Sustainable Hydrogen Production Through Solar Powered Electrolysis

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***Abstract*—The increasing demand for clean and sustainable energy has led to growing interest in hydrogen as a future energy carrier. This paper presents the design, hardware implementation, and performance analysis of a solar-powered hydrogen production system based on water electrolysis. The proposed system integrates a photovoltaic (PV) panel, a DC–DC buck converter with Maximum Power Point Tracking (MPPT) control, an electrolyser, and a battery energy storage unit to ensure stable and continuous operation. The hardware implementation was carried out to regulate the variable output of the solar panel and to provide a controlled DC supply to the electrolyser for efficient hydrogen generation. Experimental observations obtained from the hardware setup are supported by simulation studies performed using MATLAB/Simulink under different operating conditions. The results demonstrate stable voltage regulation, effective utilization of solar energy, and reliable hydrogen production. The developed system confirms the practical feasibility of solar-powered electrolysis as an environmentally friendly approach for sustainable hydrogen generation and provides a foundation for future improvements and real-world renewable energy applications.**

***Index Terms*—Electrolysis, Green hydrogen, MPPT, Renewable energy, Solar photovoltaic system**

I. INTRODUCTION

The increasing use of fossil fuels and the resulting environmental problems, such as air pollution and global warming, have created a strong need for clean and renewable energy sources. In this context, hydrogen has gained significant attention as a future energy carrier because of its high energy density and its ability to produce energy without harmful emissions. Hydrogen can be used in various applications including power generation, transportation, and industrial processes. However, most of the hydrogen produced today comes from fossil-fuel-based methods, which release large amounts of carbon dioxide and are not environmentally sustainable.

Green hydrogen production through water electrolysis using renewable energy sources offers a clean alternative to conventional methods. Among the available renewable sources, solar energy is widely preferred due to its abundance, easy availability, and direct conversion into electrical energy using photovoltaic (PV) systems. Despite these advantages, the output power from solar panels varies continuously with changes in sunlight intensity and temperature, which makes it difficult to supply stable power to an electrolyser.

To overcome this challenge, power electronic converters with Maximum Power Point Tracking (MPPT) control are used to extract maximum power from the PV system while maintaining a regulated output voltage. In addition, incorporating a battery energy storage system helps in storing excess energy during high solar availability and supplying power during low or no sunlight conditions. This paper presents the modelling and simulation of a solar-powered hydrogen production system that integrates a PV panel, DC–DC boost converter with MPPT control, battery storage, and an electrolyser. The proposed system aims to improve solar energy utilization and achieve reliable and sustainable hydrogen generation.

II. RELATED WORK

Several studies have been carried out on hydrogen production using renewable energy sources, particularly solar energy, to reduce dependence on fossil fuels. Previous research has shown that integrating

photovoltaic (PV) systems with water electrolysis is a promising approach for clean hydrogen generation.
Recent studies highlight the importance of power electronic converters and control strategies in improving system efficiency. Researchers have demonstrated that the use of Maximum Power Point Tracking (MPPT) techniques significantly enhances power extraction from PV systems under varying solar conditions. Without proper regulation, direct coupling of PV panels to electrolysers leads to voltage instability and reduced hydrogen output.
Other works have focused on different electrolyser technologies, such as Proton Exchange Membrane (PEM) and alkaline electrolysers, and concluded that PEM electrolysers offer better efficiency and faster response when operated with renewable energy sources. The integration of battery energy storage systems has also been reported to improve system reliability by compensating for the intermittent nature of solar energy.
Although existing studies confirm the feasibility of solar-powered hydrogen production, many systems suffer from power fluctuations and limited energy utilization. Based on these observations, this work focuses on a regulated solar-powered electrolysis system using a DC–DC boost converter with MPPT control and battery storage to achieve stable operation and efficient hydrogen production.

III. SYSTEM DESCRIPTION AND WORKING

The proposed system aims to produce hydrogen in an eco-friendly manner by using solar energy as the main power source. It consists of a photovoltaic (PV) panel, a DC–DC boost converter with Maximum Power Point Tracking (MPPT) control, an electrolyser, and a battery energy storage unit. All these components work together to ensure efficient energy conversion and continuous hydrogen generation.
The PV panel converts sunlight directly into DC electrical power. However, the output from the solar panel is not constant, as it changes with variations in sunlight intensity and temperature. To handle this variation and to extract the maximum possible power from the PV panel, an MPPT technique is used. The MPPT controller continuously adjusts the duty cycle of the DC–DC boost converter so that the PV system operates at its optimum power point under different conditions.
The DC–DC boost converter is used to regulate the varying voltage from the PV panel and supply a stable DC voltage to the electrolyser. This voltage regulation is important to protect the electrolyser from sudden fluctuations and to improve its operating efficiency. The regulated power is then fed to the electrolyser, where water is split into hydrogen and oxygen through an electrochemical process. Hydrogen gas is produced at the cathode, while oxygen is released at the anode.

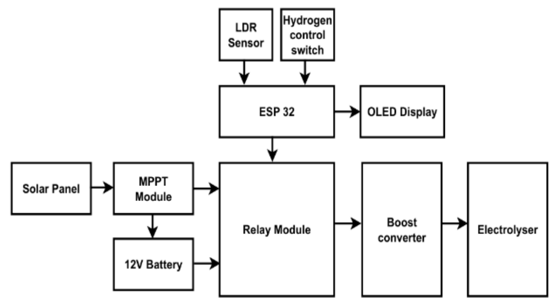

Fig.1 Block Diagram of Solar powered electrolysis

To maintain uninterrupted hydrogen production, a battery storage system is included in the setup. When excess solar power is available, the battery gets charged and stores energy. During periods of low or no sunlight, the battery supplies power to the electrolyser, ensuring continuous system operation. This integration of power control and energy storage improves system reliability and makes the proposed setup suitable for sustainable hydrogen production.

IV. METHODOLOGY AND SIMULATION SETUP

The methodology of the proposed system focuses on effectively converting solar energy into hydrogen using a controlled and stable electrolysis process. The overall approach involves modelling each subsystem, integrating them into a single framework, and evaluating system performance under different operating conditions. MATLAB/Simulink is used as the simulation platform due to its flexibility in modelling power electronic systems and renewable energy sources.
The photovoltaic (PV) panel is modelled to represent real operating conditions by considering variations in solar irradiance and temperature. Since the output from the PV panel is variable in nature, a DC–DC boost converter is used to regulate the voltage supplied to the electrolyser. To ensure maximum power extraction from the PV system, a Maximum Power Point

Tracking (MPPT) technique based on the Perturb and Observe (P&O) algorithm is implemented. This algorithm continuously monitors the PV voltage and current and adjusts the converter duty cycle to maintain operation at the maximum power point.

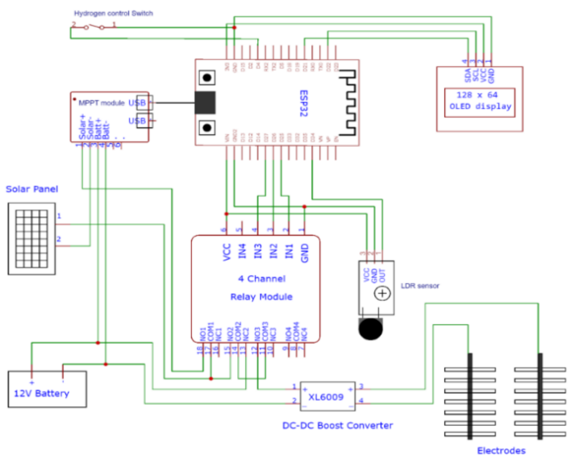

Fig.2 Circuit Diagram of the system

The regulated DC output from the boost converter is supplied to the electrolyser, which is modelled to simulate the water electrolysis process. The hydrogen production rate is directly related to the current supplied to the electrolyser, making proper voltage and current control essential for efficient operation. A battery energy storage system is integrated into the model to store excess solar energy during high irradiance conditions and to provide backup power when solar energy is insufficient.

The complete system is tested under different operating modes, including high solar availability, reduced solar input, and battery-supported operation. Key performance parameters such as PV output voltage, converter efficiency, system stability, and hydrogen generation behaviour are observed and analysed. This simulation-based methodology helps validate the effectiveness of the proposed system before practical implementation.

V. HARDWARE IMPLEMENTATION

The hardware implementation of the proposed solar-powered hydrogen production system was carried out to validate the practical feasibility of the simulated model. The system integrates a photovoltaic (PV) panel, a DC–DC boost converter with Maximum Power Point Tracking (MPPT) control, an electrolyser, a battery energy storage unit, and basic measuring and protection components. All hardware elements are selected to ensure stable operation, efficient energy conversion, and safe hydrogen generation.

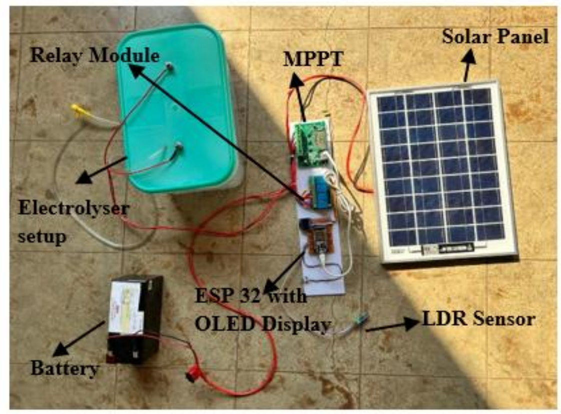

Fig.3 Hardware implementation

The photovoltaic panel acts as the primary energy source and converts solar energy into direct current (DC) electrical power. Since the output from the PV panel varies with changes in sunlight intensity and temperature, direct connection to the electrolyser is not suitable. Therefore, the PV output is fed into a DC–DC boost converter, which regulates the voltage to the required level for electrolyser operation. The converter is controlled using an MPPT algorithm based on the Perturb and Observe method, which continuously adjusts the duty cycle to extract maximum power from the solar panel under varying environmental conditions.

The regulated DC output from the boost converter is supplied to the electrolyser, where water is split into hydrogen and oxygen through an electrochemical process. Hydrogen gas is produced at the cathode and collected for observation, while oxygen is released at the anode. The rate of hydrogen generation depends on the electrical input supplied to the electrolyser, highlighting the importance of stable voltage and current regulation.

To ensure uninterrupted operation, a battery energy storage system is integrated into the hardware setup. During periods of high solar availability, excess energy from the PV panel is stored in the battery. When solar power is insufficient or unavailable, the battery supplies power to the electrolyser, allowing continuous hydrogen production. Measuring instruments such as voltmeters and ammeters are used to monitor

voltage and current at different stages of the system. Protective elements, including fuses and reverse polarity protection, are incorporated to enhance system safety and reliability.
The complete hardware setup was tested under different operating conditions to observe system behaviour, voltage stability, and hydrogen generation performance. The successful implementation demonstrates that the proposed system can efficiently utilize solar energy for sustainable hydrogen production and serves as a practical foundation for future scaling and real-world applications.

VI. RESULTS AND DISCUSSION

The performance of the proposed solar-powered hydrogen production system was evaluated through simulation using MATLAB/Simulink. The system was tested under different operating conditions to analyze voltage regulation, power utilization, and hydrogen generation behaviour. The obtained results confirm the effectiveness of the proposed methodology in achieving stable and continuous hydrogen production.

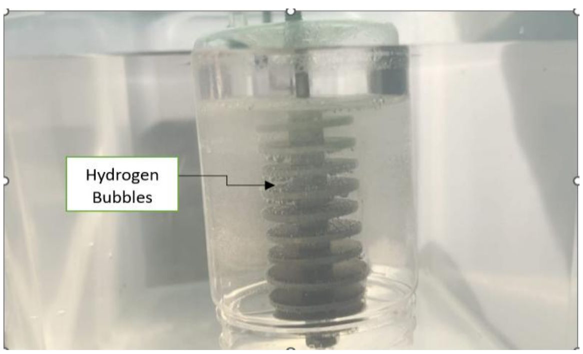

Fig.4 Hydrogen Bubbles at the electrode

The photovoltaic (PV) panel output varied with changes in solar irradiance, producing a fluctuating DC voltage. However, the DC–DC boost converter, controlled by the MPPT algorithm, successfully regulated this varying input and supplied a stable voltage to the electrolyser. This regulation is essential for protecting the electrolyser and ensuring efficient electrolysis. The MPPT controller was able to track the maximum power point effectively, resulting in high power extraction efficiency from the PV system.
The electrolyser operation showed a clear relationship between the supplied current and the rate of hydrogen generation. Hydrogen production started once the threshold voltage was reached, and the generation rate increased with an increase in current. This confirms that proper voltage and current control significantly improve hydrogen output. The simulation results also showed minimal voltage ripple at the electrolyser input, indicating stable operation of the power conditioning stage.
The battery energy storage system played an important role in maintaining system reliability. During periods of high solar availability, excess energy was stored in the battery. When solar input was reduced or unavailable, the battery supplied power to the electrolyser, allowing uninterrupted hydrogen production. This behaviour demonstrates the effectiveness of the energy management strategy in handling the intermittent nature of solar energy.
Overall, the simulation results validate that the proposed system efficiently utilizes solar energy for hydrogen production. The coordinated operation of the PV panel, MPPT-controlled boost converter, battery storage, and electrolyser ensures system stability, improved energy utilization, and reliable hydrogen generation, making the system suitable for sustainable energy applications.

VII. CONCLUSION

This paper presented a solar-powered hydrogen production system based on water electrolysis, aimed at achieving clean and sustainable energy generation. The proposed system successfully integrated a photovoltaic (PV) panel, a DC–DC boost converter with Maximum Power Point Tracking (MPPT) control, a battery energy storage system, and an electrolyser to ensure efficient and stable hydrogen production.
Simulation results obtained using MATLAB/Simulink demonstrated that the MPPT-controlled boost converter effectively regulated the variable solar output and improved overall energy utilization. The inclusion of a battery storage system addressed the intermittency of solar energy and enabled continuous system operation under varying solar conditions. The electrolyser performance showed a direct relationship between electrical input and hydrogen generation, confirming the effectiveness of the power conditioning and control strategy.
Overall, the results indicate that solar-powered electrolysis is a feasible and environmentally friendly method for hydrogen production. The proposed

system provides a simple and scalable approach for green hydrogen generation and can be further extended by incorporating advanced control techniques, improved storage methods, and hardware implementation for real-time validation in future work.

APPENDIX

This appendix briefly provides additional information about the simulation setup used in this study. The proposed solar-powered hydrogen production system was modelled and analysed using MATLAB/Simulink. The model included a photovoltaic (PV) panel, a DC–DC boost converter with MPPT control, a battery energy storage unit, and an electrolyser. Standard operating parameters were selected to represent a small-scale laboratory system and to evaluate performance under different solar conditions.
The simulation was carried out to observe voltage regulation, power flow, and hydrogen generation behaviour under varying irradiance levels. These additional details support the understanding of the system design and help validate the results presented in the main sections of the paper.

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