the 4-layered photoelectrode has a current density of 2.77 mA/cm² vs 2.61 mA/cm² for the 3-layered permutation, and (ii) compared to dark conditions for the 4- and 3-layered photoelectrodes, light exposure shows enhancements 0.46 mA/cm² and 0.1 mA/cm², respectively.

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INVESTIGATION OF HYDROGEN PRODUCTION FROM ORGANIC WASTES THROUGH A BIO-ELECTROCHEMICAL PATHWAY

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ABSTRACT – OH21

This research establishes a novel bio-electrochemical framework that links citric acid biosynthesis with hydrogen production. Wastes, including orange, apple, kiwi, persimmon, and beetroot, were used as renewable feedstocks for solid-state fermentation (SSF). *Aspergillus Niger* inoculation significantly enhanced productivity, reaching up to 3.1 g/kg citric acid on orange peel and 1.15 g/kg from persimmon peel, demonstrating efficient conversion across all substrates. Persimmon and beetroot were explored for the first time, confirming their suitability as alternative substrates. The resulting citric acid serves as a green electrolyte for hydrogen generation via electrolysis, illustrating a circular approach that integrates biological waste conversion with clean energy production.

Keywords: Hydrogen production, Citric acid, Solid state fermentation, Electrolysis

1. INTRODUCTION

Over the past century, the global energy system has relied primarily on fossil fuels such as coal, oil, and natural gas, which have fostered industrialization and socioeconomic development [1]. However, the continued combustion of these carbon-rich resources has led to serious environmental impacts [2]. Consequently, the global energy landscape is transitioning towards renewable and cleaner alternatives to address environmental, economic, and health concerns [3]. Recent advances in hybrid technologies such as bio-electrochemical systems, microbial fuel cells, and electrolysis-based hydrogen production highlight the potential of integrating biological resources with electrochemical pathways [4]. Hydrogen has emerged as a critical vector for deep decarbonization, producing only water when used in fuel cells or combustion systems, making it suitable for heavy industry, transportation, and power generation [5]. While green hydrogen from renewable energy electrolysis offers a sustainable pathway, economic and infrastructure challenges remain [6]. Beyond hydrogen, biologically derived organic compounds are gaining importance as complementary clean energy carriers [7].

The current study develops an integrated system to produce citric acid from fruit and vegetable wastes, such as orange, apple, kiwi, persimmon, and beetroot, via solid-state fermentation (SSF). persimmon and beetroot are used as novel substrates, and the resulting citric acid is used for hydrogen production via electrolysis, combining biological synthesis and electrochemical conversion in a unified and sustainable framework.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental system was developed to investigate citric acid production from fruit and vegetable wastes under controlled solid-state fermentation (SSF) conditions. The produced citric acid will subsequently be used as an electrolyte in an electrolysis system for hydrogen generation, forming an integrated bio-electrochemical pathway. The overall integrated system is presented in Fig. 1.

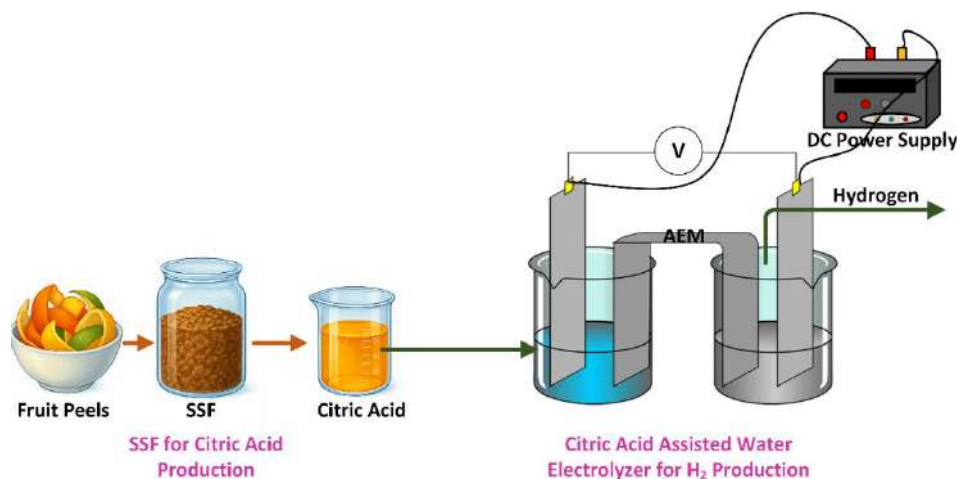


Fig. 4. Schematic representation of the integrated bio-electrochemical system for hydrogen production from citric acid

Orange, apple, kiwi, persimmon, and beetroot peels were used as substrates, fermented under both natural and *Aspergillus Niger*-inoculated conditions at 30 °C and >85 % humidity for 10-12 days. After fermentation, citric acid was extracted (1:10 w/v) at 60 °C and quantified by acid-base titration using 0.1 M NaOH. This setup ensures consistent SSF performance and serves as a basis for future electrochemical hydrogen generation integration. This configuration demonstrates a circular and sustainable pathway in which organic waste is first converted into a valuable intermediate product and then used as an energy carrier for clean hydrogen production, highlighting the potential of waste-to-energy integration within renewable energy frameworks.

Modeling

The analysis focused on determining citric acid yield and biomass formation during SSF while verifying the accuracy of titration results. Citric acid concentration in the extract was calculated using the titration equation:

$$C_{CA} = \frac{V_{NaOH} \times N_{NaOH} \times 192.12}{1000} \quad (1)$$

Since 20 g of dried substrate was used for each trial, the final concentration was normalised accordingly. Biomass growth was evaluated based on changes in the substrate mass before and after fermentation, using:

$$Y_{Biomass} = \frac{m_{final} - m_{initial}}{m_{initial}} \quad (2)$$

which provides an indication of fungal proliferation and substrate consumption.

3. RESULTS AND DISCUSSION

This section presents experimental findings on citric acid production via solid-state fermentation and its integration into a bio-electrochemical hydrogen production system. The SSF inoculated with *Aspergillus Niger* demonstrated faster and higher citric acid production than native microflora, confirming the effectiveness of targeted inoculation. As shown in Fig. 3, inoculated samples reached the highest yield within 6-8 days, with orange peel yielding the highest yield (~3.1 g/kg), followed by apple (~1.5 g/kg), persimmon (~1.15 g/kg), and kiwifruit (~1.05 g/kg). Biomass formation followed a similar trend, with orange peel supporting the highest fungal growth (~24 g/kg), indicating strong substrate utilization and enzymatic activity.

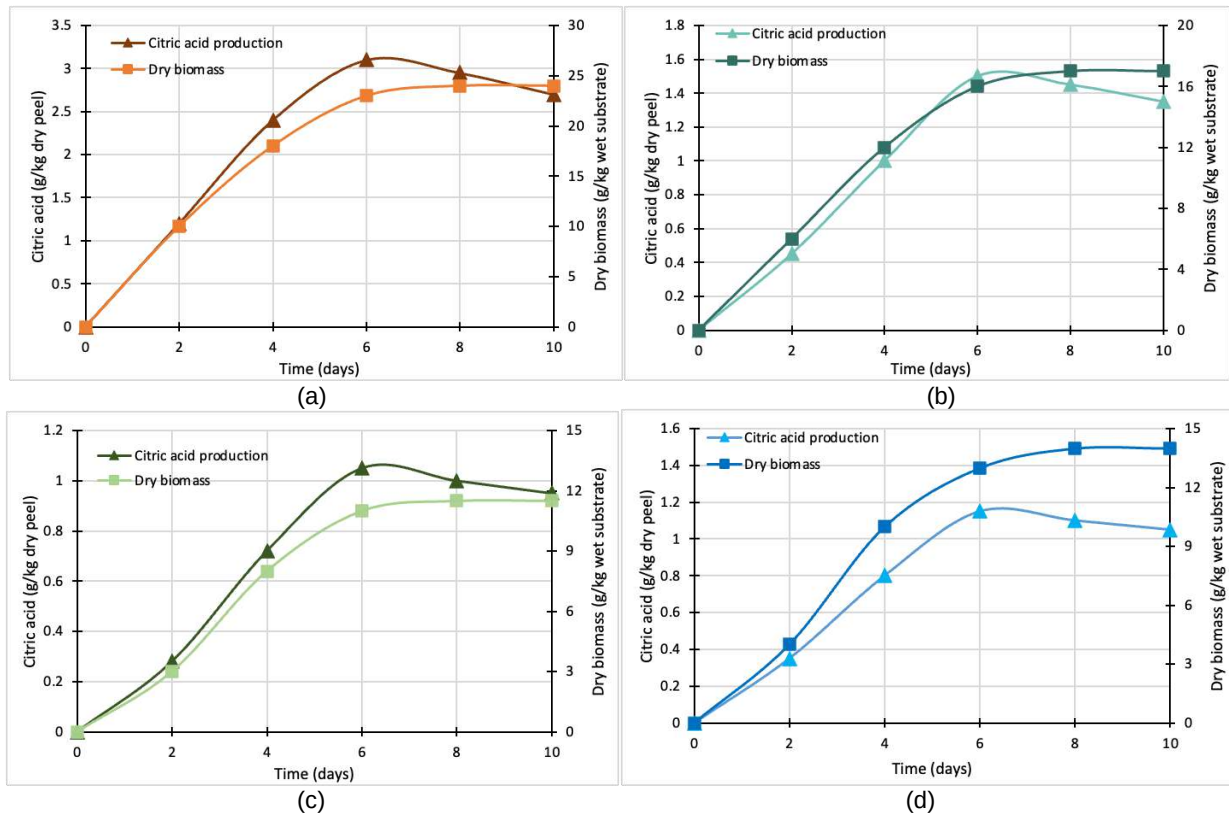


Fig. 5: Citric acid production and dry biomass formation from pre-dried (a) orange peel, (b) apple peel, (c) kiwi peel and (d) persimmon peel under *Aspergillus Niger*-inoculated solid-state fermentation for 10 days

As shown in Fig. 4, the pH decreased from ~3.8 to below 3.3, confirming strong acid production in the inoculated SSF systems. Orange peel showed the steepest decline, reflecting higher metabolic activity, while persimmons maintained a slightly higher final pH due to slower acid release or greater buffering from tannins and phenolics.

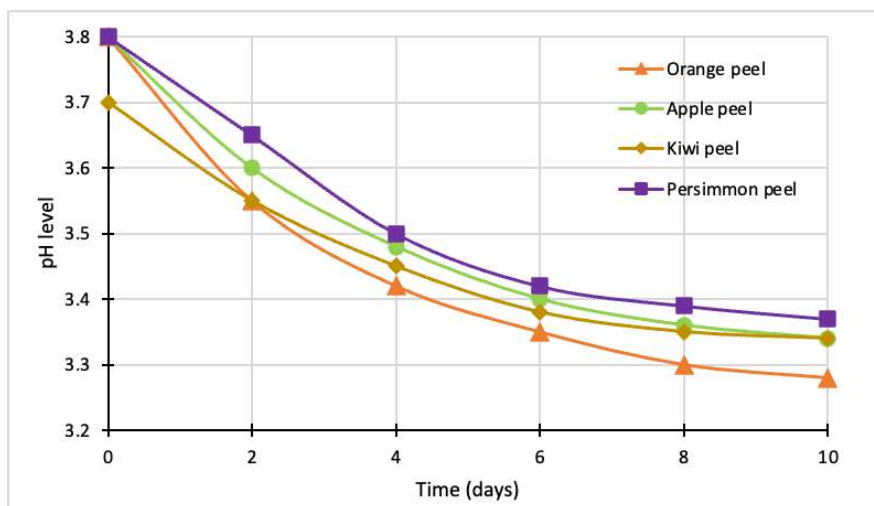


Fig. 6. Temporal changes in pH during *Aspergillus Niger*-inoculated solid-state fermentation of different pre-dried substrates

CONCLUSIONS

This study demonstrated the conversion of low-cost residues into valuable biochemicals by developing a SSF system to produce citric acid from waste. Inoculation with *Aspergillus Niger* significantly increased yield and kinetics, reaching a maximum citric acid concentration of ~3.1 g/kg in dry substrate with orange peel, followed by apple (1.5 g/kg), persimmon (1.15 g/kg), and kiwi (1.05 g/kg). Persimmon and beetroot were introduced for the first time as new substrates, confirming their potential as alternative feedstocks for bio-citric acid production. These findings validate the SSF process as the biological basis for an integrated bio-electrochemical system in which the produced citric acid will be used as an electrolyte for hydrogen production via electrolysis, advancing a sustainable and circular waste-to-energy pathway.

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TECHNO-ECONOMIC ANALYSIS OF PEM ELECTROLYZERS USING RENEWABLE ENERGY SURPLUS

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ABSTRACT – OH9

With the expansion of renewable energy is fed into the grid, managing the fluctuations in electricity supply is becoming a real challenge. For a sustainable energy transition not only production but also energy storage and flexible system integration are of strategic importance. Hydrogen can play a crucial role in the energy system with Proton Exchange Membrane (PEM) electrolysis. This study looks into whether it's technically and economically feasible to operate a 5 megawatt PEM electrolyzer using surplus renewable energy in Spain. Hourly electricity market data from Red Electrica de Espana (REE) were used for modeling. Three scenarios were examined: completely off grid operation based on solar, pure grid operation both continuous and price controlled and a hybrid model., hydrogen production, levelized cost of hydrogen (LCOH) analyzed each scenario. Continuous grid connected operation LCOH =€4.61/ kg H₂. When operation is flexibly adjusted to price fluctuations, costs can be reduced to €3.73/ kg H₂. Off-grid systems based on solar energies have higher cost €8.19/ kg H₂ due to their limited availability. The results shows PEM electrolyzers can efficiently utilize both surpluses from renewable sources and volatility, reducing the cost of green hydrogen to a competitive level, while contributes to decarbonization and stabilization.

Keywords: Levelized cost of hydrogen (LCOH), PEM electrolyzer, Techno-economic analysis

1. INTRODUCTION

The world energy demand is increasing day by day and people are feeling the effects of climate change in daily lives so In recent years, government policies and net-zero targets have made the shift toward clean and sustainable sources in the energy sector necessary. Especially solar and wind energy are outshining to alternatives to fossil fuels. The inherent unpredictability of renewable energy sources leads to increased energy curtailment as their capacity increases. Spain expanded its renewable energy power plants after 2019, but due to these renewable energy plants approximately 1.8% of total production was curtailed in 2024 as shown in **Fig. 1**. This situation creates serious difficulties in grid operation and threatens system stability. Moreover, the waste of this clean energy causes economic potential. In order to ensure sustainable energy transformation, not only production but also energy storage and flexible system integration have strategic importance. In this context, stabilizing this excess electrical power through energy storage systems has become a critical component of the energy transition. Traditionally, this excess energy is converted through pumped hydroelectric storage or battery systems. As an alternative, hydrogen can play a crucial role in energy storage by using excess electricity with electrolysis for green hydrogen production. Hydrogen has high energy density, variable use capacity in different sectors. Green hydrogen produced from renewable sources can play an important role in decarbonizing high- emission sectors such as heavy industry, the steel industry, and transportation as well as in balancing fluctuating renewable resources. At current market conditions, the cost of green H₂ production via electrolysis is LCOH ~€5-8/kg. [3,4] These levels are not cost competitive with hydrogen derived from fossil fuels. Grey hydrogen production via natural gas steam reforming (SMR) typically price ranges from €1.0—1.8/kg without carbon capture and storage (CCS) when integrated CCS price ranges is €2.0-2.4/kg [2]. Electricity is the most significant factor influencing the economics of H₂ production via electrolysis, so considering the price of electricity, maximizing the efficiency of low-cost electricity hours is crucial.



Fig. 1. RENEWABLE CURTAILMENT IN THE PENINSULAR SYSTEM DUE TO TECHNICAL CONSTRAINTS IN THE GRID

(Source: Red Electrica de Espana – REE, 2024)

2. METHODOLOGY

This study used a 5 MW Proton Exchange Membrane (PEM) electrolyzer under different operating strategies and evaluated the technical and economic performance. Three scenarios are defined:

- (1) Fully grid-connected continuous operation,
- (2) 100% renewable off-grid operation with solar plant,
- (3) Price controlled low-cost grid electricity hybrid model. In the model, hourly electricity price data for 2024 were obtained from the Red Eléctrica de España (REE) company and a dynamic economic analysis was performed in which the electrolyzer was operated according to price fluctuations.

Hydrogen Production Model

Annual hydrogen production was calculated taking into account the electrolyzer power, capacity factor and specific energy consumption:

$$M_{H_2} = \frac{P_{el} \times C_F \times E_e \times 8760}{3600} \quad \text{Eq. (1)}$$

Economic Evaluation and LCOH Calculation

The levelized cost of hydrogen (LCOH) was calculated using the discounted cash flow analysis method. The discounted total of these recorded annual costs is proportional to the annual daily production:

$$LCOH = \frac{\sum_{t=1}^{t=N} \frac{CAPEX_t + OPEX_t + E_t + C_{H_2O}}{(1+r)^t}}{\sum_{t=1}^{t=N} \frac{M_{H_2,t}}{(1+r)^t}} \quad \text{Eq. (2)}$$

Practically annualized form:

$$LCOH = \frac{W_{ix} + W_{on} + i + C_w}{M_{H_2}} \quad \text{Eq. (3)}$$

The capital recovery factor (CRF) is provided as follows:

$$CRF = \frac{\Delta i + \Delta N}{(1+r)^w - 1}$$

Table 1. Technical and Economic Parameters

	Value	Unit	Description	Referans
CAPEX (Electrolyzer)	1200	€/ kW	PEM system investment	[3], [4]
CAPEX (PV)	1000	€/ kW	PV investment cost	[3], [4]
WACC	8	%	Discount rate	[3], [4]
Project Lifetime	20	years	Economic Lifetime	[3]
Stack Replacement Time	10	Years	Period between	[3]
Stack Replacement Cost	30	% of CAPEX	Replacement ratio	[3]
OPEX (Electrolyzer)	3	% of CAPEX /	Maintenance cost	[3]
OPEX (PV)	1.5	% of CAPEX /	PV O&M cost	[3]
Specific Energy	55	kWh / kg H ₂	Electrolyzer efficiency	[3]
Water Cost	0.05	€/ kgH ₂	Operating water cost	[3]
Load Range	10-100	%	Operational flexibility	[3]

3. RESULTS AND DISCUSSION

Three operational scenarios were simulated to assess the techno-economic performance of a 5 MW PEM electrolyzer under different energy supply strategies. The calculated values of LCOH and capacity factors reveal the strong influence of electricity price variability and operation mode on hydrogen production cost

Scenario 1: Fully grid connected continuous operation

In this scenario, the 5 MW PEM electrolyzer operates continuously 100 % capacity factory throughout the year so drawing electricity based on the current market price. The annual average electricity price for 2024 was calculated as = 63.05 €/MWh. When I compared the dataset I received from REE with the Omio data [6], to see if the value found by the program was correct, the value being the same, 63.05 €/MWh, showing that the code is working properly. The LCOH value calculated as follows is 4.61 €/kg H₂ as shown in Fig. 2. From an environmental perspective this system has indirect CO₂ emissions from the grid supply that depend completely on the grid mix. 2019'da Spain, once one of Europe's most expensive electricity markets in 2019, has transformed into one of the cheapest in just six years. In the first half of 2025, Spain's electricity price averaged €62 per megawatt-hour. This is cheaper which is around 32% cheaper than in other European countries. If another European country had been chosen, the LCOH would have been much higher due to the electricity costs.

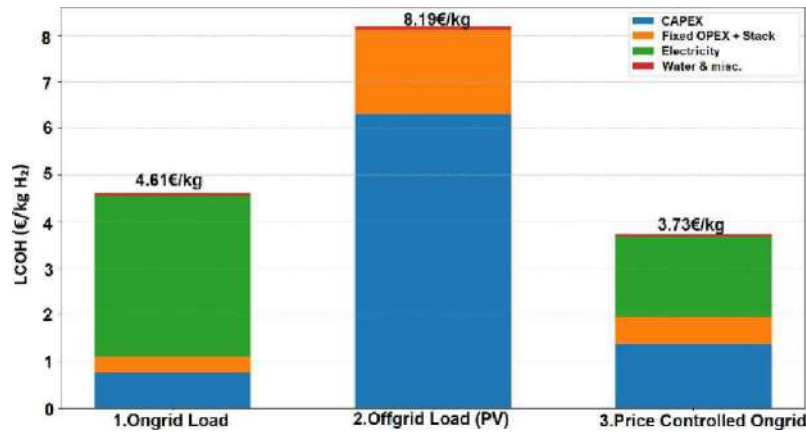


Fig. 2. LCOH by cost components for the three operation scenarios *Scenario 2:100% renewable off-grid operation with solar plant*

In this scenario, the electrolyzer is fully installed in the Tarifa region of Spain, and the system is powered by PV panels with no grid connection. The carbon footprint of the produced hydrogen is zero. Based on the simulation conducted with Renewables.ninja Solar photovoltaic power [7]., assuming a 6 MW PV installation and a 5 MW PEM electrolyzer capacity with an hourly time step of 1 h, the system's average load was calculated as 1.219 MW, resulting in a capacity factor of 24.37%. This analysis assumes a PV investment cost of €1,000,000/MW, an 8% discount rate, a 20-year project life, and fixed operating and maintenance costs of 1.5% for the PV electrolyzer specs all scenario is same [3]. Consequently, LCOH is calculated as \$8.19/kg H₂ as shown in **Fig. 2**. This value is consistent with the range of 7-10 €/kg reported in the literature for fully off-grid systems. Since the capacity factor remains around 25%, capital expenditures account for over 70% of the total cost. While the main advantage of off-grid operation is zero emissions, the main disadvantage is high investment costs and high LCOH due to relatively low annual hydrogen production.

Scenario 3: Price controlled and a hybrid model

In this scenario, the 5 MW PEM electrolyzer system operates at full load only during low electricity prices and switches to minimum load (10%) when it exceeds €66/MWh to reduce total costs. The model, analyzed using REE's 2024 hourly average price day ahead market electricity price data for Spain, determined the optimal price threshold to be €66/MWh. Operating efficiently below this threshold lowers the average electricity cost to 31.19 €/MWh. As a result, the electrolyzer's annual capacity factor was calculated as 59.5% and LCOH 3.73 €/kg H₂ as shown in **Fig. 2**. The hybrid configuration approximately reduced %22 cost compared to the fixed grid-supply scenario from 4.61 €/kg to 3.73 €/kg. Due to price flexibility, hydrogen production is concentrated during low-price periods, while electrolyzers power is decrease load down to %10 during high-price hours. This approach maintains system efficiency while effectively suppressing electricity costs.

CONCLUSIONS

A comparative analysis of three different operating scenarios shows that electricity price dynamics play a decisive role in green hydrogen production. Continuous grid-fed operation provides the highest H₂ production at 796,364 kg/yr, but is emissions-intensive due to its production mix and higher LCOH 4.61€/kg H₂. While fully renewable off-grid systems eliminate emissions, they are uncompetitive due to their LCOH 8.19€/kg H₂ due to their low capacity factor. The hybrid model achieved the lowest LCOH 3.73 €/kg H₂, achieving the optimal balance between cost and sustainability.

Table 2.Comparative analysis of three operation scenarios for a 5 MW PEM electrolyzer

Parametre	Scenario 1	Scenario 2:	Scenario 3
Electricity Source	Grid	Solar (6 MW), Offgrid	Price Controlled Grid
Load Range	%100	%10-100	%10-100
Average Annual Electricity Price	63.05 €	0	31.19 €
Capacity Factor	%100	%24.3	%56.1
LCOH	4.61 €/kg	8.19 €/kg	3.73 €/kg
H2 Production Yearly	796,364 kg/yr	193,828 kg/yr	446,891 kg/yr

NOMENCLATURE

CAPEX — Capital expenditure, €/kW
 OPEX — Operational expenditure, €/yr
 WACC — Weighted Average Cost of Capital, %
 LCOH — Levelized Cost of Hydrogen, €/kg H₂
 SEC — Specific energy consumption, kWh/kg H₂
 Pei — Rated power of electrolyzer, MW
 q_{er} — Electrolyzer efficiency, %
 CF — Capacity factor, %
 m_{h2} — Hydrogen mass flow rate, kg/h
 HHV_{h2} — Higher heating value of hydrogen, kWh/kg H₂
 t — Operation time, h/yr
 Eei — Annual electricity consumption, MWh/yr
 Cei — Electricity cost, €/MWh

Greek letters

η — Efficiency

Subscripts

el — Electrolyzer H₂ — Hydrogen

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THE FINANCIAL AND ECONOMICAL ASSESSMENT OF INTEGRATING GREEN HYDROGEN IN THE TRANSITION TOWARDS ENVIRONMENTAL SUSTAINABILITY OF DATA CENTRES

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ABSTRACT – OH6

The paper aims at evaluating the technical, financial and economic viability of developing a novel back-up power supply that uses 100% renewable energy during power outages for data centres. The proposed technical scenarios, consisting in using solar energy, energy storage solutions and green hydrogen were evaluated from a technical and financial point of view, in order to assess the financial viability of the solution with regard to stakeholder expectations.

The authors also analysed the social impact of the proposed technical scenario, with regard to the avoidable greenhouse gasses emissions, the conservation of fossil fuels in the context of energy security, and the operational safety impact, leading to a risk matrix that can prove useful for investors when deciding upon the back-up power supply approach. The paper also presents a sensitivity analysis regarding the relevant variables that have a significant influence on the overall viability of the project, such as the CAPEX, electricity price, distribution system reliability indices etc.

Keywords: Green Hydrogen, Energy Performance Assessment, Renewable Energy Sources, Back-up Power Supply, Data Centre energy management

1. INTRODUCTION

Data centres are estimated to become one of the most energy intensive end-users by the end of 2030, with a global estimated demand of 945 TWh/year [1], with a yearly grow rate of electricity demand of 15%/year in the 2025 – 2030 period [2], and a total forecasted share of 3% of the global electricity demand [1]. According to additional market research [3], the deployment of new data centres could generate an increase of power demand of up to 30% for the EU.

More than 86% of IT leaders consider reliability as the most critical factor when designing a data centre. 74% of the data centre market experienced at least one significant outage over the last year, with 46% experiencing an average of 1.5 outages/year. The loss of power was responsible for 13% of these events [4]. This statistical analysis is relevant, as research showed that the average cost for data centers downtime can range between 427 USD up to 9,000 USD per minute [5].

The transition towards environmental sustainability, imposed by en-force European Directives [6] - [8], generates an additional burden to data centre development in Europe, as most of the conventional back-up power supply used today are represented by a mix of UPS and fossil fuel powered electrical generators.

International literature review proves the general importance of data center power supply. In [9] the authors have analyzed a system that includes PV panels, a hydrogen microturbine and fuel cells (supplied with green hydrogen) and power batteries for supplying energy to a data center. A technical and economic analysis has been performed aiming at comparing the costs of energy supply for data center.

In [10] the authors have presented different scenarios of an energy system for a data center. They have performed an economic and sustainability analysis of all scenarios emphasizing the cost of energy supply.

In [11] an economic analysis on the hydrogen-powered data center is presented. Configurations of hydrogen-powered and traditional data centers are compared and the differences focus on backup power system, converter/inverter, fuel cell subsystem, carbon emission, hydrogen and electricity consumptions. Economic analysis is conducted to evaluate the feasibility to power the data center with hydrogen energy source.

In [12] authors have performed a survey of the current state of data centers and hydrogen-based technologies along with a discussion of the hydrogen storage and infrastructure requirements needed for large-scale backup power applications at data centers. Thermodynamic, exergetic and thermoeconomic analyses [13] were performed on two types of double-effect LiBr–water absorption refrigeration systems (ARS) for use with a 5-kW high-temperature proton exchange membrane fuel cell (HT-PEMFC) as a heat source.

2. DATA CENTER MODELING

The present paper aims at evaluating the technical, financial and economic viability of a novel back-up power supply using 100% renewable energy during power outages for data centers.

The modeling for the data center was based on a Tier II design (N+1) [14] – see Fig.1 – in which the back-up power supply is powered by two UPS systems (1 normal use and 1 for back-up) in case of very short-term interruptions in the general power supply or until the back-up power generators start and by two diesel fueled generators (1 normal use and 1 for back-up) in case of medium to long term interruptions. The modeling of the base case scenario was conducted considering the hypotheses presented in Table 1.

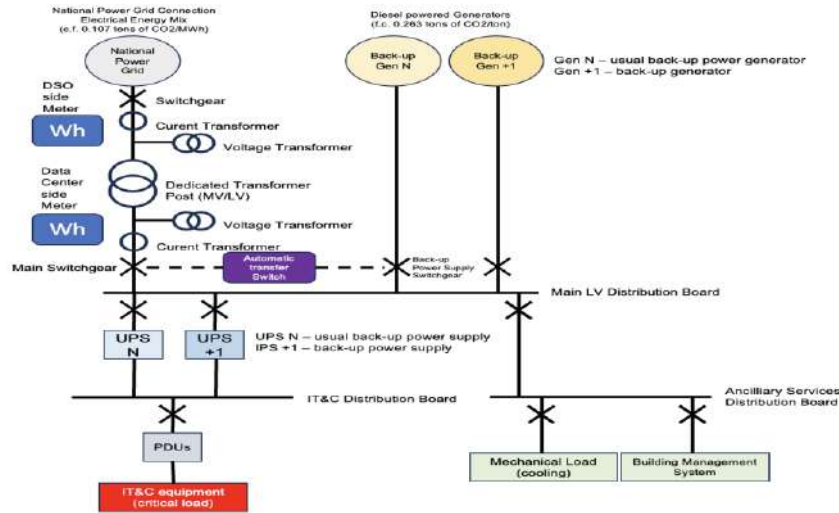


Fig. 1. Base Case scenario

Table 1. Hypotheses for base case scenario

Parameter	Notation	Value	Measuring Unit
Total installed power	$P_i^{total} = P_i^{critical} + P_i^{HVAC} + P_i^{BMS}$	10	kW
Back-up Gen rated capacity	P_r^{GEN}	5.5	kW
UPS rated capacity	C_r^{UPS}	3	kWh
Number of normal interruptions considered	n_i^{normal}	1	interruptions/year
Duration of normal interruptions	t_i^{normal}	4	hours/event
Number of critical ⁽¹⁾ interruptions considered	$n_i^{critical}$	0.33	interruptions/year
Duration of critical interruptions	$t_i^{critical}$	48	hours/event

(1) – critical interruptions caused by abnormal weather conditions, 1 interruption per year, every 3 years.

Based on the input data, the environmental impact and financial cost was determined for the Base Case scenario. The methodology and results are presented in Table 2.

Table 2. Base Case Scenario operational assessment

Result	Equation	Value	M.U.
Normal interruptions – total energy demand	$W^{normal} = P_i^{total} \cdot P_r^{normal} \cdot t_i^{normal}$	36	kWh/year
Total financial cost	$C_{total}^{normal} = C_{el}^{normal} + C_{diesel}^{normal}$	19.07	EUR/year
Total economic cost	$C_{economic}^{normal,total} = A_{CO_2}^{normal,total} \cdot p_{CO_2}$	0.23	EUR/year
Critical interruptions – total energy demand	$W^{critical} = P_i \cdot P_r^{critical} \cdot t_i^{critical}$	240	kWh/year
Total financial cost	$C_{total}^{critical} = C_{el}^{critical} + C_{diesel}^{critical}$	133.96	EUR/year
Total economic cost	$C_{economic}^{critical,total} = A_{CO_2}^{critical,total} \cdot p_{CO_2}$	1.52	EUR/year
Regular operation of the data center	$W_y = P_i^{total} \cdot t_f \cdot k_{av} - W^{normal} - W^{critical}$	69.804	kWh/year
Electricity cost	$C_{el}^y = W_y \cdot p_{el}$	11,169	EUR/year
Total economic cost	$C_{economic}^y = A_{CO_2}^y \cdot p_{CO_2}$	0.59	EUR/year
Base Case Scenario Aggregation			
Total financial cost	$C_{total} = C_{total}^{normal} + C_{total}^{critical} + C_{el}^y$	11,322	EUR/year
Total economic cost	$C_{economic}^{total} = C_{economic}^{normal,total} + C_{economic}^{critical,total} + C_{economic}^y$	2.35	EUR/year

As shown, the proposed topology for the power supply of the data center should cover three operational scenarios: **A.** Normal Operation Conditions, **B.** Short term power outages and **C.** Long term power outages. Fig. 2 shows the architecture of the power supply.

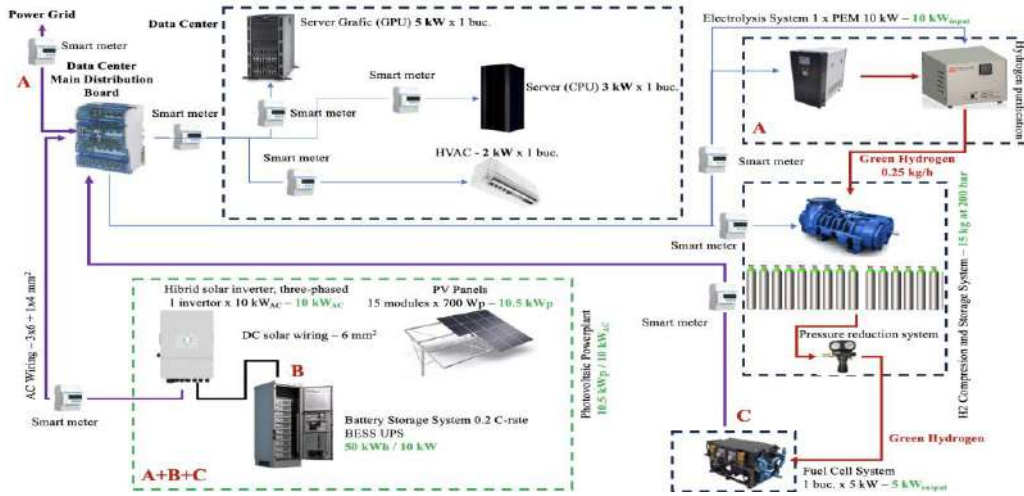


Fig. 2. Proposed data center architecture

The technical and financial inputs are presented in Table 3, whilst the operational, financial and economical results of the proposed architecture and methodology are presented in Table 4.

Table 3. Technical and financial input for the proposed architecture

Component / Parameter	Notation / Equation	Value	Measuring Unit
Photovoltaic Powerplant	P_l^{DC} / P_l^{AC}	10.5 / 10	kWp / kW _{AC}
CAPEX	$CAPEX^{PV} = c_s^{PV} \cdot P_l^{DC}$	5,512.50	EUR
OPEX	$OPEX^{PV} = oc_s^{PV} \cdot P_l^{DC}$	157.50	EUR/year
Yearly Energy Production ⁽¹⁾	W_y^{PV}	12,881.50	kWh/year
Battery Energy Storage System	BESS	50/10	kWh/kW
CAPEX	$CAPEX^{BESS} = c_s^{BESS} \cdot C_{BESS}^r$	6,000.00	EUR
OPEX	$OPEX^{BESS} = oc_s^{BESS} \cdot C_{BESS}^r$	150.00	EUR/year
Electrolyser System	PEM	10	kW
CAPEX ⁽²⁾	$CAPEX^{H_2,PEM}$	20,000.00	EUR
OPEX	$OPEX^{H_2,PEM} = oc_s^{H_2,PEM} \cdot P_r^{PEM}$	640.00	EUR/year
Fuel Cell System	PEM	5	kW
CAPEX ⁽²⁾	$CAPEX^{H_2,PEM}$	7,500.00	EUR
OPEX	$OPEX^{FC} = oc_s^{FC} \cdot P_r^{FC}$	150.00	EUR/year

(1) – Determined by simulating the PV powerplant with the specialized PVSyst software (<https://www.pvsyst.com/en/>).

(2) – Based on budgetary offers obtained by the authors.

As it can be seen in Table 3, the total CAPEX (Capital Expenditure Costs) for implementing the proposed project would amount to approximatively 39,012.50 EUR, whilst the OPEX (Operational Expenditure Costs) would be of 1,097.50 EUR/year. The proposed system would operate entirely on renewable energy, produced by the PV Powerplant. Out of the entire estimated production of 12,881.50 kWh/year, 54.35 kWh/year would be used to charge the BESS and 705 kWh/year would be used to produce and store the green Hydrogen. The methodology and results of the analysis are presented in Table 4.

Table 4. Proposed scenario operational assessment

Result	Equation	Value	M.U.
Total net CAPEX	$CAPEX^{total,net} = CAPEX^{total} - C^{GENSET}$	36,612.50	EUR
Total OPEX	$OPEX^{total} = OPEX^{PV} + OPEX^{BESS} + OPEX^{H_2,PEM} + OPEX^{FC}$	1,097.50	EUR/year
Total financial savings	$\Delta C_{savings} = \Delta W_{saving} \cdot p_{el} + \Delta D_{saving} \cdot p_{diesel}$	2,091.61	EUR/year
Total economic savings	$C_{economic}^{total} = \Delta A_{CO_2}^y \cdot p^{CO_2}$	105.52	EUR/year

3. RESULTS AND DISCUSSION

To get a better interpretation of the obtained results, an economic analysis was performed. The proposed solution has been compared with the basic scenario, and the main results are: NPV=-27,856 Eur and SPBP=21 years. A sensitivity analysis was conducted showing that the project can be attractive if 63.5% of funding are coming as grant. If the data center owner obtains such a non-refundable or low interest financing, the project will generate a NPV of 5,818 EUR, with an IRR of 14%/year making it viable for deployment.

CONCLUSIONS

A novel hybrid renewable back-up power supply architecture for data centers was proposed and analysed. It was proven that from a technical and energy demand / supply point of view the proposed system can easily cover even the worst-case scenario interruptions, with a net zero environmental impact.

However, at the current prices the proposed system seems to lack the economic viability. To make the project attractive 63.5 % of funding should come as a grant. A more in-depth analysis could help increase the attractiveness of implementing a hybrid, renewable energy based alternative solution.

ACKNOWLEDGEMENT

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OXIDATION OF IRON(II) MONOSULFIDE BY HYDROGEN SULFIDE WITH THE PRODUCTION OF MOLECULAR HYDROGEN

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ABSTRACT – PH5

Understanding the reaction mechanism of the oxidation of iron(II) monosulfide (FeS) with hydrogen sulfide (H₂S) can be essential because the reaction can have important applications, because in addition to pyrite (FeS₂), the reaction releases molecular hydrogen (H₂), which is a clean fuel. Therefore, the interaction between iron(II) monosulfide and hydrogen sulfide was analyzed by Density Functional Theory (DFT) calculations. The corresponding physical properties of the species involved in the process (FeS, H₂S, H₂ or FeS₂) were determined. The reaction energy associated with the process $\text{FeS} + \text{H}_2\text{S} = \text{FeS}_2 + \text{H}_2$ is -311.5 kJ mol⁻¹. The main reaction intermediate analyzed was FeS-SH₂, a species that characterizes the adsorption of hydrogen sulfide on the FeS surface.

Keywords: FeS oxidation, FeS₂, H₂ production

1. INTRODUCTION

Iron monosulfide phases (FeS) are formed in reducing media. Therefore, when they come into contact with an oxidant such as molecular oxygen (O₂) or ferric iron (Fe³⁺) they oxidize and produce sulfuric acid (H₂SO₄).



The formation of sulfuric acid leads to the phenomenon of Acid Mine Drainage (AMD), through which the environment is contaminated with toxic species of copper, cadmium, lead or arsenic. Therefore, the oxidation of iron(II) monosulfides with molecular oxygen or ferric iron has aroused the interest of many researchers [1,2]. In contrast, the oxidation of iron(II) monosulfide (FeS) with hydrogen sulfide (H₂S) has attracted much less attention, and, consequently, few details are known about the mechanism of interaction between FeS and H₂S [3,4].



Knowledge the reaction mechanism of this process can be essential because the reaction of iron(II) monosulfide with hydrogen sulfide can have important applications, because in addition to pyrite (FeS₂), the reaction generates molecular hydrogen (H₂). Hydrogen is a fuel that can be used to produce clean energy [5-10]. In the combustion process, the main products are energy and water, a harmless product for the environment. However, hydrogen production poses significant challenges, especially since most hydrogen is currently produced from fossil fuels. The reaction (3) may be an alternative for obtaining hydrogen, starting from inorganic species.

The objective of this study was to analyze the interaction between iron(II) monosulfide and hydrogen sulfide through Density Functional Theory (DFT) calculations.

2. COMPUTATIONS

Density Functional Theory computations were performed with the BP energy functional using Amsterdam Density Functional program package and the DZP basis set [11]. The corresponding bonding energies (E) of the species involved in the reaction (3) were determined. E was also determined for the adsorption product of H₂S on FeS. All data obtained for the mentioned species are those of optimized structures. Reaction energies (E_r) were determined as the difference between the bonding energies of the reaction products and the bonding energies of the reactants. Convergence was achieved for all the calculations presented.

3. RESULTS AND DISCUSSION

Table 1 presents the bonding energies of the species marked as: FeS, H₂S, FeS₂, H₂ and FeS-SH₂. The optimized structure of the FeS (i.e. (FeS)₂) species is shown in Fig. 1a. Fig. 1b shows the optimized structure of H₂S. The bonding energy values associated with these structures are presented in Table 1. Also presented in Table 1 are the bonding energies of FeS₂ (i.e. (FeS₂)₂) and H₂. The corresponding structures are shown in Figs 1c and 1d. Using the data in Table 1, the reaction energy (ΔE_r) of reaction (3) was evaluated. The value obtained is negative (Table 2), as is the value of the free enthalpy of reaction (ΔG^r₂₉₈ = -33.1 kJ mol⁻¹) which is calculated from the values of the free enthalpy of formation (ΔG⁰₂₉₈) of the corresponding species existing in the literature [12,13].

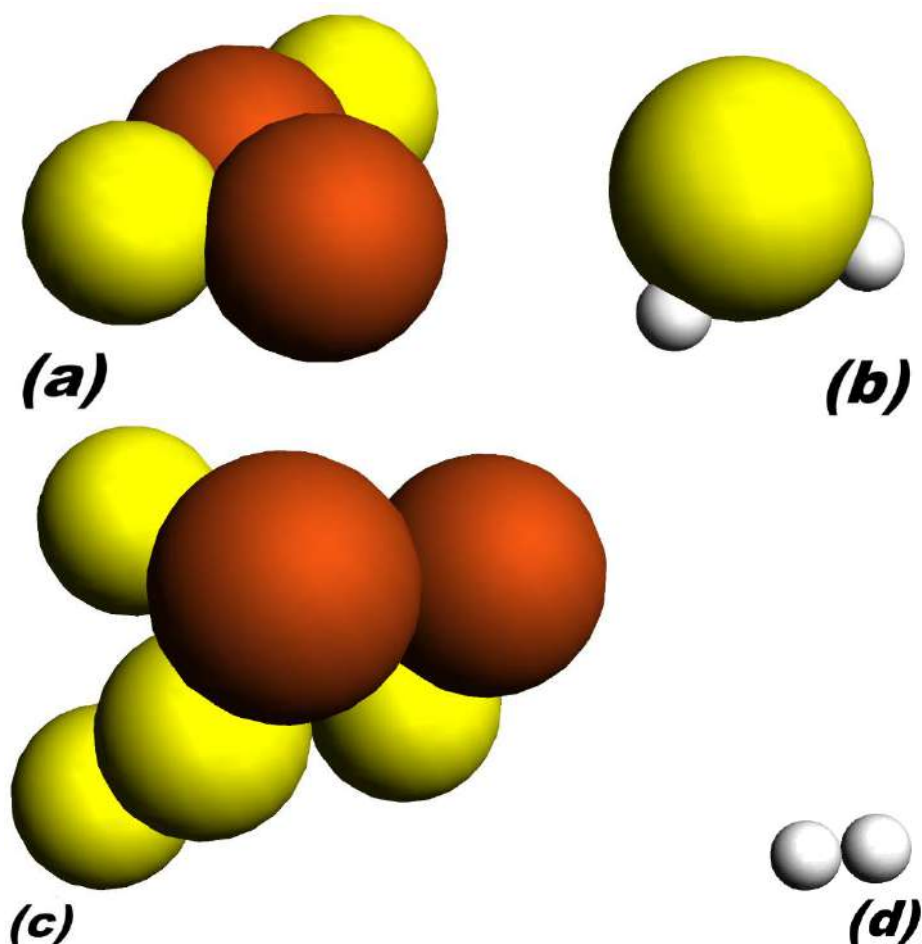


Fig. 1. Optimized structure of (a) FeS (i.e. $(\text{FeS})_2$), (b) H_2S , (c) FeS_2 (i.e. $(\text{FeS}_2)_2$) and (d) H_2 . Fe atoms are brown, sulfur atoms are yellow, and hydrogen atoms are white

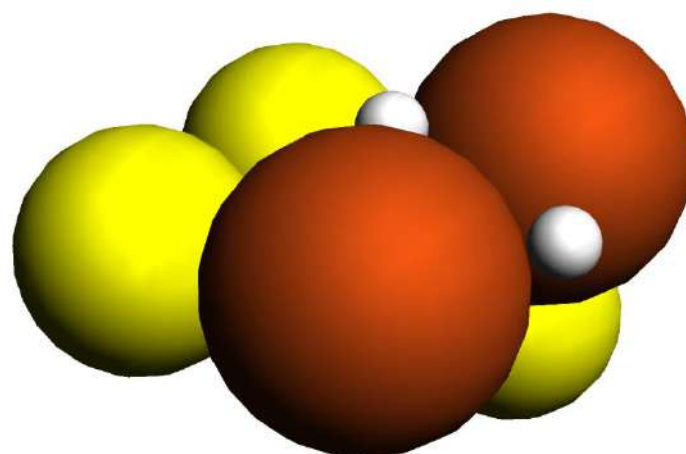
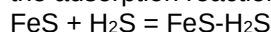


Fig. 1. Optimized structure of FeS-SH_2 (i.e. $(\text{FeS})_2\text{-SH}_2$). The Fe atoms are brown, the sulfur atoms are yellow, and the hydrogen atoms are white

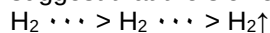
Table 1. Bonding energies of the species marked as: FeS, H_2S , FeS_2 , H_2 and FeS-SH_2

Species	E / kJ mol^{-1}
FeS (i.e. $(\text{FeS})_2$)	-2486.3
H_2S	-1051.8
FeS_2 (i.e. $(\text{FeS}_2)_2$)	-3206.6
H_2	-643.0
FeS-SH_2 (i.e. $(\text{FeS})_2\text{-SH}_2$)	-2926.0

Using the bonding energy of the FeS-H₂S (i.e. (FeS)₂-SH₂) species from Table 1, the energy associated with the adsorption reaction of H₂S on FeS was evaluated:



The value obtained for the reaction energy is presented in Table 2. The value being positive shows that the adsorption process of H₂S on FeS is not spontaneous, and reaction (4) may be the slowest step of the overall process (Eq. (3)). Such a conclusion contradicts the results obtained by Rickard and Luther [4] which suggest that the slowest step is a diffusion process, that of H₂, one of the reaction products.



Therefore, new investigations are needed to establish as clearly as possible the importance of a chemical process, such as reaction (4), in the transformation of H₂S into H₂. Since in the case of a chemical process certain existing bonds are broken and new ones are formed, it is necessary to determine additional physical characteristics of the reacting species.

Table 2. The reaction energy (ΔE_r) for reactions (3) and (4)

Reaction	$\Delta E_r / \text{kJ mol}^{-1}$
(3)	-311.5
(4)	+612.1

CONCLUSIONS

The main conclusions of the study are:

- The reaction energy value for the reaction of H₂ formation from FeS and H₂S is negative, which shows that the process is spontaneous.
- The reaction energy value for H₂S adsorption on FeS indicates the possibility that this reaction is the slowest rate step of the H₂ formation process.
- Details of the mechanism of reaction (3) can be obtained by determining additional physical characteristics of the species participating in reactions (3) and (4). Understanding of the mechanism is very important to evaluate the correct potential of using reaction (3) as a hydrogen-generating reaction.

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COMPARATIVE SIMULATION OF GREEN HYDROGEN PRODUCTION VIA WATER ELECTROLYSIS FROM PHOTOVOLTAIC, WIND, AND HYBRID SYSTEM IN TRNSYS

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ABSTRACT – OH15

This study evaluates four scenarios for green hydrogen production via water electrolysis, using an alkaline electrolyzer powered by renewable energy, or supply with energy for the grid (yellow hydrogen). Simulations were performed with TRNSYS using meteorologic data from Meteonorm 8 for Galbiori, Constanța, Romania. The four models for the analyzed scenarios were created in TRNSYS as follows:

- 60 kW alkaline electrolyzer powered by electricity produced using photovoltaic panels (PV).
- 60 kW alkaline electrolyzer powered by electricity produced using wind turbines.
- 60 kW alkaline electrolyzer powered by electricity produced 50% from PV and 50% from wind turbines.
- 60 kW alkaline electrolyzer powered by electricity from the national power grid.

The objectives for the modeling and simulation in TRNSYS were as follows:

- Calculation of the power production potential from PV.
- Calculation of the power production potential from wind turbines.
- Calculation of the annual electricity production from PV.
- Calculation of the annual electricity production from wind turbines.
- Calculation of the annual electricity production from both PV and wind turbines.
- Calculation of the hydrogen production for all four analyzed scenarios.
- Calculation of the electrolyzer operating period over the year.

The results of the study highlight the following:

- The PV system operates 3,615.85 h/year, producing 38,640.77 Nm³/year of hydrogen, while the wind system operates 4,588.5 h/year, producing 40,716.95 Nm³/year. Continuous energy supply boosts hydrogen production to 127,216.68 Nm³/year and improves system efficiency and electrolyzer life cycle.
- The hybrid system operating hours increased by about 1,000 h/year compared to PV and 400 h/year compared to wind. The hydrogen production flow rate increased slightly to 41,769.21 Nm³/year. The differing source potentials and lower power per source extended operation time but reduced electrolyzer efficiency.

Keywords: renewable energy, hydrogen, electrolysis, wind, photovoltaic

1. INTRODUCTION

Hydrogen is expected to play a key role in the swift away from pollution energy sources (coal, gas, oil) due to its potential as clean energy vector. Currently, the use of hydrogen in the energy sector is limited; however, a significant increase in its importance is anticipated with the large-scale implementation of green hydrogen production technologies and the progressive decarbonization of the economy.

The simulations were carried out in the TRNSYS program, whose hydrogen module is dedicated to simulating energy systems that include hydrogen production, storage, and utilization.

The electrolyzer was powered directly by wind, photovoltaic, or hybrid energy sources. This is important because the lifetime of the electrolyzer decreases significantly when it is powered by a highly variable energy source, and even more so when it experiences long periods without electrical supply.

2. SYSTEM DESCRIPTION AND METHOD

To implement project in the TRNSYS software, components from the hydrogen and electric module were used, as well as from other components, depending on the specific requirements of each individual scenario. The TRNSYS-based model includes PV, wind turbine, hybrid systems, and a 60 kW alkaline electrolyzer (Type 160). The simulations use Meteonorm 8 data for Galbiori, Romania. The hybrid scenario shares equal power contribution from PV and wind. The electrolyzer efficiency and hydrogen output were compared across all configurations.

The following is a detailed enumeration of the system components used: photovoltaic panels; wind turbine; controller for constant power mode and variable power mode; alkaline electrolyzer; converter (DC/DC) or inverter (AC/DC); busbar and compressor.

- 60 kW alkaline electrolyzer powered by electricity produced using photovoltaic panels (PV).
- 60 kW alkaline electrolyzer powered by electricity produced using wind turbines.
- 60 kW alkaline electrolyzer powered by electricity produced 50% from PV and 50% from wind turbines.
- 60 kW alkaline electrolyzer powered by electricity from the national power grid.

Based on the results of the TRNSYS modeling and simulation, the four scenarios were compared on the following factors: operating time; annual amount of hydrogen produced and electrolyzer operating efficiency. An advanced alkaline electrolyzer (60 kW, TRNSYS Type 160) was used for the simulations. Hydrogen generation through water electrolysis was modelled as a function of temperature, current density, and power input. Efficiency was calculated according to Faraday's law and adjusted for thermal losses.

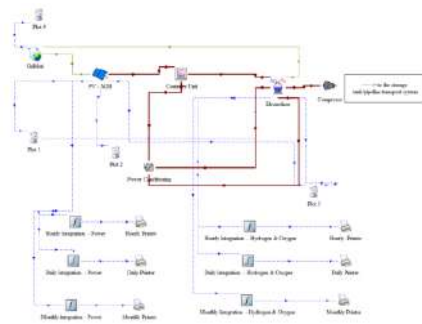


Fig. 1. Schematic of the hydrogen system in TRNSYS– photovoltaic power source

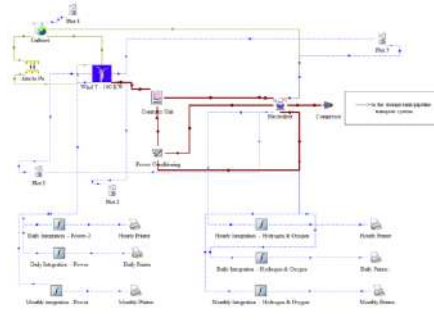


Fig. 2. Schematic of the hydrogen system in TRNSYS – turbines power source

The Fig.1 and 2 shows the components of a hydrogen production facility based on water electrolysis, in which the electrical energy required for the operation of the electrolysis is generated using wind turbines and photovoltaic panels.

3. RESULTS AND DISCUSSION

The TRNSYS simulations provided hourly profiles of energy production and hydrogen generation for each of the four configurations. The results focus on electrolyzer operating hours and annual hydrogen yield.

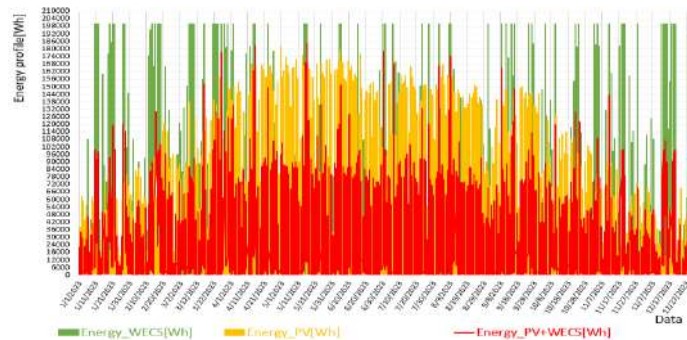


Fig. 3. Hourly electric energy production throughout the year

Fig. 3. Presents the annual energy production profiles for PV, wind, and the hybrid system, and is also relevant to the overall comparison.

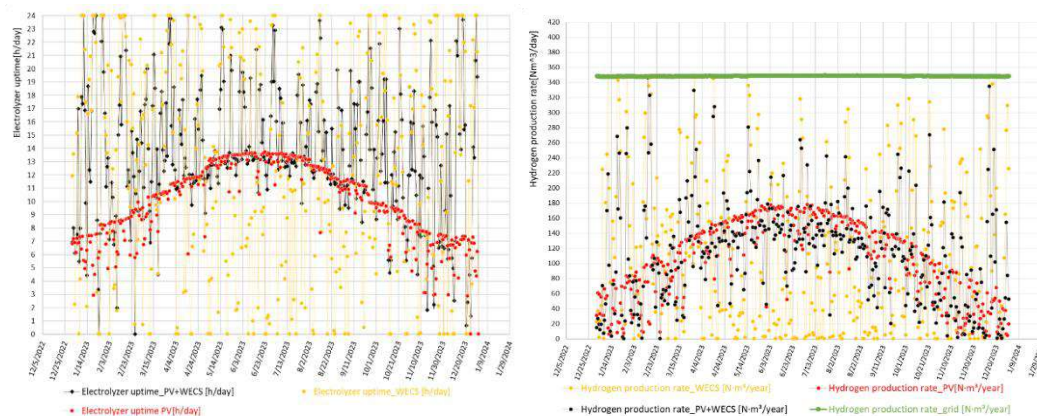


Fig. 4. Variation of the daily operating hours of the electrolyzer when powered directly by the PV system, the WECS, and the hybrid system (50% PV + 50% WECS)

Fig. 5. Variation of the daily hydrogen production rate of the electrolyzer when powered directly by PV, WECS, a hybrid system (50% PV + 50% WECS), and the grid

Fig. 4. Presents the daily operating hour profile to the alkaline electrolyzer is presented for all system where the PV system operated the maximum 14 hours per day and minimal approximately 5 hour per day while WECS and the HYBRID system operate the maximum 24 h/day and minimal 0 h/day with several days of no energy production or low energy production. The hybrid system operated more time during the year.

Fig. 5. Presents the variation in hydrogen production during water electrolysis when the system is supplied with electrical energy from the four different sources. The alkaline electrolyzer, when is supply by PV, WECS and Hybrid system operates intermittently at variable power, temperature variable and current density, which decrease hydrogen production rate and operating life of the electrolyzer.

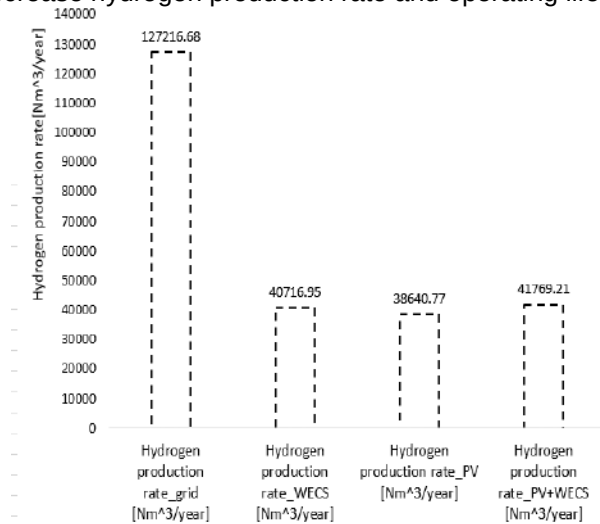


Fig 6. Representation of the hydrogen production rate per year

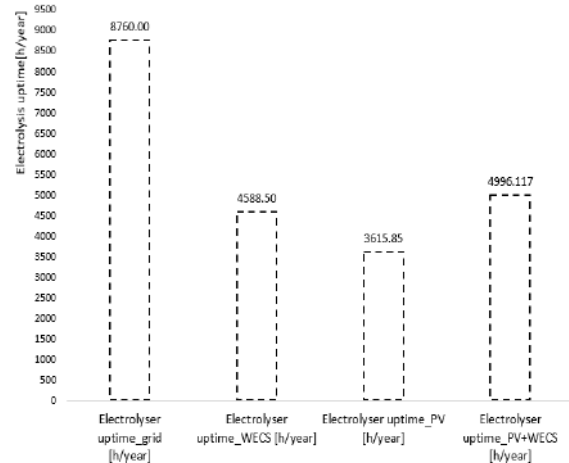


Fig 7. Representation of the number of operating hours per year of the electrolyzer

Fig. 6 and 7 present the annual values cumulative values of hydrogen production flow rate and the number of operating hours of the alkaline electrolyzer for the four system.

Table 1 summarizes the cumulative monthly and annual hydrogen production and operating hours of the alkaline electrolyzer for the four systems (PV, WECS, HYBRID SYSTEM and GRID).

Tabel 1. Centralizer - Hydrogen Production Rate and Operating Hours

Data	Flow rate grid [N·m³/year]	Flow rate WECS [N·m³/year]	Flow rate PV [N·m³/year]	Flow rate PV+WECS [N·m³/year]	Electrolyzer uptime_grid [h/month]	Electrolyzer uptime WECS [h/month]	Electrolyzer uptime PV [h/month]	Electrolyzer uptime PV+WECS [h/month]
1/1/2023	10764	4447	1379	2656	744	465	208	421
2/1/2023	9750	3987	1875	2870	672	411	216	359
3/1/2023	10800	4306	3194	3689	744	457	301	456
4/1/2023	10457	3438	4003	4035	720	390	336	429
5/1/2023	10813	2870	4738	4505	744	344	400	451
6/1/2023	10469	2611	4788	4397	720	325	399	463
7/1/2023	10822	2561	4946	4539	744	315	408	456
8/1/2023	10821	2676	4599	4272	744	324	372	449
9/1/2023	10466	3084	3770	3664	720	362	322	420
10/1/2023	10808	3241	2872	2836	744	377	274	379
11/1/2023	10453	3347	1426	1975	720	383	192	335
12/1/2023	10795	4149	1050	2330	744	437	189	379
Total/year	127217	40717	38641	41769	8760	4589	3616	4996

CONCLUSIONS

The TRNSYS simulations compared four configurations for green hydrogen production using a 60kW alkaline electrolyzer. The PV system operated 3616 h/year, producing 38641 Nm³ of hydrogen, while the wind system reached 4 589 h/year and 40717 Nm³. The hybrid configuration achieved about 1000 additional operating hours compared to PV and 400 more than wind, with a slightly higher hydrogen yield (41769 Nm³).

Although the hybrid source improved operating stability, the electrolyzer efficiency decreased due to temperature fluctuations under variable renewable input. Continuous energy supply (grid) resulted in the highest hydrogen yield (127217 Nm³) but lacked renewable contribution. These findings indicate that hybrid renewable systems can enhance utilization time and stability of hydrogen production units. Future work will focus on integrating thermal management and buffer energy storage to maintain optimal electrolyzer performance under fluctuating renewable conditions.

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GREEN HYDROGEN IN ROMANIA'S DISTRICT HEATING SYSTEMS – ECONOMIC IMPACTS ON END-CONSUMERS AND RISK ASSESSMENT

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ABSTRACT – OH7

Through the European Green Deal, the European Union aims for Europe to become the first climate-neutral continent by 2050, and through the 2022 RePowerEU initiative, it seeks to reduce dependence on natural gas and accelerate the use of renewable energy sources. In this context, green hydrogen emerges as a key energy carrier in the energy transition.

Successful integration of hydrogen into District Heating Systems (DHS) requires careful consideration of its effects on end consumers and the cost of thermal energy supply. Thus, new technologies and fuels must not only be technically feasible but also economically acceptable for users, relative to the population's level of affordability.

The aim of the article is to analyze the integration of green hydrogen into DHS, assessing the effects on the final price through a comparative financial modeling, based on the cost scenarios for gas and green hydrogen and the additional investments required for the infrastructure. The article also includes the associated risks, focusing on the economic impact and potential consequences of changing the fuel source. The results show that although the costs of green hydrogen are high, the evaluation of end consumers and inclusion in calculation methodologies are essential for strategic decisions.

Keywords: Green Hydrogen, District Heating Systems, Energy Transition

1. INTRODUCTION

Currently, worldwide fossil fuels are indispensable in the economy, and these are limited resources. If the current pace of consumption of fossil fuels continues, they will become insufficient in the second half of the Twenty-First Century. High consumption of fossil fuels in the second half of the twentieth century contributed to global warming and triggered climate change. In this context, various options were analyzed to identify alternative energy sources capable of reducing dependence on fossil fuels and greenhouse gas (GHG) emissions. [1]

The European Green Deal aims to position Europe as the first climate-neutral continent by 2050. Key targets include reducing emissions by at least 55% by 2030 (compared to 1990 levels) and ensuring a just transition. [2]

DHS play a vital role in urban areas by increasing energy efficiency, enabling waste heat recovery, supporting the integration of renewable energy sources, and reducing GHG emissions. [3]

Hydrogen offers the potential for integration into DHS, either through direct use in dedicated equipment or by blending it with natural gas in existing infrastructure. Transitioning to hydrogen requires a clear, predictable and non-discriminatory policy framework that allows investment and market development without affecting competitiveness. [4]

Green hydrogen is a renewable energy source produced by electrolysis of water using electricity from renewable sources, with high storage potential and flexibility, allowing to harness surplus energy and balance networks. [5]

The production of 1 kg of hydrogen by electrolysis requires about 52 kWh of electricity. The hydrogen obtained has a superior calorific value of 39.4 kWh, which implies a theoretical maximum efficiency of 75%, the remaining 25% representing losses, mainly thermal. These losses can be reduced by coupling energy sectors, especially if production facilities are located near urban areas, where low-temperature heating networks could harness waste heat, increasing the attractiveness of the use of electrolysis. [6]

Building from this context, the article aims to assess the economic impact of the integration of green hydrogen in the DHS in Romania, focusing on the costs incurred by the final consumers.

District Heating Systems

The first DHS appeared in the United States in the 1880s and were adopted in Europe starting from the 1920s. Over time, these systems have evolved into several technological generations, each characterized by significant improvements in efficiency and performance. [7]

The first (1GDH) used high-temperature steam and fossil fuels. The second (2GDH), emerging in the 1930s, switched to pressurized hot water for improved safety and efficiency. The third (3GDH), developed in the 1970s–1980s, introduced underground pre-insulated pipes and cogeneration, boosting energy performance. The fourth (4GDH), focuses on lower temperatures, renewable integration, and waste-heat recovery to enhance sustainability. In Europe, all generations coexist, though third-generation systems remain the most common. [8]

The emerging fifth generation of DHS (5GDH) explores near-ground temperature, bidirectional systems using distributed heat pumps and renewable energy, aiming to enable simultaneous heating and cooling and support full network decarbonization. [9]

Building on this generational evolution, European systems gradually transitioned from transporting heat through steam to using hot water as the heat transfer medium, which proved to have major advantages. Consequently, most newly implemented DHS in Europe use hot water, while older steam-based systems have been either replaced or adapted for hot water use. [10]

The development of DHS in Europe also influenced Romania and the first DHS were introduced in the 1970s, but their substantial expansion took place in the early 1980s, in the context of an accelerated process of industrialization and urbanization. [8]

In 1989, 351 localities were equipped with DHS, and in 2022, 49 operators are responsible for 49 systems, which collectively serve 50 locations in 28 counties and Bucharest. With a total installed capacity of 7,501 MW, these systems provide heating and hot water to urban areas. The total length of the DHS network in Romania is 4,624 km, which corresponds to an indicator of 2.42 km of pipeline per 1,000 inhabitants.

In present, renewable and fossil energy sources for Romania's DHS and cooling (DHC) systems are dominated by natural gas (79.9%), followed by coal (14.4%), biomass (2.3%), fuel oil (2.1%), nuclear (0.7%), and geothermal (0.6%). Current systems are third generation, operating below 100 °C with average heat distribution losses of 35%.

Thus, the DHS in Romania provides thermal energy for over 1 million households, representing 11% of the total housing stock of the country, of about 9.6 million apartments and houses maintaining operational continuity and reliable heat supply to consumers remains a key priority. [11]

Green hydrogen integration and infrastructure adaptation

Romania has a long tradition in hydrogen production, dating back to the rapid growth of the chemical industry in the mid-20th century. At Târnăveni, ammonia was produced for the first time globally via thermocatalytic methane conversion, which also generated hydrogen. Thus, in the hydrogen economy, the Romanian energy system has two major advantages: significant renewable energy resources and an existing natural gas distribution network. Although the theoretical potential of renewable energy is high, the amount economically exploitable with current technology is much more limited. [12]

According to the literature, one of the ways to produce green hydrogen is by decomposing water through thermolysis, electrolysis or photo electrolysis processes. Among these, electrolysis is considered the most effective method, as it does not produce carbon dioxide (CO₂) or other greenhouse gases. [13]

European Studies and projects show that the integration of hydrogen into existing gas infrastructure can generate significant cost savings for households, industry and transport, avoiding major investments in new grid infrastructure. Early adoption of hydrogen-compatible equipment and infrastructure greatly reduces transition costs, while delaying implementation increases additional expenses. Converting natural gas to green or low-carbon hydrogen allows continued use of existing networks and warehouses, providing cost savings for consumers.

The existing natural gas network plays a key role in the transport and storage of hydrogen and is considered a key element for the transition to a climate-neutral energy system. This can be used either by mixing hydrogen with natural gas at concentrations up to 10-20% volume without major changes, or by completely reconverting pipelines to transport 100% hydrogen. The experience of European and international pilot projects such as HyDeploy (UK), HyBlend (USA), NATURALHY, HIGGS, THyGA, H21, H100 and HYNET demonstrates the feasibility of integrating hydrogen into existing infrastructure, highlighting the importance of safety, materials and operating pressures. Concrete examples of projects, such as the 12 km pipeline from the Netherlands reused for 100% hydrogen, illustrate the adaptation potential of the existing network. Demonstration projects continue to be essential for testing hydrogen mixtures and for the complete reconversion of infrastructure, helping to reduce costs and develop the necessary technologies. [4]

Romania's natural gas network, made of polyethylene and steel pipelines, is compatible with hydrogen blends up to 20–23%, as shown by the 20HyGrid pilot project. Integration requires minimal adjustments, maintains over 98% combustion efficiency, and poses no major safety risks. [14]

Economics aspects of green hydrogen

According to [15], based on data from the International Energy Agency (IEA), global hydrogen production in 2022 was approximately 95 Mt. However, only a very small fraction (<100 kt) came from electrolysis due to high costs. In 2020, the cost of production of green hydrogen was around 4.5 €/kg H₂, nearly twice the cost of hydrogen produced from fossil fuels with carbon capture (CCS). The final cost depends mainly on the price of renewable electricity. With the falling costs of wind and solar energy, the price of green hydrogen is expected to fall significantly. For example, by 2050, the difference between wind and photovoltaic production costs could be reduced to just 0.4 €/kg. International economic analyses show significant variations depending on geographical conditions.

The cost of green hydrogen production in 2024 ranges between 6.42 €/kg and 16.54 €/kg, with an average value of approximately 11.48 €/kg, which provides a reference for comparison with natural gas costs.

Considering a higher heating value of 141.7 MJ/kg H_2 [4] for hydrogen, the average production cost of 11.48 €/kg corresponds to approximately 292 €/MWh.

Looking ahead, projections for 2030 indicate lower costs due to expected decreases in renewable electricity prices and improvements in electrolyzer efficiency. The production cost of green hydrogen is estimated at around 82 €/MWh in Australia, 57–74.5 €/MWh in Saudi Arabia, and 73.7–89 €/MWh in Germany, providing a reference for future energy planning. For graphical purposes, the midpoint value of approximately 81.4 €/MWh is considered for Germany. [15]

According to the average quotations recorded on the Romanian Commodities Exchange (BRM), the price of natural gas in 2024 was approximately 53.34 €/MWh [16]. In Europe, natural gas prices are projected to increase by around 3.6 % per year under the Ener Blue scenario. [17]

The EU carbon tax is regulated under Directive (EU) 2003/87/EC (EU ETS). Directive (EU) 2023/959 updates it with measures supporting climate neutrality, including market stability adjustments and the Carbon Border Adjustment Mechanism (CBAM). [18]

Consequently, a CO_2 tax is included in the natural gas price, which is currently 75.78 €/t CO_2 [19] with an emission factor of 0.202 t CO_2 /MWh [20] Projections indicate that under the current design of the EU Emissions Trading System II, carbon prices could reach €156 per ton of CO_2 by 2030. [21]

2. MATERIALS AND METHODS

This study will conduct an analysis of the possibility of integrating green hydrogen into DHS, assessing the impact on final price to consumers through comparative financial modeling, based on cost scenarios for green gas and hydrogen and the additional investments required for infrastructure. The article also includes a risk analysis, focusing on the economic impact and potential consequences of changing the fuel source.

A graph was created to illustrate the projected price evolution of hydrogen, natural gas (including the CO_2 tax), and the 20 % hydrogen – 80 % natural gas mixture, allowing for a comparative assessment of fuel costs over time.

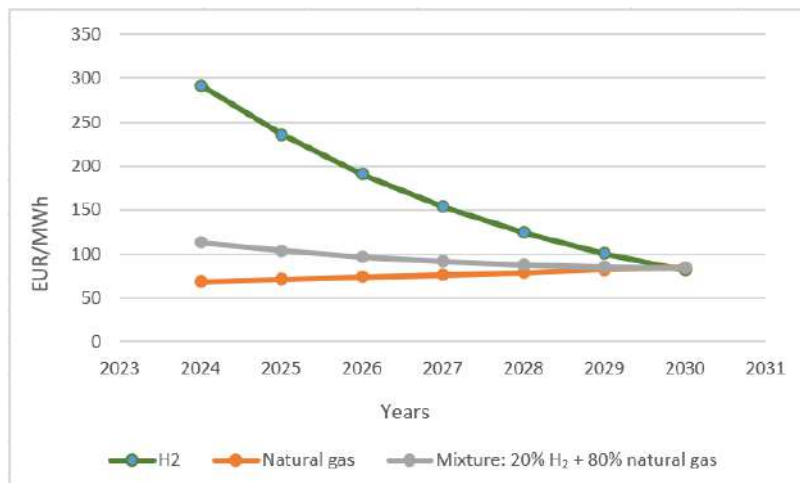


Fig. 1. Price trends

By 2030, hydrogen is expected to be slightly cheaper than natural gas, while the hydrogen-natural gas mixture falls somewhere in between. Considering potential CO_2 tax obligations on natural gas, incorporating hydrogen could reduce overall costs and offer a more cost-effective solution in the long term.

In case of non-payment of the CO_2 tax, an additional cost is added to the final natural gas price. As stated in Article 16 of Directive 2003/87/EC, operators who fail to surrender sufficient allowances are subject to a penalty of €100 per tonne of CO_2 equivalent emitted in excess. [18]

3. RESULTS AND DISCUSSION

Currently, the prospects for increasing the share of green hydrogen in natural gas in DHS in Romania by more than 20-23% are not seen, due to limitations related to the transport and compression of gas. At the same time, there is a risk that the benefits of hydrogen will be limited by its participation in the mixture.

The use of hydrogen in thermal energy production equipment is possible only after replacing the existing units with new hydrogen-ready ones. Even the mixture of 20% hydrogen and 80% natural gas is not possible in current equipment.

Also, there is a risk that the introduction of hydrogen cannot be achieved due to the lack of investments in compatible equipment for its combustion or the slow speed of replacement of current equipment.

The production of hydrogen at the place of consumption or its transport from the place of production to the place of consumption (without mixing with gas) will be affected by the risks related to the availability of Water Resources and the lack of equipment capable of burning 100% hydrogen.

CONCLUSIONS

The economic benefit of the presence of 20% hydrogen in natural gas can lead to a reduction in the total cost of fuel in 2030, in particular by eliminating part of the CO₂ tax that applies to natural gas.

At the same time, the environmental and efficiency benefits of mixing hydrogen with natural gas remain limited by its relatively low share in the fuel mix.

The use of hydrogen to produce thermal energy in DHS is feasible only with specially designed or modernized equipment to be prepared for hydrogen. Therefore, existing systems are optimized for natural gas and substantial investments in new technologies, DHS upgrades, and regulatory adjustments are needed before large-scale hydrogen integration can be achieved.

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EXPERIMENTAL INVESTIGATION OF NEW ANODE FLOW FIELD DESIGNS WITH DIFFERENT INTERNAL GEOMETRIES FOR PEMEC PERFORMANCE

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ABSTRACT – OH10

Flow channel design in Polymer Electrolyte Membrane Electrolyzer Cell (PEMEC) systems plays a critical role in optimizing mass transfer efficiency and cell performance. Within the scope of this study, flow channel designs made of 316L stainless steel with differentiated internal geometries were developed and experimentally characterized for the PEMEC anode side flow areas. The channel configuration with a single inlet and outlet was maintained, and the channel width and depth were kept constant, but variety was provided in the internal geometric patterns of the channels. With this approach, the effect of geometric parameters on electrolyzer performance was systematically investigated. Performance evaluations were conducted at temperatures of 30°C, 40°C, and 50°C, as well as under variable anode flow rates. Electrical characterization was performed through voltage-current (I-V) measurements taken with the aid of a power supply, and current densities in the range of 0.9–1.7 A/cm² were obtained at a constant voltage of 2 V. In addition, the performance of the proposed new flow model was tested at different anode flow rates, and a sensitivity analysis was performed. The experimental findings are considered to offer a new approach for PEMEC anode flow field design and contribute to the development of highly efficient flow field configurations.

Keywords: PEMEC, Flow field design, 316L metal plate, Operating parameters, Electrochemical analysis

1. INTRODUCTION

In recent years, with the continuous development of industry and technology, increasing demands have continued to grow at an equal rate. Energy production methods that rely primarily on traditional fossil fuel energy sources continue to be widely used. These energy production methods continue to cause environmental problems such as environmental degradation and rising temperatures. In addition, issues such as energy supply and security associated with the use of these resources are being faced [1,2]. Consequently, research into the use of green and more environmentally friendly alternative energy sources is increasing day by day. Among these, hydrogen energy stands out as the most promising candidate. The use of this energy carrier will facilitate a significant energy transition, both in reducing carbon emissions and in promoting more environmentally friendly applications [3]. The easiest way to produce environmentally friendly hydrogen with zero carbon emissions is considered to be an effective technological production method using water electrolysis with a proton exchange membrane. The proton exchange membrane electrolyzer cell (PEMEC) is considered the most important alternative for producing hydrogen with high gas purity at varying voltage values [4]. The primary objective of PEMEC is to convert water into hydrogen and oxygen. Pure water in the anode active area passes through the diffusion layer and reaches the catalyst layer. It is split into protons via an external power source. The oxygen bubble produced in the anode active area leaves the anode along with the water flow. On the other hand, hydrogen ions that pass to the cathode region as a result of the reaction combine to form hydrogen gas. In general, the hydrogen production rate depends on varying voltage and current densities [5]. The shape and geometry of the flow field used in a PEMEC are important for the efficient operation of the cell. This is because the reactant distribution must be uniform throughout the reaction, and the resulting thermal energy must be transferred with appropriate efficiency. Different flow field designs have been used in PEMECs, with a preference for serpentine and parallel designs [6]. The flow field used significantly affects the distribution of reactant and product quantities and the distribution of electrochemical reactions throughout the operation, as well as cell and fuel temperatures. Therefore, it has been reported that the flow field must be designed to ensure homogeneous and efficient transmission [7]. Researchers have focused primarily on parallel and serpentine flow fields in their studies of flow fields [8]. In studies conducted on parallel flow fields, the flow mass has always been directed towards vertical areas connected to this channel along the bottom and side directions of the channel. Depending on the flow field design, high flow velocities related to pressure are achieved in the sections close to the inlet and outlet areas. However, low flow velocities occur in the central regions of the active area, causing an uneven gas-water distribution. Such parallel flow field designs have focused on achieving a more uniform reactor distribution [9]. For the serpentine flow area, studies have emphasized the flow transmission of liquid water without the formation of stagnant zones along the curved flow path. However, due to the longer flow path, a significant pressure difference is created, causing the gas accumulation to increase in the outlet sections. Improvement studies are being conducted on changing the number of channels between serpentine flow areas, reactant distributions, and temperature distributions. It has been reported that this type of design, which has been studied, targets improvements in water removal

performance and flow intensity [10]. Kasukurthi [11], In his study on PEM electrolyzers, he emphasized that the flow rate and temperature distribution are not equal in a single-inlet parallel flow design. It was found that the flow distribution was significantly improved by varying the number of channels. However, it was reported that the flow field patterns were inconsistent in the proposed design. Toghiani [8], They evaluated the performance of PEM electrolyzers using different flow field patterns: parallel, single-channel serpentine, double-channel serpentine, triple-channel serpentine, and quadruple-channel serpentine. The results obtained indicate that the dual-path serpentine model exhibits better performance depending on the hydrogen flow density. It has been explained that the parallel flow field pattern has a lower pressure drop. In the current study, based on the research conducted, a new design for the serpentine flow field is proposed. The flow channels in the new design were examined by creating a specific number and arrangement of semicircular obstacles within the single-channel flow field design. This flow field design was processed on a stainless steel metal plate and presented in a single-cell module. The new flow area cell aims to achieve a more homogeneous reactant distribution based on the structural properties of serpentine flow areas with varying numbers of internal channel obstacles. Furthermore, the proposed design provides a parametric comparison of the current density at different temperatures between the traditional single-channel serpentine flow area. This research provides an experimental application to optimize PEMEC flow field designs and determine optimal operating conditions.

2. MATERIALS AND METHODS

Flow field design and production for PEMEC;

Research has been conducted on the structure of different flow field models for PEMEC. The components of the single PEMEC module consist of a proton exchange membrane at the center, a cathode/anode double-sided catalytic layer, a cathode and anode diffusion layer, a metallic stainless steel flow plate created for the cathode and anode, and an end support layer that serves to connect the cell as a whole. A serpentine flow channel pattern and a differentiated flow area design with semi-circular dimensions within the flow area were proposed for the flow area. The metal flow area design was created by processing it with a metal laser, forming a similar cross-flow path. The dimensional parameters are specified comparatively for both flow areas in Table 1. The general design dimensions specify the channel height, width, and rib width, as well as the flow area and cell dimensions. The end plates used in the structure of the differentiated transparent PEMEC are made of plexiglass to enable flow control and reduce the total cell weight. The plexiglass has a total size of 100 mm × 100 mm and a thickness of 5 mm. The current collection plate is made of 316L stainless steel plate with a thickness of 1 mm for both the anode and cathode. The current collection plate is also integrated with the end plate as a flow area by laser cutting a serpentine flow channel. The flow area plates have a cross-sectional area of 100 mm × 100 mm and an active area of 25 cm² in the shape of a square. Titanium foam was used for the anode GDL, and carbon paper (TGP-H-060, Toray Industries, Inc., Japan) of the same thickness was used for the cathode. The membrane electrode assembly (MEA) is made of Nafion 117. IrO₂ and Pt are used as catalysts for the anode and cathode, respectively. The membrane active area is 50 mm × 50 mm and is commercially purchased. For cell assembly, eight evenly spaced bolts were assembled with an insulating layer on the inner surface of each to ensure adequate insulation. The eight bolts were assembled crosswise and tightened to a torque of 3.0 Nm. Assembly was completed by tightening all eight bolts in a specific crosswise clockwise direction.

Table 1. Sections and dimensions of single cells created for PEMEC

Flow area types	Serpentine
Bipolar plate	Stainless steel plate
End plate material	Plexiglass
End Plate thickness	5 mm
Active area	25 cm ²
Flow area depth	1 mm
Cell area	100 cm ²

3. PEMEC TEST SYSTEM AND TEST PROCEDURES

Research has been conducted on the structure of different flow field models for PEMEC. The components of the single PEMEC module consist of a proton exchange membrane at the center, a cathode/anode double-sided catalytic layer, a cathode and anode diffusion layer, a metallic stainless steel flow plate created for the cathode and anode, and an end support layer that serves to connect the cell as a whole. A serpentine flow channel pattern and a flow area design with obstacles in the shape of a semicircle within the flow area were proposed for the flow area. The metal flow area design was created by processing it with a metal laser, forming a similar cross-flow path. The dimensional parameters are specified comparatively for both flow areas in Table 1. The channel height, flow area, and cell dimensions are specified in the general design dimensioning. In this study, a performance evaluation was conducted for PEMEC flow fields under different conditions. The voltage current density was examined for three different water temperatures for the

serpentine flow field. Subsequently, a performance evaluation of the straight serpentine and modified half-circle flow-obstructed designs was presented. The operating parameter values applied during the experiment in the PEMEC single cell are given in Table 2.

Table 2. Test parameters applied for PEMEC	
Deionized water inlet temperature	30°C, 40°C, 50°C
Hydrogen Produced	Humidity
Deionized water flow rate	10 mL/min
Operating voltage value	2 V

4. RESULTS AND DISCUSSION

In this section, the performance effect of the PEMEC operating temperature was examined at 10 °C increments from 30 °C to 50 °C. The condition was examined at a constant flow rate of 10 ml/min of deionized water from the operating parameters. The water flow rate was maintained at a constant and continuous level. When the cell inlet water temperatures reached the desired values of 30, 40, and 50 °C, polarization curves were recorded after a 10-minute waiting period, and the voltage/current density values are shown in Fig. 1. The electrochemical performance of PEMEC was compared with the voltage values obtained at the same current density.

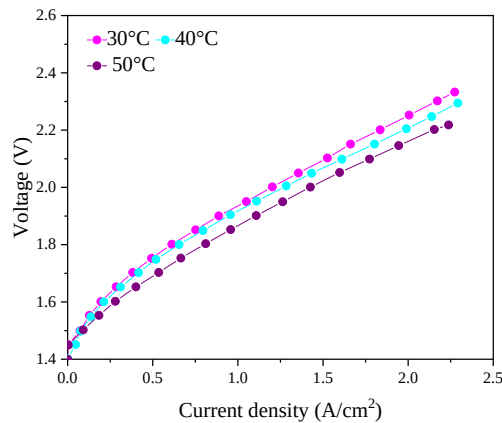


Fig. 1. Performance evaluation of three different temperatures for serpentine flow field PEMEC

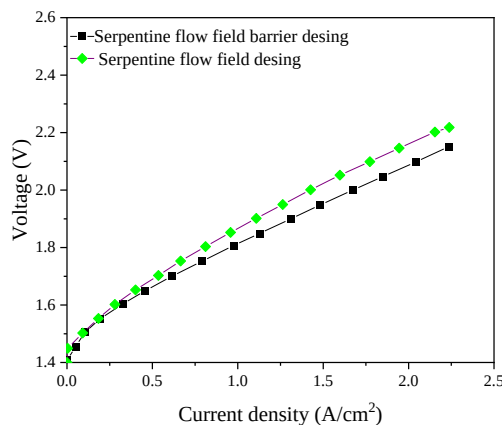


Fig. 2. Performance evaluation of two different cell types based on serpentine flow field

The high voltage value at 30 °C cell temperature can be explained by the high voltage value. However, the voltage value decreased when the temperature was increased to 50 °C. The electrochemical performance of PEMEC showed a significant increase as the electrolyzer temperature rose from 30 °C to 50 °C. It is expected that the electrochemical performance of the electrolyzer will increase further as the input temperature values increase. At increasing temperature values, the cell experiences a decrease in activation potential at high temperatures. This situation causes molecules to have higher kinetic energy due to the increased thermal energy during chemical reactions. As a result, improved electrochemical reactions and an efficient cell operating module have been created. For a constant 2 V value, hydrogen production capacity is

lowest at 30 °C and highest at 50 °C. The effect of two different flow field patterns with differentiated serpentine and serpentine flow fields on the polarization curve is shown in Fig. 2. Polarization curves were obtained from test data at a constant water inlet temperature of 50 °C, an inlet water flow rate of 10 mL/min, and ambient pressure in experimental systems. The test results show that for a constant 2V value, a current density of 1.42 A/cm² was obtained in the serpentine flow design, while a current density of 1.67 A/cm² was obtained in the differentiated serpentine flow area design. The results indicate that the cell with the differentiated serpentine flow area design achieved better performance compared to the cell with the flat serpentine flow area.

CONCLUSIONS

The performance of PEMEC varies depending on many parameters, primarily the flow field design, as well as operating parameters such as water inlet temperature, water flow velocity, current density, and operating pressure. In this study, the effect on PEMEC performance was examined after the design and optimization of two fundamentally different flow fields. This performance difference led to the development of a different design model by adding half-circle combinations of a specific order and similar size to the serpentine flow field and its design. This innovative flow field ensures sufficient water supply within the channels and the removal of oxygen and hydrogen bubbles formed in the anode and cathode regions, resulting in more efficient operation. During the experimental process, electrochemical processes and thermodynamic principles were combined with single-cell models and an experimental setup. Among the research parameters, hydrogen production increased with rising values of modified water inlet temperatures of 30°C, 40°C, and 50°C at ambient pressure and a constant flow rate of 10mL/min. The new combination of circular obstacles symmetrically placed in the serpentine flow area increases the diffusion of liquid water on the MEA surface. At the same time, gas discharge efficiency is increased by preventing the coalescence of gas bubbles formed in the catalytic layer

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LANDSCAPE OF OFFSHORE ENERGY HUBS, CRITICAL RAW MATERIALS AND GREEN HYDROGEN

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ABSTRACT – OH5

The aim of this study is to investigate various facets of offshore energy hubs which are linked with development of offshore wind farms and production of green hydrogen and other e-fuels. Research approach targets to implement the perspective of critical raw materials and their supply value chain regarding development of offshore wind farms and production of green hydrogen. Rich insights are collected from various industrial views and stakeholders and current research projects. Offshore energy hubs can play an important role in green transition and can contribute to energy security in Europe. Nevertheless, energy transition is material intensive and requires a sound policy landscape in place together with medium and long-term sagacious strategies of actions. Moreover, updated road maps for offshore energy hubs and green hydrogen need to be in place and more balanced narratives about the global supply chain for the critical raw materials.

Keywords: Offshore Energy Hubs, Offshore Wind, Green Hydrogen, Critical Raw Materials, Energy Security

1. INTRODUCTION

Development of offshore energy wind in Europe can play an important role in decarbonization efforts, reduction on fossil fuel imports and enhancement of energy security [1]. Important infrastructure for development of renewable energy, particularly offshore wind, are seen to be the Offshore Energy Hubs (OEH)s [2], [3]. OEHs linked to offshore wind can be used for decarbonization of the energy system, and can contribute to an efficient energy storage, distribution and green hydrogen production. Lüth and Keles [2] analyzed the main drivers in development and sources of risk of OEHs, notably for the energy infrastructure linked with the North Sea and Baltic Sea. Ibrion and Nejad [3] highlighted different aspects of energy islands that are connected to offshore wind farms and offshore green hydrogen production and their potential for development of green corridors initiatives. The focus was particularly on the energy islands planned to be developed in the basin of the North Sea and the Baltic Sea [3]. The aim of present study is to investigate various facets of offshore energy hubs which are linked with offshore wind farms and production of green hydrogen and other e-fuels. Research approach targets to bring to attention facets from the landscape of critical raw materials and how their supply value chain can impact the development of offshore wind farms and production of green hydrogen. Insights are drawn from the state-of-art analysis of academical works and ongoing industrial projects, and further blended with the findings from stakeholders for offshore energy hubs, green hydrogen and critical raw materials. Within the following sections, insights are offered about offshore energy hubs, green hydrogen, critical raw materials and associated policy landscape in European Union.

2. OFFSHORE ENERGY HUBS

Offshore energy hubs (OEH)s are known also as energy islands. The concept is applicable to both offshore/onshore energy systems at a large scale [2]. Energy islands can serve as hubs for energy collection from surrounding offshore wind farms and to facilitate interconnection with other countries. Energy islands can be scalable for future offshore wind farms and can accommodate facilities for energy storages, and technologies and facilities for green hydrogen production and other alternative fuels [1]. Investments and costs linked with OEH are very high, thus the benefits must also be large in order that the project becomes economically feasible. The economics of offshore projects influence definitely the viability of OEH projects, but also regulatory framework, market design, technical innovations, environmental considerations and, the geopolitical matters need to be considered [2]. Rich academical works and projects have been linked to study of OEHs in the West of Europe [2], [3]. However, the East of Europe and Far East of Asia offer examples of OEHs which need to be brought to attention.

The Hainan island which is situated in the South China Sea offers a good example of the offshore energy hub/energy islands in China. The target is to transform the Hainan island which relies on coal for its energy needs into a clean and green energy island. The energy production in Hainan energy island is aimed to be generated from development of solar and wind power. The Hainan energy island targets also to support production of green hydrogen, ammonia and methanol.

The Chinese coastal provinces accommodate a number of megacities and major industrial hubs which contribute with around 25% and 30% to the Chinese solar and wind capacity, but also consume almost half of the China's electricity. Moreover, the Chinese coastal provinces accommodate also the largest offshore wind supply chain hubs. The offshore wind represents around 9% of the Chinese total wind power capacity, but contributes to more than 50% of the offshore wind capacity in construction on the global arena. As of March

2025, China has emerged as the world's offshore wind powerhouse, and aims for further development of its offshore wind industry in order to deliver stable electricity to grid, and decarbonize heavy industries in the coastal areas. Pilot projects in Guangdong, Shandong and Fijian targets the production of green hydrogen from offshore wind [4], [5].

A Romanian-Bulgarian energy island is seen as an innovative solution for making usage of offshore wind deployment in the Black Sea. The energy island in this basin is seen able to address grid challenges, and to develop interconnections with other countries around the Black Sea such as Turkey and Georgia, and further on, Azerbaijan, near Caspian Sea. This energy island and the offshore wind deployment in the Black Sea are seen to boost the energy security in the Black Sea area and to contribute to a regional market price stability. The energy island in the Black Sea can offer alternative import routes for clean energy. There are also plans for building a HVDC cable with contribution from Romania, Bulgaria, Georgia, Azerbaijan and Hungary which will interconnect the Turkish and Georgian power grid with the Romanian and Bulgarian power grids through the Romania-Bulgarian energy island. Moreover, the offshore wind energy in the Black Sea can also contribute together with the energy from onshore wind and solar to the hydrogen production in Dobrogea area which has the prerequisites to be transform into a green hydrogen valley. There are also discussions for revival of the methanol production in Romania with focus on green methanol production from green hydrogen and CO₂ capture [1], [6].

3. GREEN HYDROGEN

As per estimates, electrolysis represents around 2% of total global hydrogen production in the world. Currently, there are four main types of electrolyzers: Alkaline (ALK); Proton Exchange Membrane (PEM); Anion Exchange Membrane (AEM); and Solide Oxide electrolyzers (SOE). ALK is the most mature which operates at scale, but can operate at less than 100 C degrees. PEM electrolyzers are modular, scalable and represent around 70% of the new projects, and can operate at 70-90 Celsius degrees. AEM and SOE are relatively in early stage both technologically and economically. However, SOE can operate at much higher temperature, at 700-800 Celsius degrees [7].

In the production of green hydrogen from renewable energy, critical raw materials such as platinum, ruthenium and iridium play a critical role. As a concrete example, platinum and iridium are employed in PEM electrolyzer. Moreover, platinum and ruthenium are used for some types of fuel cells. Among the main drivers for electrolysis costs are seen to be renewable energy accessibility, the cost and supply of platinum group metals such as catalyst in electrolyzer (PEM) and fuel cells, and supply/cost of REEs (SOE) [7]. Hydrogen presents different challenges in terms of production costs, storage, transportation, and safety. Hydrogen is a key component for production of ammonia, methanol and other synthetic fuel. Cost of production, scale-up of electrolysis and efficiency losses in storage and transport will have their impact on hydrogen as a niche solution or a dominant energy carrier in the future. Expansion of renewables, decrease in cost of renewable and advances in electrolysis technologies and cost reduction in electrolysis are part of forecasts to make the green hydrogen more cost effective in the coming decades [8].

4. CRITICAL RAW MATERIALS AND POLICY LANDSCAPE IN EUROPEAN UNION

Critical raw materials (CRMs) are seen as the backbone for green transition, and ensuring their supply chain is fundamental for the European economic stability. CRMs power the global economy and renewable energy technologies such as offshore wind and solar, electrical vehicles, high-tech electronics and many strategic technologies. The European Union issued the Critical Raw Materials Act (CRMA) in March 2023, and which further entered into force in May 2024. It contains a list of 34 CRMs, including 17 strategic raw materials. These CRMs are vital for EU economy, but highly vulnerable to global supply chain disruptions. The supply chain of CRM is dominated by a small number of countries, particularly China. As an example, in terms of rare earth elements (REEs), China dominates global arena as provides more than 68% of the world extraction and more than 85% in their processing. EU lacks an REE domestic mining production and metal making, but has some very limited processing capacity for some of REEs [9].

The European Commission selected in March 2025, a first round of 47 strategic projects and in June 2025, the second round of other 13 strategic projects which involve mainly countries outside of EU. All of these strategic projects aim to secure for EU the supply of critical and strategic raw materials. Within these strategic projects, as per CRMA, the permit granting process will not exceed a period of 27 months for extraction projects, and 15 months for other type of projects. Nowadays, the permitting process is very lengthy and can take from 5 until 10 years or even more [10], [11].

Towards European energy security and Critical Raw Materials, Europe has aimed to develop strategic partnerships with Greenland and Ukraine. Moreover, in order to secure strategic value chain, investments opportunities in Central Asia emerged. The EU-Latin America cooperation on critical raw materials is also under focus. In line with CRM diplomacy/RAW Materials Diplomacy, and which mainly focus on green and digital areas, EU has aimed to develop policy dialogues, strategic partnerships and to establish frameworks of cooperation regionally, bilaterally or multilaterally with an array of non-EU countries which possess valuable and considerable mineral reserves such as: Serbia, Uzbekistan, Kazakhstan, Norway, Australia,

Canada, Argentina, Chile, Rwanda, Namibia, Zambia, Congo. Moreover, additional relations are with China, Japan, USA, Brazil, Uruguay, Mexico, Peru, the African Union and the Euro-Mediterranean Partnership (EUROMED). Starting from 2021 until July 2025, EU has developed 14 CRM partnership which aim to contribute to diversification and strengthen the supply chain for CRM [9].

5. DISCUSSION

Energy islands and offshore wind farms require a wide range of CRMs, including and not limited to REEs, natural graphite, copper, platinum group metals and other strategic raw materials. The green transition and development of offshore wind farms and green hydrogen production is strongly influenced by availability of CRMs [3]. Impressive targets have been set for development of offshore wind in EU and worldwide. Moreover, the demands for the REE permanent magnets in offshore industry seem also to rise dramatically in the coming decades. However, the supply chain for the REEs, and permanent magnets is highly concentrated in China [12].

In April 2024, China issued the REE Management Regulations which implemented various regulation and rules about exploitation, management, quota and usage of REE; the creation of REE product traceability system was particularly aimed to be developed by the Chinese governmental organizations. Furthermore, in April 2025, China announced the upcoming export controls on 7 REEs (including heavy REEs) [13]. During 2025, the USA-China tariff conflict has unfolded further, and their economic and strategic confrontation further escalated. China has announced on 9 October 2025, tighter export control on REE, materials, associated technologies and equipment. Extra 5 REEs have been added to the control REE list of China, and the restricted REE list was announced to increase from November 2025 onward. Moreover, China has imposed new obligations, compliances and licencing requirements on exporters and downstream users of REEs. All the specific stages of REE value chain are subject to control and new mechanisms are in place for licencing, traceability and compliance. A very complex system and enforceable law of China is scrutinizing the export of REE, technologies and transfer of technical expertise. The impact of this export control will become more visible in sectors such as automotive industry, semiconductors, renewable energy, and other strategic areas where REEs are largely employed. High supply instability, increased cost, operational delays, and high uncertainty are among major challenges which are currently faced by industries and companies. In Europe and worldwide, critical industries have faced strategic vulnerabilities and require prompt and wise actions in order to assure their survival and functions. Technological sovereignty of China is undeniable and its position as an indispensable hub in the world for CRMs and REEs is strengthened [14], [15]. For the coming decades, China seems to hold a dominant position in the worldwide REEs supply chain and market. Most of the REE mining, processing and magnet manufacturing are located within the Chinese territorial borders and its areas of influence. CRMs, and particularly, REEs, are heavily linked with energy security in Europe and worldwide. Disruptions and uncertainty linked to the supply chain of REEs can heavily impact offshore industry, the green transition and other strategic industries [15].

Starting from December 2023, China implemented export controls on graphite. Graphite is one the CRMs which are exposed to a high risk supply [13]. China as a global producer of graphite (natural and synthetic graphite), in terms of large production, refining skills and high quality graphite has started to enforced export limits on graphite from the spring of 2025. Moreover, special permits are required for export of graphite, not limited to high-purity and high-strength graphite. Starting from November 2025, China will introduce export restrictions on all types of graphite, both natural and synthetic graphite together with the equipment and processes necessary for their production. Graphite is critical for electric vehicles, aerospace, semiconductors, and is also critical for solar panels and wind turbines. In the wind turbines, graphite mineral is used in bearings, lubrication systems, generator, electrical components, lightning protection system, grounding system, in the production of composite materials for wind turbine blades, for thermal management applications (thermal conductivity and good insulator), and for structural components such as nacelle. Natural and synthetic graphite is also critical for battery storage system such as lithium-ion batteries, and particularly, as anode material. Graphite is further employed for renewable energy storage systems for wind and solar farms. The green hydrogen production will be also impacted as the graphite is used for electrodes and membranes [14], [16]. In order to assure an European resilience versus energy prices volatility and disruptions encountered by the global supply chains, it is recommended to develop the European extraction and processing industry, to simplify permitting, to establish strategic partnerships with other countries, to secure retaining of scrap within Europe and promote circular economy, to encourage advancement in recycling technology, to support the initiative "Made in Europe" and support local industries and creation of regional jobs, to encourage local investments, to invest in skills and education, and to intensify materials research [17]. The confrontation between China and West over CRMs requires different strategies of actions for example diplomatic actions, maritime and logistical security, priority allocations, pursuing mining and refining opportunities, and support of reduction, substitution and material research and innovation. A diplomatic balanced approach among China and other geopolitical players around world is recommended in order to attenuate high geopolitical tensions and to assure viable solutions linked with the REEs supply chain and to avoid more devastating consequences of a lasting economic crisis [15], [14].

CONCLUSIONS

Offshore Energy Hubs (OEHs) are considered to be strategic offshore energy infrastructures which are linked with development of offshore wind farms and future production of green hydrogen and other e-fuels. OEHs can contribute to energy security in Europe, and can play an important role in green transition. CRMs, notably graphite and REEs have emerged as cornerstone for green energy transition, development of offshore wind turbines, OEHs, green hydrogen and renewable energy storage. China is the dominant supplier in the world for REEs, graphite and other strategic and CRMs. Recent geopolitics and waves of new tariffs, export controls and restrictions during 2025 has impacted and brought a high uncertainty for many critical industries, not limited to offshore wind and critical infrastructures such as OEHs. CRM, particularly, REE are part of energy security of China, EU, and other geopolitical players around the globe. Securing a stable and resilient supply chain for CRMs is critical for the energy security. A road map for OEHs, offshore wind and green hydrogen is heavily influenced by geopolitics and the global supply chain for the critical raw materials, and notably, REEs and graphite. Moreover, the road map is influenced by market dynamics, technological developments, policy perspectives relevant to CRMs, and strengthened connections among projects, industry, and policymakers which can inform and influence future policy recommendations and strategies. To achieve Energy Transition goals, attenuation in geopolitical tensions and global collaboration is indeed needed today more than ever.

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ENHANCED HYDROGEN EVOLUTION PERFORMANCE USING NICKEL-COATED STAINLESS STEEL CATHODES IN ALKALINE ELECTROLYSIS

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ABSTRACT – OH₂

In this study, the improvement of stainless steel cathodes used in alkaline electrolysis for hydrogen production through nickel coating and the effect of different operating parameters on hydrogen generation were investigated. Nickel coating was applied by electroplating to enhance the corrosion resistance and catalytic activity of stainless steel. Nickel coated stainless steel cathodes with different surface areas were tested in a cylindrical electrolyser under various electrolyte concentrations and applied voltages. The experiments showed that nickel coated stainless steel cathodes significantly improved hydrogen production performance compared to uncoated stainless steel. The highest hydrogen generation was achieved at 3 V and 1 M KOH. A comparative analysis using electrodes with different surface areas revealed that hydrogen production increased proportionally with the effective surface area; however, an increase in electrode surface area did not always translate into improved hydrogen generation, confirming the critical role of electrode geometry in reaction kinetics. These results demonstrate that low-cost nickel coatings on stainless steel can be used as promising electrodes for efficient and durable hydrogen production systems.

Keywords: Energy, Electrolysis, Hydrogen, Electrodeposition, Electrodes

1. INTRODUCTION

Hydrogen generation via electrolysis occurs by applying an electric current to an electrolyte solution, causing water to split into hydrogen and oxygen gases [1]. Water electrolysis offers a sustainable pathway for hydrogen generation, but the cost and efficiency of electrodes remain major challenges [2]. Stainless steel, though inexpensive and corrosion resistant, exhibits poor catalytic activity toward the hydrogen evolution reaction (HER). Nickel, on the other hand, provides high HER activity and stability in alkaline environments [3]. Therefore, using nickel-coated stainless steel instead of bare stainless steel is an effective approach to enhance hydrogen production performance. This study aims to analyse the influence of electrode surface area on hydrogen generation using nickel-coated stainless steel cathodes, under controlled voltage and electrolyte concentration.

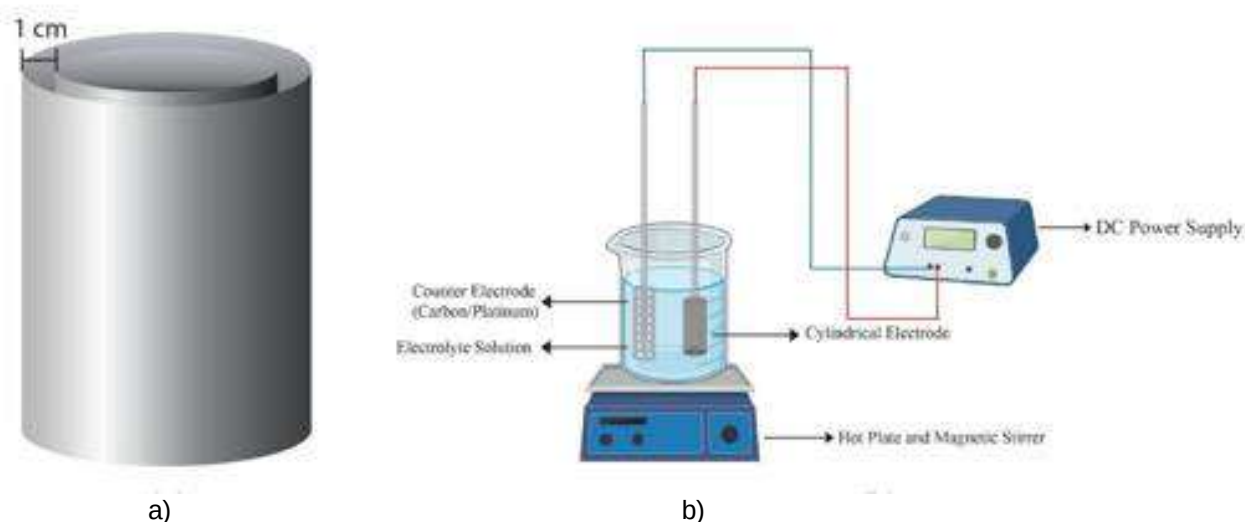


Fig. 1. (a) Cylindrical anode and cathode electrode design (b) Schematic for electrodeposition method

2. MATERIALS AND METHODS

Nickel was electrodeposited onto stainless steel substrates following surface cleaning with ethanol and acid treatment. The electrolysis cell consisted of a 400 ml cylindrical electrolyser operating at atmospheric pressure and room temperature (approximately 24 °C). Electrolysis experiments were carried out using electrodes with different surface areas (80, 130, 180, 230, 280, and 330 cm²) under various KOH concentrations (0.5, 1, and 2 M) and applied voltages (2, 3, and 4 V). Hydrogen production was measured using a gas sensor, while a pump and a flowmeter were employed to maintain a constant gas flow.

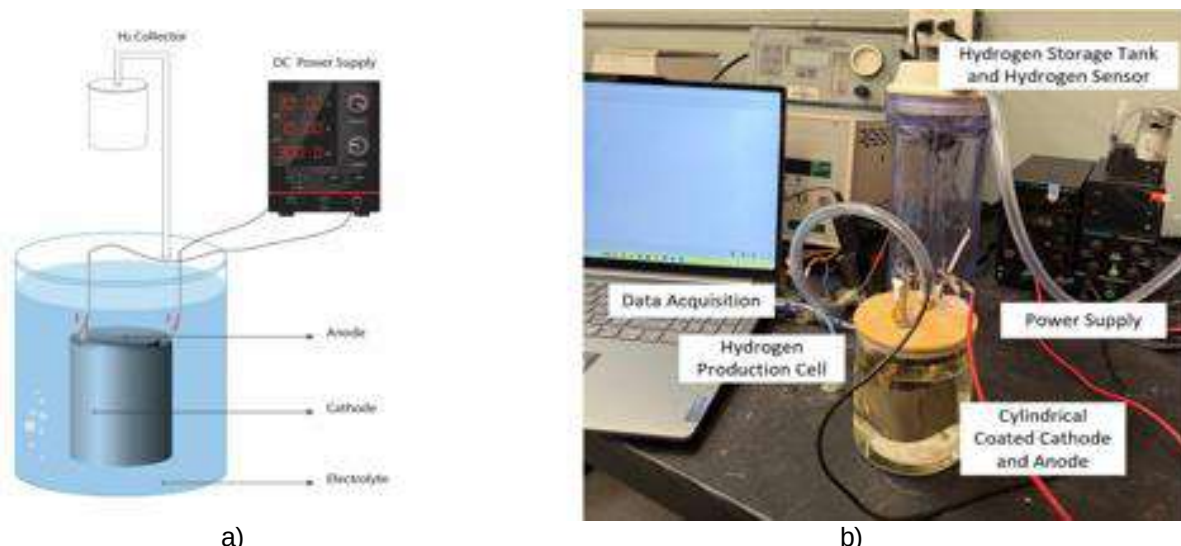


Fig. 2. Novel cylindrical electrolyser for hydrogen production. (a) schematic illustration and (b) experimental setup

3. RESULTS AND DISCUSSION

Fig. 3(a) shows the relationship between hydrogen production rate and electrode surface area for nickel-coated stainless steel cathodes. The hydrogen generation rate increased with electrode surface area, reaching a maximum of approximately 45 mg h^{-1} at 180 cm^2 . This improvement is attributed to the larger number of active nickel sites available for the hydrogen evolution reaction (HER) and enhanced charge transfer across the electrode-electrolyte interface. However, beyond this optimum value, the hydrogen production rate slightly decreased, which can be explained by increased bubble accumulation and diffusion limitations that hinder mass transfer on larger electrode surfaces. Thus, although a higher surface area generally promotes higher activity, excessive enlargement can cause transport-related inefficiencies. Fig. 3(b) presents the variation of hydrogen production with repeated electrolysis cycles for electrodes with different surface areas. A gradual decline in hydrogen generation was observed for all electrodes over multiple cycles, indicating mild surface degradation or partial loss of active sites. The most stable performance was achieved with the 180 cm^2 electrode, which maintained hydrogen production above 40 mg h^{-1} after five cycles, demonstrating strong adhesion and durability of the nickel coating. In contrast, electrodes with smaller (80 cm^2) or excessively large (330 cm^2) surface areas exhibited faster performance deterioration, suggesting that both insufficient and excessive surface areas negatively affect stability and gas release dynamics.

Overall, these results confirm that the nickel coating significantly enhances hydrogen evolution activity compared to uncoated stainless steel and that the optimal surface area (180 cm^2) provides the best balance between catalytic activity, gas detachment, and long-term stability under alkaline electrolysis conditions.

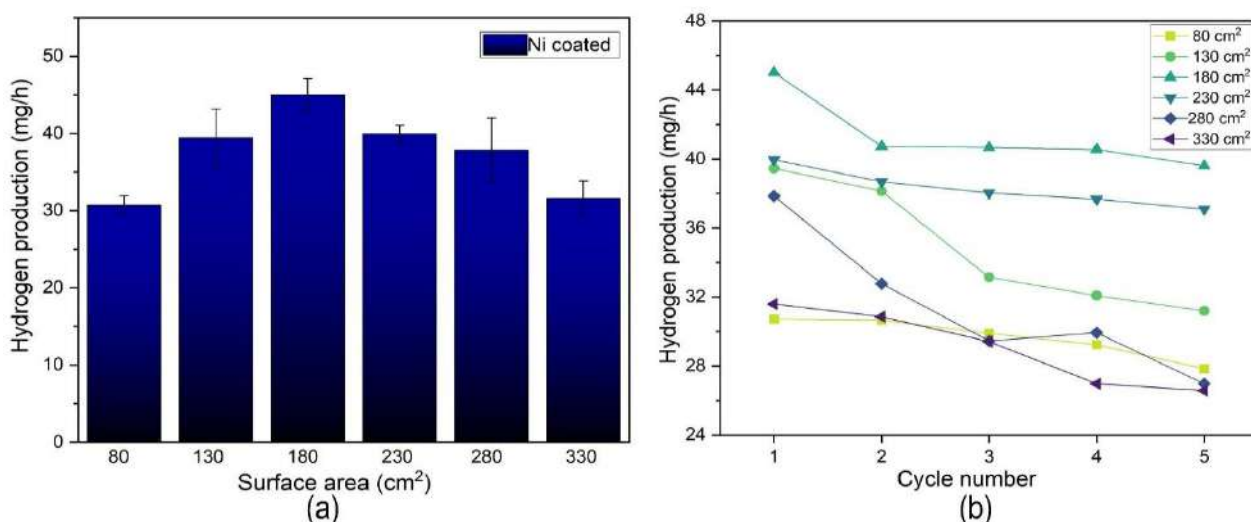


Fig. 3. Hydrogen production performance of Ni-coated electrodes with varying surface areas. Tests were carried out at 3 V in 1 M KOH at room temperature: (a) Hydrogen generation after 1-hour electrolysis and (b) Production stability over five consecutive cycles

CONCLUSIONS

The hydrogen generation rate was highly influenced by the electrode surface area, with the optimum performance achieved at 180 cm², where the balance between catalytic activity and gas release was most effective. Further enlargement of the surface area led to reduced efficiency due to bubble accumulation and diffusion limitations. Stability tests confirmed that the 180 cm² electrode retained its activity over multiple cycles, highlighting the strong adhesion and durability of the nickel coating. This study indicates that surface modification through nickel coating, combined with appropriate electrode geometry, provides a practical strategy for enhancing the efficiency and long-term stability of alkaline electrolysis systems for hydrogen production.

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INVESTIGATION OF RENEWABLE-BASED HYDROGEN AND ETHANOL PRODUCTION SYSTEM

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ABSTRACT – OH19

Hydrogen plays a critical role in the transition to alternative fuel production. In this regard, integrated production systems are coming to the fore in fuel production. The proposed system involves the production of renewable-based hydrogen and ethanol. The chemical reaction between captured carbon dioxide and hydrogen produced via an alkaline electrolyzer to obtain ethanol is being investigated. Aspen Plus was used to design and analyze the integrated production process. The renewable-based multigeneration system's hydrogen and ethanol production capacities were 0.00233 kg/s and 0.00526 kg/s, respectively. The system's overall energy and exergy efficiencies were 54.5% and 59.2%, respectively. The system characteristics were examined through sensitivity analysis studies.

Keywords: Green hydrogen, ethanol, geothermal energy, wind energy, electrolysis

1. INTRODUCTION

The increasing demand for energy and the resulting rise in fossil fuel consumption have brought about environmental problems [1]. Carbon emissions caused by fossil fuel use require alternative fuel solutions. At this point, integrated systems that convert materials into numerous useful outputs through chemical processes come to the fore. There are multiple studies in the literature on multi-production systems [2]. Oner and Dincer [3] proposed an integrated system that produces electricity, fresh water, and ethanol based on solar and biomass. The system was analyzed thermodynamically, and its overall energy and exergy efficiencies were found to be 53.1% and 41%, respectively. There are different production methods for ethanol, which is used as a valuable chemical and fuel additive. Renewable-based ethanol production is achieved through carbon dioxide hydrogenation in the current system. Each subsystem in the process has also been modelled, and its energy and exergy efficiencies have been evaluated.

2. METHODOLOGY

This study obtained ethanol through the chemical reaction of captured carbon dioxide and hydrogen produced in the electrolyzer. Carbon dioxide and hydrogen streams are compressed to a pressure of 30 bar. The substances brought to the reaction temperature and pressure are fed into the ethanol production reactor. The streams separated according to the conditions are then sent to the distillation column for ethanol. The purified ethanol is kept ready for use. Each subsystem has been simulated using the Aspen Plus software in the proposed system, analyzed thermodynamically, and subjected to sensitivity analysis studies. Mass, energy, entropy, and exergy balance equations have been established for each subsystem. Various assumptions have been made for the calculations, with ambient temperature set at 25°C and ambient pressure at 1 bar. The schematic representation of the system is shown in Fig. 1.

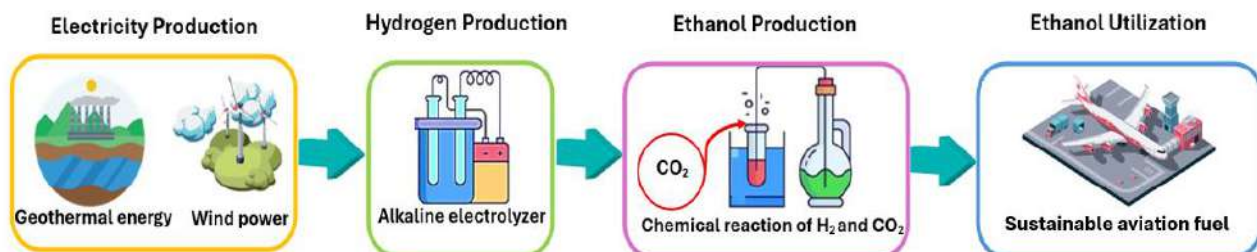


Fig. 1. Schematic layout of the system

3. RESULTS AND DISCUSSION

Fig. 2a shows energy and exergy efficiencies of the proposed system. The energy and exergy efficiencies of the system were found to be 54.5% and 59.2%, respectively. Fig. 2b shows the hydrogen and ethanol production capacities of the system. As a result of the chemical process, hydrogen and ethanol were produced at flow rates of 0.00233 kg/s and 0.00526 kg/s, respectively.

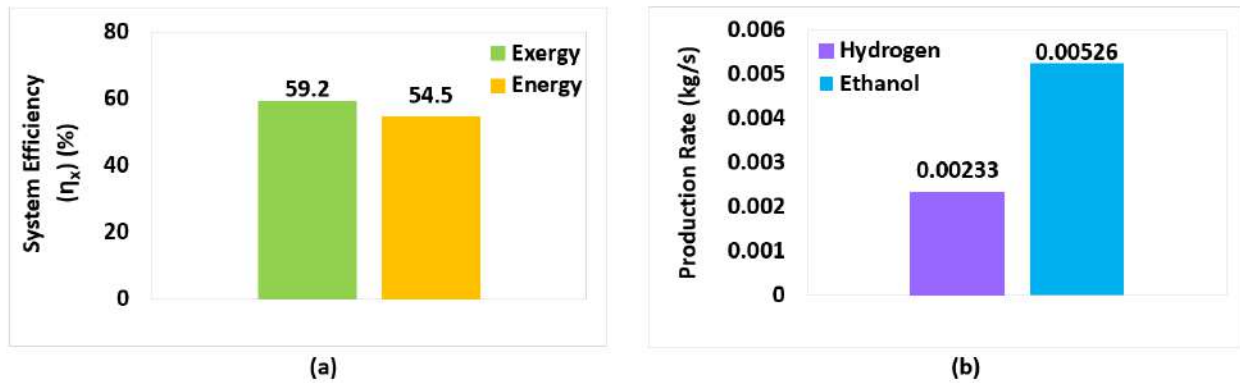


Fig. 2. Energy and exergy efficiencies of the system (a), and hydrogen and ethanol production capacities (b)

The green energy required for hydrogen production in the system is provided by geothermal and wind energy. When wind speeds and power capacities are examined by month, electricity production is calculated to be 301.62 kW in July, when wind speeds are at their highest. When geothermal and wind resources are used in a hybrid way, it is seen that the system is fed with an average of 400.323 kW of green energy, and thus seasonal imbalances can be avoided. Alkaline electrolyzer, PEM fuel cell, and ethanol production subsystems within the process are examined. The alkaline electrolyzer was operated at 80 °C and 10 bar pressure conditions for efficient electrochemical performance.

CONCLUSIONS

This study presents a novel ethanol production pathway that integrates CO₂ captured from industrial flue gas with hydrogen from an alkaline electrolyzer, enabling the hydrogenation of CO₂ to ethanol. All process units were modelled using Aspen Plus, and performance was evaluated using thermodynamic and sensitivity analyses under various conditions. According to the thermodynamic assessment, the system operates with 54.5% energy efficiency and 59.2% exergy efficiency. Furthermore, parametric analyses aimed at simplifying process integrity for various regions have facilitated examining the system across multiple operating scenarios.

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TECHNO-ECONOMIC COMPARISON OF DOMESTIC AND IMPORTED GREEN HYDROGEN SUPPLY PATHWAYS FOR GERMANY

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ABSTRACT – OH14

Germany's updated National Hydrogen Strategy doubles the domestic electrolysis target to 10 GW by 2030, yet projections suggest that 50–70% of national hydrogen demand will require imports. This raises a strategic dilemma between strengthening local renewable capacities and leveraging cost advantages from regions with higher solar resources. This study compares two supply pathways for green hydrogen: (i) domestic production in Germany using hybrid photovoltaic–wind systems with battery storage, and (ii) production in Morocco via a hybrid CSP–PV plant, with hydrogen converted into ammonia for maritime shipment. The Levelized Cost of Hydrogen (LCOH) is used as the primary evaluation metric, complemented by sensitivity analyses on different renewable fraction achieved. Preliminary results indicate that domestic production ensures higher energy security but at higher costs, while imports from Morocco could achieve significantly lower LCOH values, particularly under favorable financing and scale conditions.

Keywords: Green hydrogen, Hydrogen supply chain, Optimization, LCOH

1. INTRODUCTION

Germany has embraced the challenge of meeting the European hydrogen targets by developing a highly ambitious National Hydrogen Strategy, aiming to achieve a national hydrogen demand of 90–130 TWh by 2030. Forecasts indicate that only 20–30% of this supply will be produced from renewable sources and can therefore be classified as green hydrogen [1]. This limitation is primarily driven by the country's limited availability of renewable resources, as well as by the strong competition among different sectors within the German energy market.

Several studies have investigated the potential for hydrogen imports to Germany. More broadly, Moritz et al. [2] analyze multiple pathways for supplying green hydrogen to the European market, while Alhadhrami et al. [3] focus on potential imports from Saudi Arabia. Eißler et al. [4] examine the green hydrogen supply chain from Australia to Germany, taking into account hydrogen derivatives and various delivery options. Moreover, several authors, including Bhandari et al. [5] and Pinto et al. [6], highlight that the abundant solar and wind resources in Africa could enable the production of low-cost green hydrogen. The ammonia-based import route is further supported by regional planning initiatives, such as the ammonia decomposition plant announced by Uniper at the port of Wilhelmshaven [7].

On the other hand, Sclaro et al. underlines the possibility to exploit the off shore wind farm excess to produce hydrogen to reduce financial risk [8]. The work by Schmitz et al. analyze the impact of import prices and one of the main findings relies on various scenarios that promote a domestic production [9].

Nevertheless, to the best of the authors' knowledge, there remains a lack of comprehensive studies evaluating the delivery of hydrogen streams to Germany under varying contributions from renewable energy sources. Building upon their previous work [10], the authors aim to compare domestic hydrogen production with imports from North Africa, assessing both pathways' ability to provide a steady hydrogen supply to Germany while accounting for different fractions of green hydrogen in the overall energy mix.

2. MODELS AND METHODS

The hydrogen supply chains considered in this study are illustrated in Fig. 1. Depending on the scenario, different system components are included. In the domestic production case (Fig. 1a), hydrogen is generated from photovoltaic panels and wind turbines installed in Hamburg, which supply electricity to an electrolyzer. Excess production is managed through a Battery Energy Storage System (BESS) and interaction with the electrical grid. Given the variability of renewable sources and the requirement for a continuous hydrogen flow, part of the produced hydrogen is directly injected into the gas grid, while fluctuations are balanced using compressed gas storage.

In the import scenarios (Fig. 1b), electricity generation is provided by photovoltaic panels and a solar tower concentrating solar power (CRS) plant equipped with thermal energy storage based on molten salts and a steam turbine. Hydrogen is transported to Germany in the form of ammonia, which requires additional infrastructure for both synthesis and on-site decomposition. The ammonia synthesis process operates under steady-state conditions; consequently, the electrolyzer must also operate in a stable regime to continuously supply hydrogen to the Haber–Bosch unit. The production site is assumed to be located near Casablanca, given its proximity to the port.

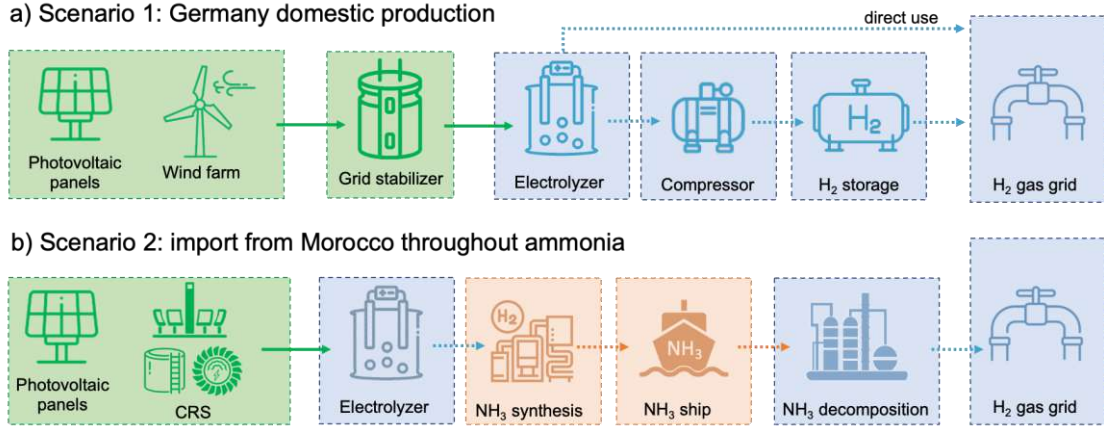


Fig. 1. Schematic of the hydrogen supply chain in the two considered scenarios

The analysis was carried out using an in-house model developed in Trnsys. Transient simulations were performed to assess the dynamic behavior of the system over a one-year period. A simulation time step of 7.5 minutes was adopted as a trade-off between computational cost and numerical accuracy. Both design and off-design operating conditions were analyzed for each component through performance maps or mathematical models accurately reproducing the thermo-physical behavior. Climatic data were obtained from the Meteonom global climatological database. An economic assessment was also conducted to determine the Levelized Cost of Hydrogen (LCOH) for the two investigated pathways, as defined by Eq. (1). The hydrogen production cost (\$/kg H₂) was calculated based on the installation cost of each component, annualized using the Capital Recovery Factor (CRF) according to its lifetime, and operation and maintenance (O&M) costs. Additionally, the cost of imported electricity was included, assuming a unit price of 0.20 \$/kWh.

Key performance indicators and economic assumptions adopted in the analysis are summarized in Table 1. Unless otherwise specified, reference values were taken from [10].

$$LCOH = \frac{\sum_{i=component} CRF_i \cdot CI_i + C_{el} \cdot E_{import}}{H_2 prod_{ann}} + O\&M \quad (1)$$

Table 1. Summary of main performance parameters and cost of each component

	Technical	Economic		
		Capital investment	O&M	
Photovoltaic	Module efficiency = 0.209 Temperature derating coefficient = -0.39 %/°C	793 \$/kW _p	19 \$/kW-yr	
Wind turbine	Rated power output = 2 MW @15m/s	1100 \$/kW	20 \$/kW-yr	
Battery storage	Round trip efficiency = 0.75	328 \$/kWh	7.25 \$/kWh-yr	
Central Receiver System (including solar field, thermal storage and steam turbine)	Function of design receiver thermal power as presented in [11]		66 \$/kW-yr + 3.5 \$/MWh	
Electrolyzer	Efficiency = HHV 82%	2000 \$/kW	2%*	
Compressor	Intercooled reciprocating compressor	4500 \$/kW	20%*	
H2 storage	Max pressure 250 bar	825 \$/kg _{H2}	1*	
NH3 synthesis	Electrical consumption = 0.74 kWh/kg _{NH3} - including air separation unit, NH3 synthesis (Haber Bosch process) and NH3 liquefaction	751 \$/kg _{H2}	5%*	[12]
NH3 ship – from Morocco to Germany	-	-	0.1 \$/kg _{H2}	[13]
NH3 decomposition	34 kWh/kg _{H2} – including H2 purification	-	4.62 \$/kg _{H2}	[14–16]

* % of the total investment divided by the annual production

Optimization

A multi-variable optimization was performed to determine the optimal system configuration for each scenario at varying renewable fractions (RF). The Trnsys model was coupled with the GenOpt software, which executed thousands of annual simulations. In this process, the optimization algorithm selects variable combinations from a defined search space to minimize a target objective function (Eq. 2). A penalty factor

was added to the Levelized Cost of Hydrogen (LCOH) to discard solutions that failed the minimum required RF and the target hydrogen output. A two-step algorithm, which couples the Particle Swarm Optimization method with the Hooke-Jeeves algorithm, was employed to enhance the identification of the global optimum. For both scenarios, the optimization variables included the nominal power of the renewable generators. In the domestic scenario additional optimization variables are the electrolyzer power, Battery Energy Storage System (BESS) capacity, and hydrogen tank capacity.

$$TF = LCOH + f_p(RF \text{ target}, H_2 \text{ delivered})$$

(2)

3. RESULTS AND DISCUSSION

The optimization results for the considered cases are summarized in Table 2. Due to limited resource availability, the renewable generators in Germany show a higher nominal power, despite the lower electric load. The Moroccan scenario is characterized by a higher annual energy demand, driven by the ammonia synthesis requirements. Furthermore, the need for steady operation necessitates a larger storage capacity to compensate for production fluctuations. It is worth noting that achieving a Renewable Fraction (RF) greater than 80% leads to a significant oversizing of both renewable generators and storage systems to meet the hydrogen demand. Consequently, an even greater portion of energy must be dissipated (i.e., curtailed), as storage systems large enough to capture this excess energy become economically unviable.

Fig. 2 provides a detailed breakdown of the Levelized Cost of Hydrogen (LCOH). Importing hydrogen from Morocco is shown to be more economically advantageous than domestic production across all renewable penetration (RF) levels. This holds true even when accounting for the 4.62 \$/kg_{H2} average cost associated with the on-site ammonia-to-hydrogen conversion required for the import pathway. This cost benefit is most significant for fully renewable (100% RF) production. In the Moroccan scenario, the cost of grid electricity imports has a substantial impact, particularly at lower RF values, which identifies 80% as the optimal renewable fraction. Notably, the LCOH is largely independent of the delivery volume, as the capital costs of the system components scale almost linearly.

Table 2. Results of the optimize solutions

		Domestic production			Import from Morocco		
Radiation DNI/GHI	kWh/m ²	902.1/1015.1			1892.5/1894.1		
Mean wind velocity @100 meters	m/s	8.46			4.67		
RF		60	80	95	60	80	95
Photovoltaic	MW	420	720	660	300	350	850
Wind farm	MW	140	228	840	-	-	-
BESS	MWh _e	30	60	390	-	-	-
CRS turbine power	MW	-	-	-	40	75	160
CRS solar receiver power	MW _{th}	-	-	-	300	500	800
Equivalent capacity of thermal energy storage	MWh _e	-	-	-	294	602	1529
Total investment cost	M\$	875.17	1366.50	2252.30	368.10	593.06	1041.00
Annual Electric Load	GWh	625.10	631.69	635.79	691.72		
Annual Export	GWh	68.10	240.85	890.79	31.08	48.86	222.59

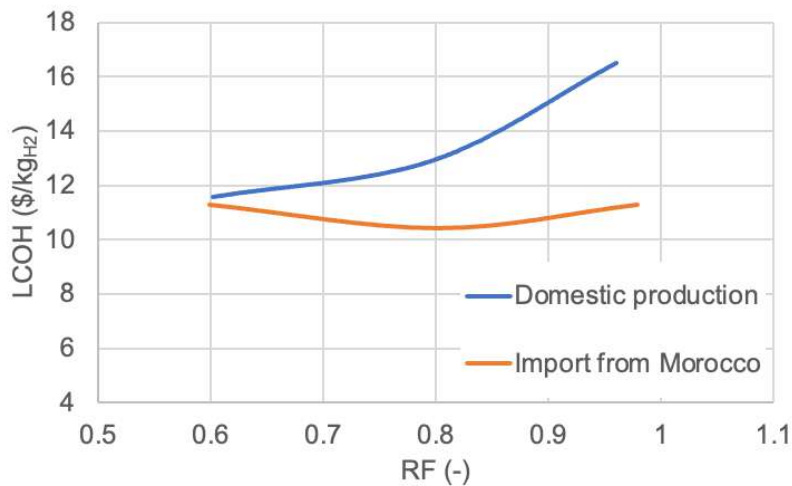


Fig. 2. Schematic of the hydrogen supply chain in the two considered scenarios

CONCLUSIONS

This study presented a techno-economic comparison between two alternative green hydrogen supply pathways for Germany: domestic production based on hybrid photovoltaic–wind systems and import from Morocco via ammonia synthesis and decomposition. The proposed TRNSYS-based transient model, combined with a multi-variable optimization routine, enabled a detailed evaluation of the dynamic behavior and economic performance of both systems.

Results indicate that domestic hydrogen production ensures higher energy autonomy and operational flexibility but leads to a substantially higher Levelized Cost of Hydrogen (LCOH) due to limited renewable resource availability and storage requirements. Conversely, hydrogen imported from Morocco - produced through a hybrid CSP–PV system and transported as ammonia - achieves a lower LCOH across all renewable fractions, even when accounting for ammonia synthesis and cracking costs. The analysis also highlights that renewable fractions above 80% result in significant system oversizing and energy curtailment, suggesting that an 80% renewable share represents the optimal trade-off between cost and sustainability.

The outcomes highlight the importance of developing import infrastructure and international cooperation while maintaining domestic capacity for grid stability and energy security.

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EFFICIENCY ASSESSMENT OF A PORTABLE HYDROGEN-WATER GENERATOR

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ABSTRACT – OH26

This study examined hydrogen generation and dissolution behaviour in a portable hydrogen-water (HRW) generator operated at 25 °C. Mass balance and equilibrium analysis were applied across three stages: before electrolysis, sealed after electrolysis, and immediately after opening the cap of the device. The device achieved a dissolved-hydrogen concentration of 4.3 ppm under a 2.72 atm partial pressure - about 5.5 times higher than the solubility limit at 1 atm. The increased concentration results from the elevated internal pressure during electrolysis. If the headspace contained only hydrogen, the attainable concentration would approach 8 ppm. Material characteristics also play a critical role: metal containers, being impermeable, can sustain higher internal pressures and minimise hydrogen loss, whereas polymeric bottles limit attainable pressure and allow gradual permeation. These findings highlight the combined importance of headspace composition, sealing integrity, and vessel material in determining achievable hydrogen concentration and stability in HRW systems.

Keywords: Hydrogen, Hydrogen-rich water, Hydrogenation, Hydrogen-infused water, Hydrogenated water

1. INTRODUCTION

Molecular hydrogen has recently attracted strong interest as a bioactive and functional gas, particularly when delivered through hydrogen-rich water (HRW). Since the seminal report by Ohsawa et al. (2007) [1], research on its therapeutic and antioxidant effects has expanded rapidly, paralleled by the emergence of a large HRW market [2], encompassing ready-to-drink products, hydrogen-releasing tablets [3], and portable generators intended for personal use. Among these, portable HRW generators - especially bottle-type and cup-type devices, have gained significant popularity due to their convenience [4],[5]. Most commercial units electrolyze water according to the stoichiometry: $2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$, dissolving a fraction of the produced HRW back into the same water without external reagents [6]. Not all generated hydrogen can dissolve in water. At fixed temperature, the dissolved concentration is bound by Henry's law, which sets the equilibrium solubility as a function of the hydrogen partial pressure in the headspace [7], [8]. During electrolysis in a sealed vessel, part of the H_2 partitions to the liquid and part accumulates in the headspace. The accumulated headspace H_2 raises its own partial pressure, which in turn raises the equilibrium solubility in the liquid [9]. This mechanism helps reach higher dissolved hydrogen while sealed, but it also means that a significant fraction of the total H_2 exists as headspace gas. When the vessel is opened, that gas rapidly vents to ambient and is effectively lost for dosing, even if the sealed measurement looked favorable. These coupled effects create two distinct performance questions. First, how much of the electrical input becomes chemical fuel (H_2) at the end of electrolysis while the bottle remains sealed. Second, how much of that fuel is retained in the system immediately after opening, when the headspace contribution disappears. The aim of this study was to quantify how water and electrical energy inputs are transformed, across the stages before hydrogenation, after hydrogenation (sealed), and immediately after opening, into hydrogen-rich water (HRW) and headspace gases, using coupled mass balances and energy/exergy analyses. The scope of this study is single production run at ~25 °C across the three states.

2. SYSTEM DESCRIPTION

We investigate a portable hydrogen-water generator in three states (Fig. 7):

- 1) S_1 (before hydrogenation) - the bottle contains liquid water with dissolved oxygen (DO) (m_{w1}, m_{DO1}).
- 2) S_2 (immediately after hydrogenation while sealed) - electrical input E drives electrolysis; part of the produced hydrogen dissolves in the liquid (m_{DH_2}) and part remains in the headspace together with oxygen ($m_{H_2(\text{headspace})}, m_{O_2(\text{headspace})}$). A portion of the generated oxygen also dissolves into the liquid, increasing the DO level at S_2 .
- 3) S_3 (immediately after opening) - the cap is removed and the headspace gases discharge to ambient.

Inputs and functional product: Inputs are water and electrical energy (supplied during $S_1 \rightarrow S_2$). HRW at opening S_3 (liquid plus the DH). Headspace gases are internal inventory at S_2 and vent on opening; they are therefore not included in the functional product but are reported separately as stored energy at S_2 and as opening losses at S_3 .

System Boundary: Within $S_1 \rightarrow S_2$ (sealed): headspace and dissolved gases are inside the control volume; no losses are counted. Across $S_2 \rightarrow S_3$ (opening): headspace gases cross the boundary and are counted as losses relative to the functional output (HRW). Hence, chemical energy credited at S_2 exceeds the delivered fuel at S_3 by the headspace fraction.

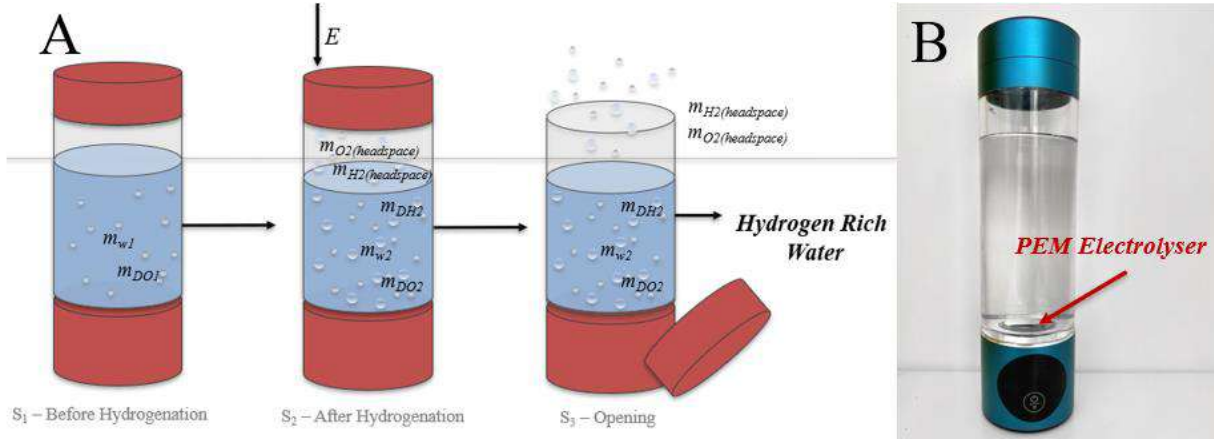


Fig. 7. (A) Hydrogenation stages of water before, during, and after electrolysis; (B) portable PEM-electrolyser device used for hydrogen-rich water generation

3. METHODOLOGY

In this section, the experimental assumptions, data acquisition methods, and analytical approach used to evaluate hydrogen generation and dissolution are described.

Study Assumptions

From the start of electrolysis until opening, no mass leaves the bottle; all gases produced remain within the liquid or headspace. The bottle is opened and weighed/checked within a few seconds; DH/DO changes during these first seconds are assumed negligible for the S₃ measurement. H₂/O₂/air in the headspace behave ideally at the measured T and P_{total} . The initial headspace is room air at ambient Temperature (T) and Pressure (P); its moles are computed by the ideal gas law from the measured volume. Dissolution of H₂ and O₂ follows Henry's law at the reported temperature; water activity is taken as unity; salinity and pH effects on solubility are neglected. The observed liquid-mass decrease is attributed to electrolysis consumption; evaporation or aerosol losses are negligible at the timescale and conditions used. Water electrolysis is the only significant reaction (no chlorine/ozone formation, no catalytic recombination to water inside the vessel).

Data Acquisition

Initial headspace: the initial headspace at S₁ was treated as room air in a known total volume V_{head} . Species volumes were obtained directly from the air composition in vol%. Moles were then obtained by first converting to mass using the molar mass species (via the ideal-gas density at the ambient T, P) and dividing by Molar mass (M_i). Here R is the gas constant; T is absolute temperature; P is ambient pressure:

$$\rho_i = \frac{PM_i}{RT}, \quad m_i = \rho_i V_i, \quad n_i = \frac{m_i}{M_i}, \quad (1)$$

Total gas generation (S₁ – S₃): the measured decrease in system mass from S₁ to S₃ stages was used to determine total O₂ and H₂ gasses generation by stoichiometry. These totals are carried forward to determine the headspace composition and DH. All mass measurements were taken using an analytical balance with an accuracy of ± 0.0001 g.

Sealed state (S₂): Knowing the initial moles of gases present in the headspace at S₁ and the H₂ and O₂ generated in the process, headspace pressure, hydrogen partial pressure, H₂ gas in headspace and DH at S₂ were computed using the following equations:

$$P_{\text{total}} = \frac{n_{\text{total}}RT}{V_{\text{headspace}}}, \quad P_{H2} = P_{\text{total}} \frac{n_{H2(\text{headspace})}}{n_{\text{total}}} \quad (2)$$

Where P_{total} is the total pressure in headspace, n_{total} – moles of total gas in the headspace, R – gas constant, T – temperature (K), $V_{\text{headspace}}$ – headspace volume and $n_{H2(\text{headspace})}$ is the moles of H₂ in the headspace.

$$C = H \cdot P_{H2} \quad (3)$$

Where C is the dissolved concentration, H is Henry's constant, and P_{H2} is the partial pressure of H₂ in the headspace. Electrical input (E_{elec}) was computed from the power and run time. pH, ORP, DO, and conductivity were measured using electrochemical meters equipped with the corresponding electrodes.

Energy and Exergy Accounting

At S₁, the energy of the system inputs is calculated adding the electrical input and initial water energy (E_{w1}) (water internal energy (U_{w1}) + chemical energy of DO ($E_{\text{chem}(DO1)}$):

$$E_{S1} = E_{w1} + E_{\text{elec}}, \quad E_{w1} = U_{w1} + E_{\text{chem}(DO1)} \quad (4)$$

The corresponding total exergy is:

$$Ex_{S1} = Ex_{w1} + Ex_{\text{elec}}, \quad (5)$$

where $Ex_{\text{elec}} = E_{\text{elec}}$ because electrical work is pure exergy, and Ex_{w1} includes the physical and chemical exergy of the initial water and dissolved oxygen relative to the environment. At S₂, the energy of the system

is calculated adding the HRW energy (E_{w2}) (Water internal energy at that stage (U_{w2}) + chemical energy of DO ($E_{chem(DO2)}$) + chemical energy of DH ($E_{chem(DH2)}$) and Internal energies of generated headspace gasses:

$$E_{s2} = E_{w2} + U_{H2(headspace)} + U_{O2(headspace)}, \quad E_{w2} = U_{w2} + E_{chem(DO2)} + E_{chem(DH2)} \quad (6)$$

The corresponding exergy is:

$$Ex_{S2} = Ex_{w2} + Ex_{H2(headspace)} + Ex_{O2(headspace)} \quad (7)$$

The exergy balance between S_1 and S_2 is then:

$$Ex_{elec} = (Ex_{S2} - Ex_{S1}) + Ex_{dest,S1 \rightarrow S2} \quad (8)$$

At S_3 , the energy of the system is the energy of the HRW (E_{w3}), the headspace gases produced in this stage are vented and considered as losses. The energy of HRW at S_3 is considered equal to the one at S_2 . The exergy of the system is likewise equal to the exergy of the HRW in the sealed state (S_2). The exergy loss associated with venting is therefore:

$$Ex_{dest,S2 \rightarrow S3} = Ex_{H2(headspace)} + Ex_{O2(headspace)} \quad (9)$$

4. RESULTS

After the electrolysis, the oxidation–reduction potential (ORP) shifted from +224 mV to –613 mV, indicating the development of a reducing environment commonly associated with hydrogen-rich water. However, although negative ORP values are often used as an indirect indicator of HRW, several studies have shown that ORP does not quantitatively reflect dissolved hydrogen concentration and should not be used as its proxy [10]. The DO increased slightly from 0.88 to 0.99 ppm, indicating partial dissolution of the generated oxygen into the liquid phase. The pH also rose from 8.05 to 8.28. Conductivity showed a minor change from 206 to 208 $\mu\text{S cm}^{-1}$. These variations confirm that the process enriched the water with molecular hydrogen while shifting the redox balance toward a strongly reducing state, typical of PEM-based hydrogen generation. Water-quality parameters are summarised in Table 1, and the state variables in Table 2:

Table 1. Measured water-quality parameters before and after hydrogenation

Parameter	Before Hydrogenation	After Hydrogenation
pH	8.05 $\pm$ 0.01	8.28 $\pm$ 0.01
DO (ppm)	0.88 $\pm$ 0.02	0.99 $\pm$ 0.05
ORP (mV)	224 $\pm$ 9.3	-613 $\pm$ 19.8
Cond. ($\mu\text{S/cm}$)	206 $\pm$ 3	208 $\pm$ 5

Table 2. State summary (measured & calculated variables)

S_1	S_2	S_3
$m_{w1} = 253.9113 \text{ g}$	$m_{w1} = 253.9113 \text{ g}$	$m_{w1} = 253.8051 \text{ g}$
$m_{DO1} = 0.0002234 \text{ g}$	$m_{DO2} = 0.0002525 \text{ g}$	$m_{DO2} = 0.0002525 \text{ g}$
$m_{DH1} = 0 \text{ g}$	$m_{DH2} = 0.001085 \text{ g}$	$m_{DH2} = 0.001085 \text{ g}$
$P_{total} = 1 \text{ atm}$	$P_{total} = 5.2147 \text{ atm}$	$P_{total} = 1 \text{ atm}$
$P_{H2} = 0 \text{ atm}$	$P_{H2} = 2.72 \text{ atm}$	$P_{H2} = 0 \text{ atm}$
	$m_{O2(headspace)} = 0.0002525 \text{ g}$	
	$m_{H2(headspace)} = 0.010794 \text{ g}$	

At 25 °C, the measured hydrogen mass corresponds to ≈ 4.3 ppm dissolved hydrogen, about 5.5 times higher than the 1 atm solubility limit. This elevated value results from the 2.72 atm hydrogen partial pressure established during electrolysis. Because the headspace also contains oxygen and air, the effective P_{H2} is lower than total pressure; if pure hydrogen filled the headspace, the attainable DH would approach ≈ 8.2 ppm. Once the bottle is opened and the overpressure dissipates, the dissolved concentration rapidly returns toward the 1 atm equilibrium level, consistent with earlier observations of substantial DH loss within a few hours after exposure [11].

Beyond headspace size and gas composition, container material strongly influences both the maximum pressure achievable and the rate of hydrogen loss after generation. Pressure-tolerant materials such as stainless steel or aluminium can safely sustain higher internal pressures and therefore reach higher initial DH than polymeric bottles [12]. This material effect becomes even more pronounced during storage. Tanaka et al. (2020) [6] reported that metal containers maintained stable DH for 12 hours, whereas all plastics lost nearly all hydrogen same time. Glass also performed poorly. This could have been attributed to the leakage through the cap seal [13]. Similar behaviour was reported in a separate study comparing container types: HRW produced in a stainless-steel vessel had an initial concentration of 12 ppm, declining to 9 ppm over seven days, while HRW stored in glass bottles fell from 10 ppm to undetectable levels within two days [14].

CONCLUSIONS

The portable HRW generator produced 0.001085 g of hydrogen, yielding 4.3 ppm dissolved hydrogen at 25 °C under a 2.72 atm partial pressure. This concentration exceeds the 1 atm solubility limit by more than fivefold, demonstrating the strong effect of elevated pressure during electrolysis. However, the presence of oxygen and air lowers the effective hydrogen partial pressure, reducing attainable DH. The choice of container material further constrains performance: stainless-steel or aluminium vessels can sustain higher pressures and minimise gas permeation, while polymeric bottles restrict both pressure buildup and hydrogen retention. Future HRW systems should therefore emphasise headspace purity, sealing, and material optimisation to enhance achievable and stable hydrogen concentrations.

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MAGNETIC ION EXCHANGE RESIN FOR SUSTAINABLE STRONTIUM RECOVERY FROM SALINE WATER

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ABSTRACT – OH27

Synthesis and performance of magnetic graphene oxide/iron oxide–functionalized ion exchange resin for sustainable strontium (Sr^{2+}) recovery from saline water. Brine mining extracts valuable elements like Sr^{2+} , used in ceramics, pyrotechnics, alloys, and energy storage, from sources such as seawater and brine. Recovering Sr^{2+} sustainably and cost-effectively is challenging, especially achieving high selectivity. This study modifies commercial ion-exchange resins with magnetic graphene oxide ($\text{GO}/\text{Fe}_3\text{O}_4@ \text{IEX-R}$) via in situ co-precipitation, enhancing adsorption, selectivity, and regeneration. SEM, Raman, XRD, and FTIR confirm the successful coating of Fe_3O_4 and $\text{GO}/\text{Fe}_3\text{O}_4$; nitrogen gas improves magnetization, surface uniformity, and thermal stability. $\text{GO}/\text{Fe}_3\text{O}_4@ \text{IEX-R-2}$ removes 99% of Sr^{2+} from a 1000 ppm solution. Max adsorption capacity is 20 mg/g. The resins show excellent Sr^{2+} selectivity at pH 2–10 and can be regenerated with 1 M NaCl, maintaining stability over five cycles with minimal capacity loss. Incorporating graphene oxide and magnetic iron oxide enhances kinetic, selectivity, and separation performance. These magnetic, regenerable resins effectively recover Sr^{2+} from high-salinity water. Furthermore, the $\text{GO}/\text{Fe}_3\text{O}_4@ \text{IEX-R-2}$ shows the best removal of the Zn, Pb, Ag, Co, Ni, Ba, Cu, and Cr metals at room temperature.

Keywords: Brine, graphene oxide, strontium removal, seawater, iron oxide, magnetic resin

1. INTRODUCTION

Water security is fundamental for all living organisms since freshwater resources are essential for drinking, agriculture, and sustainable energy generation. However, the growing dependence on nuclear energy has raised environmental concerns due to the release of radionuclides such as strontium-90 (^{90}Sr) into various water resources. The high solubility, long half-life (28.9 years), and biological toxicity of ^{90}Sr make it one of the most hazardous fission products. Its chemical similarity to calcium allows it to accumulate in human bones and teeth, increasing the risk of bone cancer and leukemia [1-3]. Therefore, developing efficient and sustainable technologies for ^{90}Sr removal is vital for ensuring water safety and protecting human health [4-6]. Desalination and treatment processes such as reverse osmosis, nanofiltration, membrane distillation, and electrodialysis have been used to remove radionuclides from contaminated water but face limitations such as high energy demand, fouling, and low selectivity. Ion-exchange resins are among the most effective materials for Sr^{2+} removal; however, their poor thermal and chemical stability may cause secondary environmental problems [7-10]. To overcome these challenges, recent research has focused on surface modification of ion-exchange resins using magnetic nanoparticles. In this study, a strong cation exchange resin was modified by in-situ co-precipitation of graphene oxide (GO) and Fe_3O_4 nanoparticles to enhance its adsorption capacity, stability, and selectivity toward ^{90}Sr ions in different water environments.

2. METHODOLOGY

The magnetic ion exchange resin was synthesized by the co-precipitation method. First, 3 g of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ was dissolved in 40 mL of ethanol, followed by IEX-R addition under continuous stirring. After 24 hours, the resin was washed with deionized water, then added to the $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ solution, followed by the addition of graphene oxide solution, and allowed to stir for 10 minutes. Sodium hydroxide (1 M) was then used to adjust the pH to 11. After 1 hour of continuous stirring, the $\text{GO}/\text{Fe}_3\text{O}_4@ \text{IEX-R-2}$ was separated by the sedimentation process, then washed with deionized water, followed by ethanol to allow the resin to dry more quickly. Fig. 1 shows the modification process of the IEX-R surface with $\text{GO}/\text{Fe}_3\text{O}_4$ nanoparticles.

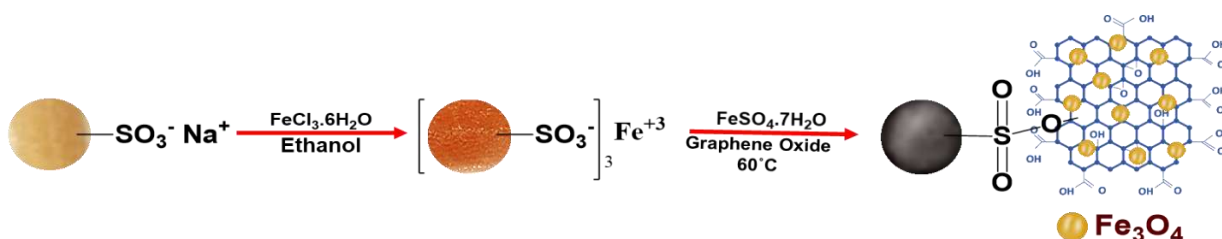


Fig. 1. Schematic illustration of the co-precipitation process of $\text{GO}/\text{Fe}_3\text{O}_4$ nanoparticles on the resin surface. The treated IEX-R was swollen in $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ for 24 hours, followed by $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ / graphene oxide addition

3. RESULTS AND DISCUSSION

Fig. 1 shows the scanning electron microscopes (SEM) of three ion exchange resin types, commercial strong acidic cation exchange resin (IEX-R), Fe_3O_4 @IEX-R-2, and $\text{GO}/\text{Fe}_3\text{O}_4$ @IEX-R-2. Fig. 1b and 1c indicates the change in the resin surface roughening when the resin surface was coated with iron oxide nanoparticles and graphene oxide iron oxide nanoparticles, respectively. The thin layers of graphene oxide coated with iron oxide was clearly shown in Fig. 1d.

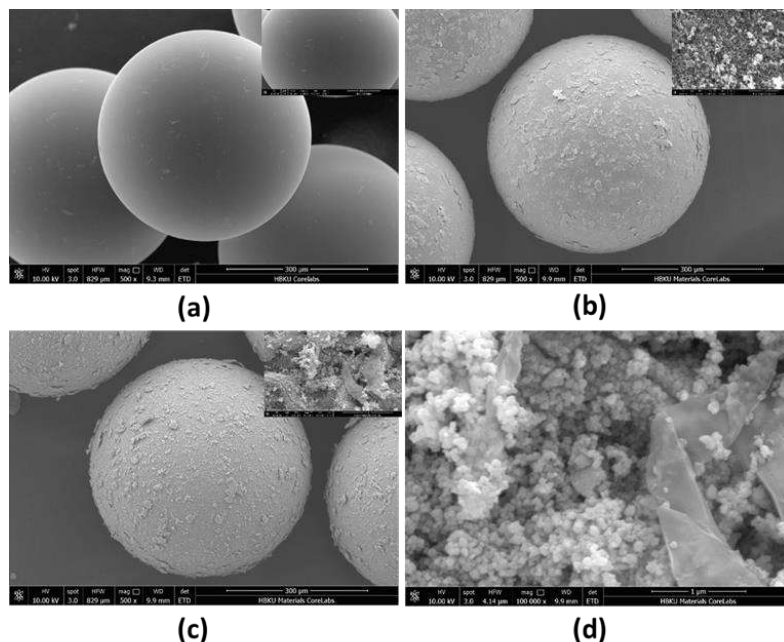


Fig. 2. SEM images of (a) commercial strong acidic cation exchange resin, (b) Fe_3O_4 @IEX-R-2, (c) $\text{GO}/\text{Fe}_3\text{O}_4$ @IEX-R-2 composites, (d) the thin layer of graphene oxide coated with iron oxide nanoparticles on the ion exchange resin surface

Fig. 2 shows the adsorption capacity of the three resin types IEX-R, Fe_3O_4 @IEX-R-2, and $\text{GO}/\text{Fe}_3\text{O}_4$ @IEX-R-2 at room temperature. The IEX-R shows a poor adsorption capacity at pH 7 compared with pH 2 and 10 during the first three hours. Both modified magnetic ion exchange resins show high adsorption capacity in the first three hours at all tested pH values.

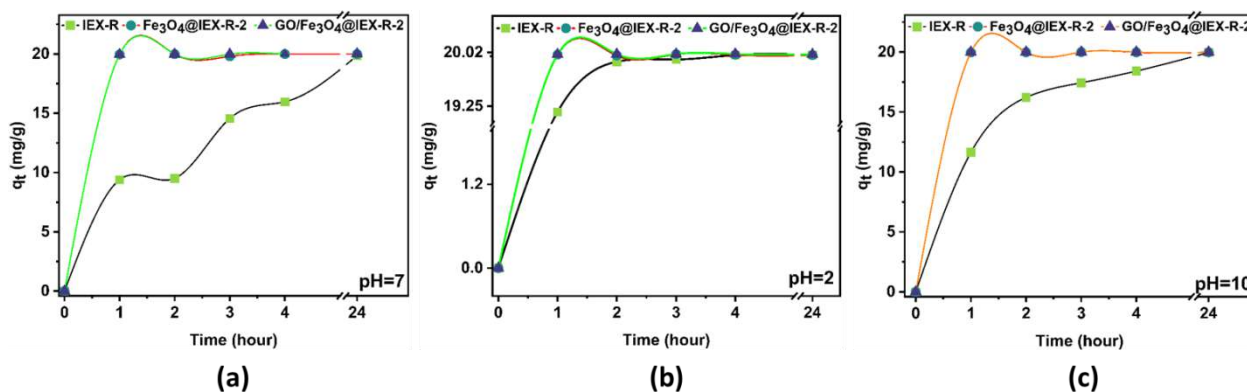


Fig. 3. Change in the adsorption capacity for strontium ions per time in hour when three resin types were used (Fe_3O_4 @IEX-R-2, IEX-R, and $\text{GO}/\text{Fe}_3\text{O}_4$ @IEX-R-2) at (a) pH7, (b) pH2, and (c) pH10.

Fig. 3a shows the changes of distribution coefficient (K_d) of strontium ions in different synthetic water including brine, seawater, and groundwater. Both modified ion exchange resin shows better adsorption and selectivity toward strontium ions. Fig. 3b indicates the using of burette in column study to study the selectivity of ion exchange resin in the present of Na, Mg, Ca, and K, the $\text{GO}/\text{Fe}_3\text{O}_4$ @IEX-R-2 shows the highest selectivity of strontium followed by Fe_3O_4 @IEX-R-2 then IEX-R. Furthermore, the adsorption capacity of $\text{GO}/\text{Fe}_3\text{O}_4$ @IEX-R-2 and IEX-R were also studied in Zn, Pb, Ag, Co, Ni, Ba, Cu, and Cr metals removal. Fig. 3c shows that the $\text{GO}/\text{Fe}_3\text{O}_4$ @IEX-R-2 has the best removal for all metals compared with IEX-R at room temperature.

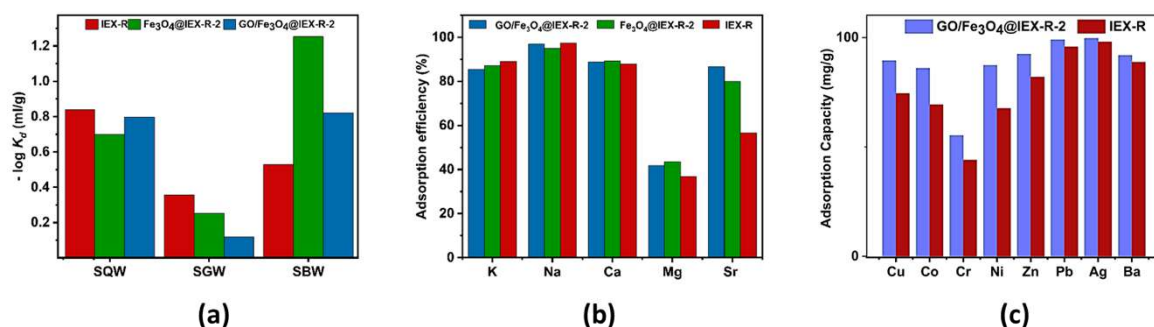


Fig. 4. (a) The distribution coefficient (k_d) for $GO/Fe_3O_4@IEX-R-2$, $Fe_3O_4@IEX-R-2$, and IEX-R in concentrated Sr^{+2} solution ($Sr^{+2} = 13.408$ ppm) and low concentrated Sr^{+2} solution (6 ppm) of synthetic brine, Qatari seawater, and groundwater, respectively. (b) Adsorption efficiency for several metals ions (K, Na, Ca, Mg, Sr) using $GO/Fe_3O_4@IEX-R-2$, IEX-R, and $Fe_3O_4@IEX-R-2$ at room temperature using burette, (C) adsorption capacity of $GO/Fe_3O_4@IEX-R-2$ and IEX-R for several metals ions including Zn, Pb, Ag, Co, Ni, Ba, Cu, and Cr at room temperature.

CONCLUSIONS

Commercial cationic ion-exchange resins were modified with graphene oxide (GO) and magnetic Fe_3O_4 nanoparticles to improve their Sr^{2+} adsorption capacity and selectivity. A uniform and thermally stable nanoparticle coating was achieved via in situ co-precipitation under a nitrogen atmosphere. The $GO/Fe_3O_4@IEX-R-2$ resin achieved 99% Sr^{2+} removal efficiency and a maximum adsorption capacity of 20 $mg\ g^{-1}$, following the Langmuir isotherm ($R^2 = 0.999$), indicating monolayer adsorption behavior. The modified resin exhibited stable adsorption across a pH range of 2–10 and high selectivity for Sr^{2+} over competing ions ($Sr > Mg > Ca > K > Na$) in simulated seawater. Regeneration with 1 M NaCl resulted in minimal capacity loss after five cycles. These results confirm that GO/Fe_3O_4 -coated resins are efficient, regenerable, and magnetically recoverable sorbents for sustainable strontium removal. Furthermore, the $GO/Fe_3O_4@IEX-R-2$ shows the best removal of the Zn, Pb, Ag, Co, Ni, Ba, Cu, and Cr metals at room temperature.

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ANALYSIS OF A HYDROGEN-POWERED BACKUP ENERGY SYSTEM FOR A DATA CENTER

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ABSTRACT

In the context of increasing digitalization and data dependency, ensuring the continuity of power supply to data centers has become a critical priority. Data centers host essential digital infrastructure, and any interruption in energy supply can lead to substantial operational, financial, and security-related consequences. Integrating innovative solutions, can significantly enhance the reliability and autonomy of data centers in critical scenarios, contributing to both energy security and environmental sustainability.

Based on the specialized literature, which shows that the size of data centers varies between 5 and 200 MW of installed electrical power, the architecture of a small-scale data center has been proposed. This architecture is proportionally modeled after large-scale data centers and consists of one CPU server rack with an installed electrical power of 10 kW. Based on this configuration, several backup power supply solutions have been proposed and analyzed: a modular battery energy storage system (BESS); a small-scale photovoltaic power plant (PVPP) combined with a modular BESS; a modular BESS integrated with a containerized hydrogen-based system for distributed power generation, using either fuel cells or internal combustion engines.

To identify the most suitable configuration, a comparative analysis was conducted, considering technical performance, scalability, energy efficiency, environmental impact, and system autonomy.

Keywords: Hydrogen backup system, Data center resilience, Fuel cell technology, Energy storage, Green hydrogen

1. INTRODUCTION

The increasing digitalization and data dependency leads to a high priority need of ensuring the continuity of power supply to data centers. Data centers host essential digital infrastructure, and any interruption in energy supply can lead to substantial operational, financial, and security-related consequences. Therefore, the development of resilient and sustainable backup energy systems is imperative. Integrating innovative solutions, such as hybrid systems powered by green hydrogen, can significantly enhance the reliability and autonomy of data centers in critical scenarios, contributing to both energy security and environmental sustainability.

In [1] the authors have analyzed a system that includes PV panels, a hydrogen microturbine and fuel cells (supplied with green hydrogen) and power batteries for supplying energy to a data center. A technical and economic analysis has been performed aiming at comparing the costs of energy supply for data center. In [2] the authors have analyzed different scenarios for an optimal design of an energy system (including hydrogen) for data centers. The paper presented several scenarios for covering the power demand. Paper [3] presents sizing of a hybrid system to power a datacenter of 500 kW composed of photovoltaic panels, winding turbines, batteries and fuel cells.

The authors have also analyzed different sizing of the proposed system. In [4] the authors have presented different scenarios of an energy system for a data center. They have performed an economic and sustainability analysis of all scenarios emphasizing the cost of energy supply. In [5] authors have performed a survey of the current state of data centers and hydrogen-based technologies along with a discussion of the hydrogen storage and infrastructure requirements needed for large-scale backup power applications at data centers. The present paper analyses different energy system configurations for energy supply of a data center.

2. MATERIALS AND METHODS

The study considers a small-scale pilot data center with an installed electrical power of 10 kW, composed of: a CPU server rack (3 kW), a GPU server rack (5 kW), and an air-conditioning unit (2 kW). Operational reduction assumptions during outages are [6-8]: **Normal event** - one grid outage/year, duration = 4 h/event, assumed load reduction 10% $\Rightarrow$ average backup load = 9 kW (36 kWh for 4 h); **Critical event** - one grid

outage/year, duration = 48 h/event, assumed load reduction 50% $\Rightarrow$ average backup load = 5 kW (240 kWh for 48 h).

Four backup supply configurations were evaluated:

(A) Battery-only system (UPS mode) — modular battery energy storage system, buffer for immediate hold-up and supply during outage. Report example sizing: 300 kWh / 10 kW (modular).

(B) PV + BESS — small photovoltaic plant sized to match local peak AC load (10 kW AC), combined with the same modular BESS (300 kWh/10 kW in the report example). The PV system used for simulations: 15 $\times$ 700 Wp bifacial half-cut modules $\rightarrow$ 10.5 kWp DC $\rightarrow$ 10 kW AC. Simulated first-year production = 12,881.5 kWh/yr (PVSyst).

(C.1) BESS + Fuel Cell Hydrogen System: 5 kW PEM fuel cell module + H₂ storage

(C.2) BESS + Internal combustion engine (ICE) Hydrogen System: small genset adapted to H₂ blends (market devices are “H₂-ready” but not 100% H₂ at small powers); the paper analyzes cogeneration modules and mixed-fuel operation.

Each configuration was analyzed regarding energy autonomy, storage capacity, scalability, and environmental performance. For this analysis, a few assumptions were made. Lower Heating Value (LHV) of hydrogen: 120 MJ/kg = 33.33 kWh/kg (standard LHV). PEM fuel cell electrical efficiency: $\eta_{FC} = 55\%$ (representative mid-range value for small PEM stacks). Small ICE electrical efficiency: $\eta_{ICE} = 31\%$ [9]. BESS round-trip efficiency: $\eta_{BESS} = 92\%$ and maximum usable DoD is 90%. Equations (1-4) used for calculations:

Energy to be supplied by the backup for an outage of duration t with average backup load P_{backup} :

$$E_{demand} = P_{backup} \cdot t \quad (1)$$

BESS nominal capacity required to supply E_{demand} , accounting for DoD and round-trip efficiency:

$$C_{BESS,nom} = \frac{E_{demand}}{DoD \cdot \eta_{BESS}} \quad (2)$$

Required chemical energy from hydrogen to produce electrical energy $E_{H2,e}$ at efficiency η_{gen} (fuel cell or ICE):

$$E_{H2,chem} = \frac{E_{H2,e}}{\eta_{gen}} \quad (3)$$

Mass of hydrogen required:

$$m_{H2} = \frac{E_{H2,chem}}{LHV_{H2}} \quad (4)$$

3. RESULTS AND DISCUSSION

Battery-only systems can meet short-duration outages but require large storage for 48-hour autonomy. Using Eq. (1)–(2) and the paper outage assumptions: for a normal event (4 h, backup load 9 kW $\rightarrow$ $E_{demand} = 36$ kWh), the required nominal BESS capacity is 43.48 kWh, hence, to cover a 48-h outage exclusively with BESS, the required nominal capacity would be ~ 290 kWh (≈ 300 kWh). BESS-only is technically feasible for the 4-h case with a small system (≈ 44 kWh). For a 48-h outage the BESS-only solution requires several hundreds of kWh of battery capacity, with high CAPEX and charging impacts. The pure BESS option has the advantage of simplicity, fast response and zero local emissions at point of use, but has a major disadvantage when considering the recycling cost and environmental impact.

PV baseline: 10.5 kWp (15 $\times$ 700 Wp) $\rightarrow$ simulated first-year production = 12,881.5 kWh/yr (PVSyst). The PV plant output is used for: charging BESS (90 kWh/yr (2 cycles)), powering the electrolyzer (if installed), and providing partial supply to the data center in normal operation. For outage handling PV contributes indirectly by keeping BESS charged during grid availability and enabling local green hydrogen production in variants that include on-site electrolysis (see D scenarios). PV + BESS reduces fossil energy dependence and reduces the size and hydrogen needs of H₂-based subsystems. PV + BESS is an attractive hybrid for resilience and renewables share; however, PV alone cannot supply long outages because it depends on irradiance (meteorological conditions, which usually are adverse during voltage supply interruptions periods – as they represent one of the most common causes for interruptions) and storage.

BESS + H₂ distributed generation (Variants C.1 — fuel cell, C.2 — ICE): BESS is used to cover the normal event completely (36 kWh) and to buffer until the H₂ generator reaches full output during critical events. Accordingly to the described scenario, authors propose a 50 kWh / 10 kW BESS for the hybrid schemes (smaller than the pure-BESS 300 kWh case because H₂ generation supplies prolonged outages). For the critical event, the proposed energy allocation is: BESS contribution during critical event: 41.40 kWh and H₂-generator contribution during critical event: 198.60 kWh (this is the electrical energy to be produced from hydrogen). To compute hydrogen mass required for the 198.60 kWh electrical contribution, Eq. (3)–(4) were applied. Result (C.1): ≈ 10.8 kg H₂ required to produce 198.6 kWh electric with a 55% PEM fuel cell. Result (C.2): ≈ 19.2 kg H₂ required for a 31% ICE electrical efficiency.

Comparison and operational notes:

Fuel cells (C.1) require less hydrogen mass due to higher electrical efficiency (≈ 11 kg vs ≈ 19 kg for ICE). Fuel cells provide quiet operation, low local emissions (no CO₂ at the point of use) and fast ramping in many PEM implementations. They do require higher-purity H₂.

ICE gensets (C.2) are more mature in some power ranges and can be less costly per kW installed, but at small power they are commonly supplied today as combined-heat-and-power modules (cogeneration) and may not

operate on 100% H_2 at small sizes [9]. ICE operation on H_2 (or H_2/CH_4 blend) introduces NO_x formation concerns and, depending on fuel origin, lifecycle CO_2 . Current commercial “ H_2 -ready” modules accept partial H_2 blends only (e.g., 20–40%) at small powers; pure- H_2 ICE modules at tens of kW are less common.

At point of use, a PEM fuel cell generating electricity from H_2 produces negligible CO_2 (assuming H_2 is not a fossil-derived blend). ICE burning hydrogen also produces no CO_2 if the fuel is pure H_2 , but in practice small ICEs often run on blends ($CH_4 + H_2$) so CO_2 is proportional to the fossil component (fig.1). As the amount of H_2 in the fuel mixture increases, the lower heating value (LHV) also rises (fig.1); however, the higher combustion temperature leads to an increase in NO_x emissions for ICEs while fuel cells produce negligible NO_x [10]. Lifecycle emissions depend on H_2 production route (electrolytic green H_2 vs fossil-based H_2) [11-13].

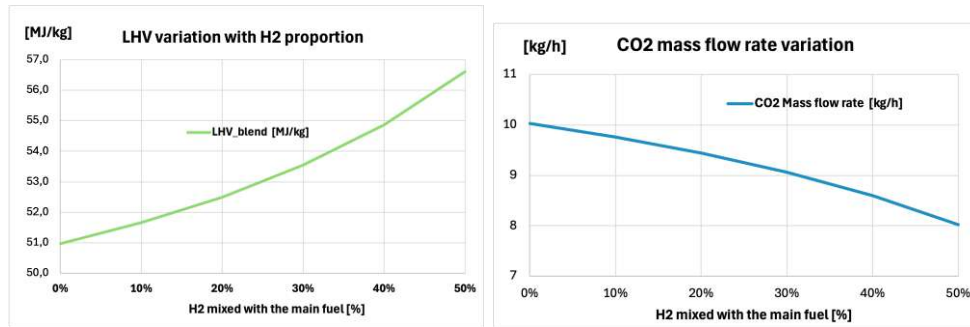


Fig. 1. Lower Heating Value (LHV) and CO_2 emissions for ICEs using fuel blends ($CH_4 + H_2$)

In Table 1, the analysis of the studied solutions is summarized in a comparative form, with emphasis on the type of equipment used, their ability to withstand power outage periods, as well as their complexity and environmental impact.

Table 1. Summary comparison

Metric / Variant	A: BESS only	B: PV + BESS	C.1: BESS + FC	C.2: BESS + ICE
Example BESS (nominal)	300 kWh / 10 kW	300 kWh / 10 kW	50 kWh / 10 kW	50 kWh / 10 kW
PV installed (kWp)	—	10.5 kWp → 12,881.5 kWh/yr	10.5 kWp	0.5 kWp
H_2 mass for critical event (198.6 kWh _e)	—	—	~10.8 kg H_2 ($\eta_{FC} = 55\%$)	~19.2 kg H_2 ($\eta_{ICE} = 31\%$)
BESS needed to cover 4h normal event	≈ 44 kWh (calc)	≈ 44 kWh	50 kWh chosen	50 kWh chosen
Ability to cover 48h without H_2	Requires ≈ 290 kWh (≈300 kWh)	Same	No (needs H_2)	No (needs H_2)
Local emissions at point of use	0 (battery)	0 (PV+BESS)	0 CO_2 (fuel cell)	0 CO_2 if pure H_2 ; NO_x possible
Complexity	Low	Medium	High (H_2 handling, purification)	High (H_2 handling, engine adaptation)

Based on technical and market considerations, the study concludes the hybrid solution: BESS: 50 kWh / 10 kW (UPS to cover normal events and buffer until H_2 system is online), with PV: 10.5 kWp (10 kW AC) producing ≈12,881.5 kWh/yr, for a H_2 subsystem: containerized PEM electrolyzer (10 kW input), compressor to 200 bar, hydrogen storage (cylinder bank) and PEM fuel cell 5 kW for islanded generation. On-site PV can fully power electrolyzer annual demand and charge BESS cycles (fig. 2).

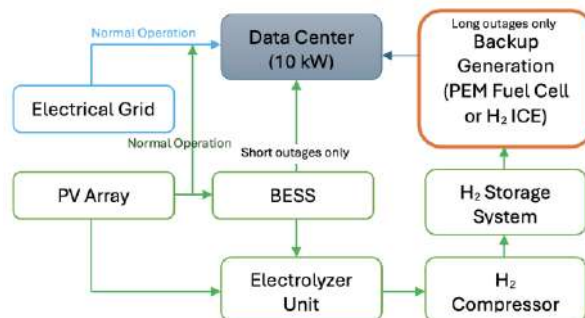


Fig. 2. System architecture of the proposed hydrogen-based backup energy system

This aggregated hybrid yields the best trade-off between autonomy, renewables share and installation footprint for the pilot.

CONCLUSIONS

This work presents a technical analysis of several resilient backup energy configurations for a small-scale data center. Battery-only architectures can ensure short autonomy but become oversized and costly for extended outages. Adding photovoltaics improves sustainability but does not adequately increase autonomy without large storage capacity. The hydrogen hybrid approach, integrating a PEM fuel cell with battery support and on-site green hydrogen production, offers the most balanced performance. Approximately 11 kg of stored hydrogen can ensure 48-hour autonomy under critical conditions, while the 50 kWh BESS fully covers normal outages and transient responses.

The proposed PV + BESS + containerized PEM fuel cell configuration is recommended as the optimal sustainable backup energy solution for small scale data center applications.

Trade-offs and practical constraints: H₂ handling and fuel cell integration increase system complexity (purity, compression to 200 bar, safety and leak detection). ICEs present a potentially lower CAPEX per installed kW but suffer reduced efficiency and possible NO_x emissions and, in practice, are often limited to partial H₂ blends at small sizes. Fuel cells are preferred where low local emissions and compactness matter.

ACKNOWLEDGEMENT

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HISTORICAL PARALLELS AND DEVELOPMENT PERSPECTIVES BETWEEN THE NATURAL GAS INDUSTRY AND THE EMERGING HYDROGEN ECONOMY. PUBLIC ACCEPTANCE OF HYDROGEN, AS COMPLICATED AS THAT OF GAS OR NUCLEAR

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Abstract

This article examines historical analogies between the development of the natural gas industry during the first half of the twentieth century and the ongoing transition toward a hydrogen-based economy. Using an interdisciplinary comparative framework—historical, technological, economic, and geopolitical—the study identifies structural mechanisms that shape industrial maturation in both sectors. By analyzing infrastructure, cost evolution, regulation, social acceptance, and national energy strategies, the paper argues that hydrogen follows a developmental trajectory similar to that of natural gas, yet accelerated by climate pressures, decarbonization imperatives, and targeted public policies. Although the parallels are significant, hydrogen differs fundamentally in its systemic role—as an energy carrier, storage medium, and integrator within renewable-based systems. The findings may inform infrastructure planning, regulatory design, and long-term energy investment strategies toward 2050.

Keywords: hydrogen, natural gas, energy transition, infrastructure, decarbonization, 2050 scenarios, energy policy

1. INTRODUCTION

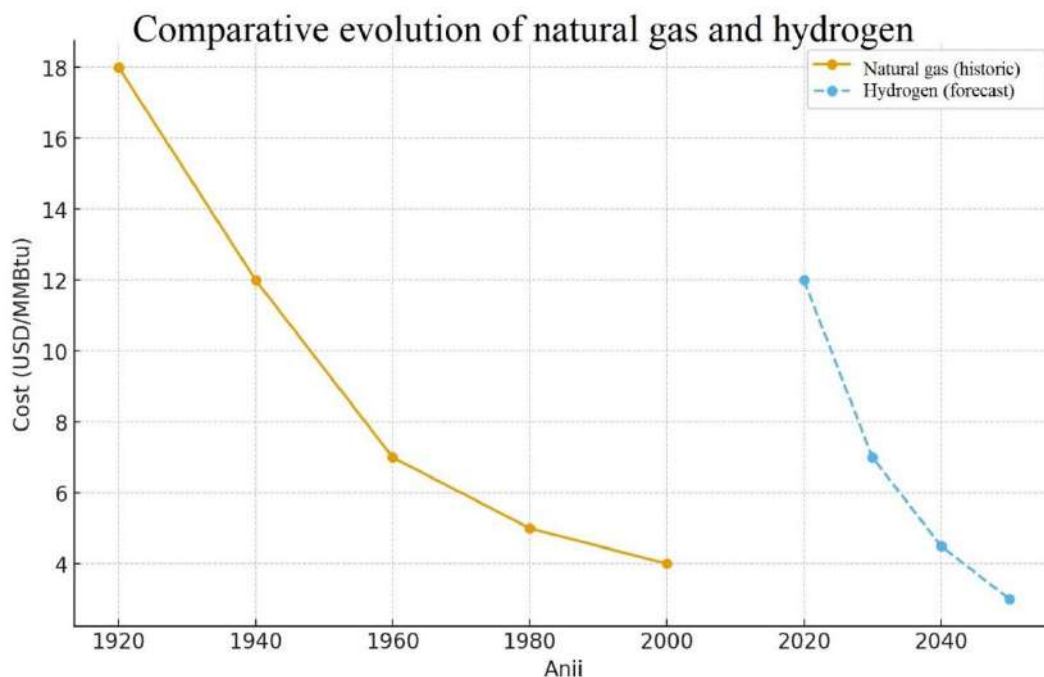
Natural gas became a cornerstone of economic modernization during the first half of the twentieth century, shaping industrial production, urban development, geopolitics, and international trade. Today, hydrogen occupies a similar historical position—promoted as a strategic solution for decarbonizing hard-to-abate sectors and enabling the restructuring of global energy systems.

Understanding how the natural gas industry evolved can provide analytical insight into the potential pace, barriers, and developmental pathways of the emerging hydrogen economy.

2. METHODOLOGY

This study employed:

- Comparative historical analysis — industrial archives, energy development timelines, and sectoral reports from 1909–2025.
- Systematic literature review — peer-reviewed hydrogen research (2015–2024) and energy transition studies.
- Infrastructure and technology assessment — production, transport, storage, and distribution systems.
- Policy analysis — national hydrogen strategies in the EU, United States, and Japan.
- Exploratory scenario modeling — qualitative futures assessment toward 2050.
- Economic data presented are illustrative and intended for comparative reasoning, not quantitative forecasting.



3. HISTORICAL CONTEXT: BUILDING THE NATURAL GAS INDUSTRY

Around 1920, the natural gas sector remained local and technologically fragmented, dominated by manufactured “town gas.” Industrial expansion was enabled by:

- large geological discoveries,
- high-pressure transmission pipelines,
- industrial-scale compression technologies,
- standardization of calorific content and safety norms,
- vertically integrated energy companies and early regulatory structures.

As infrastructure expanded, economies of scale rapidly reduced costs, facilitating mass adoption across households and industry.

4. CURRENT STATE OF THE HYDROGEN INDUSTRY

Although hydrogen has long been used in chemical and refining sectors, only recently has it been framed as a systemic energy vector. Present-day characteristics include:

- predominantly site-based industrial production,
- pilot-scale regional hydrogen hubs,
- high capital costs for electrolysis and carbon capture,
- limited dedicated transport and storage infrastructure,
- absence of unified international certification and trading standards.

Unlike natural gas, hydrogen’s rise is driven not by market demand alone but by climate policy, technological innovation, and decarbonization mandates.

5. KEY DEVELOPMENTAL PARALLELS

Etapă evolutivă	Developmental Stage Natural Gas	Period	Developmental Stage Hydrogen	Period Estimation
Phase 1 Local production, urban distribution grids Pilot projects	<i>Local production, urban distribution networks</i>	1910 - 1919	<i>Pilot projects, industrial centers</i>	2025 - 2030
Phase 2 Energy Valey	<i>Natural Gas Valey</i>	1920 - 1927	Hydrogen Valey	2030 - 2035
Phase 3 Regional pipeline networks Repurposed gas pipelines, dedicated corridors	<i>Regional pipeline networks</i>	1927 - 1946	<i>Reused gas pipelines, dedicated corridors</i>	2035 - 2040
Phase 4 National energy systems Cross-border hydrogen infrastructure	<i>National energy systems</i>	1946 - 1979	<i>Cross-border hydrogen infrastructure</i>	2040 - 2050
Phase 5 Global LNG trade Liquid hydrogen, ammonia, e-fuels	<i>Global LNG trade</i>	>1980	<i>Liquid hydrogen, ammonia, electronic fuels</i>	>2050

Natural gas has gone from high costs to competitiveness through scaling, technological innovation, integration into extended energy chains and public investment. Hydrogen will follow the same trajectory. The development of gas has imposed safety standards, its classification as a public service and tariff regulation. Hydrogen is now entering the same phase: classification of the “color of hydrogen”, regulation of blending with gas, infrastructure authorization.

Both industries have faced concerns about explosiveness, odor, urban accidents — elements that have led to the creation of technical standards and information campaigns.

Romania provides a relevant example of parallelism, having one of the oldest gas industries in Europe and the world, an extensive national transport infrastructure and important underground storage capacities.

In the table below we have a parallelism regarding the conditions that determined the emergence of the natural gas industry in Romania and the conditions that could determine the emergence of the hydrogen industry as an energy vector in Romania.

What caused Gas Valley to appear?	What can cause Hydrogen Valley to appear?
• High energy demand,	• Even greater energy demand,
• Local gas availability,	• Local availability of hydrogen,
• Wide scope of use,	• Wider scope of use,
• Inconvenience and nuisance,	• Inconvenience and hassle,
• Gas price correlation,	• Lack of hydrogen price correlation,
• Gas promotion,	• Lack of hydrogen promotion,
• Information campaigns,	• Lack of information campaigns,
• Acceptability,	• Unacceptability,
• Convenience,	• Inconvenience,
• Favorable context.	• Unfavorable context.

Currently, Romania has high potential to produce green hydrogen thanks to wind energy in Dobrogea, already has experience in testing hydrogen blending in natural gas distribution networks and is involved in European IPCEI projects on hydrogen.

Thus, the regulatory and infrastructural experience in the Romanian gas sector can accelerate the development of hydrogen.

6. HYDROGEN SCENARIOS UNTIL 2050

Evolution scenarios until 2050 can consider three scenarios:

Scenario 1 — Policy-Driven Acceleration

- carbon pricing surpasses 150 €/t CO₂,
- large-scale hydrogen pipeline networks built across Europe,
- hydrogen becomes dominant in steel, fertilizers, and heavy transport.

Scenario 2 — Incremental Transition

- hydrogen adoption remains industry-focused,
- infrastructure grows gradually,
- regional divergence in market maturity.

Scenario 3 — Technological and Economic Stagnation

- renewable electricity remains costly,
- public resistance delays infrastructure projects,
- biogas, electrification, and batteries outcompete hydrogen.

7. PERCEPTION SHAPES SOCIAL LEGITIMACY

Historical analogy does not imply deterministic replication; however, it highlights structural patterns:

- infrastructure development precedes market expansion,
- industrial transitions require institutional stability,
- risk perception shapes social legitimacy,
- state intervention can accelerate or impede technological diffusion.

The defining difference is that hydrogen emerges from climate necessity—transforming the interplay between public policy, private investment, and market formation.

8. PUBLIC ACCEPTANCE

Public acceptance is a possible but not easy process that was won in the past by natural gas and nuclear energy.

The gas, nuclear and hydrogen industries appear as two different technological paradigms, united by the same challenge: social acceptability. It is not technical performance or safety records that define their destiny, but the way society perceives, understands and culturally integrates them.

Natural gas or nuclear energy is a mature technology, with a secure infrastructure and a rich history. It functions like a precise organism, governed by physics, engineering and strict regulations. And yet in the collective imagination, it remains accompanied by the memory of a few rare but publicized accidents. Thus,

the perceived risk becomes disproportionate to the real statistical risk — a consequence explained by cognitive psychology and the theory of social risk amplification. Ionizing radiation, invisible and intangible, amplifies anxiety, not through data, but through symbolism.

The younger and still expanding hydrogen industry is facing a similar phenomenon. From a chemical and engineering point of view, hydrogen is well understood, predictable, manageable. And yet, its association with volatility, flammability, and historical episodes such as the Hindenburg fire build or disproportionate public narrative. Its physical characteristics — rapid diffusion, almost invisible flame — transform it, in collective representations, into an insidious risk, hard to perceive and therefore hard to accept.

Natural gas, nuclear, or hydrogen become such case studies on the difference between risk and fear, between scientific evidence and social imaginary. Their acceptance depends not only on technical parameters, but also on institutional transparency, public education, the credibility of economic actors, and the ethics of political decisions. Where trust is lacking, a position is born, regardless of the objective benefits. The two industries are, in the end, less rivals and more mirrors of each other. They illustrate that the energy transition is not just an engineering project, but also a cultural one. Technologies do not automatically become accepted—they must be explained, contextualized, integrated into a collective sense of safety and progress. Only then can their promise—whether transformed into energy, heated by fission, or propelled by hydrogen—be perceived not as a threat but as a shared resource for the future.

CONCLUSIONS

The hydrogen economy does not represent a radical historical discontinuity but an accelerated reiteration of lessons learned from natural gas and nuclear development. If strategically integrated—technologically, institutionally, and socially—hydrogen could become a foundational component of a net-zero global energy system. The past does not dictate the future, but it offers a valuable blueprint for avoiding systemic inefficiencies, regulatory delays, and infrastructural bottlenecks.

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DECENTRALISED HYDROGEN FARMING FROM PUBLIC CARPARK INFRASTRUCTURE: A TECHNO-ECONOMIC ANALYSIS

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ABSTRACT

The green hydrogen has great potential as an E-fuel, to address the challenges of conventional hydrocarbon fuels with a clean, renewable fuel for the mobility sector. As a green fuel, green hydrogen addresses greenhouse gas emissions in the transportation sector by facilitating nearly zero tailpipe emissions, enhanced system efficiencies, rapid refuelling, and the substitution of fossil fuels, thereby supporting decarbonization and global climate objectives. This conceptual study designs and models a decentralised carport PV-hydrogen farming system, along with its techno-economic analysis framework for a 100 kW solar-powered PEM electrolyser system within public carport infrastructure in Kuala Lumpur, Malaysia. The study assessed the technical viability and cost dynamics of decentralised green hydrogen production, compression, storage and refuelling to hydrogen vehicles. The analysis examines the feasibility and scalability of green hydrogen production utilising local solar resources, as well as the logistical requirements for hydrogen vehicle refuelling. It also evaluates economic factors, such as capital and operational expenditures, the levelized cost of electricity (LCOE), and the levelized cost of hydrogen (LCOH). The results reveal that the 100-kW carport solar system is projected to generate approximately 138,315 kWh of solar energy annually and produce 2,605 kg of hydrogen. Green hydrogen farming from carport PV presents a potential method for facilitating the renewable energy transition, offering a scalable solution for sustainable mobility in Malaysia while directly aligning with national renewable energy objectives and Malaysia's Hydrogen Economy and Technology Roadmap.

Keywords: Hydrogen Farming, Carport PV, Green Hydrogen, Hydrogen Fuel

1. INTRODUCTION

Global energy demand is increasing exponentially and directly effecting the social, economical and environmental balance by increasing pressure on markets, driving up prices, GHG emissions and climate change. Access to clean energy and fuel is shifting into one of the fundamental needs of present era because globally vehicles are projected to double by 2050, particularly in developing economies. The accelerated transition to clean and sustainable energy-fuel systems is crucial to mitigate climate change and sustainable revolution. The transportation sector is responsible for approximately 21% of direct global CO₂ emissions and decarbonising this sector has become one of the global challenges which has to be addressed with immediate effect [1]. Key enablers to the energy transition include renewable energy technologies, green hydrogen E-fuel systems, and energy-efficient infrastructure, which collectively support resilient and low-carbon urban ecosystems. When produced via electrolysis powered by renewable sources such as photovoltaic (PV) systems, hydrogen enables zero-emission mobility, emitting only water as a by-product in fuel cell operation green hydrogen stands out as a transformative solution for decarbonising transportation.

The integration of solar photovoltaic systems on the carport or car parking areas and existing infrastructures with electrolyser based green hydrogen production offers a promising decentralised approach to the fuel production. These systems utilise underused urban surfaces, like parking lots and public infrastructures to serve as dual-purpose energy-fuel production hubs that generate renewable electricity and convert it into clean fuel in the form of Green hydrogen. The hydrogen produced through the process can be compressed, stored, and used for on-site vehicle refuelling, reducing dependence on centralised power grids and fuel dependency [2]. This carport PV hydrogen farming system supports positioning green hydrogen as a critical resource of climate neutrality, particularly in urban and peri-urban areas having high solar irradiance and resource like in tropical climatic regions. Solar-to-hydrogen technologies and Hydrogen fuel cell electric vehicles (FCEVs) offer several advantages over conventional battery-electric vehicles, including fast refuelling times, extended driving ranges, and high operational efficiency, making them particularly suitable for sustainable mobility such as cars, buses, trucks, and urban logistics [3]. Expanding hydrogen refuelling

infrastructure is vital to overcoming range issues of hydrogen fuel vehicles and accelerating the adoption of hydrogen mobility. Carport PV based hydrogen generation integrated to refuelling system provides a scalable and resilient pathway for clean fuel production.

Background study

Solar photovoltaic (PV) carport systems are a feasible method for incorporating renewable energy production into current urban infrastructures, while meeting the increasing need for decentralised energy systems. Habib et al. (2023) specified that monopitch carport structures can attain an 82% performance ratio and a levelized cost of electricity (LCOE) of 0.12 USD/kWh, which is comparable to the grid-supplied energy rate of 0.35 USD/kWh [4]. Sanjay et al. (2023) showed that a bifacial photovoltaic system with a 45° tilt attained the shortest payback period of 7.3 years for rooftop photovoltaic-based electric vehicle charging, whereas a monofacial system with a 30° slope produced a levelized cost of electricity (LCOE) of 0.8988 SEK/kWh and an electric vehicle charging cost of 0.1471 SEK/km, demonstrating the advantageous techno-economic performance of optimised building structures integrated system configurations for sustainable mobility [5]. Malek et al. (2024) studied the practical viability of a 6.3 kWp photovoltaic carport integrated with an electrolyser and stationary energy storage, underscoring its potential for decentralised hydrogen production in urban environments [6]. These advancements correspond with a wider worldwide transition towards hydrogen economies, whereby renewable-powered electrolysis provides a zero-carbon method for hydrogen fuel production. Economic assessments suggest a payback time of around seven years for large-scale solar hydrogen facilities, attributed to decreasing electrolyser costs and enhanced photovoltaic efficiency [7]. In tropical climatic regions like Malaysia, with annual solar irradiance ranging from 1,500 to 1,900 kWh/m², integrating solar carport infrastructures with decentralised hydrogen systems is a potential tool that can be adapted to the opportunity under the National Energy Transition Roadmap (NETR). In Malaysia, the average commercial electricity tariff is approximately RM 0.43/kWh, or 0.10 USD/kWh, and solar carports offer a resilient technical microgrid system for decentralised renewable energy production and storage [4]. Integrating PEM electrolysers within carport structures across public parking areas can thus support urban hydrogen hubs, minimise reliance on centralised refuelling infrastructure, and achieve a reduction in urban transport emissions. The ongoing Mobile Hydrogen Refuelling Station (MHRS) initiative, managed by Nano Malaysia Berhad, highlights national efforts to accelerate the adoption of hydrogen mobility by dispensing up to 50 kg of hydrogen per day [8]. Although academic research in the present scenario is focusing on this area, studies on decentralised solar-powered green hydrogen systems, specifically assessing their technical and economic feasibility in tropical urban environments such as Malaysia, are limited. This research evaluates the techno-economic viability of hydrogen generation and refuelling infrastructure based on solar carports for sustainable urban energy transitions. (Fig. 1).



The objective of this study is to evaluate the techno-economic feasibility of decentralised hydrogen production and refuelling infrastructure integrated into solar carports within urban public parking systems in Malaysia. By leveraging photovoltaic energy, the proposed system aims to produce on-site green hydrogen, supporting sustainable mobility solutions, particularly for hydrogen vehicles. The study aims to conduct a fundamental analysis of system design, energy conversion efficiency, cost implications, and scalability potential to determine the practical viability and long-term benefits of deploying such systems in Malaysian cities. The novelty of this study lies in its holistic framework, which integrates solar carport-based photovoltaic systems with green hydrogen production, storage, and refuelling infrastructure. This approach combines techno-economic modelling under Malaysia's tropical conditions to deliver scalable, space-efficient, and sustainable urban mobility solutions.

2. METHODOLOGY

The design methodology, parameters, and technical specifications for a decentralised hydrogen production and refuelling system supplied by photovoltaic energy from a solar carport in a city in Malaysia have been discussed in this section. The methodology for the Carport PV-Green Hydrogen Farming system, integrated with a hydrogen refuelling dispenser to supply hydrogen fuel for FCEVs or hydrogen vehicles, is applied to this conceptual study. It incorporated design and analysis of the Carport PV system, electrolyser design and modelling, hydrogen compression and storage systems integrated with hydrogen dispensers to maximise operational efficiency and cost-effectiveness. Fig. 1 represents the conceptual image of this research. The research question was addressed by modelling and simulating solar carport systems for green hydrogen production and refuelling requirements, based on actual system components, with a techno-economic analysis for the tropical climatic region. The simulation software PVSyst has been used as a tool which allows for detailed modelling of such systems, including all relevant boundary conditions

Basic Description of the Decentralised Carport PV-Green Hydrogen Farming System

The decentralised carport PV-green hydrogen farming system represents an innovative approach to coupling urban renewable energy generation with on-site electrolysis-based green hydrogen production for sustainable transportation and distributed hydrogen fuel supply. The proposed system consists of a solar photovoltaic (PV)-integrated carport infrastructure equipped with a modular proton exchange membrane (PEM) electrolyser unit, reverse osmosis (RO) water purification system, hydrogen compressor, and both intermediate low-pressure and final high-pressure storage tanks, all located within or adjacent to public parking facilities, integrated with a high-pressure hydrogen refuelling dispenser unit. This decentralised framework enables each carport installation to function as a compact hydrogen farm, autonomously generating e-fuel directly from solar energy without reliance on centralised grids or large-scale hydrogen plants.

The Carport photovoltaic system consists of high-efficiency PV panels, such as monocrystalline or bifacial types, mounted on elevated carport structures that both shade parked vehicles and optimise solar energy harvesting. These systems comprise key components, including photovoltaic (PV) modules, carport structures, inverters, and battery storage units. The electricity generated by the carport PV system is directed to a power conditioning unit equipped with maximum power point tracking (MPPT) controllers to stabilise the output. The system also includes inverters and battery storage units to enhance operational resilience. A small-scale lithium-ion BESS buffers short-term variability from cloud cover and supports start-up power for the electrolyser and compressor units. This hybrid energy configuration enhances the reliability and consistency of hydrogen generation in decentralised urban settings where partial shading and load intermittency can occur.

Green hydrogen production uses a proton exchange membrane (PEM) electrolyser, powered directly by Carport PV systems, which in turn use treated municipal water or harvested rainwater. The regulated renewable energy powers a PEM electrolyser system located in a secured technical enclosure adjacent to the parking bays. Water supply is derived from a treated municipal or harvested rainwater source, preconditioned using filtration, deionisation, and softening units with RO purifiers to meet electrolyser feed water purity requirements. The produced hydrogen gas is then directed to an intermediate tank and then to the compression and storage module. The compression process typically elevates hydrogen pressure to 700 bar, because the end-use requirements focus on hydrogen cars and the storage system design using a multi-stage, isothermal compressor. Hydrogen is stored in a Type II intermediate tank and, after compression, in Type IV composite cylinders housed in a ventilated containment room. Hydrogen dispensing infrastructure forms the terminal interface of the system. The setup includes low-flow refuelling dispensers for fuel cell electric vehicles (FCEVs) or storage cylinders intended for secondary distribution.

Site Selection and Climate Profile

In this study, a public car park lot located in Kuala Lumpur, Malaysia, has been selected due to its urban context and suitability for solar integration. The site (3°06'46"N 101°40'15"E) in Lembah Pantai, Kuala Lumpur, is a parking area featuring an open and unobstructed car-parking area, representative of typical public or private parking areas in the city. The dimensions and layout of the parking lot roof are based on typical design standards for Malaysian public infrastructure and existing parking areas in the location. Kuala Lumpur experiences a tropical rainforest climate, characterised by high humidity, consistently warm temperatures, and significant rainfall throughout the year. According to the Köppen-Geiger climate classification, the climate is classified as Af [9]. The region of Lembah Pantai is a federal constituency in the Federal Territory of Kuala Lumpur and exhibits a favourable Global Horizontal Irradiation (GHI) of 4.554 kWh/m² per day and a moderate wind speed average of 3.4 to 4.6 mph, making it ideal for solar PV systems. The consistent tropical temperature range (27–29 °C), with annual precipitation exceeding 2,900 mm, further supports stable solar energy as well as green hydrogen generation.

Technical modelling

The study models a 100 kW solar carport PV system designed for a parking area in Kuala Lumpur, Malaysia, utilising a 10° tilt angle and south-facing orientation. The carport design serves a dual function, providing shaded parking for vehicles while integrating renewable energy generation within limited urban land availability. The proposed system utilises high-efficiency monocrystalline PV modules with efficiencies ranging from 20% to 21%, featuring a nominal capacity of 550 W, which requires approximately 182 solar modules. The system

operates through inverters, converting the generated DC electricity into AC for direct export to PEM electrolyzers. The Performance Ratio (PR) for ground-based or carport PV installations typically ranges between 0.84 and 0.86, taking into account inverter inefficiencies, temperature effects, dust accumulation, and wiring losses. The annual energy yield (E) is estimated using the standard photovoltaic energy model:

$$E = P(\text{Install}) \times H \times PR \quad (1)$$

Where, E = Energy output (kWh), P(Install) = Installed power capacity (kW), H = Solar irradiance on the tilted panel surface (kWh/m²/day, month or year), PR = Performance ratio (dimensionless). [10]

To assess and forecast energy production, the PVsyst simulation tool is utilised. PVsyst integrates high-resolution solar radiation datasets, including Meteonorm 8.0 (1991-2009) – synthetic data - and user-defined parameters, such as tilt, azimuth, shading, and installation efficiency, to estimate monthly and annual PV output. It also calculates expected system losses, inverter efficiency, and temperature derating effects. For this 100 kW carport PV design, one unit of DC to AC inverter with 110 kW nominal capacity is adequate to support the installation. The total DC array allows moderate oversizing of PV panels (182 × 550 W = 100.1 kWp) to ensure optimal power output under imperfect irradiance conditions.

By mass, 1 kg of H₂ requires 9 kg of water, and in the practical scenario, calculating 10 L of water to generate 1 kg of hydrogen. The RO water purification is designed for 100 L of water purification per day, connected to the small storage water tank to ensure a continuous water supply for a 100 kW electrolyser, with minimal operational energy use of 2 - 6 kWh/m³. The electrolyser operates at an efficiency of 70 %, consuming approximately 55 kWh of electricity to produce 1 kg of hydrogen. Additional energy inputs are required for water purification (0.04 kWh/kg of H₂), hydrogen compression from 1 bar to 700 bars (3-6 kWh/kg) and refuelling (1-3 kWh/kg of H₂). From the total hydrogen produced, the Excel-based modelling framework estimates the weight (kg) and volume (m³) of hydrogen produced. The model converts daily energy usage into a continuous power demand (per hour) across 7 h per day. The pressure of hydrogen generated from the PEM electrolyser is up to 30 bar, and it is filled in an intermediate type 2 hydrogen tank before compression. Normally, in cars, hydrogen is stored in a tank with a pressure of 700 bar. From the intermediate tank, hydrogen is compressed to 700 bars using a compressor and stored in a type IV compressed storage tank.

The total energy requirement for a system involving hydrogen production, water desalination, and liquefaction is the sum of the energy consumed by each major component, which are the electrolyser, the water purification system, the compression module and the refuelling dispenser unit [10].

$$\text{Total energy needed from other source (kWh)} = \text{Energy for compression (kWh)} + \text{Energy for water purification (kWh)} + \text{Energy for dispenser unit} \quad (2)$$

$$\text{Total energy consumption (kWh)} = \text{Energy for compression (kWh)} + \text{Energy for water purification (kWh)} + \text{Energy for dispenser unit} + \text{Energy for electrolysis} \quad (3)$$

$$\text{Hydrogen produced (kg)} = \text{Total energy generated from carport PV} / \text{Total energy consumption per kg of hydrogen} \quad (4)$$

The storage volume and tank capacity of hydrogen at a pressure of 700 bar represent critical design parameters in hydrogen storage systems. Prior to compression, hydrogen is typically contained in an intermediate Type II tank at an average pressure of approximately 20 bar, occupying around 0.625 m³ per kilogram of hydrogen. After compression, the gas volume decreases substantially, resulting in a higher density and occupying a volume of about 0.025 m³ per kilogram of hydrogen, which is stored in Type IV high-pressure storage tanks. The daily average rate of compressed hydrogen production or utilisation can be determined from these volume relationships, as expressed in Eqs. (10) and (11).

$$\text{Volume of Hydrogen in intermediate tank,} \\ \text{Uncompressed H}_2 \text{ Volume (m}^3\text{)} = \text{Hydrogen produced(kg)} / \text{Density of H}_2 \text{ at 20bar} \quad (5)$$

$$\text{Volume of Hydrogen in compressed tank,} \\ \text{Compressed H}_2 \text{ Volume (m}^3\text{)} = \text{Hydrogen produced(kg)} / \text{Density of H}_2 \text{ at 20bar} \quad (6)$$

$$\text{Daily Average compressed Hydrogen} = \text{Hydrogen compressed (m}^3\text{)} / \text{Number of days} \quad (7)$$

Hydrogen vehicle refuelling demand modelling estimates daily hydrogen demand based on vehicle refuelling rates, refuelling pressure (typically 700 bar for cars). Each of the hydrogen vehicle need around 5 kg of hydrogen to complete refuelling. Typical Hydrogen production per day from a representative carport PV system with specific installed capacity was estimated and calculated the number of fuel cell vehicles can be refuelled using equations.

$$\text{Number of cars to refilled (Monthly),} \\ \text{Number of refuelling} = \text{Monthly hydrogen generation (kg)} / \text{Capacity of vehicle hydrogen fuel tank} \quad (8)$$

In economic modelling CAPEX and OPEX of the system is calculated and the LCOE as well as LCOH is calculated accordingly.

3. RESULTS AND DISCUSSION

This section details the calculated renewable energy production and resulting green hydrogen yield based on the 100 kW PV array designed on car parking area in Kuala Lumpur. The analysis breaks down the estimated energy required for the core electrolysis process versus the balance of plant requirements for water

purification, compression, and dispensing, presenting the net energy conversion efficiency on both a per-kilogram and annual basis. Based on the design assumptions of a 100 kW solar photovoltaic (PV) system, operating under an average specific yield of 3.854 kWh/kW/day, the system generates approximately 385 kWh/day of usable DC energy at the inverter output. Assuming a consistent solar resource and system availability, this translates to an annual PV energy generation of 138,300 kWh/year. Considering the total energy needed for 1 kg of hydrogen production to refuelling 60 kWh/kg H_2 , the system is expected to produce and refill daily hydrogen output of 6.32 kg H_2 /day at 700 bar pressure. The monthly hydrogen output will be 192.1 kg H_2 per Month, on average. Annual hydrogen output 2,305 kg H_2 /year. Considering the average refuelling of a hydrogen car tank is 5kg, in a year, 460 cars can be fully refuelled. This production aligns well with typical tropical irradiance levels observed in Malaysia, where consistent solar intensity ensures steady hydrogen output throughout the year, with slight variations due to monsoon and seasonal cloud cover.

The photovoltaic (PV) system generates an average daily energy output of approximately 380 kWh/day. On a monthly basis, this translates to an estimated 11,526 kWh/month. Regarding the total energy required for hydrogen production, the system is capable of producing approximately 6.32 kg of hydrogen per day, which is sufficient to refuel the vehicle's tank. Equating to an average of 192.1 kg/month of hydrogen in 700 bars. This production is directly related to the PV output and assumes continuous electrolyser operation during the 7-hour solar window. The daily water requirement is 63.2 litres, amounting to 1921 litres/month and 23052.5 litres/year. For water purification, 1 m³ requires 5 kWh of energy. Per day, an average of 0.32 kWh of energy is required, a monthly average of 9.61 kWh, and a yearly average of 115.26 kWh. For 20 20-bar intermediate tank before compression, it's designed to use a type II hydrogen storage tank. The density of hydrogen in that state will be 1.6 kg/m³. The daily average of 3.95 m³ of hydrogen will be generated. With 3 3-day buffer period, 11.85 m³ of hydrogen will be stored. The intermediate tank capacity is designed to be 12 m³. To store hydrogen at 700 bar, an additional 3.35 kWh/kg H_2 is required for compression. This results in a daily energy demand of 21.17 kWh, equivalent to 643.55 kWh/month and 7,722.59 kWh/year. High-pressure hydrogen Storage Requirements are necessary for post-compression storage. At 700 bar, hydrogen has a density of approximately 40 kg/m³. The daily production of 6.32 kg H_2 requires 0.158 m³ (158 L) of storage. For operational resilience, a 3-day buffer is recommended, necessitating 0.474 m³ (474 L) of high-pressure storage capacity. This capacity can be accommodated in standard Type-IV composite cylinders or a modular storage cascade of 500L. Including water purification and dispensing, the total auxiliary energy requirement reaches 31.15 kWh/day, with a monthly average of 960.52 kWh/month or 11526.25 kWh/year.

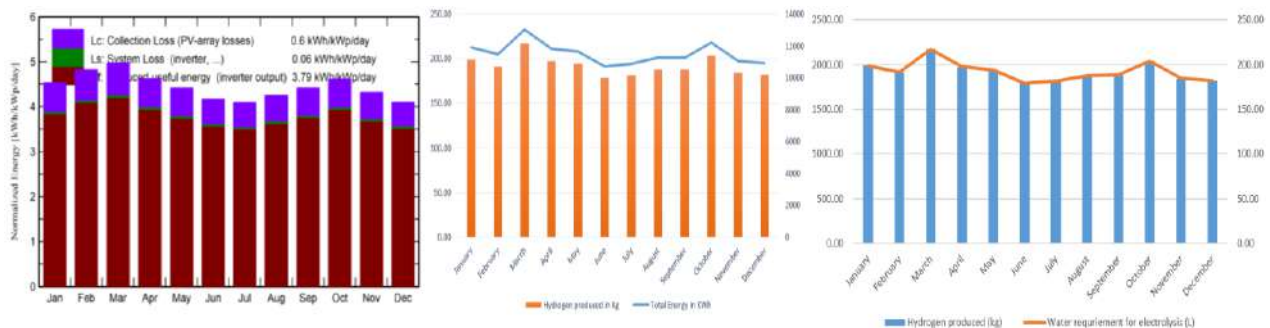


Fig. 1 a. Nominal energy generated

Fig. 1 b. Total energy generated Vs Hydrogen produced

Fig. 1 c. Total energy generated Vs Hydrogen produced

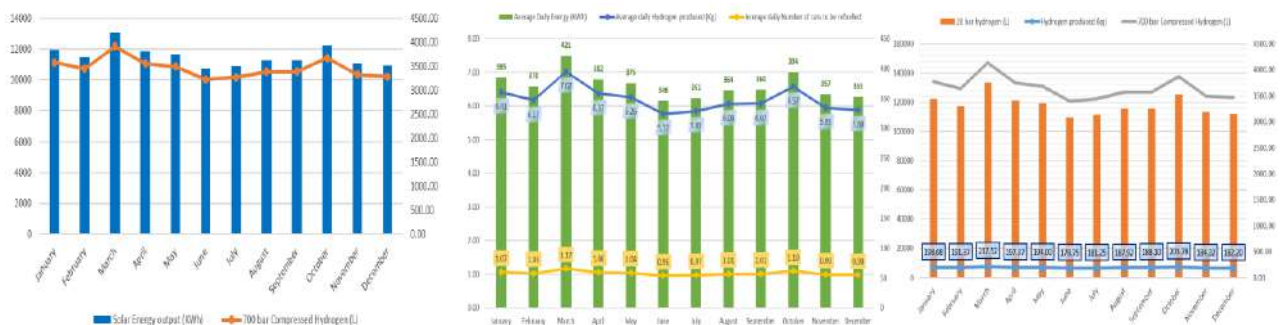


Fig. 1 d. Solar energy generated Vs 700 bar compressed Hydrogen volume

Fig. 1 e. Average daily energy Vs hydrogen produced Vs number of cars refuelled

Fig. 1 f. Hydrogen produced Vs 20 bar hydrogen volume Vs 700 bar hydrogen

System demonstrates a well-balanced integration between solar generation and hydrogen production. The use of a 100 kW PV array ensures sufficient energy for both electrolysis and auxiliary loads. The modularity of the system allows for scalability, while the relatively low water and energy requirements for compression and purification make it suitable for decentralized green hydrogen applications. The designed 100 kW carport PV hydrogen farming system demonstrates the technical feasibility of decentralized hydrogen generation in tropical regions. The integration of renewable power ensures zero-carbon hydrogen, aligning with national energy transition goals. While the system's efficiency is limited by the inherent conversion losses in electrolysis and compression, optimization opportunities exist through, Higher-efficiency PEM stacks, Smart load management to match PV generation peaks and Waste heat recovery from electrolyser and compressor systems. Overall, the proposed configuration supports sustainable hydrogen production with minimal water consumption and localized energy autonomy, making it well-suited for small-scale mobility or research applications in Malaysia and similar tropical environments.

CONCLUSION

This paper presents a conceptual study of feasibility and techno-economic analysis of a carport PV- green hydrogen farming system integrated with onsite refuelling hydrogen dispenser unit using a 100 kWp photovoltaic array combined with a PEM electrolyser, specifically designed for tropical climatic regions like Malaysia. The solar system integrated to the selected car parking area can generate electricity of a daily average around 380 kWh/day, which can be used in PEM electrolyser to generate 6.32 kg of average daily green hydrogen per day, based on an average daily specific yield of 3.79 kWh/kW/day. It is projected that the annual production of green hydrogen is 2305 kg, and for this 23052.5 litres of water is consumed. For the auxilliary systems like RO water purification, compression and refuelling required energy is 11526.25 kWh. The findings show that this kind of technology is feasible and can be used to make green hydrogen in a decentralised perspective. The predicted storage needs (0.474 m³ for a 3-day buffer) show that it may be used for refuelling or industrial purposes. From a design point of view, these characteristics show that this can be adapted to small-scale refuelling applications or research demonstration units with further technological advancements and economical viable systems can be potentially integrate into urban fuel-energy infrastructure. This design framework provides a reproducible paradigm for sustainable hydrogen generation in tropical areas, which helps with decarbonisation objectives and energy resilience. Future studies may look at how performance changes with the seasons, how to save costs, and how to connect with smart grid or hybrid storage systems. The suggested method has potential to be an effective technology for decentralised green hydrogen farming in regions with adequate sunshine and precipitations. The generating green hydrogen with solar power will help the country meet its decarbonisation targets and provide a clean, scalable option for future energy systems especially for sustainable transportation and clean energy.

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DETERMINATION OF OPTIMAL OPERATING CONDITIONS FOR HYDROGEN PRODUCTION WITHIN SENSITIVITY ANALYSIS

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ABSTRACT

This study presents the results of a sensitivity analysis conducted to determine the optimal operating conditions for hydrogen production. As a prominent alternative to fossil fuels, the significance of hydrogen energy continues to grow. The announcement of carbon-neutral energy policies and hydrogen roadmaps by various countries further underscores the increasing relevance of hydrogen in the global energy landscape. In this study, a Proton Exchange Membrane (PEM) electrolyzer is utilized for hydrogen production. Experimental data were analyzed using robust statistical methods to perform a sensitivity analysis. The results indicate that the optimal temperature range for efficient hydrogen production lies between 38°C and 45°C.

Keywords: Hydrogen production, PEM, Sensitivity analysis

1. INTRODUCTION

The global climate crisis poses one of the most urgent and universal challenges facing humanity today. It transcends national borders and demands coordinated international efforts to reduce greenhouse gas emissions and transition toward sustainable energy systems. Scientific consensus, such as for NASA, highlights three primary contributors to global climate change: anthropogenic (human-induced) activities, volcanic eruptions, and variations in solar radiation [1]. Among these, anthropogenic factors—such as the burning of fossil fuels for energy, transportation, and industrial processes—are the most significant and, importantly, the most manageable. Addressing these human-driven causes is therefore central to any meaningful strategy for mitigating climate change. In response, both developed and developing nations are shaping their energy policies around the overarching goal of decarbonization. The necessity of achieving independence from fossil fuels has become increasingly evident—not only as a measure to combat climate change but also to safeguard energy security in a world experiencing overlapping global shocks [2]. Recent events, including pandemics, devastating natural disasters, and geopolitical conflicts, have exposed the fragility of global energy supply chains. These disruptions have intensified the urgency for resilient, clean, and decentralized energy systems that can withstand external shocks and reduce dependence on volatile fossil fuel markets. In this context, hydrogen has emerged as a cornerstone of future sustainable energy systems [3]. Its high energy density and zero carbon emissions upon combustion make it an attractive alternative fuel and a strategic energy vector in the global push for clean energy. Hydrogen offers versatile applications across sectors—from decarbonizing heavy industry and long-haul transport to enabling seasonal energy storage and balancing power grids dominated by intermittent renewable sources. Its ability to store surplus electricity from wind and solar installations positions hydrogen as a critical enabler for the integration of renewables and for enhancing grid flexibility and stability. Consequently, governments around the world are publishing national hydrogen strategies and investing heavily in hydrogen infrastructure, signaling strong policy momentum. These initiatives are fostering a wave of research and innovation aimed at improving the efficiency, scalability, and affordability of hydrogen production technologies. Among various hydrogen production methods, Proton Exchange Membrane (PEM) electrolysis stands out due to its high responsiveness, compact system design, and potential for integration with renewable electricity sources. However, for PEM electrolyzers to be both energy-efficient and cost-effective at scale, a deeper understanding of their operational behavior under varying conditions is essential. Temperature, current density, pressure, and humidity are among the key parameters influencing the electrolyzer's performance and hydrogen output [4].

This study contributes to the ongoing effort to optimize hydrogen production systems by focusing on the identification of optimal operating temperature ranges for a PEM electrolyzer. Unlike conventional statistical methods that can be sensitive to measurement noise and experimental anomalies, this research applies robust statistical techniques, including Theil-Sen and Huber regression models, to perform a sensitivity analysis. These methods are particularly well-suited to experimental datasets where precision and resistance to outliers are critical for drawing reliable conclusions.

By integrating robust analytical methods with experimental data, the study aims to derive practical insights into the conditions that maximize hydrogen production efficiency. Such findings not only support the technological advancement of PEM electrolyzers but also align with the broader global objective of accelerating the transition to a low-carbon, hydrogen-based economy.

2. HYDROGEN PRODUCTION

Despite the threat of global warming, hydrogen energy has emerged as one of the most promising alternatives to fossil fuels. As the most abundant element in the universe, hydrogen does not exist freely in nature and must therefore be produced through various methods. For this reason, hydrogen is not a primary energy source but rather considered an energy carrier or fuel. Hydrogen can be produced using different energy types and raw materials through a variety of techniques. Currently, over 90% of global hydrogen production is still based on fossil fuels such as coal and natural gas [5]. However, the environmental friendliness and economic sustainability of hydrogen depend on the use of renewable energy sources in its production. In this context, water and renewable energy sources constitute the fundamental components of green hydrogen production. At present, only about 2% of global hydrogen is produced via electrolysis of water [6]. Given that approximately 11.2% of the water molecule consists of hydrogen, the potential of this method is notably high.

Hydrogen production methods are generally classified into four main categories: thermochemical, electrochemical, biological, and photochemical processes. Thermochemical methods include fossil fuel-based techniques such as steam methane reforming (SMR) and coal gasification, which offer high efficiency but are not sustainable due to significant carbon emissions [7]. Thermochemical cycles, by contrast, enable the decomposition of water at high temperatures [8]. Electrochemical methods are primarily based on water electrolysis, in which water is split into hydrogen and oxygen using renewable energy sources like wind and solar power. Alkaline, proton exchange membrane (PEM), and solid oxide electrolyzers stand out with distinct operating temperatures and efficiency profiles [9]. Biological methods utilize microorganisms to convert organic waste into hydrogen through photofermentation and dark fermentation, although they face limitations in efficiency and scalability [8]. Photochemical processes aim to directly harness solar energy via photoelectrochemical cells or microalgae to split water molecules, yet challenges such as material stability and high production costs continue to hinder their widespread application [10].

From a sustainability perspective, green hydrogen (produced via electrolysis using renewable energy) is of critical importance for achieving net-zero emission targets, while blue hydrogen (SMR combined with carbon capture technologies) plays a transitional role. The widespread adoption of these technologies is closely tied to technological maturity, cost optimization, and the extent of policy support.

3. METHODOLOGY

This study investigates the optimal operating temperature for hydrogen production using a Proton Exchange Membrane (PEM) electrolyzer through robust sensitivity analysis. In Fig. 1, hydrogen production system shows at experimental study. The research methodology is based on experimentally collected data and employs statistically resilient modeling techniques to ensure the validity of insights derived from real-world measurements. Data were logged at approximately 10-minute intervals to capture short-term variations in performance. The temperature range explored spans from 20°C to 60°C, which encompasses the expected operating envelope for typical low-temperature PEM electrolyzers. The raw data were subsequently cleaned to remove erroneous or missing entries and standardized to ensure consistency in unit representation and sampling frequency. Each data point consists of a timestamp, input temperature (°C), and hydrogen production rate (kg/s). Prior to analysis, the dataset underwent preprocessing to remove missing entries and minimize the influence of any potential measurement errors. The recorded dataset includes time-stamped entries consisting of three primary variables;

- Time (hh:mm) – Captures the exact timestamp of each measurement, allowing for trend visualization and temporal resolution.
- Temperature (°C) – The input temperature to the PEM electrolyzer, varied systematically across the experimental sessions.
- Hydrogen Production (kg/s) – The observed rate of hydrogen generation, measured using calibrated flow meters or mass measurement equipment, depending on the experiment setup.

To evaluate the sensitivity of hydrogen output to variations in temperature, robust regression models were selected over traditional least squares methods, due to their enhanced ability to handle outliers and non-ideal experimental conditions. Two models were applied: Huber regression and Theil-Sen estimation. Huber regression minimizes the effect of extreme values by combining squared error loss for inliers with linear loss for outliers, offering a compromise between least squares and absolute deviation techniques. Theil-Sen estimation, on the other hand, is a non-parametric method that calculates the median slope among all pairwise combinations, making it particularly reliable for datasets with irregular distributions or heteroscedasticity. All data preprocessing, model fitting, and visualization tasks were performed using the Python programming language within the Google Colab environment. This cloud-based platform provided a streamlined workflow for integrating data analysis and statistical computation. Key libraries such as pandas, numpy, matplotlib, and sklearn were used to clean the dataset, apply robust regression techniques, and generate visual representations of the sensitivity results. The analysis yielded temperature intervals where hydrogen production is maximized, and the robust models allowed for the identification of reliable performance trends even in the presence of noisy or imperfect data. This methodology ensures that the conclusions drawn from the study are not only statistically sound but also practically applicable to real-world PEM electrolyzer systems operating under variable thermal conditions.



Fig. 1. PEM electrolyser

4. SENSITIVITY ANALYSIS

One of the foundational motivations for robust analysis, as discussed in the classic statistical literature [11], is the recognition that real-world data is rarely "clean." Experimental measurements—especially in engineering, energy systems, and hydrogen production—often include errors, noise, or extreme values caused by sensor inaccuracies, environmental fluctuations, or human error. Huber regression is widely used for its robustness against noise and outliers in fields such as signal processing and feature selection [12]. Extended its applicability by proposing a regularized Huber regression algorithm enhanced through semi-supervised learning. The findings showed that incorporating unlabeled data improves the method's learning performance and generalization, with a learning rate comparable to the optimal rate of ordinary least squares (OLS). Robust methods like Huber regression or Theil-Sen estimation strike a balance between efficiency (when data is well-behaved) and resilience (when data includes outliers). These approaches offer more stable and generalizable results, making them ideal for applications in applied sciences where data uncertainty is unavoidable.

4.1. Robust Regression Approach

To ensure reliable estimation of sensitivity trends despite potential data noise and measurement anomalies, robust regression techniques were employed. In particular, Huber regression was used to obtain a baseline robust fit that reduces the influence of outliers by applying a hybrid loss function—quadratic for small residuals and linear for large deviations. The results from the Huber model indicated a positive correlation between temperature and hydrogen production, with diminishing gains at higher temperatures. In the Huber regression analysis Fig. 2, the gray points represent the experimental measurements of hydrogen production at various input temperatures. The green dashed line is the regression line fitted using the Huber method, which is known for being resistant to outliers while maintaining high efficiency for well-behaved data.

The Huber regression line follows the general trend of the data, capturing the overall positive relationship between temperature and hydrogen production: as the temperature increases, hydrogen production also tends to increase. However, at higher temperatures, the growth in hydrogen production appears to plateau, suggesting diminishing returns beyond a certain point. The red point marks the "Huber robust point" — the data point closest to the Huber regression line. This point represents the most statistically typical measurement in the dataset, meaning it is highly aligned with the overall trend and is minimally influenced by noise or irregularities. The Huber regression model indicates that the optimal operational range lies where the slope of the regression line is highest (around 38°C–45°C), after which the benefits of increasing temperature become less significant.

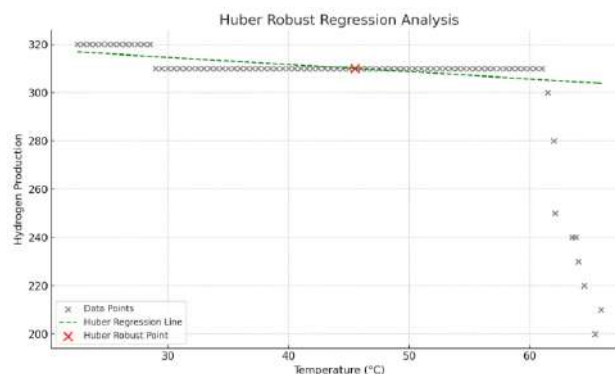


Fig. 2. Huber Robust Regression Analysis

4.2. Theil-Sen Estimator

To strengthen the reliability of the findings, the Theil-Sen estimator was also applied. The Theil-Sen estimator, known for its resistance to outliers and suitability for datasets with non-constant variance, calculates the median slope among all pairwise points. This method confirmed the general trend identified by Huber regression and further refined the estimate of the most efficient operational temperature range. The Theil-Sen line exhibited a consistent positive slope between 38°C and 45°C, highlighting this interval as the optimal region for hydrogen output. Outside this range, the slope decreased or plateaued, suggesting either a performance saturation or system inefficiency at higher or lower temperatures.

In the Theil-Sen regression analysis Fig. 3, the same experimental data points are plotted, but the blue dashed line represents the regression line calculated using the Theil-Sen estimator. The Theil-Sen method computes the median of all possible pairwise slopes, making it extremely robust against outliers and ideal for datasets with heteroscedasticity (non-constant variance). Compared to Huber regression, the Theil-Sen line is even more stable and less sensitive to isolated irregular points in the dataset. It does not overreact to local fluctuations, providing a "median trend" that better reflects the dataset's central behavior.

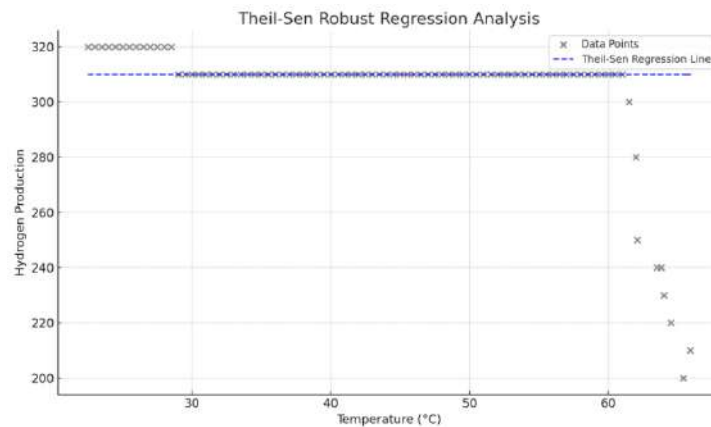


Fig. 3. Theil-Sen Estimator

5. RESULTS AND DISCUSSION

The robust regression analysis revealed that hydrogen production is significantly influenced by operating temperature. Both Huber and Theil-Sen methods consistently identified a performance plateau within a specific thermal range. The analysis determined that the optimal temperature range for hydrogen production is between 38°C and 45°C. Within this range, the system demonstrated maximum hydrogen yield with stable performance. These findings validate the application of robust statistical models in experimental optimization studies.

Table 1. compares the performance of Huber regression and Theil-Sen estimation methods applied to experimental data from hydrogen production. Both robust models demonstrated that the optimal operating temperature for maximizing hydrogen output lies between approximately 38°C and 45°C. In practical terms, these findings offer actionable guidance for the operation of PEM electrolyzers. Operators can optimize system settings by maintaining the electrolyzer temperature within the 38–45°C range to achieve higher efficiency and more stable hydrogen output. Additionally, using robust statistical monitoring (Huber or Theil-Sen analysis) can help identify and correct operational anomalies in real time, improving the reliability and longevity of PEM-based hydrogen production systems.

Thus, the application of these robust methods not only validates the experimental results but also provides a scientifically grounded operational strategy for enhancing performance in real-world hydrogen energy projects.

Table 1. Comparative of two regressions

Analytical Aspect	Huber Regression	Theil-Sen Regression
Sensitivity of Outliers in Analysis	Moderate; down-weights the influence of outliers through a hybrid loss function	Very low with a high resistance; utilizes median slope estimation to effectively neutralize outlier impact
Data and Line Behavior	Captures general data trend with moderate adaptability to local variation	Represents central tendency with high stability and resistance to data irregularities
Identification of optimal temperature range (°C)	38°C – 45°C	38°C – 45°C
Identification of Robust Point on the graph	Identified on the graph, provides a specific robust point closest to the fitted model	No specific point marked was marked, focuses on global trend rather than individual point robustness

CONCLUSIONS

The findings of the above study are highly relevant for the design and operation of PEM electrolyzers, especially in contexts where thermal management and energy efficiency are critical. System operators and engineers can use this temperature range as a benchmark for configuring PEM units in renewable-integrated systems, improving electrolyzer lifespan, output consistency, and cost-efficiency. Additionally, the use of robust regression techniques demonstrated in this study provides a methodological blueprint for future experimental optimization in the hydrogen energy sector.

The results confirm a clear and consistent relationship: hydrogen production increases with temperature up to a certain threshold, after which the efficiency either stabilizes or declines. Both robust methods reinforce that operating within the 38–45°C range maximizes hydrogen yield while maintaining system stability. The Huber model allowed for slight sensitivity to data variance, capturing nuanced deviations, while the Theil-Sen model emphasized the core trend, ensuring reliability under uncertain or noisy conditions. Given hydrogen's growing role in national and international decarbonization strategies, especially as a means of energy storage and sectoral integration, the ability to define precise operational parameters represents a significant step toward the deployment of scalable, clean hydrogen technologies.

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THERMODYNAMIC ANALYSIS OF GEOTHERMAL BASED HYDROGEN AND ELECTRICITY GENERATION

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ABSTRACT

In this study, the production of electricity and hydrogen using a geothermal energy source is examined from a sustainability perspective. The proposed system consists of a turbine, two heat exchangers, a pump, a cooling unit, a PEM electrolyzer, and a water production system. The thermodynamic analysis of the system is conducted with a holistic approach. Approximately one-fourth of the electricity generated in the system is directed to the PEM electrolyzer for hydrogen production, while the remaining portion is supplied to the grid. To evaluate the system's performance, a thermodynamic analysis has been carried out. The energy efficiency of the system is calculated as 9.77%. Furthermore, the sustainability index (SI) of the system is determined to be 1.114.

Keywords: Geothermal energy, Hydrogen production, Sustainable energy

1. INTRODUCTION

Technological advancements, the growing demand for a higher quality of life, and environmental concerns have contributed to a continuous increase in the demand for renewable energy sources in the contemporary world [1-3]. In addition to wind, solar, and natural gas, geothermal energy is another significant renewable energy source. The thermal energy stored in the Earth's crust is manifested as a mixture of hot water and steam, which is referred to as geothermal energy. The two primary sources of heat within the Earth are: (1) magma that has entered the Earth's crust and rises toward the surface, and (2) the Earth's internal heat, which increases as depth within the crust increases. Geothermal energy is typically classified into three categories based on temperature values, though methods and classifications may vary between countries: low-temperature fields (20-70°C), medium-temperature fields (70-150°C), and high-temperature fields (above 150°C) [4]. Temperature gradients, which vary with extraction depth, can be leveraged for applications such as heating, cooling, and electricity generation. This energy source is ubiquitous and available year-round, independent of seasonal fluctuations [5]. Owing to these advantageous characteristics, the global utilization of geothermal energy, both for direct applications and power generation, has seen a steady increase since 1995 [6,7]. It appears that, through electricity generated from various renewable energy sources, the cost of hydrogen production can be reduced to competitive levels over the coming decades.

Li and Zoghi have investigated a cascade power generation system comprising three components: a modified Kalina cycle (MKC), an organic Rankine cycle (ORC), and a liquefied natural gas (LNG) subsystem. In their study, the electrical energy generated is utilized for both the cooling system and hydrogen production via a proton exchange membrane electrolyzer (PEME). The net output power of the configured system is 451.8 kW, while the hydrogen production rate is 2.274 kg/h [8]. Zhang and et al. proposed generating power, cooling capacity, freshwater, and hydrogen based on a binary geothermal system. In their design, the best performance for the organic Rankine cycle was achieved with the R12-R114 combination. The net output power of thier system was 856.06 kW, and the hydrogen production capacity was 0.743 kg/h, while the payback period was determined to be 3.76 years [9]. Li and et al. conducted a study of a geothermal-based system employed for desalination and electricity and hydrogen production. The capacities of the system for electricity, cooling, freshwater, and hydrogen production are obtained to be 782 kW, 881.6 kW, 0.286 kg/s, and 0.181 kg/h, respectively [10]. Siddiqui and Ishaq have also carried out a tri-generation system based on the combined use of solar and geothermal resources. In this paper, hydrogen production is achieved through the CuCl cycle, while the system also provides useful outputs such as electricity and cooling. The hydrogen production cycle in the studied system has an energy efficiency of 35.3% and an exergy efficiency of 35.9% [11]. In the study by X and colleagues, which targets hydrogen production through a geothermal-based dual-loop organic Rankine cycle and proton exchange membrane electrolyzers, an analysis of energy and exergy performance, as well as economic feasibility, has been conducted. The electricity generation capacity of the studied system was determined to be 1.38 kW, while the hydrogen production capacity was found to be 5.39 kg/h. The researchers obtained an exergy efficiency of 38.96% for the system [12].

The novelty of this study lies in the utilization of geothermal energy as the required energy source and the condensation of atmospheric humidity as the water supply for green hydrogen production. In this way, the two essential parameters for green hydrogen production are obtained through a sustainable approach. Furthermore, the primary objective of the study is to perform the thermodynamic analyses of an integrated system and to determine the key parameters necessary for system optimization.

2. MATERIALS AND METHODS

This section presents the operating principle and thermodynamic analysis of the proposed system. The measurement points required for the thermodynamic analysis and the relevant balance equations are discussed.

2.1. Case study

In the presented study, an integrated thermodynamic system is investigated in which both electricity and hydrogen are produced utilizing geothermal energy. Geothermal fluid, entering the heat exchanger at approximately 130°C (state 1), transfers its heat to the working fluid R1234yf used in the ORC system (state 2). In HE-1, the working fluid is converted to superheated vapor and then enters the turbine under high pressure, where it expands and exits (state 3). After leaving the turbine, the working fluid passes first through HE-2 and then to the condenser (state 5) to return to the liquid phase. The liquid exiting the condenser is compressed by a pump (state 7) and then passes through HE-2 and HE-1 (state 4), thus completing the cycle. The electricity generated by the turbine expansion is used both for hydrogen production and for feeding into the grid. Approximately one-fourth of the electricity produced by the turbine is consumed in a PEM electrolyzer for hydrogen production. The study aims to meet two essential parameters for green hydrogen production: the provision of electricity from a renewable energy source and the availability of water. In this work, water is considered as a resource similar to energy. Therefore, to ensure both sustainable energy generation and green hydrogen production, water is produced from atmospheric humidity instead of depleting existing water resources. The water obtained by condensing atmospheric humidity (state 9) is used in the electrolyzer. The flow diagram of the system presented in Fig. 1 illustrates this process.

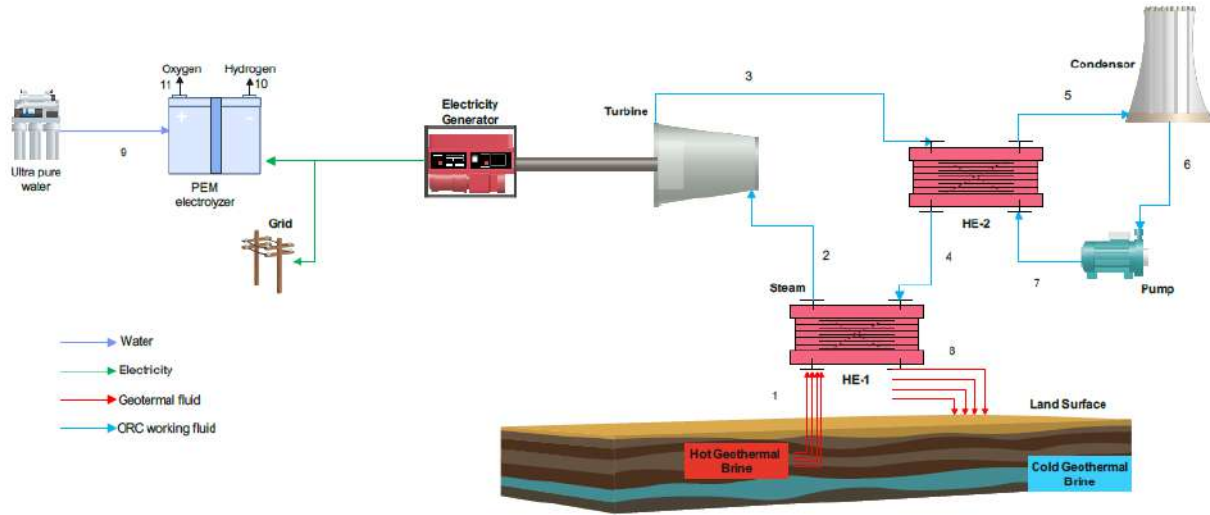


Fig. 1: Flow chart of the geothermal energy based hydrogen and power generation system

2.2. Thermodynamic analysis

In this section, the thermodynamic balance equations used for the mathematical modeling of the proposed system are presented. The Engineering Equation Solver (EES) program was used for the thermodynamic analysis. The following thermodynamic assumptions were made for the mathematical modeling:

- The entire process is steady-state.
- Potential and kinetic energy changes are neglected.
- Heat and pressure losses in the equipment are neglected.

The following balance equations were applied to each component for the thermodynamic analysis [13, 14].

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad [1]$$

$$\sum \dot{Q}_{in} + \sum \dot{W}_{in} + \sum \dot{m}_{in} h_{in} = \sum \dot{Q}_{out} + \sum \dot{W}_{out} + \sum \dot{m}_{out} h_{out} \quad [2]$$

$$\eta_{sys} = \frac{\dot{m}_{H_2} LHV + \dot{W}_{net}}{\dot{m}_1 (h_1 - h_8)} \quad [3]$$

The parameters presented in Table 1 are taken into consideration for the system design and thermodynamic analysis. The values in Table 1 are transferred into the EES software and used for the parametric evaluation. In addition, the values required for the thermodynamic analysis, such as the heat exchangers' effectiveness and the turbine isentropic efficiency, are also provided in the relevant table.

Table 1. Desing and analysis parameters of the presented study

Parameters	Value	Unit
Geothermal water temperature	130	°C
Geothermal water mass flow rate	8.12	kg/s
Heat exchangers effectiveness	0.92	-
Turbine isentropic efficiency	85	%
Turbine inlet pressure	31.47	bar
Turbine inlet temperature	127	°C
ORC mass flow rate	1.9	kg/s
ORC mass flow	R1234yf	-

3. RESULTS AND DISCUSSION

This section highlights the thermodynamic analysis results of the presented study. The results, obtained through a parametric study, demonstrate how system efficiency varies under different operating conditions. The values provided in Table 1 were entered into the EES software to carry out the thermodynamic analysis. Fig. 2(a) presents the temperature-entropy (T-s) diagram of the ORC system, while Fig. 2(b) shows the pressure-enthalpy (P-h) diagram. In Fig. 3, the relationship between the turbine inlet temperature and the system's energy efficiency is illustrated. The resulting curve reveals that the energy efficiency of the system changes significantly with respect to the turbine inlet temperature. Above a certain threshold temperature (approximately 160–170 °C), the system operates more efficiently; however, beyond this point, marginal gains in efficiency decrease due to thermodynamic limitations.

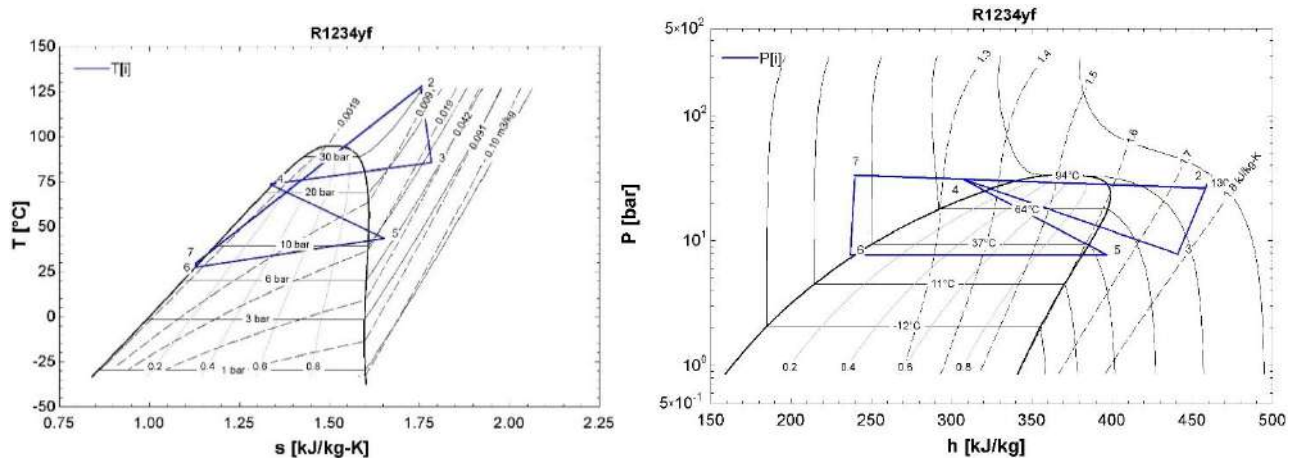


Fig. 2. T-s and P-h diagram of the presented system

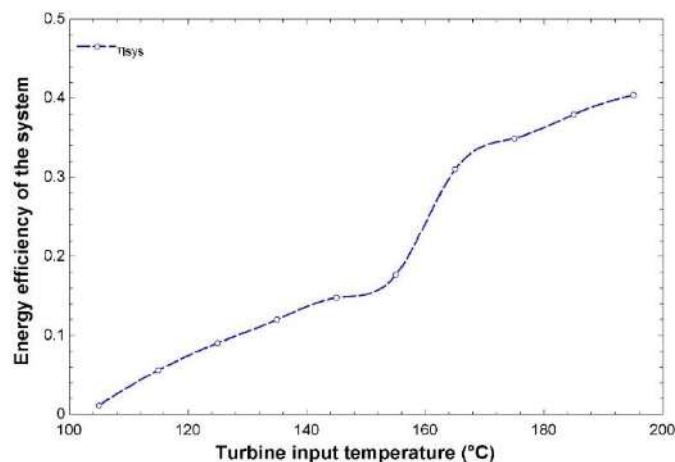


Fig. 3. Effect of turbine input temperature on the system energy efficiency

The Fig. 4 illustrates the variation of system energy efficiency and hydrogen production amount with respect to the power fraction. The graph reveals that as an increasing portion of the electricity generated by the turbine is utilized for hydrogen production, the system's energy efficiency decreases significantly. This

decline is attributed to the reduction in the net electric output of the system, as the electricity is redirected from the grid to the electrolysis process. In contrast, the hydrogen production amount increases linearly with the power fraction, indicating that the supplied electrical energy is effectively converted into hydrogen through the electrolyzer. These results highlight the need for optimization between energy efficiency and hydrogen production capacity, emphasizing that this trade-off must be carefully considered in the system design.

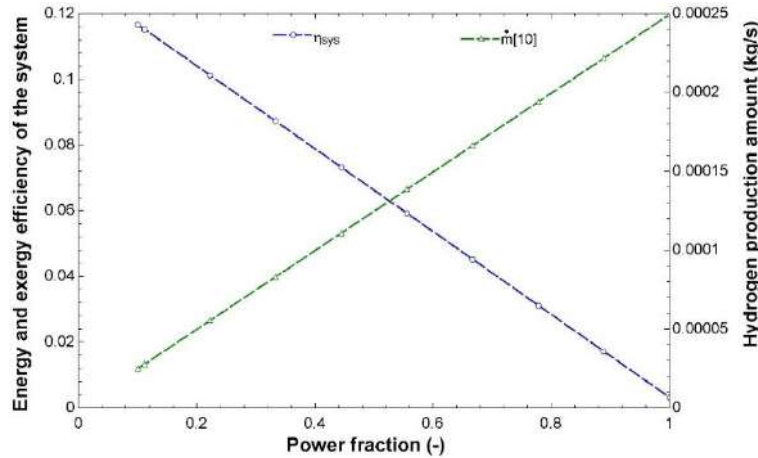


Fig. 4: Effect of power fraction on system energy efficiency and hydrogen production

4. CONCLUSIONS

In this study, a geothermal-based hybrid energy system integrating an ORC and a PEM electrolyzer was thermodynamically analyzed to assess its performance in simultaneously generating electricity and hydrogen. The proposed system utilizes geothermal energy as the primary heat source and atmospheric humidity as the water source, thereby offering a sustainable pathway for green hydrogen production. The results indicate that the system achieves an energy efficiency of 9.77% under baseline conditions, with a sustainability index of 1.114. Parametric analysis revealed that increasing the turbine inlet temperature positively affects system efficiency, particularly within the range of 160–170 °C. However, efficiency gains diminish at higher temperatures due to thermodynamic constraints. Furthermore, an increase in the power fraction allocated to hydrogen production leads to a linear rise in hydrogen output, but causes a significant decline in overall system energy efficiency. This trade-off highlights the necessity of carefully balancing electricity delivery to the grid and hydrogen generation, depending on operational goals and energy demands. The novelty of the study lies in its dual sustainability approach—utilizing renewable geothermal heat and non-traditional water sources. The findings confirm that the integration of electricity and hydrogen production through geothermal energy is technically feasible and environmentally beneficial. Nevertheless, future work should focus on expanding the system model to include economic assessments, component-level efficiency improvements, and the integration of thermal energy storage to enhance operational flexibility and long-term performance.

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AN INVESTIGATION OF LINDEN-DERIVED ACTIVATED CARBON FOR HYDROGEN STORAGE

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ABSTRACT

This study evaluates the evaluation of activated carbon obtained from linden for hydrogen storage purposes and investigates the effect of ultrasonic activation with HCl. Linden leaves are first pyrolyzed at 330 °C and then activated with 25 mL of HCl solution in an ultrasonic bath at a frequency of 37 kHz for 60 min. The activated carbon is dried at 110 °C and prepared for hydrogen storage experiments. In the gravimetric experiments, 5 g of adsorbent is used, and the hydrogen storage capacity is determined at 25 °C and in the pressure range of 1 to 4 kPa. The results show that the storage capacity increases with pressure and varies between 0.29-0.54 wt.%. The capacity obtained from linden exhibits similar or higher performance than many waste-based carbons such as olive pomace and corn cob. In conclusion, the study demonstrates that linden offers a promising alternative for hydrogen storage applications as a low-cost, easily accessible, and sustainable biomass source.

Keywords: Hydrogen storage; Activated carbon; Biomass waste; Chemical activation; Energy Storage

1. INTRODUCTION

Hydrogen stands out as an important energy carrier in sustainable energy systems due to its high specific energy density, environmentally friendly use, and wide range of applications. However, one of the main challenges limiting the widespread use of hydrogen technologies is the development of safe, efficient, and cost-effective storage methods [1]. While existing storage techniques include compressed gas, liquefaction, and metal hydrides, solid-state storage systems based on porous carbon materials have gained increasing attention due to their advantages such as low density, adjustable porosity, chemical stability, and low production costs. In recent years, carbons produced from biomass-derived waste materials offer a sustainable and economical solution for hydrogen storage. Literature indicates that such waste-based carbons generally exhibit hydrogen storage capacities in the range of 0.2-0.8 wt.% [2]. These studies demonstrate that the activation method, precursor structure, and pore distribution directly determine hydrogen adsorption behavior, particularly at low pressure. Although many biomass materials have been evaluated in the literature, the hydrogen storage performance of linden-based carbons has been virtually unexplored. Linden leaves, due to their lignocellulosic structure and low ash content, offer the potential to form a stable carbon skeleton.

This study experimentally investigates the hydrogen storage behavior of linden-derived carbons physically activated with HCl for the first time. Experiments were conducted at a temperature of 25°C and a low-pressure range of 1 to 4 kPa, with a fixed adsorbent mass of 5 g. The obtained capacity values show a regular increase with pressure, demonstrating that the carbon obtained from linden exhibits similar performance to other waste-based adsorbents reported in the literature. Thus, this study proposes a new biomass source for hydrogen storage technologies and contributes to the diversity of sustainable carbon materials.

2. MATERIALS AND METHODS

In this study, linden leaves are used as a biomass source for activated carbon production. The collected leaves are first washed with water; surface impurities are removed and dried at room temperature. They are then ground to obtain a uniform particle size. The prepared biomass samples are first pyrolyzed at 330°C to form the basic carbon structure. The carbon obtained from pyrolysis is subjected to ultrasonication with 25 mL of hydrochloric acid (HCl) solution during the activation phase. The activation process is carried out in an ultrasonic bath operating at a frequency of 37 kHz for 60 minutes. This process ensures effective penetration of the HCl into the carbon structure, removes mineral residues, and promotes pore development.

After ultrasonic activation is complete, the samples are filtered and washed with distilled water until a neutral pH is achieved. The samples are then dried at 110°C and prepared for use in hydrogen storage experiments. Before each test, activated carbon powders are pre-dried at 80°C to completely remove moisture from the samples.

Hydrogen storage performance is determined using the gravimetric method. 5 g of activated carbon is used in the tests. The sample is placed in the hydrogen reactor, the reactor is vacuumed to remove air and moisture from the system, and hydrogen gas is injected in a controlled manner. Experiments are conducted at 25°C and a pressure range of 1 to 4 kPa. Once the system reaches steady state, the adsorption rate is recorded.

The hydrogen storage capacity is calculated using the following equation:

$$C \text{ (wt.\%)} = \left(\frac{m_f - m_i}{m_i} \right) \times 100 \quad (1)$$

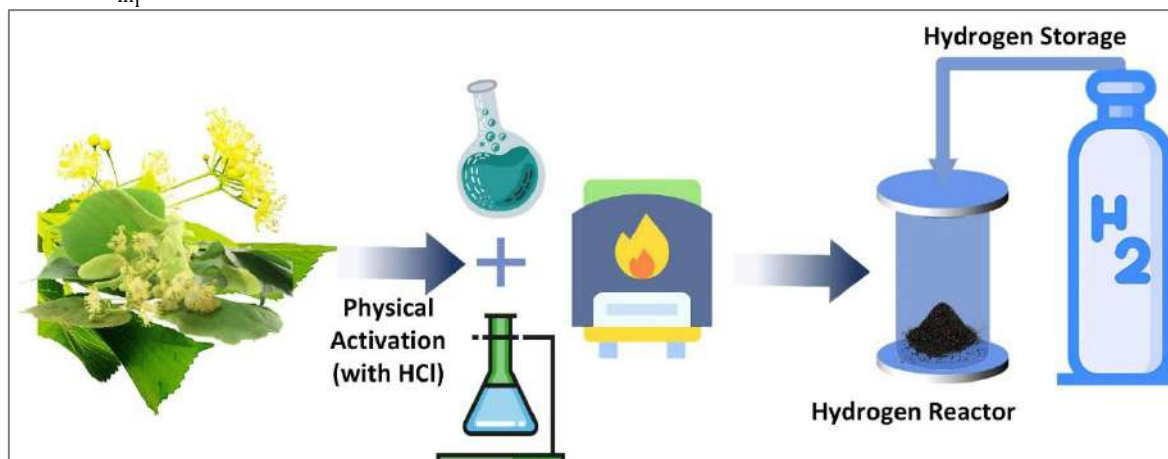


Fig. 1. The solid-state hydrogen storage flow scheme with linden derived activated carbon

3. RESULTS AND DISCUSSION

Hydrogen storage experiments were conducted at 25°C to investigate the adsorption behavior of linden-based carbon ultrasonically activated with HCl at low pressures. The results show that the hydrogen storage capacity increases steadily with increasing pressure. The measured capacity values are 0.29 wt.% at 1 kPa, 0.36 wt.% at 2 kPa, 0.39 wt.% at 3 kPa, and 0.54 wt.% at 4 kPa. The highest capacity value of 0.54 wt.% obtained in the study indicates that HCl-ultrasonic activation effectively enhances pore development and that micropores play an active role at low pressures. The results are presented in Fig. 2.

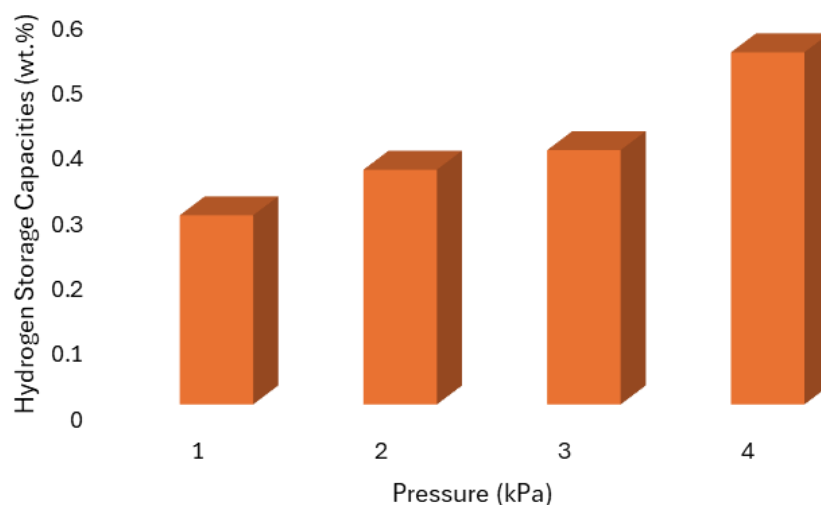


Fig. 2. Hydrogen storage capacities of linden derived activated carbon with different pressures at 25 °C

The maximum capacity of the linden-based activated carbon is also compared with other waste-based carbons reported in the literature. In this comparison, carbons produced from different biomass materials, including olive pomace, corn cob, horse chestnut, and coffee beans are evaluated with 0.126 wt.%, 0.44 wt.%, 1.48 wt.%, and 0.60 wt.%, respectively.

The results are presented in Table 1 and Fig. 2. The capacity obtained from linden is approximately four times higher than that of olive pomace, on par with corn cob. It performs similarly to coffee bean carbon. While horse chestnut carbon has a higher capacity, this result is generally attributed in the literature to aggressive chemical activation and very high surface area. In contrast, the HCl, ultrasonic activation method used in this study is more environmentally friendly, safer, and less costly, yet still achieves competitive storage capacity.

Table 1. Hydrogen storage capacities of activated carbons derived from various wastes

Waste Material	Hydrogen Storage Capacities at 298K (wt.%)	Reference
Linden (Present study)	0.54	-
Olive Pomace	0.126	[3]
Corn cob	0.44	[4]
Horse chesnut	1.48	[5]
Coffee beans	0.6	[6]

The results show that, although linden is a biomass that has not previously been evaluated in the field of hydrogen storage, it can become a highly efficient adsorbent with the appropriate activation method. Ultrasonic bath application accelerates pore development by allowing HCl to better penetrate the carbon surface, contributing to the activation of micropores, which are particularly critical for low-pressure physical adsorption. Therefore, lime carbon is being added as a strong alternative among sustainable, low-cost, and environmentally friendly carbon materials.

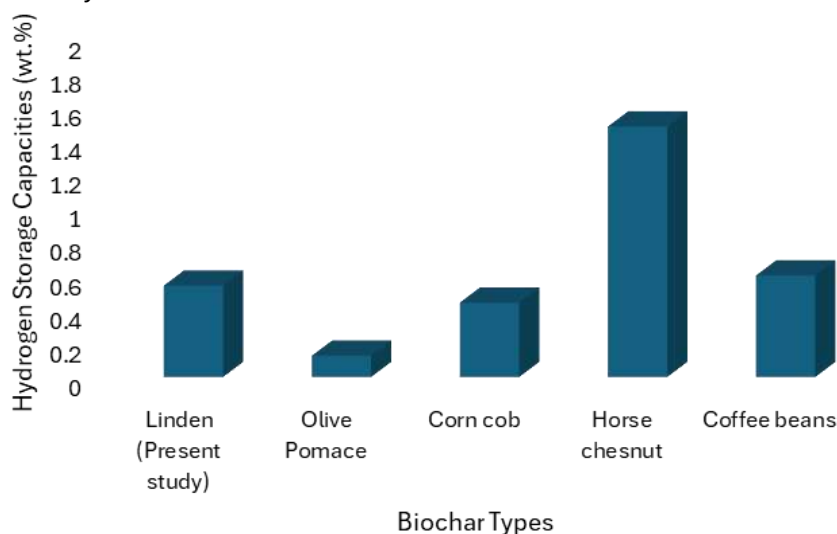


Fig. 3. Hydrogen storage capacities of activated carbons derived from various biomass wastes at 25°C

CONCLUSIONS

This study demonstrates that linden-derived activated carbon can be utilized for hydrogen storage using ultrasonic activation with HCl. The results indicate that linden-derived activated carbon stores hydrogen between 0.29 and 0.54 wt.% at 25°C and a pressure range of 1 to 4 kPa. Ultrasonic activation at 37 kHz enhances pore development, providing significant adsorption capacity even at low pressure. Compared to other waste-based carbons reported in the literature, linden carbon exhibits superior or similar performance to many biomass materials such as olive pomace and corn cob. In conclusion, linden, as a low-cost, easily accessible, and sustainable biomass source, represents a promising alternative for hydrogen storage applications.

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IEES&ICH2P 2025 CONTRIBUTIONS

ENABLING SYSTEMIC SUSTAINABILITY: HOW TECHNOLOGICAL INNOVATION DRIVES THE CIRCULAR BIOECONOMY

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THE CONTRIBUTION ABSTRACT – KSE2

The circular bioeconomy is a crucial strategy for tackling global challenges like biodiversity loss and climate change. This abstract explores how technological innovation acts as a key driver for achieving systemic sustainability within these complex systems. The keynote synthesizes insights from transition management and Earth System Governance theories to present a holistic approach, moving beyond technology alone to integrate it with economic, social, and political innovations. To illustrate these concepts, the keynote will present examples from pilot projects and "real-world research" platforms, such as the Leibniz Lab Systemic Sustainability and the Living Lab Leibniz Innovation Farm for Sustainable Bioeconomy InnoHof. These examples showcase how co-creation and the co-design of pathways through interdisciplinary research can lead to effective and practical sustainability solutions. Ultimately, this talk advocates for an integrated innovation strategy that leverages technology to drive a successful and sustainable circular bioeconomy.

INTEGRATED MULTIFUNCTIONAL HYBRID PV-X TECHNOLOGIES FOR POLYGENERATION FROM THE SUN

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THE CONTRIBUTION ABSTRACT – KSE3

By 2050, solar technologies are projected to deliver the majority of the world's electricity as part of an energy transition that is already well underway. Although solar energy can be used to provide either heat or electrical power, conventional options are designed for only one of these purposes. In particular, photovoltaic (PV) panels are typically less than 20% efficient in delivering electricity from the sun's energy with the remainder lost to the environment as waste heat. At the same time, it is well known that PV panels experience a deterioration in performance (efficiency) when they are operated at higher temperatures, and that this leads to high losses especially when the solar resource is at its highest. A drop in efficiency of up to 20% can be expected when PV cells reach operating temperatures of ~60-70 °C, which is easily experienced in hot climates. This loss has motivated the development of 'hybrid' PV-thermal (PV-T) solar collector technology, which combines PV modules with a contacting fluid (gas or liquid) flow in various geometries and configurations. The fluid is used to recover some of the waste heat from the cells, thus delivering a potentially useful thermal output from the collector, while simultaneously cooling the PV cells, thus increasing their electrical efficiency. PV-T collectors offer advantages when space is at a premium and there is demand for both heat and power, and have been shown to be a highly efficient technology capable of achieving system efficiencies (electrical plus thermal) of up to 60-70%. By far the most common use of the thermal-energy output from existing PV-T systems is to provide hot water at 50-60 °C for households or low-temperature commercial use. However, a wide range of opportunities arise at higher temperatures, if the heat can be used to drive power-generation cycles (e.g., with organic Rankine cycles, thermoelectric generators, amongst other), thermally-driven heating or cooling (e.g., with desiccant, ad/absorption cycles), and even desalination, fuel production or other processes, which are viable typically above ~80 °C and become increasingly efficient at progressively higher temperatures. In this talk, we will present conventional and advanced hybrid PV-T collector designs along with their underpinning operational principles, discuss the challenges and opportunities of further developing this technology, and of integrating it within wider solar-energy systems capable of the affordable provision of cooling, heating and power. We will also propose a new concept that we refer to as 'PVX' solar collectors, which harnesses additional performance benefits when these secondary processes are integrated synergistically with the PV cells and performed directly within the collector.

A SYSTEMATIC APPROACH TO EXERGY EFFICIENCY WITH APPLICATIONS TO CLOSED, STEADY-FLOW AND UNSTEADY-LOW SYSTEMS

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THE CONTRIBUTION ABSTRACT – KSE4

Exergy efficiency is viewed as the degree of approaching reversible operation, with a value of 100 percent for a reversible process characterized by zero entropy generation or equivalently zero exergy destruction. As such, exergy efficiency becomes a measure of thermodynamic perfection. There are different conceptual definitions of exergy efficiency, most of which are intended for steady-flow devices. In this presentation, general exergy efficiency relations are developed for closed, steady-flow and unsteady-flow systems and their use is demonstrated by applying them to various devices including nozzles, diffusers, valves, and heat exchangers. The extended system analysis is emphasized and explicit exergy efficiency relations are developed for the extended systems as well as the physical systems. Extended system analysis is more meaningful because it provides a more realistic picture of the entire process's thermodynamic performance rather than just what occurs within the physical system. It is also much simpler since exergy losses associated with heat loss and with matter purged into the environment, if any, are zero. The merits of different definitions of exergy efficiency are assessed, and the concepts of exergy loss and exergy destruction are put into proper perspectives. Also, the practicality of the use of the term exergy loss X_{loss} is questioned, and limitations on the definition $\eta_{ex} = W_{act,out}/W_{rev,out}$ are discussed. With the unified approach presented and the insights provided, the controversy and confusion associated with different exergy efficiency definitions are largely alleviated.

AN ACROSTIC APPROACH TO HIGH TEMPERATURE HEAT PUMPS

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THE CONTRIBUTION ABSTRACT – KSE5

Exergy efficiency is viewed as the degree of approaching reversible operation, with a value of 100 percent for a reversible process characterized by zero entropy generation or equivalently zero exergy destruction. As such, exergy efficiency becomes a measure of thermodynamic perfection. There are different conceptual definitions of exergy efficiency, most of which are intended for steady-flow devices. In this presentation, general exergy efficiency relations are developed for closed, steady-flow and unsteady-flow systems and their use is demonstrated by applying them to various devices including nozzles, diffusers, valves, and heat exchangers. The extended system analysis is emphasized and explicit exergy efficiency relations are developed for the extended systems as well as the physical systems. Extended system analysis is more meaningful because it provides a more realistic picture of the entire process's thermodynamic performance rather than just what occurs within the physical system. It is also much simpler since exergy losses associated with heat loss and with matter purged into the environment, if any, are zero. The merits of different definitions of exergy efficiency are assessed, and the concepts of exergy loss and exergy destruction are put into proper perspectives. Also, the practicality of the use of the term exergy loss X_{loss} is questioned, and limitations on the definition $\eta_{ex} = W_{act,out}/W_{rev,out}$ are discussed. With the unified approach presented and the insights provided, the controversy and confusion associated with different exergy efficiency definitions are largely alleviated.

SYNERGIES BETWEEN THE ENERGY-ACTIVE BUILT ENVIRONMENT AND GREEN HYDROGEN TECHNOLOGIES: A REVIEW

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THE CONTRIBUTION ABSTRACT – OE2

The development of synergies between the energy-active built environment and green hydrogen technologies represents a pivotal pathway toward achieving decarbonization and energy resilience objectives in the construction sector. The concept of the energy-active built environment refers to an integrated system of buildings that not only consume energy efficiently but also produce, store, and intelligently manage it through the convergence of renewable energy sources, digital technologies, and flexible consumption–production infrastructures. Within this framework, green hydrogen emerges as a crucial clean energy vector, providing complementary solutions for seasonal renewable energy storage, on-site energy supply, and the reduction of fossil fuel dependency in the building sector.

This review article delivers a comprehensive synthesis of current scientific literature addressing the integration of green hydrogen within sustainable buildings. It emphasizes the political, economic, social, technological, environmental, and legislative (PESTEL) dimensions that shape this transition. By applying a combined SWOT–PESTEL analytical framework, the study identifies the main barriers, drivers, and opportunities inherent in these synergistic interactions. The large-scale deployment of green hydrogen technologies across the energy-active built environment requires coherent public policies, sustainable financial instruments, social awareness and engagement, technological standardization, environmental compliance, and a clear, adaptive legislative framework to ensure a robust and integrated energy transition in the built environment. Moreover, the implementation of these solutions must align with long-term sustainability objectives, including carbon footprint reduction, enhanced energy efficiency, and improved resilience of buildings to climate change impacts.

Keywords: green hydrogen, energy - active buildings, renewable energy integration, sustainable built environment, energy transition.

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CATALYTIC OXIDATION OVER IRON INCORPORATED MESOPOROUS MOLECULAR SIEVES (FE-JLU-15)

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THE CONTRIBUTION ABSTRACT – PE2

Fe-containing mesoporous materials (Fe-JLU-15) prepared by using semifluorinated surfactant as a template, has been synthesized by microwave-hydrothermal (M-H) process. The characterization by several techniques of this material has shown that several iron species could be identified at the surface of the pore walls of the mesoporous silica and the surface area and pore volume of the Fe-JLU-15 are lower than those prepared by conventional-hydrothermal synthesis. The catalytic activity of this materials was tested for the phenol hydroxylation and wet phenol oxidation with H₂O₂ under mild reaction conditions (P= 1atm and T= 40°C). The effect of pH, H₂O₂/PhOH molar ratio and stability of the catalyst on the oxidation process was also investigated. Phenol oxidation and H₂O₂ decomposition show that Fe-JLU-15 is active and stable in aqueous solution. The total amount of dissolved iron is less than 5 wt% of the iron initially contained in the catalyst. In phenol hydroxylation, catechol and hydroquinone were observed as the major products, with a high selectivity for catechol (CAT/ HQ = 2.7 and 63.5 % phenol conversion).

AUTOMATION AND CONTROL SYSTEM REVAMP OF A NATURAL GAS COMPRESSORS STATION

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THE CONTRIBUTION ABSTRACT – PE3

This article aims to describe the process of modernization of the Stoenesti compression station, mainly covering the automation system architecture and the HMI interfaces, the benefits of using a modern software solution in monitoring and controlling a gas compression station and the key role that the implemented solution has in ensuring predictive maintenance.

At the Stoenesti compression station, there are four screw electro-compressors operating simultaneously, namely K1, K2, K3 and K4. The compressors are working in 2 pairs K1 and K3, K2 and K4 respectively. Gas compression is distributed in two stages. The first stage of compression consists of K1 and K3 compressing the received gas to a maximum value of 6.5 bar after which compressors K2 and K4 begin the second stage of compression to a maximum value of 30 bar.

The automation system that was in place at the compression station was outdated, making maintenance and diagnosis complicated for operators. The modernization project's main purpose is to make the communication between operator and compression station easier. This was achieved by revamping the existing automation systems for all compressors and linking each automation box to a HMI (Human – Machine Interface) panel for operators to interact with. The PLCs (Programmable Logic Controller) have also been replaced, and HMI interfaces attached offer an overview of the corresponding compressor with all the elements and parameters that need monitoring such as valves, pressure transducers, oil cooler etc. To further facilitate the diagnosis and maintenance, the modernized automation system offers a set of alarms that appear on the screen for the operators to see when a critical threshold associated to a parameter has been reached, a failure has occurred or a fault occurs along the measurement lines. Warning and alarm thresholds are set in the software program for the monitored parameters, in order to ensure the safe operation of the compressors.

ENERGY TRANSITION DYNAMICS IN ROMANIA: RENEWABLE SOURCES INTEGRATION AND DECARBONIZATION PATHWAYS IN THE CONTEXT OF EUROPEAN CLIMATE POLICIES

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THE CONTRIBUTION ABSTRACT – OE3

This study presents a comprehensive analysis of Romania's energy transition over the period 2008-2024, examining the evolving role of renewable energy sources in achieving national and European decarbonization objectives. The research investigates the structural transformation of Romania's energy mix, which comprises hydropower, hydrocarbons, coal, nuclear energy, wind, photovoltaic, and biomass sources. Through statistical analysis of power generation data from Transelectrica, the study reveals significant shifts in energy production patterns: coal-based generation decreased by 74.4% compared to 2008 levels, while renewable sources expanded substantially, with wind power reaching over 700 MW average annual capacity, photovoltaic exceeding 230 MW, and biomass contributing 50 MW. The research demonstrates that the share of renewable sources in the energy mix increased from 26% in 2008 to nearly 49% in 2023, with green sources (wind, solar, biomass) growing from 0% in 2007 to 18%. The analysis reveals pronounced seasonal variability in energy production: coal and hydrocarbon generation peaks during winter months, hydropower maximizes in spring due to snowmelt, wind energy shows highest output in winter, while photovoltaic production concentrates in summer months. The study identifies critical challenges including supply-demand imbalances emerging after 2019, culminating in a deficit of -321.49 MW in 2024. The research concludes that Romania's energy system is undergoing fundamental structural change, marked by fossil fuel decline and consistent renewable energy growth. However, challenges remain in balancing supply-demand dynamics and efficiently integrating intermittent sources into the grid. These findings contribute to understanding energy transition mechanisms in developing European.

MULTILAYER NANOCOMPOSITE COATINGS FOR ENHANCED EXERGY EFFICIENCY IN CONCENTRATED SOLAR POWER SYSTEMS

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THE CONTRIBUTION ABSTRACT – PE4

The efficiency and long-term performance of Concentrated Solar Power (CSP) systems are highly dependent on the thermal and optical stability of their functional surfaces. This research investigates the development and application of multilayer nanocomposite coatings designed to enhance energy efficiency in CSP plants. By integrating nanoscale ceramic-metal composites into multilayer structures, the coatings exhibit superior solar absorptance, optimized thermal emissivity, and improved resistance to high-temperature oxidation and wear. Experimental evaluations demonstrate improvement of solar energy absorption and irreversible energy losses, leading to improved overall system performance. Furthermore, the durability of these coatings extends component lifetimes and reduces maintenance frequency, supporting sustainability and cost-effectiveness. The study emphasizes how smart surface engineering through multilayer nanocomposites contributes to clean energy conversion, resource efficiency, and the advancement of renewable technologies, aligning directly with global objectives for green power generation and sustainable development.

HIGH-ENTROPY ALLOYS FABRICATED BY ADDITIVE MANUFACTURING: FUNCTIONAL PERFORMANCE FOR ENERGY EFFICIENCY AND ENVIRONMENTAL SUSTAINABILITY

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THE CONTRIBUTION ABSTRACT – PE5

The convergence of additive manufacturing (AM) and high-entropy alloy (HEA) design enables the development of functional materials tailored for energy efficiency and environmental sustainability. This paper presents an in-depth analysis of the thermomechanical and functional properties of 3D-printed HEAs, emphasizing their relevance to energy systems and eco-efficient technologies. By correlating process parameters with microstructural features, significant enhancements in strength, thermal stability, and fatigue resistance were achieved. Performance evaluations indicate that the use of HEAs in energy-intensive applications can minimize entropy generation and improve system-level efficiency. Moreover, the environmental impact assessment confirms the potential of HEAs to extend component durability. These findings establish 3D-printed HEAs as strategic materials for next-generation energy infrastructures, clean energy conversion, and sustainable mechanical engineering applications.

SUBMERGED FRICTION STIR PROCESSING - ECO-FRIENDLY METHOD FOR LOCAL ENHANCEMENT OF MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ALUMINUM ALLOYS

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THE CONTRIBUTION ABSTRACT – PE6

Underwater friction stir processing (SFSP) is an innovative technology for local modification of the microstructure and mechanical properties, applicable to aluminum alloys. By using water as a cooling medium during processing, the thermal impact on the material in the processing area is significantly reduced, reducing the risk of oxidation and favoring grain refinement. The paper presents general aspects of SFSP processing, technological parameters and equipment used, as well as results of experimental research carried out at ISIM

Timișoara on SFSP processing of rolled and cast aluminum alloys, with thicknesses of 5–6 mm, using an experimental system adapted for liquid media. The research results show the possibility of refining the microstructure and improving the mechanical properties of aluminum alloys by SFSP processing. The paper shows the potential for applying SFSP processing as a sustainable and efficient method for processing aluminum alloys (by local modification of the microstructure and mechanical properties), providing a solid basis for further developments in the field of materials engineering. The paper fits into the conference theme by promoting green and innovative technologies.

TEST BENCH FOR REVERSING GEARBOX USED IN NAVAL PROPULSION

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THE CONTRIBUTION ABSTRACT – PE7

This paper presents the design and implementation of a test bench for the reduction–reversing gearbox used in naval propulsion systems, specifically for reducing the speed of the thermal engine and reversing the propeller's rotation. The gearbox, part of the modernized propulsion group of certain frigates, required the development of a stand capable of replicating its operational conditions while ensuring compliance with marine environment requirements. The stand incorporates a frequency converter that drives a DC motor, which actuates the gearbox in a single rotation direction, while the output direction is reversed using hydraulic clutches. The automation, developed in EasySoft, enables both control and data acquisition in manual and automatic testing modes, with monitoring of key parameters such as engine speed and power displayed on the operator panel. Experimental results demonstrate stable performance, as the vibration level did not exceed 2.5 mm/s at maximum gearbox speed, confirming proper operation without mechanical defects. The stand provides reliable monitoring and recording of system variables, ensuring a comprehensive evaluation of the gearbox's mechanical integrity and operational functionality. These results validate the efficiency of the stand in assessing the quality of the gearbox execution, supporting its integration into naval propulsion systems.

PERFORMANCE EVALUATION OF GPU-ENHANCED MULTITHREADED ALGORITHMS FOR OPTIMIZING LARGE-SCALE HIGH-PRECISION MATRIX MULTIPLICATION

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THE CONTRIBUTION ABSTRACT – OE5

This study investigates the performance optimization of large-scale, high-precision matrix multiplication through GPU-enhanced multithreaded algorithms. Six GPU-based implementations are developed and evaluated: a single-threaded baseline, a naïve multi-threaded version, two optimized multi-threaded variants computing multiple elements per thread, a shared-memory approach, and an optimized algorithm using the NVIDIA cuBLAS library. These are benchmarked against a multi-threaded CPU-based CBLAS DGEMM implementation. Results demonstrate that GPU parallelization significantly reduces runtime compared to the CPU baseline, with optimized algorithms achieving up to 1.5x speedup. The shared-memory and multi-element-per-thread approaches mitigate memory bottlenecks, though profiling reveals persistent memory-bound constraints. Proposed improvements include combining register and memory blocking for enhanced throughput. This research underscores the efficacy of GPU parallelization for compute-intensive matrix operations, offering insights for optimizing large-scale linear algebra computations.

UNRAVELLING THE IMPACT OF NO_x, CO, AND VOCs ON TROPOSPHERIC OZONE FORMATION: INSIGHTS FROM STATISTICAL AND CAUSAL ANALYSIS

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THE CONTRIBUTION ABSTRACT – OE6

The problem of seasonal and diurnal variations of ozone concentrations and their relationship with meteorological parameters is investigated for Craiova, Romania. The peak ozone formation periods and the key environmental factors influencing their variability are identified by analysing hourly and seasonal trends. The dataset (2020 – 2024) comprises hourly ozone and meteorological data, enabling a comprehensive assessment of ozone pollution dynamics. It includes two categories of data from four air quality monitoring stations : (i) 7 meteorological parameters; (ii) 13 air pollutants. Statistical and Machine and Deep Learning techniques, including time-series decomposition, correlation analysis, regression modelling, and spectral analysis, are employed to extract meaningful insights. The findings enhance understanding of ozone formation mechanisms, aiding policymakers in designing effective air quality management strategies.

Tropospheric ozone (O₃) is a secondary pollutant formed through complex photochemical reactions involving nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs). Understanding the relative contributions of these precursors is crucial for effective air quality management and emission control strategies. A multi-method approach combining correlation analysis, cross-correlation, Granger causality, and feature importance methods is used to assess the impact of NO_x, CO, and VOCs on ozone formation. The immediate and lagged effects, seasonal and diurnal variations, and feedback interactions are investigated. Results highlight the dominant role of NO_x, the significant but delayed contribution of VOCs, and the supportive role of CO in enhancing ozone formation under different meteorological conditions. The proposed framework offers actionable insights into precursor prioritisation and emission reduction policies.

Keywords: Ozone formation, Granger causality, Cross-correlation, Feature importance, Air quality management.

OUTLIER DETECTION IN OZONE AND PM DATA: IDENTIFYING EXTREME POLLUTION EVENTS USING STATISTICAL, AI, AND CAUSAL APPROACHES

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THE CONTRIBUTION ABSTRACT – OE7

Ozone (O₃) and Particle Matters (PMs) are critical air pollutants that pose risks to both human health and the environment. While average ozone and PM levels provide insights into long-term exposure, extreme pollution events often drive acute health impacts and regulatory exceedances. This study aims to develop a comprehensive framework for outlier detection in ozone and PM time series data, focusing on identifying and characterising abnormal pollution episodes. Using multi-year hourly measurements, statistical approaches (Interquartile Range, z-score, Seasonal-Trend decomposition), machine learning anomaly detection methods (Isolation Forest, One-Class SVM, Autoencoders), and causal context analysis are integrated with meteorological and precursor data. The methodology captures both univariate outliers (spikes in ozone and PMs) and multivariate anomalies (ozone and PMs events inconsistent with meteorological or precursor conditions). Case studies of detected extreme events are analysed to explore their underlying causes, such as photochemical smog episodes, stagnation events, or pollutant transport. This framework enhances robust air quality monitoring and provides actionable insights for early warning systems and informed environmental policy.

CHARACTERIZATION OF IN-SITU SODIUM DEPOSITION IN ANODE-FREE SODIUM METAL SYSTEMS

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THE CONTRIBUTION ABSTRACT – OE8

Sodium batteries are in strong demand nowadays because of the sodium metal abundance in the earth's crust, compared to lithium. In recent studies, researchers are more interested by the rechargeable Anode-Free Sodium Metal Batteries (AFSMBs). In these systems, the metal anode is deposited in situ on the anode substrate/current collector during the first charge process, with metal sources coming from the cathode. An anode-free cell typically consists of a sodium-containing positive electrode, an anode current collector (e.g., Cu or Al foil), a separator, and a liquid electrolyte.

In this work, we investigate the role of electrolyte chemistry in governing the electrochemical performance and failure mechanisms of AFSMBs. Using copper current collectors in half-cell configurations with sodium counter electrodes, we evaluated several glyme-based electrolytes containing different sodium salts.

Our results show that electrolytes containing sodium perchlorate (NaClO_4) and sodium bis(trifluoromethylsulfonyl)imide (NaTFSI) exhibited poor compatibility with cell components, leading to rapid failure. In contrast, sodium trifluoromethanesulfonate (NaCF_3SO_3) and sodium hexafluorophosphate (NaPF_6) demonstrated excellent stability, enabling more than 1000 cycles with high reversibility. s. These results highlight electrolyte selection as a critical factor for enabling stable, long-life AFSMBs and provide insights for guiding electrolyte design in practical sodium metal batteries.

ANTIMICROBIAL ACTIVITY STUDY OF SOME METAL COMPLEXES WITH AN ADENOSINE SCHIFF BASE LIGAND

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THE CONTRIBUTION ABSTRACT – PE8

This study present the antimicrobial activity of some complexes with a Schiff base derived from adenosine and p-dimethylaminobenzaldehyde. Adenosine is an endogenous nucleoside with potent vasodilator and antiarrhythmic activities. Adenosine also has anti-inflammatory activity and plays an important role in energy transfer as adenosine triphosphate (ATP) and adenosine diphosphate (ADP). P-dimethylaminobenzaldehyde has found applications in synthetic, biochemical, biomedical and analytical sciences. New complexes compounds of Cu(II), Ni(II) and Co(II) with the Schiff base derived from adenosine and p-dimethylaminobenzaldehyde have been synthesized and characterized by elemental analysis, IR, UV-Vis spectroscopy as well as from conductometric and magnetic data. This Schiff base ligand and its metal complexes were tested for their antimicrobial activity on five bacterial strains: Enterococcus faecalis ATCC, Citrobacter freundii, Salmonella sp., Staphylococcus epidermidis and Escherichia coli. The quantitative assay of the antimicrobial activity was performed by binary micro dilution method, in order to establish the minimum inhibitory concentration (MIC). From the results of the biological evaluation it was concluded that the antimicrobial activity of the tested compounds follow the order: Cu(II) complex > Co(II) complex > Ni(II) complex $\cong$ Schiff base ligand, and that, in general, biological activity increases through complexation. Therefore, the most active compound, considering both the intensity of the antimicrobial activity and the microbial spectrum proved to be the Cu(II) complex compound, which showed good activity against Salmonella sp. strain (MIC = 31.25 $\mu\text{g/mL}$), being active against all tested microbial strains. The importance of these findings lies in the fact that these compounds could be considered for the further development of novel antimicrobial drugs used for the treatment of some common diseases caused by these bacterial strains.

INVESTIGATION OF ENGINE PERFORMANCE OF RICE BRAN OIL METHYL ESTERS (RME) AS AN ALTERNATIVE FUEL

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THE CONTRIBUTION ABSTRACT – PE9

This study investigates the engine performance and emissions of rice bran oil methyl esters (RME) as a sustainable biodiesel alternative to petroleum diesel. Amid rising energy demands and environmental concerns, biodiesel from non-edible sources like rice bran oil offers a viable solution to reduce fossil fuel dependency and meet emission standards. RME was produced via transesterification using an alkaline catalyst, yielding biodiesel with properties such as density (890 kg/m³ at 15°C), viscosity (12.4 mm²/s at 40°C), acid value (7.1 mg KOH/g), iodine value (110 g I₂/100 g), saponification value (198 mg KOH/g), peroxide value (4.2 meq O₂/kg), and oxidative stability (6.3 h at 110°C), compared to crude rice bran oil. Blends of RME with diesel (B10, B20, B30, B70, B100) were tested on a Deutz F4L912 four-cylinder, air-cooled diesel engine (51 kW rated power, 3.7 L displacement) under varying loads. Performance metrics included brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and exhaust gas temperature (EGT). Results showed BTE increased by 1.15-17.68% across blends due to higher oxygen content and cetane number, enhancing combustion. BSFC rose by 2.53-16.45%, attributed to lower calorific value and higher density/viscosity. EGT elevated by 1.58-19.74%, reflecting higher combustion temperatures. Emissions analysis revealed reduced CO (2.69-8.73%) and HC (3.56-16.63%) due to improved oxidation in oxygen-rich mixtures, but NO_x increased (10.51-21.73%) from elevated in-cylinder temperatures. Overall, RME blends demonstrate superior efficiency and lower harmful emissions (except NO_x), supporting their potential for sustainable transport fuels while addressing environmental impacts like greenhouse gas reduction.

PATHWAYS TO SUSTAINABLE ENERGY IN MODERN SOCIETY: CERAMIC NANOMATERIALS FOR (PHOTO) ELECTROCHEMICAL ENERGY GENERATION

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THE CONTRIBUTION ABSTRACT – OE9

Ceramics have emerged as vital materials in the development of new energy conversion devices due to their exceptional thermal stability, chemical durability, and versatile electrical properties. This presentation focuses on the latest advances in ceramic materials that are enabling breakthroughs across a wide spectrum of energy conversion technologies: solid oxide fuel cells (SOFCs) and photocatalytic systems for solar fuel production. The inherent properties of ceramics—such as high ionic and electronic conductivity, excellent corrosion resistance, and tunable microstructures—make them ideal candidates to improve device efficiency, lifespan, and environmental sustainability.

Recent progress in ceramic synthesis techniques, such as advanced sintering methods, thin-film deposition, and nanostructuring, has allowed for precise control of microstructural features, which directly influence functional performance. For example, innovations in electrolyte and electrode materials are significantly reducing the operating temperatures of SOFCs, thereby enhancing system efficiency and lowering costs. In solar energy conversion, photocatalytic ceramics are being engineered to maximize light absorption and charge carrier separation, promoting greater hydrogen production through water splitting. Additionally, the multifunctionality of ceramics enables their integration in hybrid systems that combine different energy conversion pathways, further boosting overall device performance.

The challenges associated with integrating ceramics into commercial energy devices, including material stability under cyclic operation, interfacial compatibility, and scalability of fabrication processes are also highlighted. Strategies to overcome these barriers, such as composite material design and interface engineering, are presented and the critical role of ceramics in shaping a sustainable energy future is emphasized.

DETERMINING EMBEDDED EMISSIONS IN METALLIC PRODUCTS BY USING GHG INTENSITY AS SCIENTIFIC METRIC AND REPORTING THE RESULTS SO AS TO COMPLY CBAM STANDARDS

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THE CONTRIBUTION ABSTRACT – OE10

The purpose of the present paper is explaining – through a certain case study – how GHG intensity is used as scientific metric in determining the emissions embedded in metallic products, as well as how to report the results thus obtained in order to obey the CBAM regulation. It is well known that CBAM (abbreviation for "carbon border adjustment mechanism") is a climate policy tool designed by EU's specialists as to prevent "carbon leakage" by imposing a certain carbon price on the imported goods (among which metallic products – especially aluminum, steel and iron – arouse special interest), requiring importers to report both the embedded direct and indirect GHG (greenhouse gases) emissions embedded in their products and to subsequently purchase CBAM certificates to cover both kind of emissions at a price equivalent to the EU's ETS (emissions trading system) carbon price, the ultimate goal being to create a level playing field between EU producers and their non-EU competitors, consequently encouraging all international industry to comply with environmental standards by adopting cleaner production technologies.

EFFICIENT PHOTOANODES BASED ON MESOPOROUS CE-MODIFIED TiO₂ FOR PHOTOCATALYTIC FUEL CELL SYSTEMS

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THE CONTRIBUTION ABSTRACT – PE10

Solar energy can be converted into electricity or chemical energy by various techniques. Photocatalytic Fuel Cells (PFCs) which consume an organic or inorganic fuel to produce renewable electricity and allow simultaneous treatment of different wastewater are one of these environmental-friendly technologies.

In this work is presented an efficient strategy for synthesis of mesoporous TiO₂ modified with different Ce concentrations as powder and film through a sol-gel process in the presence of Pluronic P123 block copolymer as structure directing agent, integrated with evaporation-induced self-assembly (EISA) approach (Mureseanu et al. 2021). New photoanodes for an efficient PFC have been obtained by spin-coating the mesoporous Ce-doped TiO₂ thin film onto a bottom nanocrystalline TiO₂ layer prepared onto FTO conductive glass. The nanocomposite films were without cracks and consisted of small crystallite of anatase. The presence of cubic CeO₂ was evidenced only in Ce-modified powder samples. All materials were characterized by SEM and TEM microscopies, UV-Vis, XPS and N₂ adsorption-desorption isotherms in order to examine the textural and structural characteristics and the chemical nature of their surface. Furthermore, the photoelectrochemical characterization and photovoltaic evaluation evidenced the role of the titania compact layer, the effect of the titania mesoporous structure and the amount of cerium in composite film on the enhanced photovoltaic performance. The photocatalytic activity was evaluated for phenol photodegradation in aqueous media with very good results. Based on the obtained results these new photoanodes could be considered for the construction of an efficient PFC system.

A GREEN APPROACH TO ENERGY STORAGE SYSTEMS: EXPLORING NATURAL RESOURCES FOR THE SYNTHESIS OF BIO-BASED SILVER NANOPARTICLES

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THE CONTRIBUTION ABSTRACT – PE11

Introduction. Green synthesis of silver nanoparticles (Ag NPs) using plant extracts is known as being low-cost, non-toxic and environmental-friendly, yielding to nanomaterials with applications in various fields (photocatalysis, water treatment, biomedical applications, etc.). As they retain the known properties of Ag NPs (good electrical conductivity and surface area beneficial for energy storage), green Ag NPs have been proved to possess excellent properties that qualify them as components within energy storage systems, particularly in electrochemical energy storage, such as supercapacitors. Plant metabolites can reduce metal ions, generating nano-sized particles, that they further stabilize by encapsulation. In this study, a water extract of peas (*Pisum sativum* L.) sprouts, rich in polyphenols, was used as reducing agent.

Experimental study. An aqueous extract of germinated pea seeds has been obtained, assayed for total phenolic content using the Folin-Ciocalteu method and used to reduce AgNO₃ 10 mM solution, at 70 °C. The synthesis has been monitored spectrophotometrically and lasted 3 hours. The obtained particles were matured, purified by centrifugation, washed with distilled water, dried and analysed by FTIR, SEM, EDXS.

Results and discussion. FTIR spectrum of the obtained particles indicated the presence of organic matter (pea polyphenolic compounds). EDXS analysis revealed the presence of Ag as main component of the investigated sample (55.1% wt). C, O, Cl, P, S were also detected and quantified, indicating the presence of organic matter from the vegetal extract. SEM images evidenced an irregular morphology of the particles, with average dimensions of about 1.00-1.5 μm. However, smaller structures (25-50 nm) can also be observed.

Conclusion. Silver nanoparticles have been obtained using a green approach. Further investigations will be performed to evaluate their properties and applications as components of energy storage systems with superior performance.

GRAPHICAL USER INTERFACE TO STUDY ELECTRIC DRIVES USED ON MODERN LOCOMOTIVES

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THE CONTRIBUTION ABSTRACT – PE12

In this paper we present the structure of electric drives with traction induction motor that are used on modern locomotives fed through AC lines.

We detail the structure, mathematical model and Simulink model for each component that makes up the electric drives system (traction transformer, line side-converter, machine-side converters, traction induction motor, mechanical transmission and traction control).

Our approach enables studying and understanding through simulation the electric drives system both as individual components and as a whole.

Using Matlab App Designer we have created GUIs that could be used to simulate the behavior of the electric drives used on modern locomotives.

These items can be used as teaching material too. Developing such application is useful to deepen our understanding of the high power electric drives.

TOTAL CO₂ RELEASE FROM COMBUSTION, ELECTRIC AND HYBRID VEHICLES – A CASE STUDY FOR LATIN AMERICA'S COUNTRIES

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THE CONTRIBUTION ABSTRACT – PE13

This study investigates the total carbon dioxide (CO₂) emissions from various types of passenger vehicles in five Latin American countries: Brazil, Mexico, Argentina, Paraguay, and Ecuador. The vehicles analyzed include petrol-driven cars, short-, mid-, and long-range Battery Electric Vehicles (BEVs), Fuel Cell Electric Vehicles (FCEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Hybrid Electric Vehicles (HEVs). The study examines the total CO₂ emissions including battery production, vehicle manufacturing, and their operation, considering the energy grid mix of the selected countries for the year 2023. The results indicate that BEVs using batteries produced in Europe and/or America, which have the shortest cruising range, generate the lowest levels of CO₂ emissions, regardless of the energy mix. However, the emission values vary across different countries. In countries with a predominant share of renewable energy for the electricity generation, such as Paraguay, Brazil and Ecuador, BEVs are the most effective in reducing overall CO₂ emissions. Conversely, in countries like Argentina and Mexico, where renewable energy sources constitute a smaller share of the energy mix, the use of zero-emission vehicles is questionable. This is particularly true for long-range vehicles with batteries produced in Asia, whose emissions exceed those of internal combustion engine vehicles.

FROM WATER STORAGE TO RENEWABLE POWER: A CASE STUDY ON ISALNIȚA RESERVOIR AND ITS WIDER RELEVANCE FOR EASTERN EUROPE

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THE CONTRIBUTION ABSTRACT – OE13

Global warming and the continuous rise in energy costs highlight the need to make better use of all available resources. In many parts of Eastern Europe, dams and reservoirs were built during the last century mainly for water supply or flood protection, and most of them have never been considered for electricity production. These infrastructures, still functional and with their environmental impact already absorbed, can now provide a solid basis for new hybrid and flexible renewable energy projects.

The Isalnița reservoir, located on the Jiu River just upstream of Craiova, is a representative case. Built in the 1960s, it has been supplying the city and the nearby power plant with water for more than fifty years, but it has never generated electricity. This paper investigates the option of converting it into a hybrid system that combines floating photovoltaic panels with a low-head micro-hydro unit, also able to operate in pumped-storage mode.

The study indicates that covering 10–20% of the lake surface with floating PV would enable 13–27 MWp of installed capacity, producing 17–34 GWh annually. With a 1–2 MW hydro unit and controlled daily level variations of 0.5–1.0 m, the system could shift 15–30 MWh of solar energy each day from midday to evening peaks, thus improving local flexibility.

Besides technical performance, such a project could create jobs, reduce water evaporation, and serve as a visible example of sustainable innovation near Craiova. While the short-term economic return is limited, decreasing technology costs and access to European funds improve the long-term outlook. The Isalnița case shows how existing dams and reservoirs, originally built for non-energy purposes, can be repurposed as replicable examples of renewable integration and sustainable modernization in Central and Eastern Europe.

VALORISING OAK BARK: SCALABLE ULTRASOUND-ASSISTED POLYPHENOL EXTRACTION FOR BIODEGRADABLE LEATHER

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THE CONTRIBUTION ABSTRACT – PE14

Introduction: Oak bark, a by-product abundant in polyphenols, is a promising source of vegetable tannins. Tannins have multiple applications as leather tanning, adhesives, cement plasticisers, and in medical and agrochemical applications, due to their ability to link to biological targets and provide antioxidant, antimicrobial, and anti-inflammatory benefits.

Experimental Study: A green pilot-scale ultrasound-assisted extraction (UAE) process was developed and optimised for polyphenol extraction from oak bark, focusing on particle dimension, extraction time, temperature, and solvent type. The interactions between extracted tannins and collagen insoluble matrices were analysed using micro-DSC, ATR-FTIR, ¹H NMR, and standard tests.

Results: UAE at 50 °C for 10 minutes with 0.5% sodium hydroxide gave the highest phenolic yield. Aqueous and low-alkali extracts stabilised collagen mainly by hydrogen bonding, while alkali and sulfonated extracts formed mixed hydrogen and covalent bonds. Micro-DSC showed increased collagen denaturation temperature (up to 12–15 °C) with 0.2% and 0.5% NaOH extracts and structural homogeneity. ATR-FTIR confirmed tannin-collagen molecular interaction, and ¹H NMR revealed greater chain packing and water exclusion, correlating with improved mechanical properties. The resulting leathers matched conventional vegetable-tanned leather in resistance and structure, supporting the process's commercial viability.

Conclusion: This study offers a green, scalable method for obtaining oak bark extracts able to stabilise insoluble collagen matrices, as well as an innovative analytical approach to collagen-tannin interactions. The approach advances sustainable tanning by reducing environmental impact, producing more biodegradable leather and converting tree bark, a low-value by-product, into valuable tannins.

Acknowledgement: This work was carried out within COST Action CA22155, supported by COST (European Cooperation in Science and Technology).

THORIUM'S EXTRACTION TECHNIQUES, VALORIZATION, ENVIRONMENTAL FATE, AND TOXICOLOGICAL RISKS

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THE CONTRIBUTION ABSTRACT – PE15

Trace metals accumulated in food crops represent a critical route of human exposure, linking agricultural practices to both food security and environmental health. In this work, we investigated how soil geochemical characteristics across Romania influence the uptake of lithium (Li) and trace elements (Cu, Mn, Sr, Zn, Pb, Cd) in commonly consumed vegetables, including onion, garlic, lettuce, cucumber, and zucchini. A total of 42 paired soil–plant samples were analysed from 11 farming regions using spectroscopic methods. The surveyed soils, generally neutral to slightly acidic, shaped trace metal bioavailability and mobility, producing element-specific patterns of transfer to plant tissues. Micronutrients such as Zn and Cu displayed elevated bioaccumulation factors, consistent with physiological demand, while toxic elements like Pb and Cd were effectively excluded, remaining below European safety thresholds. Lithium uptake showed marked spatial variability, strongly tied to local soil chemistry. Non-linear soil–plant relationships observed for Fe, Zn, Sr, Mn, Cu, and Li highlighted the complexity of geochemical controls on trace metal translocation. Collectively, the results confirm a low dietary risk from vegetables in the studied regions while offering critical insights for sustainable land use and food safety monitoring.

THORIUM: EXTRACTION TECHNOLOGIES, UTILIZATION POTENTIAL, ENVIRONMENTAL DYNAMICS, AND HEALTH RISKS

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THE CONTRIBUTION ABSTRACT – PE16

Thorium (Th) is a naturally occurring element found in rare earth and clay deposits with ion-absorption properties. It is increasingly recognized as a strategic resource due to its potential applications in nuclear energy, medical treatments, the defense sector, fertilizer production, and other industrial uses. However, thorium's natural radioactivity and the byproducts generated during extraction and processing raise significant environmental and public health concerns. Residual wastes may contaminate soil, air, and water, creating long-term risks for ecosystems and human populations.

Experimental and epidemiological studies indicate that thorium can enter biological systems, leading to cellular uptake, bioaccumulation, and toxicity. These effects underline the need for responsible evaluation of thorium valorization strategies. In particular, its role in the remediation of contaminated environments highlights both opportunities and challenges for safe deployment.

Comprehensive assessments of thorium extraction methods, environmental pathways, and toxicological outcomes are essential to mitigate risks. The industrial procurement and wide use of Th generate secondary impacts that can be reduced through circular approaches emphasizing recovery, recycling, safe handling, and protective measures against accidental or occupational exposure.

Establishing effective monitoring frameworks and integrating environmental safety with technological innovation will help ensure that thorium's benefits are realized while minimizing its risks. In this way, thorium may serve as both a valuable resource and a driver for sustainable practices in energy and industry.

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THE RELATIONSHIP BETWEEN NATIONAL POLICIES AND THERMODYNAMICS: A THEORETICAL AND APPLIED STUDY ON ENERGY, EXERGY, ENTROPY, AND POLITICAL SYSTEM DYNAMICS

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THE CONTRIBUTION ABSTRACT – OE14

This study analyzes the sustainability and institutional dynamics of modern political systems by examining the fundamental concepts of thermodynamics—energy, entropy, equilibrium, open systems, and irreversibility—from the perspective of social sciences and political science, and by exploring their structural analogies with national policies. Modern political systems exhibit significant parallels with thermodynamic systems in terms of energy flow, information exchange, resource management, and the preservation of institutional order. Within this framework, thermodynamic principles are interpreted along the axes of energy inputs, available energy (exergy), and disorder (entropy) in political systems.

The study first provides a conceptual framework to demonstrate how the concepts of energy, exergy, and entropy are critical in understanding the crisis management capacity, reform potential, and institutional flexibility of political systems. Subsequently, through a comparative interdisciplinary analysis of Germany, Turkey, China, India, and the Scandinavian countries, the research discusses political energy efficiency and entropy management, applying thermodynamic concepts to the evaluation of political systems.

Ultimately, the study develops recommendations for sustainable governance within the framework of entropy management and political energy efficiency, emphasizing how energy, exergy, and entropy provide valuable analytical tools for assessing and enhancing the adaptability and resilience of political systems.

Keywords: Political Systems, Political Science, Open Systems, Institutional Balance, Democratic Regression, Sustainability, Energy, Exergy, Entropy.

EXPERIMENTAL INVESTIGATION OF FLOW FIELD DESIGN AND CHANNEL GEOMETRY ON THE PERFORMANCE OF A DIRECT ETHANOL FUEL CELL

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THE CONTRIBUTION ABSTRACT – OE15

One of the main challenges in improving the performance of direct ethanol fuel cell's (DEFC's) is the balanced distribution of reactants across the active area and the effective removal of reaction products, namely water and carbon dioxide (CO₂), from this region. In this study, flow channels were designed and fabricated for a three-dimensional DEFC with an active area of 25 cm². The effect of flow field designs with different channel structures and dimensions on fuel cell performance was experimentally investigated in comparison with the commonly used serpentine channel design. Performance evaluation was conducted using power density curves. At a constant operating temperature and fuel concentration, current-voltage and electrochemical impedance spectroscopy (EIS) measurements were performed for each design; the effect of designs with regionally varying channel widths was analyzed while maintaining a constant channel depth (1 mm). Performance tests were conducted at a 2 M methanol concentration, 50 °C operating temperature, and varying reactant flow rates (ethanol: 1–15.0 mL/min; air: 100–1500 mL/min), and the results obtained were presented graphically for performance evaluation.

Keywords: Direct methanol fuel cell; single cell testing; electrochemical impedance spectroscopy; flow field design; Operating parameters.

UPCONVERSION OF BIOGAS CO₂ USING GAS-DIFFUSION DENDRITIC BISMUTH ELECTROCATALYSTS

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THE CONTRIBUTION ABSTRACT – OE16

Electrochemical conversion of CO₂ using gas diffusion electrodes (GDEs) offers a compelling route for biogas upgrading by simultaneously increasing methane (CH₄) content and producing value-added chemicals. In this study, we develop Bi(OH)SO₄·H₂O nanorods as electrocatalysts, synthesized via a simple, low-temperature coprecipitation method that offers excellent scalability and reproducibility. These catalysts, in situ transformed into Bi oxyhydroxides, demonstrate high activity and selectivity for formate production in alkaline media, even under dilute CO₂ conditions representative of real biogas (~40% CO₂ and ~60% CH₄). The optimized GDE system achieves a partial current density (J_p) of up to ~570 mA cm⁻² and Faradaic efficiency (FE) exceeding 90% under pure CO₂. Under 40% CO₂, the system maintains a high FE with J_p of ~130 mA cm⁻² for formate production. Performance is strongly influenced by gas flow rate, revealing the need to balance CO₂ availability and suppression of hydrogen evolution. A three-cell GDE configuration connected in series further enhances CO₂ conversion efficiency, increasing methane content to ~90% without requiring gas separation or pretreatment. Real biogas tests confirm the practical feasibility of the system, though the presence of H₂S impacts early-stage performance, highlighting the importance of desulfurization. This work demonstrates a robust, modular strategy for decentralized biogas upgrading via CO₂ electroreduction.

ENGINEERING A CATECHOL DERIVED SODIUM SALT FOR STABLE HIGH-CAPACITY ORGANIC SODIUM-ION BATTERY CATHODES

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THE CONTRIBUTION ABSTRACT – PE17

The push toward sustainable, high-performance sodium-ion batteries has spotlighted organic cathode materials (OCM), favored for their lightweight, structural tunability, and eco-friendly composition. However, traditional organic electrodes often suffer from limited capacity and poor cycle life due to solubility and conductivity. In response, focus on the π -conjugated frameworks infused with catechol-derived ortho-quinone moieties as one of the research interests for the development of OCMs. In our work we aim to develop a stable, high-performance organic cathode material for sodium-ion batteries, derived from a monohydrated catechol derivative bearing sodium sulfonate functionalities. We explored how variables such as solvent system, temperature, atmosphere control, and thermal post-treatment influence the deprotonation of hydroxy groups by sodium ions in monohydrated catechol derivative, as well as the redox capacity, structural integrity, and overall electrochemical performance. Infrared Spectroscopy analysis confirmed this deprotonation reactions. We further integrated the fully converted catechol-based material into coin cells with diverse electrolytes. Through systematic variation of these configurations, we achieved 70% of the theoretical capacity a strong sign of promise for our design. Building on this encouraging result, further optimization such as exploring different electrolytes, conductive carbon with different combinations could help us push closer to full theoretical capacity and unlock the material's full potential.

Acknowledgments

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DIAGNOSIS OF THE ECOLOGICAL STATUS OF AQUATIC ECOSYSTEMS IN THE DANUBE DELTA BIOSPHERE RESERVE (2019–2024)

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THE CONTRIBUTION ABSTRACT – PE18

The Danube Delta Biosphere Reserve is one of Europe's most valuable and complex wetland systems, encompassing a variety of aquatic ecosystems with major ecological and socio-economic importance. The research aims to highlight areas vulnerable to anthropogenic pressures, and to assess the ecological status of aquatic ecosystems in relation to hydrological, physico-chemical, and biological parameters. Data were collected from eight lakes and six sites along the Danube and its branches and connected canals, representing diverse hydrological conditions and connectivity gradients.

The analysis of six-year datasets contributes to a better understanding of ecosystem functioning and supports the development of new ecological indicators to improve future monitoring and management.

The assessment followed the principles of EU Water Framework Directive (2000/60/EC), classifying water bodies into five ecological quality classes based on hydrological, physico-chemical, and biological indicators.

Most physico-chemical parameters remained within the ranges characteristic of good ecological status with pronounced seasonal variations affecting mainly oxygen concentrations, and nutrient availability. Biological assessments of macrophytes, zooplankton, macroinvertebrates, and fish revealed marked spatial heterogeneity in species diversity and abundance, with ecological quality classes ranging from Poor to Moderate.

The distribution of heavy metals concentrations showed higher values in lakes directly connected to the Danube and significantly lower values in isolated lakes. Comparative analyses of discharge rates (2019–2024) revealed notable fluctuations, with a general declining trend in certain sections, suggesting possible effects of climate variability and hydrological changes.

PERFORMANCE OF A NEW COORDINATION POLYMER AS A POSITIVE ELECTRODE MATERIAL FOR CALCIUM-ION STORAGE

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THE CONTRIBUTION ABSTRACT – OE17

Calcium-based technologies are gaining significant attention as promising alternatives in energy storage and other advanced applications due to calcium's abundance, low cost, and favorable electrochemical properties. Coordination polymers (CPs) have emerged as promising alternative cathode materials to traditional phosphate-based compounds in calcium-ion battery technology. These materials consist of metal ions linked by organic ligands, forming extended network structures that facilitate reversible calcium ion intercalation. Due to their tunable framework, high structural flexibility, and potential for improved ionic conductivity, CPs offer advantages such as enhanced electrochemical stability and capacity retention. Our study focuses on developing and scaling up a CP as a stable positive electrode material for Ca-ion technology, capable of operating under ambient air conditions. Electrochemical characterization was conducted using self-standing electrodes fabricated via a dry method in a coin cell configuration, while prototype lab-scale pouch cells have also been designed and assembled.

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ELECTROCHEMICAL PERFORMANCE EVALUATION OF QUASI-SOLID ELECTROLYTES FOR LI-S BATTERY APPLICATIONS

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THE CONTRIBUTION ABSTRACT – PE19

Quasi-solid-state electrolytes (QSSEs) are an intermediate class of electrolytes that combine features of both liquid and solid electrolytes. They are actively being researched for next-generation rechargeable batteries (Li-ion, Na-ion, Zn-ion, Li-S, solid-state lithium-metal etc.). QSSEs offer a compromise solution aiming to combine safety, high conductivity, and good interfacial contact. They are considered as a near- to mid-term solution for safer high-energy batteries, while fully inorganic solid electrolytes are still face challenges such as poor interfaces and low ionic transport.

In this context, we describe the synthesis of single-ion gel-polymer electrolytes (SIGPE) composed of Li-salt dissolved in ionic liquids and a rigid-rod polyelectrolyte, poly(2,2'-disulfonyl-4,4'-benzidine terephthalamide) (PBDT). The SIGPE materials, obtained through an ion exchange process between ionic liquids (IL) and PBDT aqueous solution, exhibit remarkable combination of high ionic conductivity (5 mS/cm at room temperature), high thermal stability and low flammability. To investigate the compatibility between the SIGPE membrane and lithium metal, lithium symmetric cells were assembled and cycled at various current densities. The electrochemical performance exhibits long-term cycling stability (≈ 500 h) at a constant current density of 0.1 mA/cm².

Acknowledgments

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EVALUATION OF ELECTROCHEMICAL BEHAVIOR OF SULF-BASED ELECTRODES IN LI-S CELLS

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THE CONTRIBUTION ABSTRACT – PE20

The performance of lithium–sulfur (Li–S) batteries is largely dictated by the electrochemical behavior of sulfur-based electrodes, which directly impacts capacity, cycling stability, and overall energy density. Based on the literature, experimental studies on Li-S batteries highlight the crucial role of rechargeable batteries in Europe's transition to climate neutrality. Growing demands from the digital economy, renewable energy, and low-carbon mobility require safer, more durable, and higher-performance batteries. Key challenges include the need for higher energy densities, reduced environmental impacts, replacement of critical raw materials such as Li, Co, and Ni, addressing socio-economic issues, improving recycling processes, and ensuring long-term stability. Given the critical role of advanced Li–S batteries in achieving sustainable energy goals, this study systematically investigates the electrochemical features of sulf-based electrodes in Li–S cells through cyclic voltammetry, galvanostatic charge–discharge, and electrochemical impedance spectroscopy. The effects of electrode composition (C-S, NiS, Ni₂S₃), sulfur mass loading (0.5 – 3.3 mg/cm²), electrolyte interactions (1M LiTFSI in DME + DOL (1:1 vol.), with/without additive (0.4M LiNO₃) and the modifications to the Celgard 2325 separator using various materials (TiO₂, MnO₂, SiO₂) are analyzed.

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RECONDITIONING OF END-OF-LIFE CYLINDRICAL CELLS FOR SECOND-LIFE APPLICATIONS

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THE CONTRIBUTION ABSTRACT – PE21

Second-life batteries represent a key component in the emerging landscape of sustainable energy storage solutions. After serving primarily in electric vehicles or other applications, these batteries enter a secondary use phase, continuing to provide energy storage capabilities. When a battery's state of health drops to around 80%, it is considered unsuitable for its original purpose. Different reconditioning techniques are used to extend lifespans and reduce waste, aligning with the principles of the circular economy.

This paper investigates the reconditioning of cylindrical Li-ion cells to mitigate degradation from repeated charge–discharge cycles. Techniques, including controlled charging and discharging cycles, voltage holds, and the maintenance of elevated temperatures tailored to the active material, are applied to recover lost capacity and achieve sufficient restored performance for less demanding applications. In this study, the recovered capacity varied depending on the techniques applied as well as on the type of active material in the cells, reaching a maximum of 99% of the initial nominal capacity. The results demonstrate that these methods can extend cell lifespan and reduce replacement costs, highlighting their potential for second-life applications in short-range electric vehicles and renewable energy storage systems.

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HYBRID OFFSHORE RENEWABLE ENERGY-BASED PROCESS MODEL FOR GREEN MARINE FUELS: HYDROGEN AND AMMONIA PRODUCTION

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THE CONTRIBUTION ABSTRACT – OE18

The intermittent nature of offshore renewables necessitates transient modeling to capture the operational dynamics of long-duration hydrogen and ammonia production. This study develops a hybrid, off-grid configuration off Cabo de Peñas, Spain, that co-deploys floating wind turbines (FOWT) and floating photovoltaics (FPV) and models time-dependent production of green hydrogen and green ammonia via Proton Exchange Membrane (PEM) electrolysis and the Haber–Bosch process. The framework couples hourly renewable generation with an integrated hydrogen buffer to sustain a near-constant ammonia output throughout the year. Co-location reduces power fluctuations: when the FPV share in installed capacity reaches approximately 80%, the Power Smoothing (PS) index attains 65%, delivering a significantly smoother power profile than wind-only or solar-only cases. Subsea hydrogen and ammonia pipelines are benchmarked against ammonia tanker transport. The preferred transport option is governed by capacity scale and distance to shore. The analysis shows that newly constructed hydrogen and ammonia pipelines can be a cost-effective option for transport over distances up to 500 km.

Keywords: Offshore renewable energy; Floating wind turbine; Floating photovoltaic; Green hydrogen; Green ammonia; Transient modeling; Offshore transport.

CONSIDERATIONS ON IDENTIFYING THE CAUSES OF FIRES IN PHOTOVOLTAIC PARKS

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THE CONTRIBUTION ABSTRACT – PE22

In this paper, the authors have first synthesized a series of causes and risk factors related to fires involving photovoltaic systems. Then, the identification of the causes of a fire that occurred shortly (less than a month) after the commissioning of an existing photovoltaic park, installed in the South-West of Romania, was exemplified. For this purpose, the analytical method of dimensioning and verification of low-voltage consumer / prosumer power supply systems was used.

Its application consisted in checking the sizing of the low-voltage inverter power supply system (checking the section for technical restrictions; choosing the switching and protection devices of the inverter cable connection to the three-phase busbar system L1, L2, L3/N).

The structure of the paper is the following:

I. INTRODUCTION

II. CASE STUDY. IDENTIFICATION OF THE CAUSE OF THE FIRE AT A PHOTOVOLTAIC PARK. VERIFICATION OF THE SIZING OF THE POWER SUPPLY SYSTEM OF LOW VOLTAGE INVERTERS.

III. CONCLUSIONS

Thus, it can be concluded that the fire at the photovoltaic park, which irreversibly affected a series of equipment / component materials, occurred primarily as a result of an abnormal operating regime of the power supply and electricity production facility - the occurrence of an electrical overload followed by a thermal overload (heating) caused by the undersizing of the section of the Growatt 70 kW inverter (WWEDBGH00P series) - Three-phase busbar system L1, L2, L3/N connecting cable, to which other aggravating elements were added, including: the adoption of inadequate electrical supply technical solutions for large prosumers, which require operational safety, such as the present one, non-compliant technical executions, etc.

In light of the findings, it is recommended to replace the affected materials, check the existing electrical installation prone to other similar incidents by replacing the non-compliant materials used.

DEVELOPMENT OF A HIGH-GAIN BIDIRECTIONAL CONVERTER FOR HYDROGEN, BATTERY, AND GRID INTEGRATED ELECTRIC VEHICLES

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THE CONTRIBUTION ABSTRACT – OE19

DC-DC power converters are essential parts of power electronics circuits. These converters play a vital role, especially when renewable energy sources (RESs) and grid integration are the issue. For many types of photovoltaic (PV) arrays, hydrogen fuel cells (FCs), or battery packs, the generated voltage is in direct current (DC) form, while the majority of the loads need to be fed by alternating current (AC) type voltages. On the other hand, the generated voltage level of these sources is not sufficient to be converted and used in grid or micro-grid systems. Therefore, DC-DC converters are used to enhance the voltage and make it ready for conversion to AC voltages. In the next step, this high DC voltage is converted to AC by using an inverter block.

Bidirectional DC-DC converters are capable of transferring power in DC form from the low-voltage side to the high-voltage side or vice versa. By applying these types of converters in connection with the grid, the grid AC power can easily be converted to DC and then used for battery charging systems.

This energy conversion is essential for grid-to-vehicle (G2V) and vehicle-to-grid (V2G) applications for electric vehicles.

This study presents a hydrogen–PV–battery-based bidirectional power converter to transfer power from the low-voltage to the high-voltage side and from the high-voltage to the low-voltage side using the same topology. The configuration includes the minimum number of semiconductor devices and passive elements such as inductors and capacitors, and presents features like minimum voltage and current stresses on key elements that guarantee the feasibility and longevity of the converters and these RES-type sources. The suggested topology presents a decreased current stress at the input side, where the converter is connected to the RES sources. This topic is essential to enhance the lifespan of the RESs and provide a longer lifetime for the overall system.

ADAPTIVE SMALL SIGNAL-BASED CONTROL OF A HIGH GAIN BIDIRECTIONAL POWER CONVERTER FOR HYBRID HYDROGEN ELECTRIC VEHICLES

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THE CONTRIBUTION ABSTRACT – OE20

The demand for green energy and application of hydrogen or photovoltaic (PV) for electrical vehicles (EVs) are enhancing each day. DC-DC converters are critical power conversion systems that regulate voltage and current levels for battery packs in electric vehicles (EVs) powered by fuel cells (FCs) or PV panels and set the voltage for electric motor through an inverter circuit. The longevity of renewable energy sources (RESs) such as the fuel cells and PV arrays is heavily influenced by the current drawn by the DC-DC converter. Additionally, the converter topology must be cost-effective, minimize voltage and current stresses on semiconductor devices, offer ease of control, and provide flexible voltage outputs to meet the dynamic demands of the battery pack. This study introduces a single switched DC-DC power converter designed specifically for fuel cell-based electric vehicles (FCEVs), controlled by a detailed small signal-based controller (SSC). The high gain feature of the suggested converter allows energy from the FC and PV to be stored in the high voltage battery pack, and then used to power the electric motor and other parts of the vehicle like lights, heating, or cooling. This means the electric vehicle only uses the proposed power converter instead of using different DC-DC converters for each energy source like the PV or FC. Later, the stored energy can provide the demanded voltage for the inverter to run the motor. This makes the whole system more efficient and cost-effective.

HYDROGEN-ENRICHED GASOLINE COMBUSTION FOR LEAN LIMIT EXTENSION AND EMISSION REDUCTION IN GDI ENGINES

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THE CONTRIBUTION ABSTRACT – OE24

The effect of hydrogen induction (0-5 liter per minute) in to the intake manifold of the small bore Gasoline Direct Injection (GDI) Engine is investigated experimentally. The intake manifold is slightly modified to accommodate the hydrogen induction system, where premixed mixture of hydrogen and air is formed in the intake manifold; attaining the excess air ratio of 1.0 to 1.2. With the increment of hydrogen fraction the fuel leaning (Gasoline) is attained and achieving economical fuel consumption rate. The decrement in torque characteristics is compensated with the increase of hydrogen fraction. The hydrogen induction improves the combustion rate and mean effective pressure; shortens the flame propagation, maximize the heat release rate and peak pressure attainment. On the emission side consistent decrease in CO and HC emission; and increase of NO_x emission since the mean gas temperature has increased. The cycle to cycle variation during the lean operating condition at 1.2 shows the combustion stability and effective flame propagation.

Keywords: Hydrogen Induction, Small Bore, Gasoline Direct Injection.

NUMERICAL STUDY OF SOLAR-HEATED CONCRETE/PCM WALL PERFORMANCE IN THREE MOROCCAN CLIMATE ZONES

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THE CONTRIBUTION ABSTRACT – OE25

The overall objective of this study is to develop a calculation tool which will make it possible to deal with the problem of the fusion and solidification of a PCM integrated into a concrete wall coupled with a solar collector integrated into the slab of a building. Heat transfers involve several mechanisms such as solar radiation, conduction, convection and phase change. It should be noted that the diversity of climatic conditions in different zones of Morocco poses a challenge for estimating the thermal performance of buildings. Depending on the climate zone, heat exchange and temperatures in the building structure vary. Thus, a stand-alone building could lose its efficiency if its location changes. Therefore, the developed code will make it possible to evaluate the effect of three different climatic zones of Morocco, characterized by winter climates of different rigorosity, on the thermal performance of the model developed in this paper. Thus, we will be able to determine if it is possible to standardize this model in different Moroccan cities.

Keywords: Passive heating, Phase change materials, Solar energy, Building Energy Efficiency.

FLOATING HYDROGEN REFUELING STATION FOR A GREEN SHIPPING CORRIDOR

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THE CONTRIBUTION ABSTRACT – OE26

This study proposes both a unique and innovative design for offshore energy hubs and develops an integrated energy conversion and management strategy. Due to the inherent intermittency of wind-generated electricity in offshore environments, hydrogen storage via offshore electrolysis was adopted as an energy storage option. The potential hydrogen production capacities were determined for selected locations in the North Sea where the wind potential can be effectively utilized. The system was designed to store hydrogen at 700 bar, and in cases where the electricity transmitted to the shore falls below the set value, the stored hydrogen is supplied to a fuel cell to ensure a secure and continuous energy supply. As a result, an overall energy efficiency of 48.1% was achieved, with an average wind speed of 9.98 m/s, indicating a remarkably high energy potential, and an annual hydrogen production capacity of 5,443.65 tons was revealed.

POTENTIAL OF RECYCLING E-WASTE INTO VALUE ADDED PRODUCTS

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THE CONTRIBUTION ABSTRACT – OE27

In India, the Central Pollution Control Board (CPCB) defined e-waste in its 2016 regulations as any discarded or rejected electrical and electronic equipment (EEE). From the years 2019-20 to 2023-24, the e-waste generation has risen significantly from 1.01 to 1.751 million metric tonnes (MT) and on track to rise 82 million tonnes, in 2030 at world level reported by the UN's fourth Global E-waste Monitor (GEM).

Recycling electronic devices can help keep the environment clean and recover energy from them. A study by Lecomte et al. (2023) found that using molten hydroxide salt can decompose certain substances, involving tiny, active particles called radicals. This method is effective in cleaning up harmful chemicals called halogenated organic compounds (US20150368563A1), as it absorbs dangerous chlorine and converts it into a safe, stable salt that doesn't escape into the air, preventing any problems.

E-waste (particularly EOL PV panels) cannot be recycled directly because of their heterogeneity in composition. However, if left untreated, the issue of increased pollution could cause catastrophic consequences for the global environment and will directly impact humans. Herein, we propose a method to treat e-waste, via a novel thermo-electrochemical conversion technology with molten salts. This technique involves high-temperature molten salt electrolysis to clear out the need for the informal sectors that still use unsafe and outdated methods to recycle e-waste and extract useful products from it (such as hydrogen and carbon nanotubes (CNTs)) while fixing and sequestering carbon. It is an attractive substitute for combustion, especially for mixed or complicated organic matter that is challenging to handle using standard methods. The suggested framework may be able to preserve value-added products (such as hydrogen and graphite), which could assist not only in reducing unsafe waste but also in accommodating the intense energy needs in multiple sectors.

A COMPARATIVE STUDY ON ENERGY DENSITIES OF VARIOUS FUELS AND BATTERIES

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THE CONTRIBUTION ABSTRACT – OE28

This study experimentally evaluates the combustion performance of solid ammonium formate (NH_4HCO_2) using a bomb calorimetric system to determine its thermochemical characteristics and energy density potential. Approximately 2 g of laboratory-synthesized ammonium formate was combusted under controlled conditions in a Parr 6775 oxygen bomb calorimeter. The results demonstrated a specific heat of combustion of 7.56 kJ.g⁻¹ (476.6 kJ.mol⁻¹), confirming the material's considerable energy release despite its light molecular structure.

ENHANCED BIOHYDROGEN PRODUCTION UNDER MIXOTROPHIC CONDITIONS USING A NATURAL MICROBIAL CONSORTIUM

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THE CONTRIBUTION ABSTRACT – OE29

This study explores mixotrophic hydrogen production using a naturally enriched algal-bacterial consortium cultivated in a 1 L photobioreactor under solar simulator illumination. The system combined light energy and glucose (1 g/L) as dual substrates to enhance hydrogen generation through the cooperation of photosynthetic and heterotrophic metabolism. Hydrogen production initiated after 12 h and reached a maximum cumulative yield of 152 mL/L after 120 h, with the highest rate observed between 60 h and 96 h. A gradual pH decreases from 7.0 to 6.3 indicated acid formation and CO₂ evolution during microbial activity. The results confirm that mixotrophic cultivation effectively enhances biohydrogen generation compared with traditional photoautotrophic systems, offering a simple and sustainable route for green hydrogen production using natural microbial consortia.

A BIOMASS-BASED INTEGRATED BIOELECTROCHEMICAL SYSTEM

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THE CONTRIBUTION ABSTRACT – OE30

This study introduces a multigeneration system that integrates anaerobic digestion and bio electrochemical cells to convert wastewater into electricity, hydrogen, and domestic hot water. Key components include, organic Rankine cycle, Brayton cycle and an integrated bio reactor that combines microbial fuel cell, microbial electrolysis and photo electrolysis unit, which together support simultaneous waste treatment and clean energy generation. The designed system has an overall energy efficiency of 38.88% and exergy efficiency of 31.36%. The system achieves a net electrical output of 6.23 MW, while producing 0.07 kg/s of hydrogen and two streams of thermal energy at different temperatures to meet residential and industrial demands. Parametric studies demonstrate that biogas yield, and reference temperature significantly affect system performance. The proposed configuration offers a scalable solution for integrating renewable energy with wastewater treatment and hydrogen infrastructure for sustainable urban applications.

INTEGRATED TIDAL-WIND-BIOMASS BASED SYSTEM WITH STORAGE FOR INUIT COMMUNITIES IN NORTHERN QUEBEC, CANADA

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THE CONTRIBUTION ABSTRACT – OE31

This short paper provides a design and analysis study of a multi-generation integrated energy system aiming to produce electricity, heating, hydrogen fuel, and freshwater for about 18,000 residents across 14 Inuit communities in the Northern Quebec region of Canada (Nunavik region). These remote Arctic communities currently depend on diesel for power and heating, resulting in high emissions, fuel transportation challenges, and economic vulnerability. The proposed system integrates tidal and wind energy resources with biomass thermochemical processing (pyrolysis and gasification) and integrates them through a Rankine cycle, Battery Energy Storage System (BESS), Proton Exchange Membrane (PEM) electrolyzer, and absorption refrigeration and desalination subsystems. The system outputs electricity, district heating, hydrogen and methane fuels, cold storage, and potable water. This system utilizes waste heat and recovers exergy to improve energy and exergy efficiencies. The simulation results estimate the potential exergy efficiency of the proposed multigeneration system exceeding 45% with an overall 30.6 MW, reducing diesel dependency by over 80%. This concept illustrates a possible, achievable method for obtaining carbon-neutral development in the Arctic and enhancing local resilience.

ENVIRONMENTAL ASSESSMENT OF FORMIC ACID SYNTHESIS BY ELECTROCHEMICAL REDUCTION OF CARBON DIOXIDE USING TIN-ELECTRODEPOSITED COPPER MESH

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THE CONTRIBUTION ABSTRACT – OE32

Electrochemical reduction of carbon dioxide provides a sustainable route to the production of valuable chemicals and fuels. In this study, an environmental assessment of the electrochemical conversion of carbon dioxide to produce 1 kg of formic acid is conducted. The inventory data is obtained through experimental methods. An H-type electrochemical cell which consists of a proton exchange membrane (PFSA D170-U), a potassium bicarbonate electrolyte solution, and a tin electrodeposited 100# copper mesh serving as the working electrode, is used during the experiment. The environmental assessment results show that the electrochemical reduction of carbon dioxide to formic acid has a global warming potential of 1.47 kg CO₂ eq/kg.FA, indicating that CO₂RR is an environmentally promising method to mitigate climate change.

EVALUATION OF THE DECONTAMINATION POTENTIAL OF FIREFIGHTING WASTEWATER – A COMPARATIVE ANALYSIS BETWEEN ELECTRIC VEHICLE FIRES AND CONVENTIONAL FIRES

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THE CONTRIBUTION ABSTRACT – PE23

The water resulting from firefighting operations represents a significant source of pollution, containing suspended solids, heavy metals, organic compounds, additives used in material manufacturing, and thermal degradation products of the materials involved in combustion. In the case of electric vehicles, this wastewater may have a distinct chemical composition compared to conventional fires, due to the presence of lithium-ion batteries, which can release lithium, cobalt, nickel ions, and other potentially toxic substances.

The proposed study aims to perform a comparative characterization of wastewater generated from extinguishing electric vehicle fires and that from conventional fires, through an experimental program based on sample collection, physicochemical analysis, and assessment of treatability. Laboratory analyses include the determination of global parameters (pH, conductivity, turbidity, COD, TOC), heavy metals, volatile organic compounds, and possible fluorinated substances.

Within the study, laboratory-scale decontamination tests will be conducted using processes such as coagulation–flocculation, adsorption on activated carbon, and advanced oxidation, in order to evaluate the potential for contaminant reduction.

The central objective of the research is to propose practical and effective solutions for the collection, treatment, and management of contaminated firefighting wastewater, as well as to explore the possibility of neutralizing toxic compounds to reduce environmental impact and minimize the risk of secondary pollution following emergency response interventions.

RECENT ADVANCES AND CHALLENGES IN WASTEWATER TREATMENT: TECHNOLOGIES, EFFICIENCY, AND ENVIRONMENTAL IMPACT

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THE CONTRIBUTION ABSTRACT – PE24

Sustainable management of water resources has become a critical priority in the context of climate change, accelerated urbanization, and increasing pollution. Urban, industrial, and agricultural activities generate significant volumes of wastewater; however, the potential for reusing wastewater, greywater, and stormwater remains largely underexploited. Local treatment of these flows represents a sustainable strategy to reduce pressure on centralized sewer networks and to decrease potable water consumption. This poster provides a synthesis of the latest technological developments in water treatment, focusing on solutions that are both accessible and high-performance, applicable in residential buildings, administrative institutions, and small communities. Modern technologies are analyzed, including compact biological treatment plants, membrane systems, constructed wetlands, and advanced oxidation processes, alongside simple methods for the collection, filtration, and reuse of wastewater, greywater, and stormwater. The benefits of these approaches are highlighted in terms of reducing water consumption, preventing urban flooding, and protecting the environment, as well as the associated challenges, including costs, maintenance, and regulatory frameworks. In conclusion, the poster emphasizes the importance of implementing integrated strategies that combine water treatment with the recovery and reuse of alternative water sources, in accordance with the principles of the water circular economy.

APPLICATION FOR SUPPORTING THE DESIGN OF VERTICAL AXIS WIND TURBINES

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THE CONTRIBUTION ABSTRACT – PE25

Sustainable management of water resources has become a critical priority in the context of climate change, accelerated urbanization, and increasing pollution. Urban, industrial, and agricultural activities generate significant volumes of wastewater; however, the potential for reusing wastewater, greywater, and stormwater remains largely underexploited. Local treatment of these flows represents a sustainable strategy to reduce pressure on centralized sewer networks and to decrease potable water consumption. This poster provides a synthesis of the latest technological developments in water treatment, focusing on solutions that are both accessible and high-performance, applicable in residential buildings, administrative institutions, and small communities. Modern technologies are analyzed, including compact biological treatment plants, membrane systems, constructed wetlands, and advanced oxidation processes, alongside simple methods for the collection, filtration, and reuse of wastewater, greywater, and stormwater. The benefits of these approaches are highlighted in terms of reducing water consumption, preventing urban flooding, and protecting the environment, as well as the associated challenges, including costs, maintenance, and regulatory frameworks. In conclusion, the poster emphasizes the importance of implementing integrated strategies that combine water treatment with the recovery and reuse of alternative water sources, in accordance with the principles of the water circular economy.

HIGH-ENTROPY ALLOYS FABRICATED BY ADDITIVE MANUFACTURING: FUNCTIONAL PERFORMANCE FOR ENERGY EFFICIENCY AND ENVIRONMENTAL SUSTAINABILITY

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THE CONTRIBUTION ABSTRACT – PE26

The convergence of additive manufacturing (AM) and high-entropy alloy (HEA) design enables the development of functional materials tailored for energy efficiency and environmental sustainability. This paper presents an in-depth analysis of the thermomechanical and functional properties of 3D-printed HEAs, emphasizing their relevance to energy systems and eco-efficient technologies. By correlating process parameters with microstructural features, significant enhancements in strength, thermal stability, and fatigue resistance were achieved. Exergy-based performance evaluations indicate that the use of HEAs in energy-intensive applications can minimize entropy generation and improve system-level efficiency. Moreover, the environmental impact assessment confirms the potential of HEAs to reduce lifecycle emissions and extend component durability. These findings establish 3D-printed HEAs as strategic materials for next-generation energy infrastructures, clean energy conversion, and sustainable mechanical engineering applications.

SUSTAINABLE ADVANCED MATERIALS FOR SOLID-STATE SODIUM-ION BATTERIES: AN EFFICIENT, SAFE AND ECO-FRIENDLY ENERGY STORAGE SYSTEM – 4SIBAT

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THE CONTRIBUTION ABSTRACT – PE27

4SIBAT Sustainable advanced materials for Solid-State Sodium-Ion BAtteries: an efficient, safe and eco-friendly energy storage system Solid-state sodium-ion batteries (SSSIBs) are emerging as the most efficient near-term solution for energy storage that avoids the use of critical raw materials. However, there is still a need to develop materials that can be used in the electrodes and electrolyte to meet the performance requirements in terms of energy density and stability. 4SIBAT project pursued the design and production, through efficient and scalable processes, of (i) sustainable carbon materials from green monomers and (ii) optimized solid-state electrolytes based on hybrid conductive gel-polymer and single ion membranes. By combining these innovative and sustainable components it is intended to have, at the end of the project, a prototype of Sustainable-SSSIB (4SIBAT) with an optimized architecture able to competitively meet the demands of a robot in real operating conditions. With the 4SIBAT project we contribute to the EU's ambition to become a world leader in renewable energy and its secure supply.

Keywords: Sustainability, Advanced materials, Solid-State Sodium Batteries, Energy

QUANTIFYING OPERATIONAL CARBON EMISSIONS OF A STRATEGIC STORMWATER PUMPING STATION IN AN ARID COASTAL ENVIRONMENT: MUSAIMEER PUMPING STATION AND OUTFALL CASE STUDY, QATAR

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THE CONTRIBUTION ABSTRACT – PE28

Critical infrastructure systems in arid regions face growing pressure to balance hydraulic reliability with carbon reduction imperatives. Water pumping stations, essential for urban drainage and groundwater control, are among the most energy-intensive components of the water-energy nexus. This study investigates the operational carbon emissions of Musaimeer Pumping Station and Outfall (MPSO) in Doha, Qatar, as a benchmark for low-carbon infrastructure operation in climate-vulnerable settings. Using two years of monitored data (2022–2024), electricity consumption and hydraulic flow records were analyzed to quantify greenhouse gas emissions and evaluate efficiency across distinct operational scenarios. The total calculated energy use reached 18.69 GWh, corresponding to 8.41 kt CO₂e and a normalized carbon intensity of 0.0705 kg CO₂e m⁻³ of water conveyed. Scenario analysis demonstrated that adaptive control through variable-frequency drives and the use of low-head conveyance pathways during dry-weather conditions significantly improve energy efficiency compared to wet-weather operation. Seasonal variability in rainfall was found to drive short-term peaks in emissions, revealing the sensitivity of operational carbon to climatic fluctuations. A renewable integration sensitivity test indicated that supplying 20% of the station's electricity demand from solar photovoltaics could reduce total emissions by nearly 1.68 kt CO₂e. These findings illustrate how data-driven optimization of pumping operations can transform conventional drainage infrastructure into adaptive, low-carbon systems. The study provides actionable evidence supporting Qatar's National Climate Change Action Plan and contributes to global strategies for decarbonizing water infrastructure under increasing climate stress.

ANALYSIS OF ROMANIA'S DISTRICT HEATING SYSTEMS WITHIN THE FRAMEWORK OF THE ENERGY TRANSITION AND THE REHEATEAST INITIATIVE

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THE CONTRIBUTION ABSTRACT – PE29

The energy transition is a strategic priority for Romania, with profound implications for the modernization and decarbonization of the urban district heating sector. District Heating and Cooling (DHC) systems represent a key component of the national energy infrastructure, contributing to greenhouse gas emission reduction, energy efficiency improvement, and the enhancement of urban energy resilience. This paper presents a comprehensive analysis of Romania's DHC systems, focusing on their current performance, fuel mix structure, and the potential for integrating renewable energy sources and waste heat recovery. The analysis highlights critical challenges—aging infrastructure, high network losses, and persistent dependence on fossil fuels—while also emphasizing opportunities associated with technological innovation and system optimization.

Within this framework, the REHEATEAST initiative seeks to reduce fossil energy consumption in DHC systems through the promotion of renewable energy integration, multi-stakeholder collaboration, and transnational optimization models. The project supports the development and validation of innovative technical and organizational solutions aimed at modernizing district heating infrastructure and enhancing the energy efficiency of DHC systems serving buildings. The outcomes provide a solid scientific and technical basis for evidence-based public policy and contribute to accelerating Romania's transition towards sustainable, low-carbon heating systems.

Keywords: decarbonization, District Heating and Cooling (DHC), energy transition, renewable integration, sustainable heating systems,

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EXCELLENCE IN THE ELECTRICAL ENGINEERING RESEARCH AREA POWER AND VOLTAGE SUSTAINING ELECTRICITY

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THE CONTRIBUTION ABSTRACT – IO2

ICMET Craiova is one of the pillars of electrical engineering research in Romania. It is recognized for its expertise in product development, testing, certification, and technology development for high-voltage and high-current equipment. ICMET Craiova originated during Romania's period of rapid industrialization. The need for high-performance electrical equipment led to the establishment of a research center within the Electroputere factory. Its activity and transformations reflect the technological dynamics of the field as well as the economic and reorganization challenges faced by the domestic industry in recent decades.

As the energy and electrical engineering industry evolved, the institute expanded its research and experimental development capabilities. It introduced high-voltage and high-power testing facilities, as well as high-current measurement equipment and facilities for testing electricity transmission and distribution system equipment. The activity included collaborating with electrical engineering manufacturers and providing technical support for large energy infrastructure projects. Its collaborations with universities, European research centers, and private companies provide access to European projects, technology transfer, and the development of specialized human capital.

IMPROVED PERFORMANCE CONTROL OF PV ARRAY AND BATTERY HYBRID SYSTEM BASED ON PI CONTROLLER TUNED WITH GREY WOLF OPTIMIZATION ALGORITHM

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THE CONTRIBUTION ABSTRACT – IO3

This article presents the performance improvement of the DC intermediate circuit voltage control system for a benchmark system consisting of a photovoltaic (PV) array, a storage battery, and a variable resistive load. The types of controllers used are classical Proportional Integral (PI) and PI tuned using the Grey Wolf Optimization algorithm (GWO). The comparative performances of these control systems are presented, in which the main indicators are response time, stationary error, overshooting, and VDC voltage error ripple. The validation of the performance of the presented control systems are achieved in the Matlab/Simulink environment.

DISTURBANCES CLASSIFICATION IN POWER QUALITY USING K-NEAREST NEIGHBORS AND DISCRETE WAVELET TRANSFORM ANALYSIS BASED ON LOW-COST HARDWARE

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THE CONTRIBUTION ABSTRACT – IO4

Given that commercial analyzers are used to analyze power quality (PQ), which are highly accurate but very expensive, this article presents a system based on a smart meter plus application software that performs the main functions of a quality analyzer but at a lower cost. Based on the acquired signals, we present the main PQ disturbances and their total harmonic distortion (THD) characteristics, but also the characteristics based on the Discrete Wavelet Transform (DWT) analysis, such as: entropy and signal energy. It is presented the training, testing and validation of an automatic classifier based on support K-Nearest Neighbors (KNN) type algorithms that can be used for the automatic classification of PQ disturbances. The practical use of the data acquisition system and the automatic classification software application by recognizing a sag with harmonics, a PQ disturbance with harmonics, that occurs in the main electrical network is presented.

ELECTRICAL EQUIPMENT FOR MEDIUM AND HIGH VOLTAGE IMPLEMENTED IN MONITORING SYSTEMS

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THE CONTRIBUTION ABSTRACT – IP2

For the creation of modern electrical equipment that ensures and guarantees operational safety, the importance of protective adapters for isolated passages, implemented in monitoring systems, is presented. A wide variety of protective adapters for isolated passages manufactured by ICMET are presented, applicable to high-voltage electrical equipment in power stations throughout the country, important components used to ensure safety and reliability in operation. This work is intended for those interested in purchasing protective adapters for isolated crossings, manufactured at ICMET Craiova, based on the execution documentation and with specialized support for performing all certification tests in accordance with the international standards in force. By implementing protective adapters in isolated crossing monitoring systems, the proper functioning of medium or high-voltage electrical equipment in electrical stations can be monitored remotely. ICMET has a tradition in designing and manufacturing medium and high voltage electrical equipment, as well as the ability to test finished products in its own laboratories, according to market requirements. Thus, based on the execution

documentation, we manufacture a wide range of protective adapters for isolated bushings, which are compatible with the type of isolated bushing, the rated voltage of the transformer, and the relevant standards. Currently, a diverse range of isolated passage protection adapters has been developed that are compatible with an isolated passage signal conditioning module. Following collaboration with interested companies on the implementation of adapters in monitoring systems, we have developed a wide range of protection adapters for isolated crossings.

SOLUTIONS FOR REVITALIZING/REGENERATING USED INDUSTRIAL OILS

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THE CONTRIBUTION ABSTRACT – IP3

The revitalization/regeneration of used industrial oils is a process of processing them to return them to a state as close as possible to their original state. This process consists of eliminating impurities, degraded additives and contaminants accumulated during use. Regeneration/treatment is an essential component of the circular economy and has major benefits for both the environment and the economy.

The regeneration of used oils is of major importance in:

- environmental protection - used oils are a source of contamination of soil, water and ecosystems. Through the revitalization/regeneration/treatment process, illegal discharge into the environment can be prevented.

- resource conservation - industrial oils are obtained from petroleum, which is a non-renewable resource. Through the revitalization/regeneration/treatment process, it is possible to reuse these oils, thus reducing dependence on crude oil and at the same time conserving natural resources.

- economy - the activities necessary to carry out the process of revitalizing/regenerating/treating industrial oils generate economic effects such as the creation of new jobs in the waste collection and processing industry, reducing the costs of maintenance and keeping electrical equipment in operation, the regeneration of used oil is less expensive and consumes less energy than refining crude oil.

In Romania, the management of used oils is strictly regulated by legislation, which prioritizes regeneration. The process of revitalizing/regenerating/treating used oils, also known as electrical insulating oils, is an essential technical process for maintaining the performance and safety of electrical equipment. These oils perform critical electrical insulation and cooling functions in transformers. As they age, their properties degrade due to contaminants and oxidation products. Revitalization aims to regain these properties, thereby extending the life of the equipment and preventing failure states.

SECURITY OF PERSONNEL IN THE MAINTENANCE ACTIVITY OF THE NATIONAL ENERGY SYSTEM BY USING CERTIFIED EQUIPMENT

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THE CONTRIBUTION ABSTRACT – IP4

Maintaining the National Energy System (SEN) in permanent operating condition involves revisions, repairs and maintenance works of all its components. Instructions, maneuvers and procedures ensure the correct framework in which each operation must be carried out within maximum personnel safety limits.

The use of safety equipment, short-circuit protection devices, protection clothing (coveralls) resistant to electric arc action certified in accredited laboratories that meet the requirements of SR EN ISO/IEC 17025:2018 and are competent to carry out testing activities, should be a constant concern.

The paper presents conditions, rules and methods for verifying the behavior of this equipment in extreme conditions at short-circuit currents and electric arcs accidentally occurring in SEN installations.

DISTRIBUTED SENSOR SYSTEM FOR REAL-TIME MONITORING OF OVERHEAD POWER LINES

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THE CONTRIBUTION ABSTRACT – IP5

This article presents a system for the real-time monitoring and evaluation of status parameters in two major components of overhead power line structures (OPL): the cable and the pillar. It is described the general architecture of this system, which is designed to measure the main operating parameters of overhead power lines (current through the OPL cable, cable temperature, cable tilt, cable oscillations, cable mechanical force, pillar tilt/vibration), and environmental parameters (ambient temperature, wind speed and direction, relative humidity, barometric pressure, rainfall, hail and ice) in the overhead power line corridor. These parameters are considered to be basic for the safe application of the dynamic load rating of power lines. The main characteristics of the sensors and communication equipment used, are also presented along with the main software application modules, used for monitoring the status of the cable and pillar, components in the overhead power line structure. The software applications are designed to monitor the main power line parameters and display the results both on the electricity supplier's intranet, using a web server and a MySQL database, and on the internet, using an IoT server for authorized users.

CONTRIBUTIONS TO THE DIGITALIZATION OF ASSETS WITHIN THE NATIONAL ENERGY SYSTEM (SEN)

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THE CONTRIBUTION ABSTRACT – IP6

The digitalization of assets in the National Energy System (SEN) is a strategic process through which the energy infrastructure is modernized using advanced digital technologies. Its main goal is to transform the grid into a smart, flexible, and secure system, capable of meeting consumption demands, integrating renewable sources, and supporting Romania's energy transition.

Transformer substations are critical nodes of the SEN, where electricity is transferred between different voltage levels. Their digitalization involves:

- Real-time monitoring using sensors and smart devices (IED, PMU, RTU);
 - Advanced automation through SCADA systems;
 - Virtual modeling of the substation for simulations, predictive analysis, and maintenance optimization;
 - Predictive maintenance – applying artificial intelligence to detect failures before they impact operation.
- These technologies turn substations into intelligent hubs that enhance system stability.

Transmission and distribution networks are the backbone of the SEN. Their digitalization means shifting from a static system to a smart grid, with the following features:

- Smart meters for consumers and prosumers.
- Advanced Distribution Management Systems (ADMS) for efficient grid operation.
- Bidirectional monitoring and control – integrating decentralized generation (solar, wind, storage).
- Big Data and AI analytics for load balancing and incident management.
- Interoperability and standardization, ensuring compatibility across digital platforms and equipment.

SAFETY EQUIPMENT FOR MEDIUM VOLTAGE ELECTRICAL CELLS EXPOSED TO ELECTRIC ARC

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THE CONTRIBUTION ABSTRACT – IP7

The device controls the fast opening of the cell circuit-breaker and possibly of the power circuit-breaker when a breakdown arc appears in the cell.

SOLID STATE SWITCH WITH HIGH EMC AND PRECISION PROPERTIES USING LIGHT-TRIGGERED THYRISTORS

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THE CONTRIBUTION ABSTRACT – IP8

Due to advantage of fast switching offered by LTT (Light-Triggered Thyristors) compared to mechanic making switches, they are used within short-circuit tests of low and medium voltage equipment where precise control of closing moment is needed.

REAL-TIME MEASUREMENT OF THERMODYNAMIC PARAMETERS GENERATED BY INTERNAL ELECTRIC ARC IN MEDIUM AND HIGH VOLTAGE INSTALLATIONS, AT HIGH POTENTIAL

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THE CONTRIBUTION ABSTRACT – IP9

Non-contact temperature measurement in live electrical equipment located in hard-to-reach areas offers essential advantages in terms of safety for test personnel and the possibility of continuous monitoring, without mechanical wear and with extremely short response times. In the event of an internal electric arc, the peak values of pressure and temperature developed inside the electrical cell are critical parameters for evaluating the design and performance of the equipment. These data are fundamental for manufacturers in the process of optimizing technical solutions and for integration into advanced protection systems and smart grids.

ASPECTS REGARDING MODERNIZATION OF HIGH POWER LABORATORY FOR LIMITING THE EFFECTS DUE TO ELECTROMAGNETIC FIELDS

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THE CONTRIBUTION ABSTRACT – IO5

Within paper there are analysed and synthesised main perturbations due to environment and to electromagnetic fields and are established measures and methods for limiting them within High Power Laboratory.

Keywords: electromagnetic fields, tests, standards, data acquisition and processing.

STRATEGIES FOR MANAGING WASTE GENERATED IN GREEN ENERGY PRODUCTION PROCESSES

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THE CONTRIBUTION ABSTRACT – IP10

The accelerated growth in the use of the photovoltaic panels in Romania raises the issue of managing the associated waste streams, particularly in light of alignment with European legislation on electrical and electronic equipment. Directive 2012/19/EU (WEEE) and its transposition through GEO 5/2015 and Law 127/2024 establish extended responsibilities for producers, but practical implementation remains limited at the national level. The analysis shows that waste can be generated in three stages: during production (silicon, glass, and chemical residues), during operation (low risks, but with possible premature failures), and at the end of the life time cycle (≈25–30 years), when volumes become really significant. Estimates indicate approximately 32,900 tons per year for Romania by 2033, while the European Union could reach 21–35 million cumulative tons by 2050. In comparison, countries from EU such as Germany and France have developed specialized recycling infrastructures, including factories capable of recovering glass, aluminum, silicon, and rare metals (silver, indium, tellurium), while Romania relies on mixed centers with low efficiency. From an economic perspective, recycling brings benefits by reducing raw material production costs and diminishing the ecological impact, with studies showing a decrease of over 50% in the environmental footprint for panels produced from recycled materials.

AN EXPERIMENTAL STUDY ON THE BEHAVIOR OF SPECIAL DESIGN BUSBARS IN LOW-VOLTAGE ASSEMBLIES IN CONTINUOUS CURRENT

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THE CONTRIBUTION ABSTRACT – IP11

This article presents an analysis of the operational behavior of special design busbars intended to conduct electrical current safely while minimizing energy losses. The busbars configuration under investigation are non-insulated to enhance convective cooling and facilitate convenient access for additional connections. A series of experimental verifications were conducted, involving multiple design variants, including the most demanding configuration in terms of thermal and electrical stress. The study aims to evaluate effectiveness, efficiency and practical applicability of these busbars systems in real world distribution scenarios.

EXPERIMENTAL STUDY ON THE BEHAVIOUR OF A 400 KV INSULATOR STRING WITH GLASS INSULATORS UNDER POWER ARC CONDITIONS

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THE CONTRIBUTION ABSTRACT – IO6

This article examines the behavior of the power arc on insulator strings in high-voltage installations, focusing in particular on scenarios where the arc is initiated using a fusible wire, used as an experimental method to simulate real fault conditions in electrical networks, where atmospheric pressure affects the electrical performance of a contaminated insulator. The experiments help to understand the phenomenon of flashover, the length of the discharge path, the propagation of the electric arc, and the arc radius under different air pressures. The research results indicate that the position of the arc point is stochastic and that the phenomenon of multipoint arcing exists. The power arc levitates and transforms into an arc with air gaps under low air pressure. The length of the discharge path is related to the air pressure and the degree of pollution of the insulator and is always shorter than the creepage distance of the insulator. The shape and propagation speed of the arc are also related to the air pressure. The research results are important for the design of insulator strings and their behavior under the action of power arc.

EXPERIMENTAL STUDY ABOUT THE SWITCHING CAPACITY OF A CIRCUIT BREAKER IN OUT-OF-PHASE SITUATION

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THE CONTRIBUTION ABSTRACT – IO7

In the experiment described in the article, the switching capacity of a 36 kV, 1250 A, 16 kA, SF6 circuit breaker is analyzed in the case of out-of-phase switching (coupling and decoupling of two non-synchronous systems). In interconnected systems, situations may occur in which the circuit breaker is closed by mistake, coupling two non-synchronous systems, which is equivalent to a short-circuit, and consequently, it is necessary to separate two generators or two sources whose voltages are in out-of-phase. The article contains a deep analysis of all situations that can occur, a description of a real life object, real life experiments in high-power circuits.

RESEARCH ON SOIL TEMPERATURE DYNAMICS WITH RELEVANCE TO SHALLOW GEOTHERMAL SYSTEMS

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THE CONTRIBUTION ABSTRACT – IP12

Soil temperature at shallow depths is a key parameter for the efficiency of ground-coupled geothermal systems. This study investigates the thermal behavior of soil at 1.5 m depth using continuous in-situ measurements over a defined monitoring period. The analysis focuses on the amplitude of temperature variations, their seasonal evolution, and the relationship with surface climatic conditions. Results show that thermal fluctuations are significantly reduced at this depth compared to surface air temperature, confirming the soil's natural buffering capacity. These findings provide practical insights for the design and optimization of shallow geothermal heat exchangers, particularly regarding stability of operation and long-term performance in renewable energy applications.

RESEARCH ON ARTIFICIAL INTELLIGENCE ALGORITHM TO PREDICT THE BEHAVIOUR ON SHORT CIRCUIT SITUATION OF A CIRCUIT BREAKER

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THE CONTRIBUTION ABSTRACT – IO8

The rapid integration of Artificial Intelligence (AI), Machine Learning (ML), and Internet of Things (IoT) technologies presents substantial potential for advancing the design, development, and operational optimization of electrical equipment. These emerging technologies facilitate enhanced capabilities in modeling, simulation, and analysis of equipment performance under real-world operating conditions. By enabling predictive diagnostics, intelligent control strategies, and adaptive system behavior, AI- and ML-driven tools contribute to greater efficiency, reliability, and sustainability in electrical engineering applications. The convergence of IoT with AI and ML further allows for real-time data acquisition and processing, thereby enabling continuous monitoring and dynamic decision-making throughout the equipment lifecycle. This article presents the development of an algorithm utilizing Artificial Intelligence (AI) techniques, aimed at simulating the dynamic behavior of electrical equipment under specific operating conditions. The performance of the proposed algorithm is evaluated by comparing its output with oscillographic data acquired during laboratory experiments conducted on actual equipment. This comparative analysis serves to validate the accuracy and reliability of the AI-based model, demonstrating its potential applicability for predictive analysis, diagnostic assessment, and real-time simulation in electrical engineering contexts.

EXPERIMENTAL STUDY ABOUT THE SWITCHING CAPACITY OF A SF₆ FREE SWITCH DISCONNECTOR

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THE CONTRIBUTION ABSTRACT – IO9

In the context of replacing sulfur hexafluoride (SF₆) in switching devices, current research directions focus on the development of alternative gases with low global warming potential, such as synthetic air, low-impact fluorinated gas mixtures, or hybrid solutions, as well as the optimization of solid-state switching technologies. Integrating these solutions into power grids requires a reassessment of equipment architecture, design specifications, and testing protocols to ensure a sustainable transition without compromising system reliability. This article presents the behaviour of an SF₆-free switch disconnecter during the making and breaking of capacitive and resistive electrical circuits.

RESEARCH ON THE BEHAVIOUR OF BIFACIAL PHOTOVOLTAIC MODULES (BPV) DEPENDING ON TYPE INSTALLATION

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THE CONTRIBUTION ABSTRACT – IP13

As the global demand for clean energy accelerates, renewable energy technologies are continuously evolving to enhance efficiency and reduce costs. Among these innovations, bifacial photovoltaic modules have emerged as a promising alternative to conventional monofacial systems. Bifacial photovoltaic technology offers a compelling solution for increasing solar energy yield due to its ability to capture radiation on both the front and rear sides, utilizing not only direct sunlight but also reflected and diffuse light. This dual-side absorption can lead to a significant increase in total energy production, depending on factors such as ground reflectivity (albedo), installation height, tilt angle, and environmental conditions. This study provides a comparative assessment of the performance of bifacial photovoltaic systems installed in two distinct scenarios: ground-mounted and residential rooftop installations.

CONSIDERATIONS ON THE PERFORMANCE OF INSTRUMENT TRANSFORMERS UNDER INTERNAL ARC FAULT TESTING CONDITIONS

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THE CONTRIBUTION ABSTRACT – IP14

This paper analyzes the behavior of instrument transformers under internal arc fault conditions, aiming to ensure the safe operation of both the devices themselves and the power system they belong to. The study evaluates the capability of transformers to withstand an internal arc occurring between high-voltage and low-voltage windings in such a way that the resulting physical effects do not endanger personnel or nearby equipment. It presents the test conditions, methodology, measurement setup, and parameters applied during internal arc fault tests, along with the results obtained from several types of instrument transformers. The findings are supported by recordings of the electrical phenomena observed during the tests for a better understanding.

MULTI-SOURCE INTELLIGENT ELECTRIC POWER SYSTEM FOR LOCAL GENERATION AND STORAGE OF GREEN ENERGY

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THE CONTRIBUTION ABSTRACT – IP15

The phenomena generated by climate change and the increase in global energy demand require innovative, sustainable energy solutions. This paper details the concept of a Multi-Source Intelligent Electric Power System (MS-IEPS), which is based on a decentralized, intelligent, and resilient energy infrastructure.

The MS-IEPS is designed to integrate multiple renewable energy sources, intelligent control, and advanced storage technologies. The system ensures the quality of the supplied energy in terms of availability, predictability, and continuity. It also ensures energy independence at the individual, local, regional, and national levels. The energy sources analyzed in this paper are photovoltaic solar energy, wind energy, and hydrogen energy obtained using electrochemical hydrogen fuel cell reactors. The storage options under consideration include partially used batteries from electric traction and/or batteries dedicated to this application. This can extend the service life of replaced storage batteries from electric cars which, although unsuitable for use in electric traction, retain much of their original storage capacity.

The proposed system can operate both connected to and independently from the grid. This provides flexibility and autonomy, both of which are particularly important in areas without grid access.

In the near future, MS-IEPS will enable the integration of electric vehicles into virtual power plants via Vehicle-to-Grid (V2G) technology.

Virtual power plants offer several key benefits, including increased energy independence, reduced greenhouse gas emissions, greater resilience to power outages, and long-term economic advantages resulting from optimized energy usage.

TRENDS AND OUTLOOK FOR COMPOSITE INSULATOR CRIMPING PROCESS

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THE CONTRIBUTION ABSTRACT – IP16

Due to their superior mechanical strength, lightweight structure, and excellent resistance to environmental stresses, composite insulators have become increasingly important in modern power transmission and distribution systems in recent decades. These insulators are made up of a fiberglass-reinforced polymer (FRP) rod, silicone rubber housing, and metal end fittings. One critical step in manufacturing composite insulators is crimping metal end fittings onto the central rod. This process ensures the insulator's mechanical stability and electrical performance throughout its lifetime. The crimping process involves mechanically deforming a metal sleeve over an FRP rod with a predefined force and displacement. The quality of this joint is crucial because it directly affects the tensile strength and environmental stress resistance of the insulator. However, ensuring joint integrity without destructive testing poses a significant manufacturing challenge due to the composite nature of the materials involved. Traditionally, quality assurance in insulator crimping has relied on operator experience, periodic destructive testing, and post-processing inspections. While these methods can identify major defects, they often fail to detect deviations in process parameters, which can result in latent defects. These limitations can be addressed by implementing a real-time crimping process monitoring system. Thanks to advancements in sensor technology and data acquisition systems, important process parameters such as crimping force, displacement, and acoustic emissions can now be continuously monitored. In recent years, acoustic emission (AE) technology has evolved into a real-time, non-destructive monitoring tool that can detect defects occurring during the manufacturing process. AE offers a promising approach for dynamic monitoring of the crimping process quality by capturing and analyzing high-frequency sound waves produced by the material under stress.

INCREASING THE EFFICIENCY OF HYBRID PHOTOVOLTAIC PANELS BY USING ECOLOGICAL COOLING SYSTEMS

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THE CONTRIBUTION ABSTRACT – IP17

In order to maximize the use of solar energy, specialized manufacturers have developed and launched hybrid photovoltaic panels (PVT), which offer applicants - especially residential buildings - both electricity and heat, being an increasingly common choice that contributes to sustainability and energy efficiency. This dual-function technology offers a higher overall efficiency than standard photovoltaic panels, using a larger part of the solar spectrum, providing electricity for energy and heat for applications such as domestic hot water or space heating. However, what happens to hybrid panels when for various reasons the thermal energy fraction is not used - the temperature increases and implicitly their efficiency decreases. The paper presents a solution to optimize the efficiency of hybrid photovoltaic panels by injecting the unused thermal energy fraction into the ground, which leads to avoiding the phenomenon of overheating of the panels, maintaining energy efficiency and increasing the lifespan of photovoltaic cells. In this regard, a functional model was developed at National Institute ICMET Craiova that includes a group of hybrid photovoltaic panels fixed to the ground, and a horizontal heat exchanger buried in the ground that absorbs the heat of the ground in the cold seasons and injects/dissipates heat in the warm seasons. The results of the theoretical and experimental research carried out highlight the fact that the ground can play the role of a thermal accumulator/regulator, thus contributing to maintaining the efficiency and lifespan of hybrid photovoltaic panels at optimal values.

INNOVATIVE SOLUTIONS FOR ECOLOGICAL COOLING AND AIR CONDITIONING WITHOUT FREONS

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THE CONTRIBUTION ABSTRACT – IP18

Currently, most industrial and personal comfort cooling and air conditioning processes are carried out with equipment that uses freons as a refrigerant. The need to develop environmentally friendly products and technologies according to the Lisbon Protocol and the EU Green Pact is justified by the need to drastically reduce greenhouse gas emissions (carbon monoxide and dioxide, chlorofluorocarbons/freons, etc.) and to limit the devastating consequences of climate change, with the goal of climate neutrality. In this direction, this paper presents an innovative solution for the development of environmentally friendly technologies and equipment with pressurized air for cooling by thermodynamic methods, which completely eliminates freons. The paper presents a cooling device and a model of a compressed air conditioning installation based on an original solution based on a national patent and a European patent application. Theoretical research into the thermodynamic processes of centrifugal expansion of compressed air is confirmed by the experimental results obtained.

THE EFFECTS OF AI AND CRYPTOCURRENCIES ON ENERGY CONSUMPTION AND HOW GREEN ENERGY COULD HELP

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THE CONTRIBUTION ABSTRACT – IO10

The rapid growth of Artificial Intelligence (AI) and cryptocurrencies generates significant global energy consumption with major environmental implications. This paper analyzes the computational demands of large-scale AI model training, the continuous operation of applications such as ChatGPT, and the Proof-of-Work consensus mechanisms securing cryptocurrencies like Bitcoin. It quantifies the scale of this energy use and

highlights its ecological footprint, particularly in terms of carbon emissions, emphasizing the tension between technological innovation and environmental sustainability. As a response, the study explores green energy solutions - integrating renewable sources (solar, wind, geothermal, hydro, wave's force), using hydrogen as vector for energy storage and grid stability - that can mitigate these adverse effects. The conclusion argues that the strategic adoption of green energy, alongside improvements in efficiency, offers a viable path toward a sustainable digital future.

MOISTURE IN TRANSFORMER UNITS: A COMPLEX AND EVER-PRESENT PROBLEM

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THE CONTRIBUTION ABSTRACT – IP19

Transformer units are complex, critical, and among the most expensive components of electricity transmission and distribution systems. The general aging of the transformer fleet, the continuous extension of operating times, the ever-increasing demand for electricity, and the use of renewable energy sources have put additional pressure on energy systems, leading to an increased risk of failures, unscheduled outages, and significant costs. Moisture, known as the number one enemy of the paper-oil insulation system of transformers, has always been a critical parameter for monitoring and diagnostic practices because it plays an important role in the degradation of the paper-oil insulation system, leading to various failures that affect the life of the transformer. This paper briefly presents the impact of moisture on the decrease in dielectric strength of oil-paper insulation and the development of partial discharges. Operating transformers with high moisture content can lead to dangerous scenarios, such as the development of free water in transformer oil or the generation of bubbles at the oil-paper interface. These events threaten the integrity of the equipment. It also offers simple, practical solutions that increase the quality and reliability of transformers and their accessories, thereby reducing costs over their lifetime.

EVOLUTION OF RESISTANCE TESTS TO TRACKING AND EROSION OF THE MATERIAL OF THE SHEDS AND OF THE HOUSING OF COMPOSITE INSULATORS. TRAKING AND EROSION TEST - 1000H SALT FOG TEST RESULTS, CONCLUSIONS

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THE CONTRIBUTION ABSTRACT – IP20

The main concern for these types of insulators has been related to the possible premature deterioration of the insulating housing, which could affect long-term performance as well as service life.

In last decades, numerous tests and procedures have been developed to verify the resistance to traking and erosion of the shed and the insulating housing material in order to improve knowledge and experience in this regard. The paper presents the chronology of the development of these tests in order to detect potential weaknesses in materials and design that could compromise the performance of insulators in service. It also includes a brief presentation of the Traking and erosion test- 1000h salt fog test and results of such tests performed in ICMET Craiova.

UNIVERSAL VOLTAGE SYSTEM FOR THE MEASUREMENT OF HIGH VOLTAGE IMPULSES, AC AND DC VOLTAGES

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THE CONTRIBUTION ABSTRACT – IP21

The universal voltage system consists of a unique HV universal divider and a digital measuring instrument intended to record and evaluate the amplitude and time parameters of measured voltages. In practice HV laboratories must have at their disposal a voltage divider designed for easy handling and being of universal use. Voltages used for acceptance tests of electric equipment in HV laboratories are essentially the 1.2/50 μ s lightning impulse voltage, the 1.2/50 μ s tail chopped lightning impulse voltage, the switching impulse voltage, the AC voltage as well as DC voltage. The HV universal divider RCR 475/500 was designed entirely at ICMET Craiova to measure LI or SI with the peak value up to 500 kV, AC voltages with the r.m.s. value up to 200 kV and DC voltages up to 200 kV.

The universal divider was designed as a transfer standard in accordance with the requirements of IEC 60060 standards for measuring all types of voltage, namely: lightning impulses, switching impulses, alternating voltages, and direct voltages. The digital measuring instrument performs analogue to digital conversion of the measured signals that are automatically processed by dedicated software with a view to determining the parameters specific to each voltage type.

The technical performances of the transfer standard were determined by comparison measurements, according IEC 60060-2, with the reference measuring systems from ICMET. In this way the traceability of the transfer standard to the German standard of PTB is assured.

DEVELOPMENT OF THE MECHANICAL TESTS TECHNIQUE FOR INSTRUMENT TRANSFORMERS, UNDER SPECIFIED MECHANICAL ENVIRONMENTAL CONDITIONS

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THE CONTRIBUTION ABSTRACT – IP22

For the family of instrument, current and voltage transformers, the manufacturer must specify the climatic, mechanical and electromagnetic environmental conditions in which the transformer is intended to operate.

Mechanical tests of instrument transformers are type tests, according to the new applicable standards. The static test loads are indicative values of the static loads that the instrument transformers must be able to withstand.

The methods of applying the static test loads to the primary terminals of the transformer are specified by the international standards in the IEC 61869 series. In practice, the equipment and the test method are developed by the laboratory.

NUMERICAL EVALUATION OF HIGH-VOLTAGE IMPULSES PARAMETERS

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THE CONTRIBUTION ABSTRACT – IP23

The measurement systems used in testing/calibration laboratories typically use software to graphically represent recorded waveforms and evaluate the parameters required by working standards. The parameter definitions and typical waveforms to be measured are in the IEC 60060-1 standard. If for some waveforms, such as AC and DC, the measurement of parameters can be done easily, for the impulse voltages there has been a continuous concern to use a uniform method at the level of different laboratories. Thus, the numerical model for evaluation of voltage impulse parameters was proposed in the IEC 60060-1:2010 standard. The implementation of any numerical parameter evaluation method must comply with the requirements of the IEC

61083 2:2013 standard which establishes the limit values of the deviations of the parameters calculated for the reference waveforms obtained using the software called "Test Data Generator (TDG)". The evaluation of the voltage impulse parameters is done with a mathematical model presented in Annex B of the IEC 60060-1 standard from 2010. The algorithm consists of determining the mean curve $u(t)$ of the real signal, which is defined by the double exponential relationship, where the unknown parameters are U_p is the peak voltage value, T_1 is the front time, T_2 is the tail time and t_0 is the zero crossing time. The problem to be solved is to identify the four parameters, such that the analytical function best approximates the set of n points of a recording corresponding to an experimental waveform.

The paper presents the implementation of the numerical method for evaluating high-voltage impulses parameters. For measuring the impulses parameters, the Levenberg Marquardt algorithm was implemented to determine the mean curve that was used to represent the test voltage.

PERFORMANCE EVALUATION OF METAL-OXIDE SURGE ARRESTERS IN HIGH-VOLTAGE POWER SYSTEMS

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THE CONTRIBUTION ABSTRACT – IP24

In high-voltage (HV) power systems, ensuring the reliability and continuity of service is critically dependent on the ability to protect equipment from transient overvoltages. These overvoltages, often caused by lightning strikes, switching operations, or insulation failures, pose significant threats to the integrity of transmission lines, substations, power transformers, circuit breakers, and other high-value assets. Without adequate protection, such overvoltages can lead to insulation breakdown, equipment failure, costly outages, and serious safety hazards. As a result, surge arresters have become indispensable components in high-voltage networks, providing the first and most direct line of defense against these potentially damaging events. Surge arresters for high-voltage applications are specially designed to operate under extreme electrical and environmental conditions. They function by limiting transient overvoltages to acceptable levels through highly non-linear voltage-current characteristics, typically using metal-oxide varistors (MOVs) made of zinc oxide (ZnO). When a surge occurs, the arrester conducts the excess energy to the ground, thereby protecting downstream equipment from voltage levels that exceed their insulation withstand capability. After the surge subsides, the arrester returns to its non-conductive state, allowing normal operation to resume. The design, selection, placement, and maintenance of surge arresters in high-voltage environments involve complex engineering considerations. These include energy-handling capacity, residual voltage characteristics, thermal stability, aging mechanisms, pollution performance, and coordination with insulation levels (insulation coordination). This paper presents a detailed investigation into surge arresters for high-voltage applications.

CONTRIBUTIONS IN THE FIELD OF ELECTROMAGNETIC COMPATIBILITY, REGARDING THE EVALUATION OF SHIELDING EFFICIENCY

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THE CONTRIBUTION ABSTRACT – IP25

The development of equipment that has electronic components in their structure has led to the need to protect both the environment and other equipment from electromagnetic disturbances emitted by this equipment. Thus, the need for the electromagnetic shield arose. The electromagnetic shield represents a conductive covering with the role of separating an area into two spaces, a space containing the electromagnetic field emitters and a space containing the object that is disturbed. Consequently, with regard to the electromagnetic field, the role of the electromagnetic shield is to separate the two spaces from each other. The materials used for electromagnetic shielding depend on the purpose for which they are used and the cost price. The shield can have a rigid configuration and therefore it is necessary to construct it so that all the activities for which it was designed are carried out. ICMET had and has concerns in this direction. The paper includes a list of ICMET contributions in the field of electromagnetic compatibility, regarding the evaluation of shielding efficiency. The experimental results of the research and development activity regarding the evaluation of the shielding efficiency, the shielding materials used and the equipment used for measuring the shielding efficiency are

presented. A brief presentation of different types of construction of the shielded enclosures that are part of the equipment of the Electromagnetic Compatibility Laboratory within ICMET is made. Thus, the semi-anechoic chamber in welded construction and the shielded chamber made of panels are described. The flexible Faraday enclosure is presented in which stirrers will be mounted in order to develop a reverberant chamber. Measurements regarding the evaluation of the shielding efficiency of the enclosures were performed in accordance with the international standards IEEE Std 299:2006, SR EN 50147-1:1999 and IEEE Std 299.1:2013 within the previously mentioned laboratory.

DETECTION OF MECHANICAL FAULTS ON POWER AND DISTRIBUTION TRANSFORMERS USING FREQUENCY RESPONSE ANALYSIS (FRA) METHOD

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THE CONTRIBUTION ABSTRACT – IP26

Frequency Response Analysis measurement at power transformers is an offline diagnostic measurement used to detect mechanical faults of the windings. It is a non-destructive tool for mechanical condition assessment of power and distribution transformers based on comparison with a reference measurement which is either a previous measurement on the same unit, a measurement on an identical transformer or a measurement on another phase of a three-phase transformer. The paper presents a description of the Frequency Response Analysis (FRA) method for diagnosing transformer faults.

ANALYSIS OF THE BEHAVIOR OF OVERHEAD POWER LINE FITTINGS IN HVAC AND HVDC TESTING CIRCUITS FOR RADIO INTERFERENCE VOLTAGE EVALUATION

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THE CONTRIBUTION ABSTRACT – IP27

The development of renewable energy sources (solar, wind) requires the development of high-voltage direct current (HVDC) power lines to make the transport of such resources more efficient. Manufacturers of fittings and equipment used for high voltage direct current transmission (post insulators, insulator strings) have become interested in evaluating the radio interference emitted by such equipment.

At present, for such an evaluation of the conducted quantities (voltage or current), the same method standards and measurement systems for test circuits are used in testing laboratories regardless of the type of test voltage applied, HVAC or HVDC.

The article highlights some aspects of the radio interference voltage measurement circuit for the two measurement methods according to the CISPR TR 18-2 and NEMA 107 standards, the circuit calibration methods, specific to the two standards, through which the level of radio interference voltage (RIV) is evaluated. The article presents the evaluation of the radio interference voltage level of a test circuit for overhead power line fittings when applying high alternating current and direct current voltages (positive polarity and negative polarity). The behavior of overhead power line fittings in the two cases and the correlation of the applied voltages with the measured RIV level are analyzed.

THE ROLE OF STANDARDIZATION IN THE FIELD ENERGY AND ENVIRONMENT

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THE CONTRIBUTION ABSTRACT – IP28

Standardization in the field of energy and environment plays a crucial role in establishing common norms, principles and technologies that promote energy efficiency, reduce environmental impact, facilitate international trade and ensure public safety and health, contributing to a sustainable and balanced future.

Key benefits: Energy efficiency, Environmental protection, Safety and health, International trade, Innovation, Consistency and trust.

APPLIED RESEARCH ON THE EFFECTIVENESS OF LIGHTNING RODS

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THE CONTRIBUTION ABSTRACT – IP29

This article presents the results of applied research, carried out by ICMET Craiova specialists in the field of evaluating the effectiveness of devices that provide protection against atmospheric electrical discharges. The effectiveness of these devices (lightning rods) can be evaluated by means of a parameter, ΔT (delta T) which represents the difference between the emission time of the lightning rod and that of a standardized Franklin rod, times determined under the same laboratory conditions, which simulate the initiation of a natural electrical discharge. It presents the method of determining the parameter ΔT (delta T) of a lightning rod by the combined application of switching voltage pulses and direct voltage, the values of the applied voltages being determined through successive tests, depending on the parameters of the evaluation circuit.

AI IN SAFETY OR SAFE AI FOR PROCESSING SYSTEMS

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THE CONTRIBUTION ABSTRACT - KSH2

The digitalized automated processing systems are equipped with shared control systems with two intelligent decision-makers: humans and automated machines (artificial intelligence – AI-driven control). The contradictory observations, states, goals, and actions may cause conflict between these decision-makers. The definitions, cause(s), and path(s) of such a conflict from a process safety perspective have not been explored and assessed. This presentation introduces an evolutionary framework that shows how a conflict between Human Intelligence (Human) and Artificial Intelligence (AI) can lead to an accident in processing facilities. The framework aims to quantify conflict risk between AI and humans. The framework's application is demonstrated on a processing system. The results indicate that conflicts are often hidden, mixed, or obscured by traditional faults, and that noises in observation and interpretation, such as sensor faults, logic errors, cyberattacks, human mistakes, and misunderstandings, can easily trigger conflicts. Safety-centered design is vital to avoid catastrophic accidents due to disputes or misalignment in AI-driven digitalized processing systems.

SESSION ON HYDROGEN, FUEL CELLS AND ELECTROFUELS

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THE CONTRIBUTION ABSTRACT – KSH3

Hydrogen produced from renewable energy sources enables decarbonization of otherwise hard to decarbonize energy sectors. The transport sector can be decarbonized with electricity from renewable energy sources, but hydrogen can greatly assist in it, particularly in heavy-duty, long-distance transport such as buses, trucks, and trains. Although hydrogen can be used as a fuel in internal combustion engines, its use in fuel cells is more efficient. Hydrogen fuel cell vehicles are, thus, also electric vehicles, and they differ from battery electric vehicles only in the way of on-board storage of energy. Batteries are of course much more efficient, but hydrogen and fuel cells offer advantages of faster refuelling, lower weight and separation of energy and power. For even heavier duty and longer distance transport such as maritime and air transportation, hydrogen storage may be a hindrance, so, instead of hydrogen, so called e-fuels, produced from renewable hydrogen, may be used. This lecture will give a comprehensive overview of technology status for hydrogen use in transport, including both vehicle technology and hydrogen supply infrastructure, and will attempt to evaluate/predict where hydrogen and fuel cells offer sufficient advantage to make significant contribution to decarbonization of transport.

POTENTIAL AND PERSPECTIVES OF MEMBRANE TECHNOLOGIES IN SUSTAINABLE H₂ PRODUCTION

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THE CONTRIBUTION ABSTRACT – KSH4

Nowadays, most of the industrial hydrogen manufacture comes still from steam reforming of natural gas, responsible for massive emissions of CO₂ and further harmful compounds in the environment. The European Green Deal is promoting measures to limit the environmental impact of future hydrogen energy processes, and among others the exploitation of renewable sources such as biogas constitutes an option over natural gas utilisation, which could favour the energy transition from a carbon-based to the hydrogen economy. In this work, the potential of membrane engineering applied to hydrogen generation and purification [1] is presented, particularly focusing on the membrane reactors technology [2], useful to meeting the stringent targets promoted by the European Clean Hydrogen Alliance, under the Strategic Research & Innovation Agenda 2021-2027. In particular, the most relevant results related to the combined housing of Pd-based membranes and foam

structured catalysts in membrane reactors (Figure 1) to generate decarbonized hydrogen from biogas reforming are presented, further highlighting the perspectives of the electrically assisted membrane reactors as a Power-to-H₂ technology, acting in the framework of the net-zero CO₂ emissions strategy.

A PARALLEL BETWEEN THE DEVELOPMENT OF THE NATURAL GAS AND HYDROGEN INDUSTRIES

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THE CONTRIBUTION ABSTRACT – KSH 7

The development of the hydrogen industry follows a similar path to that of natural gas, but adapted to current environmental objectives. Natural gas established itself in the 20th century as a cleaner energy source than coal, thanks to its efficiency and extensive transport infrastructure. Currently, hydrogen, especially green hydrogen, is promoted as a solution to reduce carbon emissions and ensure a sustainable energy transition. Both sectors have gone through common stages: resource discovery, infrastructure development and integration of global trade. While natural gas has benefited from LNG pipelines and terminals, hydrogen is starting to create its own networks and secure storage technologies. Political support remains essential: from gas investments to green strategies and European financing for hydrogen. The major difference is the goal – while natural gas was a transition stage between coal and renewables, hydrogen is the basis of a low-emission economy.

NUCLEAR HYDROGEN PRODUCTION FOR THE BALANCING AND ANCILLARY SERVICES OF THE GRIDS

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THE CONTRIBUTION ABSTRACT – IO1

This communication will indicate the advantages of hydrogen production using nuclear energy both for the energy sector and in terms of integrating fluctuating renewable energies into the energy mix. The subject is of real interest to both the scientific and energy communities, and nuclear hydrogen presents a new valence in terms of the production and use of low-carbon or even zero-carbon energies. Hydrogen production using energy provided by nuclear reactors will lead to the integration of various low-carbon energy sources. Thus, fluctuating renewable energies will be able to be integrated in a much larger quantity than at present and in a much safer manner so as to ensure the security of energy systems. Through hydrogen, the nuclear sector will not only be a supplier of power but will also become a supplier of balancing mechanisms and auxiliary services for electrical grids.

Hydrogen will bring a number of advantages to the nuclear sector: increasing the fleet of nuclear reactors or the number of nuclear power plants, improving competitiveness in relation to other low-carbon energy sources, participation in the market for low-carbon balancing mechanisms, contributions to protection against network congestion, role in spinning reserves or flexibility in the production of both hydrogen and power.

HYACADEMY.EU

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THE CONTRIBUTION ABSTRACT – IP1

The HyAcademy.EU project aims to make the most of the investments already made by the European Commission and the Member States in education and training activities in the field of hydrogen technologies. The project is based on a consortium bringing together 17 participants (15 partners and 2 associates), allowing the consolidation and exploitation of the results obtained in previous projects (TeachHy and KICstartH2).

The consortium wants, among others, to:

- build and support a network of over 100 universities offering recognized qualifications, specializations and diplomas in hydrogen technologies,
- build and support a network of over 500 schools integrating hydrogen-related subjects,
- create a network of 5 laboratories,
- provide a portal to present and connect educational programs available on the network and beyond with a minimum of 100,000 accesses to specialized documents on hydrogen-related topics,
- provide free training materials and integrate (online) teaching methodologies.

HyAcademy.EU aims to support the EU objectives of providing access to high-quality education in order to create a highly skilled workforce and jobs in the European hydrogen industry.

DETERMINATION OF OPTIMAL OPERATING CONDITIONS FOR HYDROGEN PRODUCTION WITHIN SENSITIVITY ANALYSIS

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THE CONTRIBUTION ABSTRACT – OH1

This study presents the results of a sensitivity analysis conducted to determine the optimal operating conditions for hydrogen production. As a prominent alternative to fossil fuels, the significance of hydrogen energy continues to grow. The announcement of carbon-neutral energy policies and hydrogen roadmaps by various countries further underscores the increasing relevance of hydrogen in the global energy landscape. In this study, a Proton Exchange Membrane (PEM) electrolyzer is utilized for hydrogen production. Experimental data were analyzed using robust statistical methods to perform a sensitivity analysis. The results indicate that the optimal temperature range for efficient hydrogen production lies between 38°C and 45°C.

THERMODYNAMIC ASSESSMENT OF THE GEOTHERMAL BASED ELECTRICITY AND HYDROGEN PRODUCTION FOR SUSTAINABLE ENERGY

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THE CONTRIBUTION ABSTRACT – OH2

In this study, the production of electricity and hydrogen using a geothermal energy source is examined from a sustainability perspective. The proposed system consists of a turbine, two heat exchangers, a pump, a cooling unit, a PEM electrolyzer, and a water production system. The thermodynamic analysis of the system is conducted with a holistic approach. Approximately one-fourth of the electricity generated in the system is directed to the PEM electrolyzer for hydrogen production, while the remaining portion is supplied to the grid. To evaluate the system's performance, a thermodynamic analysis has been carried out. The energy and exergy efficiencies of the system are calculated as 9.77% and 10.27%, respectively. Furthermore, the sustainability index (SI) of the system is determined to be 1.114.

QUANTIFYING THE GREEN SOLAR HYDROGEN PRODUCTION POTENTIAL OF AQUATIC SURFACES IN THE SOMEȘ-TISA HYDROGRAPHIC AREA, ROMANIA

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THE CONTRIBUTION ABSTRACT – PH1

Green hydrogen, generated via water electrolysis using renewable energy sources, has emerged as a key vector in the global transition toward low-carbon energy systems. In particular, the integration of solar energy into hydrogen production processes offers a sustainable and scalable approach that supports international objectives related to climate neutrality and long-term energy security. This article synthesizes the partial results of an ongoing research project that aims to quantify the potential for decentralized hydrogen production via solar-powered water electrolysis, with a particular focus on floating photovoltaic systems. The study examines six major reservoirs within the Someș-Tisa hydrographic basin in Romania by considering alkaline and proton exchange membrane electrolysis. The main results highlight an average specific hydrogen annual production of 4.254 kg H₂/m² when using PEM electrolysis, and 9.796% higher when using alkaline electrolysis, respectively 4.671 kg H₂/m² of water surface within artificial reservoirs. Assuming that the hydrogen produced via electrolysis is subsequently converted into electricity using a fuel cell with an efficiency of 46%, the overall sun&water-to-hydrogen-to-electricity conversion efficiency is estimated at 34.60% for alkaline electrolysis and 31.20% for PEM electrolysis. The electricity generated from hydrogen has the potential to reduce up to 73.80% of the CO₂ emissions associated with an equivalent quantity of conventionally produced electricity currently delivered through the national grid in Romania.

Keywords: electrolytic hydrogen, green hydrogen, sun&water-to-hydrogen-to-electricity conversion.

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CONCEPT OF A SOLID OXIDE ELECTROLYSIS-MOLTEN CARBONATE FUEL CELL HYBRID SYSTEM TO SUPPORT A POWER-TO-GAS INSTALLATION

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THE CONTRIBUTION ABSTRACT – OH3

This study outlines a concept for improving a power-to-gas (P2G) system through the implementation of highly efficient high-temperature electrolysis combined with a molten carbonate fuel cell (MCFC) as a CO₂ capture unit for a power plant. Laboratory scale experiments demonstrate that the MCFC could be used for CO₂ separation, opening the way to capture of CO₂ from flue gases at coal-fired power stations, while maintaining both high electric efficiency and a high CO₂ separation factor. Improved energy efficiency can be achieved by the lower electricity requirement of high temperature electrolysis compared to other technologies. Results obtained from experimental investigations show that a CO₂ separation rate in excess of 90 % is achievable through adjusting the cathode inlet flow. It should be noted that flue gas must be mixed with air before delivery to the MCFC. Controlled flow of inlet gases to the anode can raise electric efficiency to above 35 % for both laboratory-size and full-scale MCFC. The benefits of the concept are manifested by lower power consumption of the system and no energy penalty for the CO₂ capture process. Additionally, the system enjoys good thermal management because all devices run at elevated temperatures (Sabatier reactor at 300 °C, MCFC at 650 °C, solid oxide electrolyzer at 700–800 °C). The proposed improvements increase the system's competitiveness relative to alternative P2G systems and reduce the price of substitute natural gas. Secondly, it will eliminate the consumption of heat from the host coal-fired power plant. Thirdly, the entire system will be more straightforward, compact, and modular, allowing any future scale-up to be implemented without technological difficulties. Finally, the amount of energy required to produce hydrogen will decline by around 25 %.

BIFURCATION ANALYSIS IN HYDROGEN ELECTROLYSIS WITH NONLINEAR LOGARITHMIC COUPLING

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THE CONTRIBUTION ABSTRACT – PH2

A nonlinear dynamic model for hydrogen production and storage is analyzed, described by a system of three coupled differential equations for temperature, hydrogen stock, and pressure. The model incorporates a nonlinear logarithmic feedback term, which couples the hydrogen stock to the temperature dynamics, reflecting physical situations where the reservoir pressure indirectly influences heat transfer or reaction efficiency. The temperature equation accounts for environmental losses, electrical input, chemical reaction effects, and the logarithmic feedback. The hydrogen equation models production, losses, external consumption, and a pressure feedback, while the pressure equation describes relaxation towards the ideal gas law.

The stability of the system is shown to depend sensitively on the control and design parameters. Analysis of the Jacobian eigenvalues reveals that, for certain values of the logarithmic coupling, hydrogen losses, thermochemical coupling, and temperature sensitivity, the system can transition from stable regimes to instability or self-sustained oscillations. Stability maps and explicit identification of saddle points and Hopf bifurcations are presented, providing practical guidelines for the design and control of hydrogen systems.

Numerical results confirm the theoretical predictions and highlight the importance of nonlinear feedback. For large logarithmic coupling or small hydrogen losses, the system can become unstable or exhibit oscillations, with direct implications for the safety and efficiency of real hydrogen units. The original contribution consists in the introduction and systematic analysis of the logarithmic feedback term, leading to new stability and bifurcation scenarios relevant for advanced hydrogen technologies.

Keywords: hydrogen systems, stability, Hopf bifurcations.

EVALUATING CORROSION RESISTANCE AND IN-SITU PERFORMANCE OF COPPER BIPOLAR PLATES WITH PROTECTIVE Nb AND Ti-COATINGS FOR PROTON EXCHANGE MEMBRANE WATER ELECTROLYSIS

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THE CONTRIBUTION ABSTRACT – OH4

Bipolar plates (BPPs) for proton exchange membrane (PEM) water electrolysis were developed by applying protective niobium (Nb) and titanium (Ti) coatings on copper using vacuum plasma spray deposition. This study provides an in-depth characterization of the prepared BPPs in terms of ex-situ electrochemical corrosion behaviour under simulated electrolyser operating conditions, as well as in-situ performance in a 25 cm² area PEM electrolyzer. The structure and morphology of the coatings were analyzed using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD). The results revealed smooth, uniform, low porosity and phase-pure metallic coatings. Corrosion resistance, evaluated through linear polarization measurements and constant potential stress test at 2V, indicated lower corrosion current densities for the Nb coating compared to the Ti coating. Electrochemical impedance spectroscopy (EIS) further confirmed the higher corrosion resistance of the Nb coating, as evidenced by larger polarization resistance, attributed to the formation of a thicker barrier-type oxide layer. Interfacial contact resistance (ICR) measurements showed that the Nb coating exhibited lower ICR values than the Ti coating, both before and after potentiostatic stress test at 2V. In-situ performance was assessed using polarization curves recorded up to 2 A cm⁻² at 80°C and 8 bar hydraulic pressure in a modular PEM electrolyzer stack. The tested pole plates and a reference Pt-coated Ti pole plate were mounted on the anode side, while keeping the rest of the components identical. The Nb coated copper pole plate outperformed both the reference and Ti coated copper pole plates in terms of voltage and electrical efficiency.

Overall, the results demonstrate that Nb and Ti coatings effectively protect even low corrosion-resistant metals such as copper, thereby broadening the range of suitable materials for BPPs.

STABILITY AND CORROSION BEHAVIOUR OF IR-RU COATED TI-BASED ANODES FOR PEM WATER ELECTROLYSIS

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THE CONTRIBUTION ABSTRACT – PH3

Novel anodes for PEMWE were developed through a combination of a surface treatment applied to a sintered Ti-based porous transport layer, followed by the electrodeposition of Ir–Ru catalyst particles from aqueous solutions. The study aims to create an in-depth characterization of the anodes in terms of microstructure, chemical composition, and corrosion behaviour under simulated operating conditions. The microstructural evaluation was performed using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD). SEM provided insights into morphology, pore distribution, and microstructural features of the anodes, while EDS enabled qualitative elemental analysis. Complementary crystallographic data were obtained by XRD, including phase identification. The electrochemical behaviour was investigated in a 0.05 M H₂SO₄ solution with and without fluoride additions. The anodes were evaluated using a stepwise corrosion protocol, while to simulate degradation during harsh conditions, an accelerated stress test was applied by holding the potential at 2 V for 6 h. The combined structural and electrochemical analysis provides a comprehensive view of the stability and corrosion resistance of the Ir–Ru anodes, highlighting the impact of fluoride ions on their durability. The addition of fluoride to the testing electrolyte led to a significant decrease in the corrosion potential due to its aggressive interaction with the passive TiO₂ film, which destabilizes the protective layer and promotes localized dissolution, thereby reducing the overall corrosion resistance of the anodes that were not subjected to a surface treatment. The results focus on the suitability of the prepared electrodes for PEM electrolyzer application as well as the relevance of integrating advanced surface treatments combined with electrodeposition routes to achieve improved activity and enhanced stability of PEMWE anodes under realistic operating conditions.

LANDSCAPE OF OFFSHORE ENERGY HUBS, CRITICAL RAW MATERIALS AND GREEN HYDROGEN

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THE CONTRIBUTION ABSTRACT – OH5

The aim of this study is to investigate various facets of offshore energy hubs which are linked with development of offshore wind farms and production of green hydrogen and other e-fuels. Research approach targets to implement the perspective of critical raw materials and their supply value chain into development of offshore wind farms and production of green hydrogen. Rich insights are collected from various industrial views and stakeholders and current research projects. Offshore energy hubs can play an important role in green transition, and can contribute to energy security in Europe. Nevertheless, energy transition is material intensive and requires a sound policy landscape in place and medium and long-term sagacious strategies of actions. Moreover, updated road maps for offshore energy hubs and green hydrogen need to be in place and more balanced narratives about the global supply chain for the critical raw materials.

FROM WASTE TO ENERGY: ON-SITE HYDROGEN PRODUCTION WITH ALUMINUM

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THE CONTRIBUTION ABSTRACT – PH4

Achieving carbon neutrality will require the implementation of hydrogen as a primary fuel across every possible field of life. However, its low density poses significant challenges for storage and transportation. Moreover, hydrogen readily forms explosive mixtures with oxygen - with air-hydrogen mixtures being highly combustible -

raising additional safety concerns. One possible way to overcome these limitations is to produce hydrogen on-site, thereby eliminating the need for large-scale storage and transport of hydrogen.

Aluminum presents a promising option as a hydrogen precursor due to its high hydrogen yield when reacting with water (1244 cm³/g), second only to lithium (1600 cm³/g). Additionally, aluminum is relatively abundant, making up 8% of the Earth's total mass. Nevertheless, using only pure aluminum would be expensive and resource-intensive if large-scale demand rises. A sustainable alternative would be to use unused waste that contains aluminum, which not only enables hydrogen production but also helps to slow down landfill growth. Furthermore, replacing freshwater in the hydrolysis reaction with Baltic Sea water could further lower production costs and improve reaction kinetics, offering a practical and environmentally friendly approach to on-site hydrogen generation.

In this work, the aluminium content of various aluminium-containing waste materials is analysed, and potential pathways for using this waste in hydrogen production are discussed. Additionally, possible ways for the further implementation of the residual waste are overviewed, with a focus on improving resource recovery, supporting sustainability, and contributing to circular economy approaches.

Acknowledgement: This work was supported by the Swiss-Latvian Partnership in Applied Research Programme Component 2 in the areas of ICT and Smart Energy – LACISE.

THE FINANCIAL AND ECONOMICAL ASSESSMENT OF INTEGRATING GREEN HYDROGEN IN THE TRANSITION TOWARDS ENVIRONMENTAL SUSTAINABILITY OF DATA CENTRES

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THE CONTRIBUTION ABSTRACT – OH6

Data centres are estimated to become one of the most energy intensive end-users by the end of 2030, with a global estimated demand of 945 TWh/year, with a yearly grow rate of electricity demand of 15%/year in the 2025 – 2030 period, and a total forecasted share of 3% of the global electricity demand. More than 86% of IT leaders consider reliability as the most critical factor when designing a data centre. 74% of the data centre market experienced at least one significant outage over the last year, with 46% experiencing an average of 1.5 outages/year. The loss of power was responsible for 13% of these events.

The transition towards environmental sustainability generates an additional burden to data centre development in Europe, as most of the conventional back-up power supply used today are represented by a mix of UPS and fossil fuel powered electrical generators.

The paper aims at evaluating the technical, financial and economic viability of developing a novel back-up power supply that uses 100% renewable energy as opposed to the conventional means of providing electricity during power outages for data centres.

The proposed technical scenarios, consisting in using solar energy, energy storage solutions and green hydrogen were evaluated from a technical and financial point of view, in order to assess the financial viability of the solution with regard to stakeholder expectations.

The authors also analysed the social impact of implementing such a technical scenario, with regard to the avoidable greenhouse gasses emissions, the conservation of fossil fuels in the context of energy security, and the operational safety impact, leading to a risk matrix that can prove useful for investors when deciding upon the back-up power supply approach.

The paper also presents a sensitivity analysis regarding the relevant variables that have a significant influence on the overall viability of the project, such as the CAPEX, electricity price, DSO reliability indices etc.

OXIDATION OF IRON (II) MONOSULFIDE BY HYDROGEN SULFIDE WITH THE PRODUCTION OF MOLECULAR HYDROGEN

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THE CONTRIBUTION ABSTRACT – PH5

When iron(II) monosulfides are exposed to an oxidant such as molecular oxygen (O₂) or ferric iron (Fe³⁺) they oxidize and produce sulfuric acid (H₂SO₄). The formation of sulfuric acid leads to the phenomenon of Acid Mine Drainage (AMD), through which the environment is contaminated with toxic species of copper, cadmium, lead, arsenic, etc. Therefore, the oxidation of iron(II) monosulfides with molecular oxygen or ferric iron has attracted the interest of researchers. In contrast, the oxidation of iron(II) monosulfide (FeS) with hydrogen sulfide (H₂S) has attracted much less attention, and, consequently, few details are known about the mechanism of interaction between FeS and H₂S. Understanding the reaction mechanism of this process can be essential because the reaction of iron(II) monosulfide with hydrogen sulfide can have important applications, because in addition to pyrite (FeS₂), the reaction releases molecular hydrogen (H₂), which is a fuel that, when burned, produces only water, a harmless product for the environment. In this study, the results of the analysis of the interaction between iron(II) monosulfide and hydrogen sulfide by Density Functional Theory (DFT) calculations are presented. DFT calculations were performed with the BP energy functional using Amsterdam Density Functional program package and the TZP basis set. The corresponding physical properties of the species involved in the process (FeS, H₂S, H₂ or FeS₂) were determined. The energy associated with the reaction $\text{FeS} + \text{H}_2\text{S} = \text{FeS}_2 + \text{H}_2$ is $\Delta E < 0$, which shows that the process is spontaneous. The main reaction intermediate analyzed was FeS-SH₂, a species that characterizes the adsorption of hydrogen sulfide on the FeS surface.

GREEN HYDROGEN IN ROMANIA'S DISTRICT HEATING SYSTEMS – ECONOMIC IMPACTS ON END-CONSUMERS AND RISK ASSESSMENT

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THE CONTRIBUTION ABSTRACT – OH7

Through the European Green Deal, the European Union aims for Europe to become the first climate-neutral continent by 2050, and through the 2022 RePowerEU initiative, it seeks to reduce dependence on natural gas and accelerate the use of renewable energy sources. In this context, green hydrogen emerges as a key energy carrier in the energy transition. It offers the possibility of integration into District Heating Systems (DHS), both by direct use in dedicated equipment and by mixing with natural gas in existing installations. District Heating Systems (DHS) are an essential tool to meet the demand for heat energy in urban agglomerations and to reduce greenhouse gas emissions.

However, successful integration of hydrogen into DHS requires careful consideration of its effects on end consumers and the cost of thermal energy supply. Thus, new technologies and fuels must not only be technically feasible but also economically acceptable for users, relative to the population's level of affordability. In this regard, the tariff methodology applicable in Romania is taken into account.

The aim of the article is to analyze the integration of green hydrogen into DHS, assessing the effects on the final price through comparative financial modeling, based on the cost scenarios for gas and green hydrogen and the additional investments required for the infrastructure. The article also includes a risk analysis, focusing on the economic impact and potential consequences of changing the fuel source.

The results show that, although green hydrogen costs are high, end-consumer assessment and inclusion in calculation methodologies are essential for strategic decisions.

In conclusion, this analysis provides a framework for evaluating new energy carriers in District Heating Systems and offers guidance for decision-makers in planning a socially and economically viable energy transition.

BIOHYDROGEN PRODUCTION FROM LIGNOCELLULOSIC BIOMASS: COMPARATIVE EVALUATION OF AGRO-INDUSTRIAL RESIDUES

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THE CONTRIBUTION ABSTRACT – OH8

The increasing demand for sustainable and carbon-neutral energy carriers has intensified global interest in biological hydrogen production (bio-H₂) from renewable resources. Among the available feedstocks, lignocellulosic biomass (LCB) represents the most abundant and low-cost substrate, composed primarily of cellulose, hemicellulose, and lignin. Its conversion to hydrogen offers a dual benefit: valorization of agricultural and agro-industrial residues and reduction of dependence on fossil fuels.

In this study, LCB such as grape and apple pomace, wheat straw, and corn stover were subjected to alkaline pretreatment in order to reduce biomass recalcitrance and enhance the accessibility of fermentable sugars, followed by enzymatic hydrolysis using cellulase and hemicellulase cocktails to obtain fermentable sugars. Dark fermentation was carried out in 500 mL batch reactors with a working volume of 400 mL, inoculated with 10% *Clostridium beijerinckii* inoculum. Operational parameters were maintained at pH 7.5, 37 °C, and 60 rpm. A multi-channel analyzer (Gas Endeavour III) was employed for the anaerobic fermentation and quantification of biohydrogen production, while gas composition was analyzed by GC-TCD, and bio-H₂ yield was calculated. The results demonstrated that feedstock type significantly influenced hydrogen yield. Apple pomace and corn stover achieved the highest yields (86.3-110 mL H₂/g glucose), while grape pomace and wheat straw produced lower values (69.4 – 77.9 mL H₂/g glucose), likely due to higher lignin and phenolic content, which inhibited microbial activity.

Overall, this work highlights the potential of agro-industrial residues for biohydrogen generation and identifies substrate-specific constraints. Future improvements should focus on inhibitor mitigation, microbial strains adaptation, and further experimental validation to advance lignocellulosic biohydrogen production as a clean energy vector.

TECHNO-ECONOMIC ANALYSIS OF PEM ELECTROLYZERS USING RENEWABLE SURPLUS

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THE CONTRIBUTION ABSTRACT – OH9

With the expansion of renewable energy is fed into the grid, managing the fluctuations in electricity supply is becoming a real challenge. For a sustainable energy transition not only production but also energy storage and flexible system integration are of strategic importance. Hydrogen can play a crucial role in the energy system. One promising way to deal with this is by using excess green power to produce hydrogen through proton exchange membrane (PEM) electrolysis. This study looks into whether it's technically and economically feasible to run a 5 megawatt PEM electrolyzer using surplus renewable energy in Spain. Hourly electricity market data from Red Eléctrica de España (REE) and ENTSO-E were used for modeling. Three operating scenarios were examined: completely off grid operation based on solar and wind energy, pure grid operation both continuous and price controlled and a hybrid model in which renewable energy is supplemented by low-cost electricity imports from the grid. In the study, hydrogen production amount, levelized cost of hydrogen (LCOH) and carbon emissions were comparatively analyzed in cases where solar and wind energy and grid electricity are provided to the electrolyzer in different scenarios. The analysis shows that continuous grid-connected operation achieves LCOH values between €5 and €7 per kilogram of hydrogen. Off-grid systems based on renewable energies have higher costs of around 7 to 10 euros per kilogram due to their limited availability. If operation is flexibly adjusted to price developments on the electricity market, costs can be reduced to around €3 to €5 per kilogram. The results show that PEM electrolyzers can reduce the cost of green hydrogen to a competitive level, also contributes to decarbonization and stabilization of the power grid.

INFLUENCE OF HYDROGEN CHARGING ON THE CORROSION BEHAVIOR OF A CARBON STEEL

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THE CONTRIBUTION ABSTRACT – PH6

The rapid growth of the hydrogen industry demands reliable materials for diverse applications, such as storage, transportation, and utilization. Hydrogen is well known for its ability to penetrate metallic matrices and alter both mechanical and chemical properties; these effects can cause embrittlement and compromise the stability of the protective passive film that normally prevents further attack.

This paper examines how hydrogen exposure influences the corrosion resistance of a carbon steel commonly used in industrial environments where components face aggressive or moisture-rich atmospheres. To assess these effects, samples are compared before and after a controlled electrochemical hydrogen charging process. Their electrochemical response was evaluated through open-circuit potential (OCP) measurement, potentiodynamic polarization curves, and electrochemical impedance spectroscopy (EIS). The negative shift in OCP, combined with the increase in the corrosion current density and the decrease in charge transfer resistance indicates a higher corrosion tendency after hydrogen charging. Surface and near-surface analysis were performed using optical microscopy to identify general microstructural features and scanning electron microscopy (SEM) to capture finer-scale topographical changes, revealing any localized damage or modification of the passive layer after hydrogen exposure. Correlating these microscopic observations with electrochemical data provided a clearer insight into how hydrogen charging affects passive film stability and overall corrosion susceptibility. This study contributes to a broader understanding of the mechanisms through which hydrogen accelerates metallic degradation, offering insights for the design of equipment and structural components operating in hydrogen-rich or otherwise corrosive service conditions, as well as for the development of more effective corrosion-protection strategies suitable for future energy and industrial applications.

EXPERIMENTAL INVESTIGATION OF NEW ANODE FLOW FIELD DESIGNS WITH DIFFERENT INTERNAL GEOMETRIES FOR PEMEC PERFORMANCE

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THE CONTRIBUTION ABSTRACT – OH10

Flow channel design in Polymer Electrolyte Membrane Electrolyzer Cell (PEMEC) systems plays a critical role in optimizing mass transfer efficiency and cell performance. Within the scope of this study, flow channel designs made of 316L stainless steel with differentiated internal geometries were developed and experimentally characterized for the PEMEC anode side flow areas. The channel configuration with a single inlet and outlet was maintained, and the channel width and depth were kept constant, but variety was provided in the internal geometric patterns of the channels. With this approach, the effect of geometric parameters on electrolyzer performance was systematically investigated. Performance evaluations were conducted at temperatures of 30°C, 40°C, and 50°C, as well as under variable anode flow rates. Electrical characterization was performed through voltage-current (I-V) measurements taken with the aid of a power supply, and current densities in the range of 0.9–1.3 A/cm² were obtained at a constant voltage of 2 V. In addition, the performance of the proposed new flow model was tested at different anode flow rates, and a sensitivity analysis was performed. The experimental findings are considered to offer a new approach for PEMEC anode flow field design and contribute to the development of highly efficient flow field configurations. The study aims to contribute to the literature by supporting this new design strategy with experimental data.

Keywords: PEMEC, Flow field design, 316L metal plate, Operating parameters, Electrochemical analysis.

TECHNICAL ANALYSIS OF A HYDROGEN-POWERED BACKUP ENERGY SYSTEM FOR A DATA CENTER

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THE CONTRIBUTION ABSTRACT – OH11

In the context of increasing digitalization and data dependency, ensuring the continuity of power supply to data centers has become a critical priority. Data centers host essential digital infrastructure, and any interruption in energy supply can lead to substantial operational, financial, and security-related consequences. Therefore, the development of resilient and sustainable backup energy systems is imperative. Integrating innovative solutions, such as hybrid systems powered by green hydrogen, can significantly enhance the reliability and autonomy of data centers in critical scenarios, contributing to both energy security and environmental sustainability.

In this context, based on the specialized literature, which shows that the size of data centers varies between 5 MW and 200 MW of installed electrical power, the architecture of a small-scale data center has been proposed. This architecture is proportionally modeled after large-scale data centers and consists of: one (1) CPU server rack with an installed electrical power of 3 kW, one GPU server rack with an installed electrical power of 5 kW, and one air conditioning (AC) system with an installed electrical power of 2 kW. The total installed electrical power of the proposed small-scale data center is therefore 10 kW. Based on this configuration, several backup power supply solutions have been proposed and analyzed: A. A modular battery energy storage system (BESS); B. A small-scale photovoltaic power plant (PVPP) combined with a modular BESS, to ensure a significant contribution of green energy during backup operation; C. A modular BESS integrated with a containerized hydrogen-based system for distributed power generation, using either C.1. fuel cells or C.2. internal combustion engines.

To identify the most suitable configuration, a comparative analysis was conducted, taking into account technical performance, scalability, energy efficiency, environmental impact, and system autonomy.

A CLEANER AND MORE EFFICIENT SPARK-IGNITION ENGINE THROUGH HHO GAS ENRICHMENT WITH RSM-BASED OPTIMIZATION

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THE CONTRIBUTION ABSTRACT – OH12

The growing interest in alternative energy sources has accelerated the search for technologies that can enhance the efficiency and sustainability of internal combustion engines. In this context, hydrogen-oxygen (HHO) gas has emerged as a promising supplementary fuel due to its clean-burning characteristics and potential to improve combustion efficiency. In this study, the impact of HHO gas produced by an on-board hydrogen generator on the performance and emission characteristics of a single-cylinder, air-cooled spark-ignition engine was experimentally investigated. The experiments were conducted at a constant engine speed of 3000 rpm under various load conditions by introducing HHO gas through the intake manifold. The results revealed that the addition of HHO gas enhanced the thermal efficiency by up to 11%, with the maximum efficiency observed at 75% engine load. Furthermore, the brake specific fuel consumption (BSFC) exhibited an improvement of up to 23% at higher torque levels. Emission measurements indicated approximately 15% reductions in HC and CO emissions, whereas CO₂ emissions increased as a consequence of improved combustion efficiency. To further assess and optimize the engine operating parameters, the experimental data were analyzed using Response Surface Methodology (RSM). Overall, the findings demonstrate that HHO enrichment can be an effective approach for improving energy conversion efficiency and reducing harmful exhaust emissions in internal combustion engines.

SALINE WATER ELECTROLYSIS WITH SELECTIVE OXYGEN EVOLUTION REACTION VS. CHLORINE EVOLUTION REACTION

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THE CONTRIBUTION ABSTRACT – OH13

Electrolytic hydrogen production is considered a key energy transition, carbon-neutral technology when coupled with renewable energy production processes. As the H₂ price is highly dependent on geographic location, the maritime transport of as-produced H₂ at low costs to locations where the H₂ production is unfavorable is an alternative. In this regard, seawater electrolysis is promising for in situ H₂ production and overseas transport. Although the conventional electrolysis has been extensively studied in well-defined aqueous environment characteristics (e.g., electrolyte and pH), such conditions cannot be directly applied to the seawater electrolysis at a pH ~8.2 because of the presence of several types of natural inorganic species. Conventional seawater electrolysis proceeds under alkaline conditions (pH > 13) to ensure the selectivity of the oxygen evolution reaction (OER) over the chloride oxidation reaction (CIOR). In addition, membranes are required to inhibit the chlorine reduction reaction (CIRR) at the cathode and maximize the hydrogen evolution reaction (HER) while separating H₂ from O₂. Herein, we propose a novel membraneless electrolysis process for the production of high-purity H₂ from unperturbed, unbuffered seawater at pH 8.2. To achieve this goal, we attempted to synthesize CIOR-selective anodes and CIRR-inhibitive cathodes, while completely retarding the OER at the anode and maximizing the HER at the cathode. The as-synthesized anode and cathode pair drove CIOR and HER with Faradaic efficiencies of ~100% over 100 h in a single-compartment cell containing seawater at pH 8.2. This technology is expected to enable in situ seawater electrolysis to produce high-purity H₂, which can be quickly collected and transported overseas.

TECHNO-ECONOMIC COMPARISON OF DOMESTIC AND IMPORTED GREEN HYDROGEN SUPPLY PATHWAYS FOR GERMANY

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THE CONTRIBUTION ABSTRACT – OH14

Germany's updated National Hydrogen Strategy doubles the domestic electrolysis target to 10 GW by 2030, yet projections suggest that 50–70% of national hydrogen demand will require imports. This raises a strategic dilemma between strengthening local renewable capacities and leveraging cost advantages from regions with higher solar resources.

This study compares two supply pathways for green hydrogen: (i) domestic production in Germany using hybrid photovoltaic–wind systems with battery storage, and (ii) production in Morocco via a hybrid CSP–PV plant, with hydrogen converted into ammonia for maritime shipment. The Levelized Cost of Hydrogen (LCOH) is used as the primary evaluation metric, complemented by sensitivity analyses on supply volumes.

Preliminary results indicate that domestic production ensures higher energy security but at higher costs, while imports from Morocco could achieve significantly lower LCOH values, particularly under favorable financing and scale conditions. The analysis suggests that a combined approach—balancing domestic production for resilience with imports for cost competitiveness—offers the most robust pathway.

COMPARATIVE SIMULATION OF GREEN HYDROGEN PRODUCTION VIA WATER ELECTROLYSIS FROM PHOTOVOLTAIC, WIND, AND HYBRID RENEWABLE SYSTEMS IN TRNSYS

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THE CONTRIBUTION ABSTRACT – OH15

The present study analyzes four scenarios for green hydrogen production via water electrolysis, using an alkaline electrolyzer powered by renewable energy, or supplied with electricity from the grid (yellow hydrogen). Simulations were performed with TRNSYS software using meteorologic data from Meteonorm 8 for Galbiori, Constanța, Romania. The four models for the analyzed scenarios were created in TRNSYS as follows:

- 60 kW alkaline electrolyzer powered by electricity produced using photovoltaic panels (PV).
- 60 kW alkaline electrolyzer powered by electricity produced using wind turbines.
- 60 kW alkaline electrolyzer powered by electricity produced 50% from PV and 50% from wind turbines.
- 60 kW alkaline electrolyzer powered by electricity from the national power grid.

The objectives for the modeling and simulation in TRNSYS were as follows:

- Calculation of the power production potential from PV.
- Calculation of the power production potential from wind turbines.
- Calculation of the annual electricity production from PV.
- Calculation of the annual electricity production from wind turbines.
- Calculation of the annual electricity production from both PV and wind turbines.
- Calculation of the hydrogen production for all four analyzed scenarios.
- Calculation of the electrolyzer operating period over the year.

The results of the study highlight the following:

- The PV system operates 3,615.85 h/year, producing 38,640.77 Nm³/year of hydrogen, while the wind system operates 4,588.5 h/year, producing 40,716.95 Nm³/year. Continuous energy supply boosts hydrogen production to 127,216.68 Nm³/year and improves system efficiency and electrolyzer life cycle.
- The hybrid system operating hours increased by about 1,000 h/year compared to PV and 400 h/year compared to wind. The hydrogen production flow rate increased slightly to 41,769.21 Nm³/year. The differing source potentials and lower power per source extended operation time but reduced electrolyzer efficiency.

INSIDE THE MEA: STRUCTURE–TRANSPORT CORRELATIONS AT THE NANOSCALE

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THE CONTRIBUTION ABSTRACT – OH16

The efficiency of membrane electrode assemblies (MEAs) in electrochemical energy systems critically depends on the coupling between nanoscale morphology and proton transport. However, a detailed understanding of how nanoscale structure dictates proton and water dynamics is still lacking. In this study, we combine Small-Angle Neutron Scattering (SANS) and Quasi-Elastic Neutron Scattering (QENS) to elucidate the structure–transport correlations within membrane electrode assemblies (MEAs). SANS provides quantitative insights into the nanoscale organization of water domains and the evolution of ionic-channel networks with hydration, while QENS reveals the dynamic behavior of confined water and proton motion over pico- to nanosecond timescales. Together, these techniques establish a multiscale picture linking morphological heterogeneity and dynamic processes in the membrane. The results highlight how nanoscale water structuring and connectivity govern proton diffusion pathways, offering a fundamental understanding of the transport mechanisms that underpin MEA performance and durability in fuel cell environments.

SEPARATING CO₂ FROM FLUE GASES USING A MOLTEN CARBONATE FUEL CELL

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THE CONTRIBUTION ABSTRACT – OH17

A Molten Carbonate Fuel Cell (MCFC) is shown to reduce CO₂ emissions from a Coal Fired Power Plant (CFPP). The MCFC is placed in the flue gas stream of the coal fired boiler. The main advantages of this solution are: higher total electric power generated by a hybrid system, reduced CO₂ emissions and higher system efficiency. The model of the MCFC is given and described. The results obtained show that use of an MCFC could reduce CO₂ emissions by 56%, which gives a relative CO₂ emission rate of 288 kgCO₂ per MWh.

DECENTRALISED HYDROGEN FARMING FROM PUBLIC CARPARK INFRASTRUCTURE:

A TECHNO-ECONOMIC ANALYSIS

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THE CONTRIBUTION ABSTRACT – OH18

The integration of green hydrogen as an e-fuel in the transportation sector represents a critical advancement toward deep decarbonisation, driving the transition from carbon-intensive fuels to clean, sustainable mobility solutions. When utilized as a direct fuel in vehicles and hydrogen fuel cell electric vehicles, green hydrogen addresses the pressing challenge of GHG emission of the transportation sector by enabling zero tailpipe emissions, high system efficiencies, rapid refuelling and replacement of carbon-intensive liquid fuels, thereby supporting critical carbon reductions aligned with international climate targets. This research employs a techno-economic modelling framework combined with a case analysis of a 100 kW solar-powered PEM electrolyser system in public carport infrastructure in Kuala Lumpur, Malaysia, to evaluate the technical feasibility, cost dynamics, and environmental implications of decentralized green hydrogen production and storage. The analysis considers decentralized green hydrogen generation, local solar resources, carport system design, hydrogen storage, and the logistical requirements for vehicle refuelling, alongside economic parameters such as capital and operational expenditures, levelized cost of hydrogen (LCOH), and potential carbon emission reductions. Results indicate that, the 100 kW carport solar system is expected to annually generate approximately 153,356 kWh of solar energy per year and produce 2635 kg of hydrogen. Decentralized green hydrogen production from carports offers a transformative approach to advancing the renewable energy transition and provides a scalable pathway for sustainable mobility in Malaysia. This aligns directly with national renewable energy targets and supports the objectives set forth in Malaysia's Hydrogen Economy and Technology Roadmap, contributing meaningfully to the global drive toward net-zero emissions and impactful climate action.

INVESTIGATION OF RENEWABLE-BASED HYDROGEN AND ETHANOL PRODUCTION SYSTEM

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THE CONTRIBUTION ABSTRACT – OH19

Hydrogen plays a critical role in the transition to alternative fuel production. In this regard, integrated production systems are coming to the fore in fuel production. The proposed system involves the production of renewable-based hydrogen and ethanol. The chemical reaction between captured carbon dioxide and hydrogen produced via an alkaline electrolyzer to obtain ethanol is being investigated. Aspen Plus was used to design and analyze the integrated production process. The renewable-based multigeneration system's hydrogen and ethanol production capacities were 0.00233 kg/s and 0.00526 kg/s, respectively. The system's overall energy and exergy efficiencies were 54.5% and 59.2%, respectively. The system characteristics were examined through sensitivity analysis studies.

GREEN HYDROGEN PRODUCTION USING ULTRASONICALLY ENHANCED GA-DOPED ZNO PHOTOELECTRODES

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THE CONTRIBUTION ABSTRACT – OH20

This study investigates hydrogen production by combining photoelectrochemical (PEC) and ultrasonic techniques using 1% Ga-doped ZnO/ZnO electrodes. ZnO substrates are coated with Ga-doped ZnO thin films prepared by the dip-coating method, and their performance is evaluated under illumination with and without ultrasonic excitation. The application of ultrasonic waves significantly enhances the system performance, increasing the hydrogen generation rate from 0.20 to 0.50 mL cm⁻², the energy efficiency from 0.132% to 0.352%, and the Faradaic efficiency from 0.56% to 1.82%. These results demonstrate the synergistic effect of the ultrasonic field, which improves charge separation and bubble detachment, thereby enhancing overall photoelectrochemical hydrogen production efficiency.

FUTURE PROSPECTS AND TECHNO-ECONOMIC ASSESSMENT OF OFFSHORE FLOATING SOLAR-HYDROGEN HYBRID SYSTEMS IN THE COASTAL REGIONS OF ROMANIA AND MALAYSIA

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THE CONTRIBUTION ABSTRACT – PH7

The growing global focus on clean energy has increased interest in hydrogen production powered by renewable sources. This study investigates the prospects and techno-economic performance of offshore floating solar-hydrogen hybrid systems in the coastal regions of Romania and Malaysia, which represent two distinct climatic and oceanographic conditions. The main objective is to assess the technical feasibility, hydrogen production potential, and economic competitiveness of these integrated systems. While floating solar PV has received increasing attention in recent years, its integration with offshore hydrogen production and compression and evaluate system performance, energy yield, efficiency, and the levelized cost of hydrogen (LCOH) under site-specific conditions. The results indicate that offshore floating solar platforms can constantly support continuous hydrogen generation with favorable cost-performance outcomes. Furthermore, integrating

offshore floating solar with hydrogen production presents a sustainable and scalable solution for decarbonizing maritime transport, in Malaysia and Romania, while supporting national renewable energy targets and contributing to global net-zero ambitions. Future work will emphasize the development of international standards for maritime e-fuels, the adaptation of such systems at major bunkering ports, and the formulation of carbon pricing mechanisms and policy frameworks to across coastal area, offshore, and island environments.

INVESTIGATION OF HYDROGEN PRODUCTION FROM ORGANIC WASTES THROUGH A BIO-ELECTROCHEMICAL PATHWAY

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THE CONTRIBUTION ABSTRACT – OH21

This research establishes a novel bio-electrochemical framework that links citric acid biosynthesis with hydrogen production. Wastes, including orange, apple, kiwi, persimmon, and beetroot, were used as renewable feedstocks for solid-state fermentation (SSF). *Aspergillus Niger* inoculation significantly enhanced productivity, reaching up to 3.1 g/kg citric acid on orange peel and 1.15 g/kg from persimmon peel, demonstrating efficient conversion across all substrates. Persimmon and beetroot were explored for the first time, confirming their suitability as alternative substrates. The resulting citric acid serves as a green electrolyte for hydrogen generation via electrolysis, illustrating a circular approach that integrates biological waste conversion with clean energy production.

DEVELOPMENT OF RENEWABLE HYDROGEN WITHIN ROMANIA'S ENERGY POLICY

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THE CONTRIBUTION ABSTRACT – PH8

Romania's pursuit of sustainability, decarbonisation, climate neutrality, and economic competitiveness through hydrogen use in strategic sectors requires two parallel tracks: (i) nationally coordinated research and innovation projects, and (ii) a coherent, efficient legal and policy framework with targeted measures across the full value chain that also safeguard social benefits. Alignment with European clean-energy objectives demands programmes that prioritise solution deployment, technological maturation, and innovation support via sustained investment in research and innovation to accelerate renewable hydrogen technologies.

Recent national projects have initiated this trajectory. HIDROCOMB developed a combustion technology for hydrogen-enriched natural gas operating with high excess air, alongside an experimental combustion chamber model for a gas-turbine engine. H2POSTCOMB designed, built, and tested an afterburner system installed downstream of the turbine, fuelled by pure hydrogen and hydrogen-methane blends, focusing on potential CO₂-emission reductions.

Despite these advances, gaps in legislation and funding have limited the exploitation of key results and the scaling of deployable solutions. Regulatory barriers and insufficient support hinder innovation diffusion, market entry for new products and technologies, and the associated economic growth.

ENHANCED HYDROGEN EVOLUTION PERFORMANCE USING NICKEL-COATED STAINLESS STEEL CATHODES IN ALKALINE ELECTROLYSIS

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1

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THE CONTRIBUTION ABSTRACT – OH22

In this study, the improvement of stainless steel cathodes used in alkaline electrolysis for hydrogen production through nickel coating and the effect of different operating parameters on hydrogen generation were investigated. Nickel coating was applied by electroplating to enhance the corrosion resistance and catalytic activity of stainless steel. Nickel coated stainless steel cathodes with different surface areas were tested in a cylindrical electrolyser under various electrolyte concentrations and applied voltages. The experiments showed that nickel coated stainless steel cathodes significantly improved hydrogen production performance compared to uncoated stainless steel. The highest hydrogen generation was achieved at 3 V and 1 M KOH. A comparative analysis using electrodes with different surface areas revealed that hydrogen production increased proportionally with the effective surface area; however, an increase in electrode surface area did not always translate into improved hydrogen generation, confirming the critical role of electrode geometry in reaction kinetics. These results demonstrate that low-cost nickel coatings on stainless steel can be used as promising electrodes for efficient and durable hydrogen production systems.

HYDROGEN PRODUCTION FROM WASTE-ACTIVATED SLUDGE USING A MEMBRANELESS BIOELECTROCHEMICAL REACTOR

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THE CONTRIBUTION ABSTRACT – OH23

This work examines the performance of a membraneless microbial electrolysis cell (MEC) using raw sludge and waste-activated sludge as substrates. The experimental design analyses the effect of applied voltage (0.8-1.1 V), sludge ratio (RS:WAS), electrode spacing (1.5-6.5 cm), electrode area (16-28 cm²), stirring (0-400 rpm), temperature (20–50 °C), and electrode material (aluminum, graphite, other carbon). Among these, electrode spacing and electrode material had the strongest effect on performance. An intermediate spacing of 2.5 cm gives the highest gas output (584 ppm), exceeding 1.5 cm (521 ppm), 4.5 cm (370 ppm), and 6.5 cm (291 ppm). Aluminum achieves the best overall conversion, with 13.39% energy efficiency, 15.46% exergy efficiency, and 51.93% COD removal. Graphite was the stronger carbon electrode, achieving 11.53% versus 11.19% in energy efficiency, 13.32% versus 12.93% in exergy efficiency, and 43.73% versus 38.45% in COD removal.

EXPERIMENTAL INVESTIGATION OF LAYERED COPPER OXIDE MESH ELECTRODES FOR PHOTOELECTROCHEMICAL HYDROGEN PRODUCTION

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THE CONTRIBUTION ABSTRACT – OH24

In this work copper oxide mesh photoelectrodes with different layers are developed and electrochemically assessed. The copper oxide mesh photoelectrodes consist of 2, 3, or 4 layers, respectively, with varying thicknesses. Electrochemical tests are conducted under both light and dark conditions. As the number of layers increases the light response of the photoelectrodes increase; however, the onset potential slightly decreases due to the increased overall resistance of the photoelectrodes with higher thicknesses. Linear sweep voltammetry shows that the 4-layered photoelectrode bears a current density of 2.77 mA/cm² under light conditions, and 2.61 mA/cm² for the 3-layered permutation.

ECONOMIC EVALUATION OF SOLAR-BASED LIQUID HYDROGEN UTILIZATION FOR HYDROGEN PEROXIDE PRODUCTION

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THE CONTRIBUTION ABSTRACT – OH25

In this investigation, the techno-economic analysis (TEA) for the solar-based hydrogen production and conversion process integrated with solar electricity production, electrolysis, hydrogen liquefaction, the transportation process in the cryogenic form of hydrogen, and hydrogen peroxide production via H_2O_2 production processes was carried out. This process chain analysis was carried out using the hydrogen delivery scenario analysis model, HDSAM. The solar electricity fuels the electrolysis process for gaseous hydrogen production, which undergoes liquefaction and subsequent transportation via fuel cell heavy-duty cryogenic trucks to an integrated H_2O_2 production plant. Using the HDSAM scheme, the hydrogen cost for the liquid-based hydrogen fuel station was computed to be approximately 6.29 \$/kg H_2 at an investment cost of 2.43 million USD and a payback period of approximately 6.73 years. Through the integration of solar hydrogen production and the hydrogen peroxide production process, the economic feasibility for the conversion of renewable hydrogen into a high-value chemical compound enhances the cost-effectiveness of clean hydrogen technologies.

EFFICIENCY ASSESSMENT OF A PORTABLE HYDROGEN-WATER GENERATOR

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THE CONTRIBUTION ABSTRACT – OH26

This study examined hydrogen generation and dissolution behaviour in a portable hydrogen-water (HRW) generator operated at 25 °C. Mass balance and equilibrium analysis were applied across three stages: before electrolysis, sealed after electrolysis, and immediately after opening the cap of the device. The device achieved a dissolved-hydrogen concentration of 4.3 ppm under a 2.72 atm partial pressure - about 5.5 times higher than the solubility limit at 1 atm. The increased concentration results from the elevated internal pressure during electrolysis. If the headspace contained only hydrogen, the attainable concentration would approach 8 ppm. Material characteristics also play a critical role: metal containers, being impermeable, can sustain higher internal pressures and minimise hydrogen loss, whereas polymeric bottles limit attainable pressure and allow gradual permeation. These findings highlight the combined importance of headspace composition, sealing integrity, and vessel material in determining achievable hydrogen concentration and stability in HRW systems.

GREEN HYDROGEN IN THE CONTEXT OF THE SUSTAINABLE DEVELOPMENT GOALS: ROLE, CHALLENGES, AND PERSPECTIVES

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THE CONTRIBUTION ABSTRACT – PH9

Green hydrogen represents a key pillar of the European energy transition and a fundamental enabler for achieving the Sustainable Development Goals (SDGs), particularly those related to affordable and clean energy (SDG 7), sustainable industry and infrastructure (SDG 9), climate action (SDG 13), and responsible consumption and production (SDG 12). This paper provides a comprehensive assessment of how green hydrogen technologies contribute to advancing the global sustainability agenda while enhancing the economic

resilience of European energy systems. The study examines the technological maturity and sustainability performance of the main electrolysis technologies—alkaline (AEL), polymer electrolyte membrane (PEM), solid oxide (SOE), and anion exchange membrane (AEM). These are evaluated based on key sustainability indicators such as energy efficiency, lifecycle carbon footprint, renewable resource integration, and circular economy compatibility. The analysis also incorporates recent techno-economic data, exploring their decarbonization potential across critical sectors including industry, transport, and construction. Results indicate that green hydrogen holds strong potential as a catalyst for deep decarbonization and sustainable development. Nevertheless, large-scale deployment depends on the implementation of coherent regulatory frameworks, long-term investment strategies, and effective cross-sectoral cooperation among public and private stakeholders. The paper proposes an integrated vision of the hydrogen economy, aligned with the European Green Deal and the 2030 Agenda for Sustainable Development. It underscores the importance of balancing technological innovation with environmental protection, economic competitiveness, and social inclusion to ensure a just and resilient energy transition within the European context.

Keywords: green hydrogen; Sustainable Development Goals (SDGs); energy transition; sustainability; decarbonization; energy policies.

Acknowledgements: This work was supported by the National Research Grant GNAC - ARUT 2023, contract number 35/01.07.2024, Contracting Authority: Technical University of Cluj-Napoca, Romania.

MAGNETIC ION EXCHANGE RESIN FOR SUSTAINABLE STRONTIUM RECOVERY FROM SALINE WATER

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THE CONTRIBUTION ABSTRACT – PH12

Synthesis and performance of magnetic graphene oxide/iron oxide–functionalized ion exchange resin for sustainable strontium (Sr^{+2}) recovery from saline water. Brine mining extracts valuable elements like Sr^{+2} , used in ceramics, pyrotechnics, alloys, and energy storage, from sources such as seawater and brine. Recovering Sr^{+2} sustainably and cost-effectively is challenging, especially achieving high selectivity. This study modifies commercial ion-exchange resins with magnetic graphene oxide ($\text{GO}/\text{Fe}_3\text{O}_4@ \text{IEX-R}$) via in situ co-precipitation, enhancing adsorption, selectivity, and regeneration. SEM, Raman, XRD, and FTIR confirm the successful coating of Fe_3O_4 and $\text{GO}/\text{Fe}_3\text{O}_4$; nitrogen gas improves magnetization, surface uniformity, and thermal stability. $\text{GO}/\text{Fe}_3\text{O}_4@ \text{IEX-R-2}$ removes 99% of Sr^{+2} from a 1000 ppm solution. Max adsorption capacity is 20 mg/g. The resins show excellent Sr^{+2} selectivity at pH 2–10 and can be regenerated with 1 M NaCl, maintaining stability over five cycles with minimal capacity loss. Incorporating graphene oxide and magnetic iron oxide enhances kinetic, selectivity, and separation performance. These magnetic, regenerable resins effectively recover Sr^{+2} from high-salinity water. Furthermore, the $\text{GO}/\text{Fe}_3\text{O}_4@ \text{IEX-R-2}$ shows the best removal of the Zn, Pb, Ag, Co, Ni, Ba, Cu, and Cr metals at room temperature.

Keywords: Brine, graphene oxide, strontium removal, seawater, iron oxide, magnetic resin

ADVANCING LIQUID HYDROGEN FOR HEAVY-DUTY TRANSPORT: TECHNOLOGICAL INNOVATION AND POLICY PATHWAYS IN HYLICAL

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THE CONTRIBUTION ABSTRACT – PH10

Hydrogen is increasingly viewed as a key enabler of deep decarbonisation across multiple economic sectors, particularly those considered hard to abate. However, renewable hydrogen remains costly, requiring targeted policy, financial, and technological measures to accelerate cost reduction and market uptake. The heavy-duty transport sector, including aviation, maritime, road, and rail, has significant potential for hydrogen use, either directly or through hydrogen-derived fuels. In this context, liquid hydrogen offers distinct advantages for transport and storage due to its high energy density and suitability for large-scale mobility applications.

The HyLICAL project aims to address one of the main cost barriers in the hydrogen value chain by developing and validating a new magnetocaloric liquefaction technology capable of reducing energy consumption and cost.

The innovation contributes directly to improving the efficiency and economic feasibility of hydrogen liquefaction, a critical step toward enabling competitive liquid hydrogen supply for industrial and transport uses.

Building upon this technological foundation, it is important to improve the existing EU legislative and policy frameworks and identify gaps where additional regulatory and financial instruments are needed to strengthen investor confidence and accelerate hydrogen deployment. It stresses that a coherent value chain, encompassing production, liquefaction, storage, distribution, and end-use is essential for large-scale adoption.

INTEGRATING GREEN HYDROGEN INTO BUILDING ENERGY SYSTEMS: A PATHWAY TOWARD ENERGY-AUTONOMOUS AND LOW-CARBON BUILDINGS IN ROMANIA

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THE CONTRIBUTION ABSTRACT – PH11

The transition towards energy-active buildings represents a key component in achieving decarbonization targets in accordance with the European Green Deal and the European Hydrogen Strategy. This paper investigates the potential for sustaining the energy autonomy of a building through the integration of a solar–hydrogen hybrid system, designed according to the solar irradiation conditions characteristic of the five irradiation zones identified across Romania. The proposed system integrates solar energy conversion via photovoltaic panels, short-term storage in lithium-ion batteries, and the onsite production of green hydrogen through water electrolysis using surplus renewable electricity. The hydrogen produced is subsequently converted into electricity through a fuel cell, ensuring continuous operation of the building during periods of low solar irradiation. The analysis is based on multiannual average data of global horizontal irradiation, ranging from 1300 to 1650 kWh/m²/year, corresponding to different geographical regions of Romania. The results demonstrate that Romania's solar resource, combined with modern electrolytic hydrogen technologies, can ensure a high level of energy autonomy and a substantial reduction in the carbon footprint of buildings. This study highlights the technical feasibility and strategic importance of integrating green hydrogen into building-scale energy systems, fostering the transition towards energy-active, low-carbon buildings in Romania.

Keywords: energy-active building; green hydrogen; electrolysis; fuel cell; solar energy; energy autonomy.

Acknowledgements: This work was supported by the National Research Grant GNAC - ARUT 2023, contract number 35/01.07.2024, Contracting Authority: Technical University of Cluj-Napoca, Romania..

EXPERIMENTAL ASSESSMENT OF HYDROGEN EVOLUTION IN ALKALINE MEDIA

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THE CONTRIBUTION ABSTRACT – OH27

Development of techno-economically viable hydrogen production technologies is of strategic importance in combating climate change. Water electrolysis in an alkaline medium is emerging as a mature and economically feasible technology for sustainable hydrogen production. The use of efficient and stable electrocatalysts for alkaline water electrolyzers increases hydrogen production efficiency. Cost-effective and resource-sustainable copper metal-based electrocatalysts are considered promising candidates for these systems in the literature. In this study, copper-coated nickel foam electrocatalysts were initially synthesized using an electrochemical method, characterized crystallographically and morphologically, and then their effects on hydrogen evolution in an alkaline environment were investigated.

Keywords: Copper electrocatalyst, Nickel foam, Electrosynthesis, Alkaline hydrogen evolution, Linear sweep voltammetry

AN INVESTIGATION OF LINDEN-DERIVED ACTIVATED CARBON FOR HYDROGEN STORAGE

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THE CONTRIBUTION ABSTRACT – OH28

This study evaluates the evaluation of activated carbon obtained from linden for hydrogen storage purposes and investigates the effect of ultrasonic activation with HCl. Linden leaves are first pyrolyzed at 330 °C and then activated with 25 mL of HCl solution in an ultrasonic bath at a frequency of 37 kHz for 60 min. The activated carbon is dried at 110 °C and prepared for hydrogen storage experiments. In the gravimetric experiments, 5 g of adsorbent is used, and the hydrogen storage capacity is determined at 25 °C and in the pressure range of 1 to 4 kPa. The results show that the storage capacity increases with pressure and varies between 0.29-0.54 wt.%. The capacity obtained from linden exhibits similar or higher performance than many waste-based carbons such as olive pomace and corn cob. In conclusion, the study demonstrates that linden offers a promising alternative for hydrogen storage applications as a low-cost, easily accessible, and sustainable biomass source.

GENERAL SCHEDULE – IEEEES&ICH2P – 2025

Registration will begin on December 14, 2025, from 6:00 p.m. to 7:00 p.m., at the Rectorate of the University of Craiova (13 Alexandru Ioan Cuza Street).

On December 15, 2025, the first day of the event, it will take place at the Rectorate of the University of Craiova (Alexandru Ioan Cuza Street, No. 13). The schedule is as follows:

- 8:30 a.m. ÷ 9:30 a.m. – registration and welcome coffee;
- 9:30 a.m. ÷ 10:45 a.m. – opening ceremony;
- 10:45 a.m. ÷ 11:00 a.m. – coffee break;
- 11:00 a.m. ÷ 2:00 p.m. – plenary sessions (keynote speakers, invited/host speakers);
- poster sessions (from December 15th, until December 18th);
- 2:00 p.m. ÷ 2:30 p.m. – Christmas cultural event.

On December 16, 2025, the second day of the event, it will take place at the Rectorate of the University of Craiova (Alexandru Ioan Cuza Street, No. 13) and Casa Universitarilor (Calea Unirii, No. 57). The schedule is as follows:

- 9:30 a.m. ÷ 10:00 a.m. – registration and welcome coffee;
- 10:00 a.m. ÷ 1:00 p.m. – plenary sessions (Rectorate of the University of Craiova, Alexandru Ioan Cuza street no. 13);
- 1:00 p.m. ÷ 2:30 p.m. – lunch break and travel to Casa Universitarilor, which is around a 10-20 minute drive from the University of Craiova;
- 2:30 p.m. ÷ 5:30 p.m. – parallel sessions (Casa Universitarilor, Calea Unirii no. 57).

There will also be a **Gala Dinner event** on the second day, which will take place at the **Prestige Boutique Hotel** in Craiova on Matei Basarab Street at **from 6:30 p.m.**

On December 17, 2025, the third day of the event, it will take place at the Rectorate of the University of Craiova (Alexandru Ioan Cuza Street, No. 13) and Casa Universitarilor (Calea Unirii, No. 57). The schedule is as follows:

- 9:30 a.m. ÷ 10:00 a.m. – registration and welcome coffee;
- 10:00 a.m. ÷ 1:00 p.m. – plenary sessions (Rectorate of the University of Craiova, Alexandru Ioan Cuza street no. 13);
- 1:00 p.m. ÷ 2:30 p.m. – lunch break and travel to Casa Universitarilor, which is around a 10-20 minute drive from the University of Craiova;
- 2:30 p.m. ÷ 5:30 p.m. – parallel sessions (Casa Universitarilor, Calea Unirii no. 57).

There will also be a **technical visit** to the **ICMET Craiova laboratories** on Decebal Ave., No. 118A, on the third day, **from 2:30 to 4:00 p.m.**

On the fourth and final day, December 18, 2025, the event will take place at the Rectorate of the University of Craiova (Alexandru Ioan Cuza Street, No. 13). The schedule is as follows:

- 10:00 a.m. ÷ 11:45 a.m. – plenary sessions (Rectorate of the University of Craiova, Alexandru Ioan Cuza street no. 13);
- 11:20 a.m. ÷ 11:45 a.m. – coffee break;
- 11:45 ÷ 12:45 – closing ceremony.

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