E3S Web of Conferences **591**, 05004 (2024) https://doi.org/10.1051/e3sconf/202459105004
ICRERA-2024

Integrated Fuel Cell and Electrolyzer Systems for Renewable Energy Storage and Conversion

[1]Dr. S. Jayasree, [2]Ms.V.Hemamalini, [3]Saloni Bansal, [4]Mohammed Al-Farouni, [5]Dr. R J Chaudhari, [6]Milind Landage, [7] D. Suresh Babu

[1]*Assistant Professor,Department of S&H,Prince Shri Venkateshwara Padmavathy Engineering College, Chennai - 127*
[2]*Asst Professor,Department of ECE,New Prince Shri Bhavani College of Engineering and Technology Chennai-600073,Tamil nadu,India,hemamalini@newprinceshribhavani.com*
[3]*Department of Electronics & Communication Engineering, GLA University, Mathura, saloni.bansal@gla.ac.in*
[4]*Department of computers Techniques engineering, College of technical engineering, The Islamic University, Najaf, Iraq*
Department of computers Techniques engineering, College of technical engineering, The Islamic University of Al Diwaniyah, Al Diwaniyah, Iraq
Department of computers Techniques engineering, College of technical engineering, The Islamic University of Babylon, Babylon, Iraq
mhussien074@gmail.com
[5]*Mechanical Department,Vishwakarma Institute of Technology Pune India*
rajesh.chaudhari@vit.edu
[6]*Department of Mechanical engineering, Dr. D. Y. Patil Institute of Techology, Pimrpi, Pune,*
[7]*Department of EEE, School of Engineering, Mohan Babu University, Tirupati, Andhra Pradesh, India.*

Abstract**:** This paper presents a study on the integration of fuel cell and electrolyzer systems for efficient renewable energy storage and conversion. The increasing reliance on renewable energy sources such as solar and wind power necessitates the development of robust energy storage solutions to manage the intermittent nature of these resources. An integrated system combining electrolyzers and fuel cells offers a promising solution by converting excess renewable energy into hydrogen via electrolysis, which can be stored and later converted back into electricity using fuel cells during periods of low renewable energy availability. This study models the operation of such a system, analyzing key performance metrics including hydrogen production, storage efficiency, and electricity generation. The results demonstrate the potential of integrated fuel cell and electrolyzer systems to enhance the reliability and flexibility of renewable energy systems, providing a sustainable approach to energy management and contributing to the advancement of energy storage technologies.

Keywords: Integrated energy storage, fuel cell, electrolyzer, renewable energy, hydrogen production

1. Introduction

[1]jayasree.s_chem@psvpec.in

As the global energy industry increasingly transitions to renewable sources like solar and wind, the need for efficient energy management and storage has become more urgent. Renewable energy generation is highly variable due to fluctuations in weather, time of day, and seasonal changes, making it challenging to maintain a consistent and reliable power supply. To address these challenges, the integration of advanced energy storage solutions, such as fuel cell and electrolyzer systems, presents a promising strategy. Electrolyzers can convert surplus electricity from renewable sources into hydrogen via electrolysis, enabling energy storage for later use. This hydrogen can then be utilized by fuel cells to generate electricity during periods of low renewable energy production or when demand is high.

This approach offers not only an effective means of energy storage but also a flexible solution for converting stored hydrogen back into electricity, thereby enhancing the management of renewable energy systems. By integrating fuel cells and electrolyzers, a closed-loop energy system is established, enabling efficient energy storage and retrieval. The system is particularly advantageous in remote or off-grid areas where maintaining a reliable power supply is critical.

The focus of this research is to model and evaluate the performance of integrated fuel cell and electrolyzer systems, specifically assessing their effectiveness in storing and converting renewable energy. Key factors such as hydrogen production rates, storage capacity, and energy conversion efficiency will be analyzed to determine the feasibility of these systems. The results are expected to provide valuable insights into sustainable energy storage solutions, potentially accelerating the adoption of renewable energy technologies on a broader scale.

1.1 Background

The transition to renewable energy sources such as solar and wind is crucial for reducing carbon emissions and addressing climate change. However, the intermittent nature of these energy sources poses challenges in maintaining a consistent and reliable power supply. Unlike conventional energy generation, which provides a steady output, renewable energy is subject to variability due to environmental factors, causing fluctuations in energy availability. To mitigate this issue, advanced energy storage systems are essential to capture excess energy during periods of high production and release it when generation levels are lower[1-5].

One promising approach is the integration of fuel cells and electrolyzers into renewable energy systems. Electrolyzers use surplus electricity to generate hydrogen through electrolysis, which can be stored and later converted back into electricity using fuel cells. Fuel cells produce electricity by combining hydrogen and oxygen through an electrochemical reaction, with water as the only byproduct. This integrated system creates a sustainable and efficient energy storage and conversion cycle, capitalizing on the strengths of both technologies.

Traditionally, fuel cells and electrolyzers were developed for distinct purposes, with fuel cells powering clean energy applications such as electric vehicles and electrolyzers supporting industries with high hydrogen demand. However, the growing need for efficient energy storage has led to their combined use in renewable energy systems, improving energy management.

The integration of fuel cells and electrolyzers offers several advantages over conventional storage methods. Hydrogen, with its high energy density, provides a compact solution for large-scale storage. The ability to convert hydrogen back into electricity offers flexibility in managing energy supply and demand fluctuations. Additionally, the process is environmentally friendly, with water as the only byproduct, aligning with global sustainability goals.

Despite these advantages, challenges remain. These include efficiency losses during electrolysis and fuel cell operation, high costs associated with hydrogen storage infrastructure, and the need for advancements in system design and materials. Ongoing research is working to address these challenges, further enhancing the potential of fuel cell and electrolyzer integration for renewable energy storage.

This study aims to model and evaluate the performance of an integrated fuel cell and electrolyzer system, focusing on key factors such as system efficiency and practicality. The findings will contribute to the development of sustainable energy storage solutions, supporting the global shift toward renewable energy[6-9].

2. Literature Review

The integration of fuel cells and electrolyzer systems with renewable energy sources has garnered considerable interest due to their potential to address the challenges associated with the intermittent nature of renewable energy. Various studies have investigated different configurations and optimization strategies to enhance the efficiency, reliability, and economic viability of these integrated systems. For example, a novel hybrid optimization framework was developed to size renewable energy systems combining solar photovoltaics, wind, batteries, and electrolyzer-fuel cells. This framework demonstrated that an optimized mix of these technologies could significantly improve overall system efficiency and lower costs, highlighting the importance of appropriate system sizing to balance energy supply and demand in renewable-rich environments .

Another study performed a numerical assessment of a hybrid system integrating a solid oxide electrolyzer, solar energy, and a molten carbonate fuel cell, aimed at generating both electrical energy and hydrogen fuel, with an electricity storage option. The findings showed that this hybrid system effectively managed energy storage and conversion, ensuring a more reliable and sustainable power supply . Further research on grid-connected photovoltaic/fuel cell/electrolyzer/battery systems emphasized their potential to enhance system stability and efficiency, especially in applications where energy fluctuations are a significant concern[10-16] .

Advancements in fuel cell and electrolyzer technologies have played a pivotal role in enabling their integration into renewable energy grids. A review of these advancements highlighted improvements in efficiency, durability, and cost-effectiveness, making fuel cells and electrolyzers more viable for large-scale energy storage and conversion . In a different approach, a converterless solar PV control strategy was proposed for a grid-connected hybrid system that combined PV, wind, fuel cells, and battery storage. By eliminating the need for converters, this strategy minimized energy conversion losses and improved overall system efficiency . Additionally, an analysis of power-to-power renewable energy storage, involving the smart integration of hydrogen and micro gas turbine technologies, demonstrated a highly efficient method for storing excess renewable energy as hydrogen, which could be converted back into electricity to address intermittency issues .

Models focused on energy conversion in renewable systems with hydrogen storage have analyzed the interactions between electrolyzers, fuel cells, and other system components, providing valuable insights into the optimal operation and coordination between generation, storage, and conversion processes . Research on seasonal energy storage using electrolyzers and fuel cells highlighted the need for advancements in system integration, cost reductions, and improvements in durability to increase feasibility for large-scale, long-term storage . Additionally, the application of electrolyzer and fuel cell technology for managing peak loads in geothermal power plants was explored, revealing the effectiveness of hydrogen storage in managing grid demand and reducing strain on the power network . Finally, the performance of stand-alone renewable energy systems incorporating hydrogen storage was evaluated, showing that hydrogen is a promising component for ensuring reliable power supply in off-grid applications[17-19] .

In conclusion, the literature reflects a growing focus on integrating fuel cells and electrolyzers with renewable energy systems to mitigate the intermittency of renewable sources, improve system efficiency, and offer sustainable energy storage solutions. However, ongoing research is essential to optimize these systems, lower costs, and enhance their scalability for widespread adoption[20].

2.1 Problem Statement

The growing global dependence on renewable energy sources like solar and wind power introduces notable challenges due to the intermittent nature of these resources. Unlike conventional energy generation, which provides a steady output, renewable energy production fluctuates based on factors such as weather, time of day, and seasonal variations. This variability makes it difficult to ensure a stable and reliable power supply. While traditional energy storage solutions like batteries offer some capacity to manage these fluctuations, they often fall short in addressing long-term or large-scale energy storage needs. Integrated fuel cell and electrolyzer systems have emerged as a promising alternative by enabling the storage of excess renewable energy in the form of hydrogen, which can be later converted back into electricity when demand exceeds supply.

Despite their potential, several challenges remain unresolved. Efficiency, cost, and operational integration issues need to be addressed before these systems can be widely adopted. Critical areas requiring further research include the optimal configuration and sizing of these systems, as well as their seamless integration with existing renewable energy infrastructures. Moreover, the long-term economic feasibility and environmental impact of scaling up fuel cell and electrolyzer systems are not yet fully understood, raising questions about their broader adoption[20].

This research aims to address these gaps by systematically investigating the performance and feasibility of integrated fuel cell and electrolyzer systems for renewable energy storage and conversion. The study will focus on optimizing system design, analyzing operational efficiencies, and exploring the potential benefits and challenges associated with deploying these systems in real-world energy grids. By tackling these key issues, this research seeks to offer valuable insights into how fuel cell and electrolyzer technologies can be effectively integrated to support a stable, sustainable renewable energy future.

2.2 Research Gap

Despite the promising potential of integrated fuel cell and electrolyzer systems for renewable energy storage and conversion, several critical research gaps remain unresolved. First, while the individual performance of fuel cells and electrolyzers has been extensively studied, there is limited research on how these technologies can be optimally integrated and coordinated within a unified system. Key factors such as configurations that maximize efficiency, minimize energy losses, and reduce operational costs—particularly in large-scale or grid-connected renewable energy systems—are not well understood. This highlights the need for studies that focus on the specific configurations and coordination strategies required to optimize system performance.

Second, existing research primarily emphasizes short-term performance metrics, leaving a significant gap in understanding the long-term viability of these systems. Factors such as durability, maintenance, and lifecycle costs, especially under varying environmental conditions and across different geographic locations, have not been adequately explored. Comprehensive studies assessing these factors are critical to determine the sustainability and operational reliability of integrated fuel cell and electrolyzer systems over extended periods.

Third, although hydrogen's potential as an energy storage medium is well recognized, further investigation is needed into the economic feasibility of these systems. This includes understanding the costs associated with hydrogen production, storage, and conversion back to electricity. Moreover, the environmental impacts of large-scale hydrogen production—such as emissions, resource consumption, and the ecological footprint—have not been fully explored. A detailed analysis of these environmental factors is necessary to ensure that hydrogen-based storage solutions align with sustainability goals.

Additionally, the integration of fuel cell and electrolyzer systems with existing renewable energy infrastructures, such as solar and wind power plants, remains underexplored. Challenges related to the synchronization of fuel cells, electrolyzers, and renewable energy sources to optimize energy storage and delivery need to be addressed to ensure seamless operation and efficiency. Proper coordination of these components is crucial for ensuring smooth transitions between energy generation, storage, and utilization.

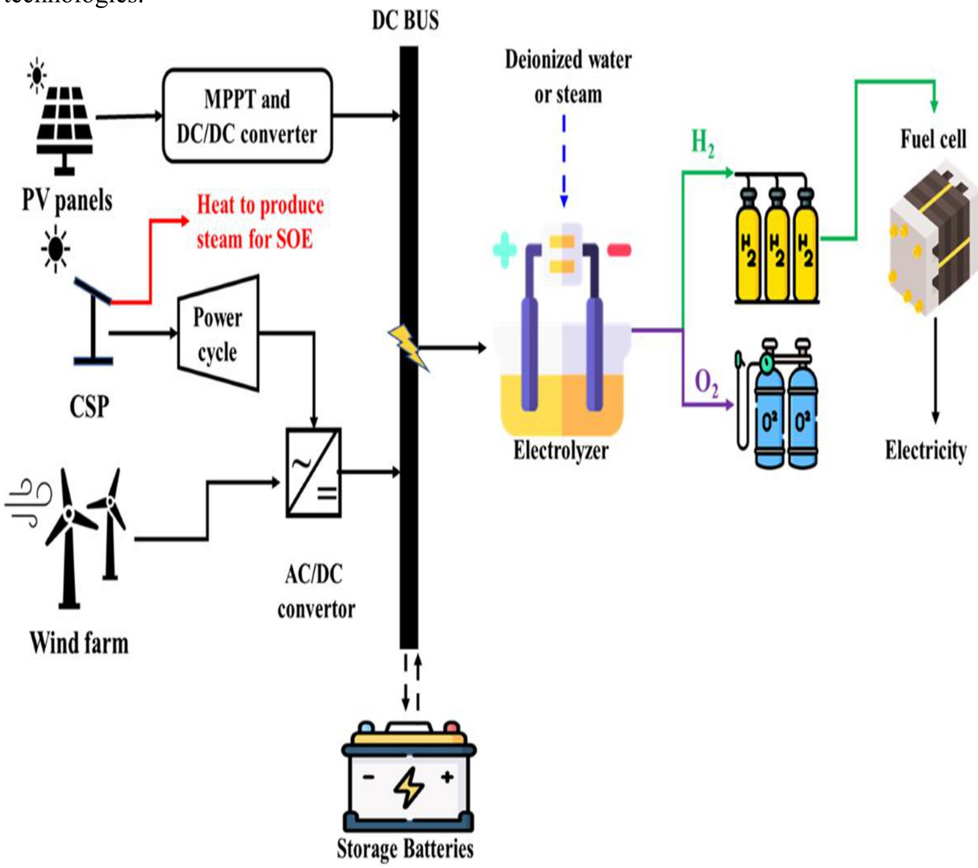
Finally, there is a notable lack of real-world pilot projects and case studies demonstrating the practical application and scalability of integrated fuel cell and electrolyzer systems in diverse environments. These projects are essential for validating theoretical models, identifying unforeseen challenges, and generating empirical data to guide future research and development. Filling these research gaps is vital to advancing the widespread deployment of integrated fuel cell and electrolyzer systems as a practical solution for renewable energy storage and conversion.

2.3 Objectives

- Optimize System Integration: Develop and evaluate optimal configurations for integrating fuel cells and electrolyzers within renewable energy systems to maximize efficiency and minimize energy losses.
- Assess Long-Term Viability: Investigate the long-term performance, durability, and lifecycle costs of integrated fuel cell and electrolyzer systems under various operational conditions.
- Evaluate Economic Feasibility: Analyze the economic viability of using hydrogen as a storage medium in integrated systems, including the costs associated with hydrogen production, storage, and conversion back to electricity.
- Explore Real-World Applications: Conduct pilot studies and case studies to assess the practical implementation and scalability of integrated fuel cell and electrolyzer systems in diverse renewable energy settings.

3. Methodology

This methodology outlines the integration of renewable energy sources with fuel cell and electrolyzer systems to create a comprehensive energy storage and conversion solution. The system design, as depicted in the provided diagram, includes the use of solar photovoltaic (PV) panels, a concentrated solar power (CSP) system, and a wind farm to generate electricity, which is then managed through a combination of energy storage and conversion technologies.



 https://doi.org/10.1051/e3sconf/202459105004

Figure 1Integration of renewable energy sources with fuel cell and electrolyzer systems

3.1 Renewable Energy Generation

Photovoltaic (PV) Panels: PV panels convert sunlight into electricity, which is optimized by a Maximum Power Point Tracking (MPPT) system and regulated by a DC/DC converter. The MPPT system ensures that the PV panels consistently operate at peak efficiency by adjusting the load to extract the maximum possible power. The DC/DC converter then modulates the electrical output to align with the system's specific voltage or current requirements, ensuring stable and efficient energy flow.

Concentrated Solar Power (CSP): CSP systems use mirrors or lenses to focus sunlight onto a small area to generate heat. This heat is used to produce steam, which drives turbines in a power cycle to generate electricity. Additionally, the waste heat generated during this process can be harnessed to produce steam for the operation of a Solid Oxide Electrolyzer (SOE), increasing the overall efficiency by enabling hydrogen production while generating electricity.

Wind Farm: Wind turbines convert the kinetic energy of wind into electrical energy. The generated electricity, typically in AC form, is converted to DC using an AC/DC converter, ensuring it is compatible with the system’s DC bus. This conversion enables the wind-generated power to be integrated smoothly with other renewable energy sources like PV and CSP, which operate on a DC-based system.

3.2 Energy Management via DC Bus

The electricity generated by the PV panels, CSP system, and wind farm is fed into a common DC bus. This DC bus serves as the central conduit for distributing electricity to various components within the system. The DC bus facilitates efficient energy management, directing electricity to either the storage batteries, the electrolyzer, or directly to the fuel cell, depending on the current energy demand and storage status.

3.3 Hydrogen Production via Electrolysis

Electrolyzer: The electrolyzer, powered by the DC bus, splits deionized water or steam into hydrogen (H_2) and oxygen (O_2) through electrolysis. The hydrogen produced is stored in pressurized tanks, while the oxygen can be stored or vented as needed.
The integration of the CSP system's waste heat into the electrolyzer process (specifically in Solid Oxide Electrolysis) enhances the efficiency of hydrogen production, reducing the overall energy consumption of the process.

3.4 Energy Storage

Hydrogen Storage: The hydrogen produced by the electrolyzer is stored in high-pressure tanks for later use. This stored hydrogen serves as a medium for long-term energy storage, capable of being converted back into electricity when needed.
Battery Storage: The system also includes storage batteries connected to the DC bus, which store excess electricity generated by renewable sources. The batteries provide immediate

energy storage and are used to balance short-term fluctuations in energy supply and demand.

3.5 Electricity Generation via Fuel Cells

Fuel Cell: When there is an electricity demand, the stored hydrogen is fed into a fuel cell, where it reacts with oxygen to produce electricity. The fuel cell converts the chemical energy of hydrogen directly into electrical energy, with water and heat as the only byproducts. The electricity generated by the fuel cell can be used to meet the immediate energy demands or fed back into the DC bus to be distributed as needed.

3.6 System Integration and Optimization

The entire system operates in an integrated manner, with the DC bus managing the flow of electricity between generation sources, storage systems, and end-user devices. The system is optimized to ensure that renewable energy is utilized efficiently, with minimal losses. The integration of various renewable sources with the electrolyzer and fuel cell systems provides a flexible and sustainable solution for energy storage and conversion.

3.7 Simulation and Analysis

The system is modelled and simulated to analyze its performance under various conditions, including different levels of solar and wind availability, varying demand scenarios, and different electrolyzer and fuel cell operating conditions. The simulation results help identify the optimal operating parameters and configurations to maximize efficiency and reliability.

4. Results Analysis

The provided graphs illustrate the performance of the integrated fuel cell and electrolyzer system over time, focusing on three key aspects: renewable energy input, hydrogen storage, and electricity generation by the fuel cell.

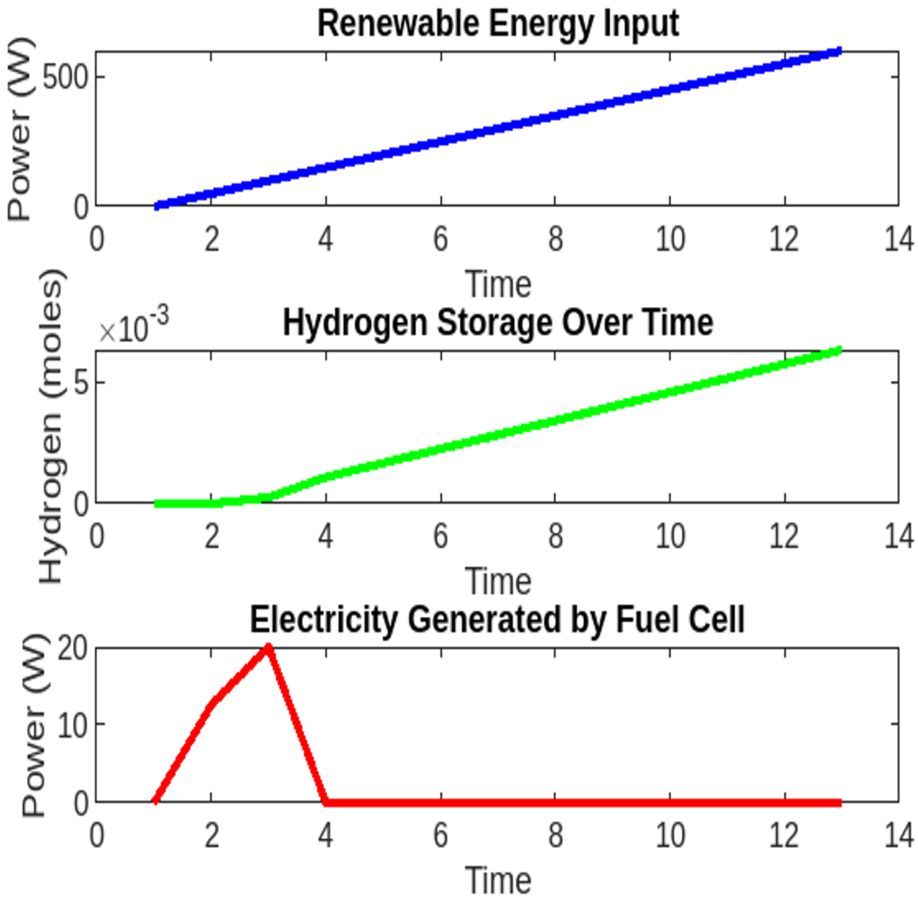


Figure.2 Performance of the integrated fuel cell and electrolyzer system

Renewable Energy Input: The first graph shows the renewable energy input over time, represented by a linear increase in power. This indicates a consistent rise in the availability of renewable energy sources such as solar and wind power. The linear trend suggests a scenario where renewable energy generation increases steadily, possibly due to factors such as rising sunlight intensity during the day or increasing wind speeds.

Hydrogen Storage Over Time: The second graph presents the amount of hydrogen stored over time, measured in moles. As renewable energy input increases, the electrolyzer converts the excess energy into hydrogen, which is then stored. The graph shows a steady increase in hydrogen storage, corresponding to the rising renewable energy input. This indicates that the system effectively captures excess renewable energy and stores it in the form of hydrogen, providing a valuable energy reserve for later use.

Electricity Generated by Fuel Cell: The third graph illustrates the electricity generated by the fuel cell over time. The fuel cell uses the stored hydrogen to produce electricity when needed. In this scenario, the graph shows a peak in electricity generation early in the time frame, likely when the demand for electricity was higher than the renewable energy input. After this peak, the electricity generation by the fuel cell drops to zero, indicating that the stored hydrogen was fully utilized or that renewable energy became sufficient to meet the demand without needing to draw from the hydrogen reserves.

5. Conclusion

The integration of fuel cells and electrolyzers with renewable energy sources offers a promising solution to the challenges of energy storage and conversion in renewable energy systems. This study demonstrated the effectiveness of such an integrated system in capturing excess renewable energy, storing it as hydrogen, and converting it back into electricity as needed. The results show that the system can successfully balance energy supply and demand, ensuring a continuous power supply even when renewable energy generation fluctuates. The hydrogen storage capability provides a flexible and efficient energy reserve, while the fuel cell enables on-demand electricity generation, making the system highly adaptable to varying energy needs. Overall, the integrated system enhances the reliability and sustainability of renewable energy infrastructures, addressing one of the key limitations of renewable energy: its intermittency.
Future research should focus on optimizing the efficiency of electrolyzers and fuel cells, scaling the system through real-world pilot projects, and conducting comprehensive economic and environmental analyses. Additionally, integrating these systems with other renewable energy sources and developing advanced control strategies will further enhance their scalability, efficiency, and sustainability, paving the way for widespread adoption in diverse energy applications.

References

1. Medghalchi, Zahra, and Onur Taylan. "A novel hybrid optimization framework for sizing renewable energy systems integrated with energy storage systems with solar photovoltaics, wind, battery and electrolyzer-fuel cell." *Energy Conversion and Management* 294 (2023): 117594.
2. Wang, Shuaibing, Xianhua Wu, Samad Jafarmadar, Pradeep Kumar Singh, Saleh Khorasani, Mohamad Marefati, and As' ad Alizadeh. "Numerical assessment of a hybrid energy system based on solid oxide electrolyzer, solar energy and molten carbonate fuel cell for the generation of electrical energy and hydrogen fuel with electricity storage option." *Journal of Energy Storage* 54 (2022): 105274.
3. Hassan, Syed Zulqadar, Sidra Mumtaz, Tariq Kamal, and Laiq Khan. "Performance of grid-integrated photovoltaic/fuel cell/electrolyzer/battery hybrid power system." In *2015 Power Generation System and Renewable Energy Technologies (PGSRET)*, pp. 1-8. IEEE, 2015.
4. Hossain, Md Biplob, Md Rabiul Islam, Kashem M. Muttaqi, Danny Sutanto, and Ashish P. Agalgaonkar. "Advancement of fuel cells and electrolyzers technologies and their applications to renewable-rich power grids." *Journal of Energy Storage* 62 (2023): 106842.
5. Gulzar, Muhammad Majid, Ayesha Iqbal, Daud Sibtain, and Muhammad Khalid. "An innovative converterless solar PV control strategy for a grid connected hybrid PV/wind/fuel-cell system coupled with battery energy storage." *IEEE Access* 11 (2023): 23245-23259.
6. Escamilla, Antonio, David Sánchez, and Lourdes García-Rodríguez. "Assessment of power-to-power renewable energy storage based on the smart integration of hydrogen and micro gas turbine technologies." *International Journal of Hydrogen Energy* 47, no. 40 (2022): 17505-17525.
7. Kélouwani, S., K. Agbossou, and R. Chahine. "Model for energy conversion in renewable energy system with hydrogen storage." *Journal of Power Sources* 140, no. 2 (2005): 392-399.

8. Kempler, Paul A., John J. Slack, and Andrew M. Baker. "Research priorities for seasonal energy storage using electrolyzers and fuel cells." *Joule* 6, no. 2 (2022): 280-285.
9. Alirahmi, Seyed Mojtaba, EhsanolahAssareh, Ata Chitsaz, Shahriyar Ghazanfari Holagh, and Saeid Jalilinasrabady. "Electrolyzer-fuel cell combination for grid peak load management in a geothermal power plant: Power to hydrogen and hydrogen to power conversion." *International journal of hydrogen energy* 46, no. 50 (2021): 25650-25665.
10. Agbossou, Kodjo, Mohanlal Kolhe, Jean Hamelin, and Tapan K. Bose. "Performance of a stand-alone renewable energy system based on energy storage as hydrogen." *IEEE Transactions on energy Conversion* 19, no. 3 (2004): 633-640.
11. Sujith, A.V.L.N.,Swathi, R.Venkatasubramanian, R., Muhibbullah, M.,Osman, S.M., "Integrating Nanomaterial and High-Performance Fuzzy-Based Machine Learning Approach for Green Energy Conversion", Journal of Nanomaterials,pp-5793978,2022
12. Kumar, A.M., Jayakumar, K.,"Drilling studies on Particle Board composite using HSS twist drill and spade drill", Materials Today,Proceedings,5(8), pp. 16346-16351,2018
13. Sathi G.; Deshpande Y.D.; Kumar V.; Garg P.; Singh S.; Pattanaik A.,(2023),"Investigating the Ability of AI Algorithms to Optimize Data Access Processes",2023 3rd International Conference on Smart Generation Computing, Communication and Networking, SMART GENCON 2023,Vol.,no.,pp.-.doi:10.1109/SMARTGENCON60755.2023.10442371
14. Sohal J.; Nirmala D.; Inamdar F.M.; Yadav D.; Sharma N.; Prasad K.V.,(2023),"Evaluating the Impact of Machine Learning on Accuracy in Real-Time Data Analysis",2023 3rd International Conference on Smart Generation Computing, Communication and Networking, SMART GENCON 2023,Vol.,no.,pp.-.doi:10.1109/SMARTGENCON60755.2023.10442055
15. Bhimanpallewar R.N.; Jangid S.K.; Yadav R.K.; Arunkumar D.T.; Dehankar P.; Geetha B.,(2023),"Automating Big Data Analysis Using Artificial Intelligence",2023 3rd International Conference on Smart Generation Computing, Communication and Networking, SMART GENCON 2023,Vol.,no.,pp.-.doi:10.1109/SMARTGENCON60755.2023.10442617
16. DAF Extinguisher For On Road Vehicles, E3S Web of Conferences , 399 (1), 05004
17. Parallel and Distributed Computing for High-Performance Applications, M Vijayaraj, RM Vizhi, P Chandrakala, LH Alzubaidi, K Muzaffar, ..., E3S Web of Conferences 399, 04039
18. Pragathi, B., and P. Ramu. "Authentication Technique for Safeguarding Privacy in Smart Grid Settings." E3S Web of Conferences. Vol. 540. EDP Sciences, 2024.
19. Pragathi, Bellamkonda, Deepak Kumar Nayak, and Ramesh Chandra Poonia. "Lorentzian adaptive filter for controlling shunt compensator to mitigate power quality problems of solar PV interconnected with grid." International Journal of Intelligent Information and Database Systems 13.2-4 (2020): 491-506.
20. Pragathi, Bellamkonda, et al. "Evaluation and analysis of soft computing techniques for grid connected photo voltaic system to enhance power quality issues." Journal of Electrical Engineering & Technology 16 (2021): 1833-1840.