Hydrogen Generation From Solar Energy Using Electrolysis

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Abstract— The increasing demand for clean and sustainable energy has encouraged the development of renewable hydrogen production technologies. This research presents a solar-powered hydrogen generation system based on water electrolysis, integrating photovoltaic energy with electrical monitoring and hydrogen leakage detection. A 12 V, 10 W solar panel is used as the primary energy source, while a DC-DC boost converter provides the required electrical supply for the electrolysis process. A 12 V, 2 Ah lithium battery and an external power supply are incorporated to support system operation under varying solar conditions. An Arduino UNO controller monitors the system using voltage, current, and hydrogen gas sensors. The measured parameters are displayed on an LCD, while a buzzer provides an immediate warning when hydrogen leakage is detected. The system is designed to demonstrate the relationship between available electrical power and hydrogen generation during experimental operation. Performance evaluation can include voltage, current, power consumption, hydrogen production rate, and leakage detection response. The proposed prototype provides a compact experimental platform for studying solar-assisted hydrogen generation and demonstrates the integration of renewable energy, electrolysis, real-time parameter monitoring, and basic safety protection.

Keywords— Solar Energy; Hydrogen Generation; Water Electrolysis; Arduino UNO; Hydrogen Leakage Detection etc.

I. INTRODUCTION

The increasing demand for energy, depletion of conventional fossil-fuel resources, and environmental concerns associated with carbon emissions have encouraged the development of renewable and sustainable energy technologies. Hydrogen is considered an important energy carrier because it can be stored, transported, and utilized in different energy applications. When produced using renewable electricity, hydrogen can contribute to reducing the environmental impact associated with conventional hydrogen-production pathways. Recent studies have therefore focused on integrating renewable energy sources with water-electrolysis technologies for sustainable hydrogen production [1], [2].

Water electrolysis is an electrochemical process in which electrical energy is used to split water into hydrogen and oxygen. The overall reaction can be expressed as \(2H_2O \rightarrow 2H_2 + O_2\). In a solar-powered configuration, electricity generated by photovoltaic (PV) panels is supplied to an electrolyzer, allowing solar energy to be converted into chemical energy stored in hydrogen. PV-electrolysis systems have received considerable research attention because they provide a direct pathway for coupling renewable electricity with hydrogen production [1], [3].

Solar photovoltaic technology is particularly suitable for small-scale hydrogen-generation systems because PV panels can directly produce DC electricity required by electrolysis systems. However, solar irradiation varies throughout the day because of weather and operating conditions. This variation can influence the voltage and current supplied to the electrolyzer and consequently affect hydrogen-production performance. Research on PV-electrolyzer integration has highlighted the importance of appropriate electrical matching, system sizing, and operating strategies for maintaining efficient hydrogen production under variable solar conditions [3], [4].

Energy storage can provide an additional means of addressing the intermittent nature of solar energy. A battery can store electrical energy when solar generation is available and provide supplementary power when solar output decreases. Recent reviews have specifically examined PV systems combined with battery storage and water electrolysis, indicating that storage can support more stable electrolyzer operation, although it also introduces additional system cost and conversion losses [2], [4].

The present research develops a compact solar-powered hydrogen-generation prototype using a 12 V, 10 W solar panel, DC-DC boost converter, 12 V, 2 Ah lithium battery, external DC power supply, and water electrolyzer. The boost converter is incorporated to provide an appropriate electrical supply to the electrolysis unit. An Arduino UNO is used as the local controller for monitoring important electrical and safety parameters. A voltage sensor and current sensor are employed to measure the electrical operating conditions, while an LCD provides local display of the measured information.

Safety is an important consideration in hydrogen-generation systems because hydrogen is highly flammable and leakage can create hazardous conditions. Recent literature identifies safety, storage, weather variation, and system efficiency among the important challenges associated with solar-powered hydrogen systems [5]. Therefore, the proposed prototype incorporates a hydrogen gas sensor for leakage detection and a buzzer for local warning. Unlike IoT-based systems, the proposed arrangement performs monitoring and warning functions locally through the Arduino controller, making the prototype relatively simple and suitable for laboratory-scale experimental investigation.

The main purpose of this research is to experimentally investigate solar-assisted hydrogen generation through water electrolysis and evaluate the associated electrical and safety parameters. The study considers solar voltage, electrolyzer current, electrical power, hydrogen-generation behaviour, and hydrogen-leakage detection. The work provides a practical platform for demonstrating the conversion of solar electrical energy into hydrogen energy while incorporating basic real-time monitoring and safety protection. Such a prototype can also support further investigation into PV-electrolyzer matching, battery-assisted operation, hydrogen production rate, and system efficiency.

II. PROBLEM IDENTIFICATION

- Fossil-Fuel Dependence: Increasing energy demand and dependence on conventional fuels create a need for cleaner and renewable energy sources. Hydrogen offers potential as a clean energy carrier for future applications.
- Renewable Hydrogen Production: Conventional hydrogen production can involve non-renewable energy sources. Therefore, integrating solar photovoltaic energy with water electrolysis provides an alternative pathway for producing hydrogen using renewable electricity.
- Variable Solar Power: Solar energy availability changes with sunlight conditions, affecting the electrical power supplied to the electrolyzer. A boost converter and battery are therefore required to support suitable system operation.
- Monitoring and Safety: Hydrogen generation requires monitoring of voltage, current, and possible gas leakage. A simple Arduino-based monitoring system with an LCD and buzzer is needed to observe operating conditions and provide leakage warnings.

A. Existing System

- Conventional Hydrogen Production: Existing hydrogen-generation systems commonly use dedicated electrolysis units or other hydrogen-production methods. The uploaded seminar focuses on using solar PV electricity to operate an electrolyzer for splitting water into hydrogen and oxygen.
- Solar-Electrolysis Configuration: The proposed existing configuration consists of solar PV generation, electrical conversion, an electrolyzer, sensing, and a microcontroller-based monitoring arrangement. The generated hydrogen can subsequently be collected for energy applications.
- Parameter Monitoring: Electrical parameters and system operation are monitored using sensors and a controller, while the display provides information about the operating condition.

B. Drawbacks

- Solar Intermittency: Solar-powered electrolysis depends on available solar irradiation. Changes in sunlight can cause variations in the electrical power supplied to the electrolyzer and consequently influence hydrogen production.
- Energy Storage Requirement: Because solar generation is variable, additional battery storage or an external electrical supply may be required to maintain suitable operation when solar power is insufficient.
- Hydrogen Safety: Hydrogen leakage is an important safety consideration because hydrogen is highly flammable. Therefore, leakage detection and an immediate warning mechanism are required during generation and storage.
- Small-Scale Production: Laboratory-scale solar-electrolysis systems generally produce limited quantities of hydrogen compared with large industrial systems, making them primarily suitable for experimental investigation and educational demonstration.

III. LITERATURE SURVEY

A) Literature Reviews

1. Pirrone, Bella and Hernández (2022), reviewed solar hydrogen production systems based on photocatalytic, photoelectrochemical, and photovoltaic-electrolyzer technologies. The study discussed the fundamental working principles, recent material developments, device engineering, scalability, and economic feasibility of solar-driven hydrogen generation. The authors highlighted that PV-electrolyzer systems provide a practical route for converting renewable solar electricity into hydrogen, while efficiency, cost, materials, and large-scale implementation remain important challenges for commercialization and wider deployment of solar hydrogen technologies.

2. Chatterjee et al. (2022), investigated the integration of photovoltaic systems with water-splitting technologies for green hydrogen production. Their review compared photovoltaic-electrolysis and photoelectrochemical approaches and discussed system design, materials, energy conversion, and scalability. The study emphasized that solar radiation provides a renewable energy source for hydrogen generation but its intermittency creates challenges for stable operation. The authors also examined earth-abundant materials and integrated device configurations aimed at improving cost-effectiveness and supporting scalable clean-hydrogen production systems.

3. Wang, Cao and Jiao (2022), reviewed proton exchange membrane water electrolysis for hydrogen production. Their study examined the fundamental electrochemical reactions, catalysts, membranes, electrodes, operating characteristics, and future development of PEM electrolyzers. PEM technology was identified as attractive because of its high current density, compact structure, high-purity hydrogen production, and compatibility with variable renewable electricity. However, catalyst cost, membrane durability, and system economics remain important challenges. The review provides a technical foundation for renewable-energy-powered electrolysis systems.

4. Li et al. (2023), reviewed solar hydrogen production using photovoltaic-electrolysis and photoelectrochemical water-splitting approaches. The study discussed the development history, operating principles, device configurations, conversion efficiency, and techno-economic considerations of solar hydrogen systems. The authors reported that both PV-electrolysis and PEC technologies have demonstrated solar-to-hydrogen efficiencies exceeding 10% in research systems. However, high system complexity, electrolyzer costs, and the gap between laboratory performance and practical large-scale deployment remain significant challenges requiring further technological development.

5. Zheng, Ma and Shao (2023), examined recent developments in efficient and scalable solar hydrogen production through water splitting. Their work focused on improving solar-to-hydrogen conversion efficiency, device architecture, material development, and scalability. The

authors identified solar water splitting as a promising pathway for green hydrogen but noted that commercialization requires improvements beyond laboratory-scale demonstrations. Their study emphasized the importance of developing efficient, stable, scalable, and economically viable systems capable of maintaining performance under practical operating conditions.

6. El-Shafie (2023), reviewed major water-electrolysis technologies, including PEM, alkaline water electrolysis, anion exchange membrane, and solid oxide electrolysis. The study compared their operating characteristics, materials, water requirements, efficiency, and technical limitations. PEM systems offer high-purity hydrogen and compatibility with renewable electricity, while AEM technology has potential for reducing dependence on expensive noble-metal catalysts. The review emphasized the importance of inexpensive materials, improved durability, appropriate water quality, and integrated renewable-energy systems for reducing hydrogen-production costs.

7. Gu et al. (2023), developed a photovoltaic-battery-PEM electrolysis system intended to support stable hydrogen production throughout the day. The researchers combined PV generation, battery storage, and PEM electrolysis and introduced an energy-management strategy to improve renewable-energy utilization. Their study showed the importance of energy storage when solar generation varies with irradiation. The work is particularly relevant to small-scale systems incorporating a solar panel and lithium battery because battery storage can help maintain electrical supply to the electrolyzer.

8. Ouabi et al. (2024), reviewed hydrogen production through photovoltaic-driven water electrolysis. Their study examined PV-electrolyzer integration, energy-storage requirements, system topologies, and electrolyzer dynamics. The authors emphasized that combining photovoltaic generation with battery storage can provide a more stable electricity supply for electrolysis. They also discussed the modular nature of PV-electrolyzer systems and their potential contribution to renewable energy storage. The review supports integrated solar, battery, and electrolyzer configurations for practical hydrogen-generation applications.

9. Arunachalam and Han (2024), investigated the integration of photovoltaic systems with PEM water electrolysis for sustainable hydrogen production. Their study focused on the challenge of variable solar radiation and the resulting requirements for appropriate PV-electrolyzer sizing and system integration. The research demonstrated the importance of matching renewable electrical generation with electrolyzer operating requirements. Their work indicates that effective PV-PEM integration can improve renewable hydrogen production while addressing fluctuations in solar availability. This approach is relevant to experimental solar-powered electrolysis prototypes.

10. Ahmed, Nagababu and Rayalu (2025), reviewed three major solar-powered hydrogen pathways: photovoltaic-electrolysis, concentrated solar-power electrolysis, and photoelectrochemical water splitting. The study compared their operating principles, efficiency, cost, scalability, and technological maturity. PV-electrolysis was identified as a relatively mature and modular approach, although intermittent solar radiation and electrolyzer costs remain challenges. CSP-electrolysis offers opportunities for high-temperature operation, while PEC systems require further improvements in efficiency, durability, and scalability before wider implementation.

B) Research Gap

- System Integration: Existing studies mainly emphasize PV-electrolyzer efficiency, with limited focus on compact, low-power prototype integration.
- Energy Storage: Further investigation is required into combining a small solar panel, lithium battery, and boost converter for stable electrolysis operation.
- Real-Time Monitoring: Limited attention is given to simple Arduino-based monitoring of voltage and current in small-scale hydrogen systems.
- Safety Monitoring: Hydrogen leakage detection using a gas sensor with a local LCD display and buzzer-based warning requires further practical investigation.

IV. PROPOSED SYSTEM

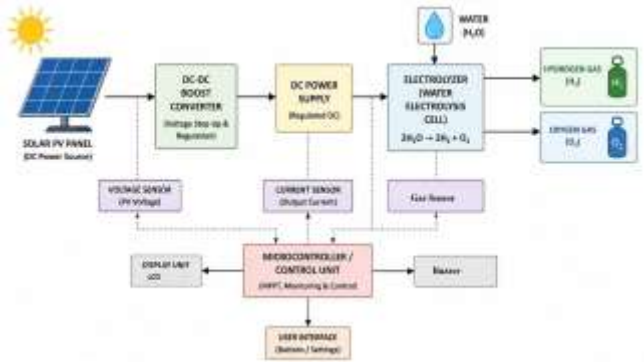


Figure 1. Block Diagram of system

- Solar Energy Generation: The solar PV panel converts sunlight into DC electrical energy, which serves as the primary power source for the hydrogen-generation system.
- Voltage Conversion: The DC-DC boost converter increases and regulates the PV voltage to provide a suitable DC supply for the electrolyzer.
- DC Power Supply: The regulated electrical power is supplied to the water-electrolysis cell for hydrogen generation.
- Water Electrolysis: Water is supplied to the electrolyzer, where electrical energy splits water into hydrogen and oxygen according to \(2H_2O \rightarrow 2H_2 + O_2\).
- Hydrogen Production: The generated hydrogen gas is collected separately as the desired energy carrier, while oxygen is obtained as the second electrolysis product.
- Voltage Monitoring: A voltage sensor measures the PV electrical voltage and provides the measurement signal to the microcontroller.
- Current Monitoring: The current sensor measures the electrical current supplied to the electrolysis system for performance evaluation.
- Gas Detection: The gas sensor detects hydrogen presence or leakage around the electrolyzer and collection section.
- Controller Operation: The microcontroller processes sensor signals and manages monitoring functions.
- Display and Safety: The LCD displays system parameters, while the buzzer provides an audible warning when hydrogen leakage is detected.

Main Features:

- Solar-Powered Operation: Uses a solar PV panel as the primary renewable energy source for hydrogen generation.
- DC-DC Voltage Conversion: The boost converter increases and regulates the available solar voltage for suitable electrolyzer operation.
- Water Electrolysis: The electrolyzer converts electrical energy into chemical energy by splitting water into hydrogen and oxygen.
- Hydrogen Generation: Produces hydrogen gas as the main useful output for potential clean-energy applications.
- Electrical Monitoring: Voltage and current sensors continuously monitor important electrical parameters during system operation.
- Arduino-Based Control: Arduino processes sensor signals and manages the local monitoring functions of the prototype.
- LCD Display: Displays measured voltage, current, and hydrogen-related system status for easy observation.
- Hydrogen Leakage Detection: A gas sensor detects the presence of hydrogen leakage around the generation and collection section.
- Audible Safety Alert: A buzzer provides an immediate warning when hydrogen leakage is detected.
- Battery Support: The 12 V, 2 Ah lithium battery provides stored electrical energy to support system operation when solar power varies.
- Experimental Design: The system provides a compact platform for studying solar energy conversion, electrolysis, hydrogen generation, electrical performance, and basic safety monitoring.

V. ADVANTAGES

- Renewable Energy: Uses solar energy as a clean and renewable source for hydrogen production.
- Clean Fuel: Produces hydrogen through water electrolysis without directly using fossil fuels.
- Energy Storage: The lithium battery stores electrical energy and supports operation during variable solar conditions.
- Real-Time Monitoring: Arduino, voltage and current sensors allow continuous monitoring of important system parameters.
- Safety Alert: Hydrogen gas detection with a buzzer provides an immediate warning during leakage conditions.
- Simple Prototype: The system provides a compact and practical platform for laboratory demonstration and experimental study.

VI. APPLICATIONS

- Educational Demonstration: Suitable for engineering laboratories to demonstrate solar energy, electrolysis, hydrogen generation, and sensor-based monitoring.
- Renewable Energy Research: Can be used for experimental studies of PV-powered hydrogen generation and electrical performance.
- Energy Storage Studies: Hydrogen can be investigated as a method of storing renewable energy for later utilization.
- Clean Energy Systems: Provides a basic platform for studying hydrogen as an alternative energy carrier.
- Future Fuel Applications: The generated hydrogen can support research related to fuel cells, transportation, and clean power-generation technologies.

VII. RESULTS AND DISCUSSION

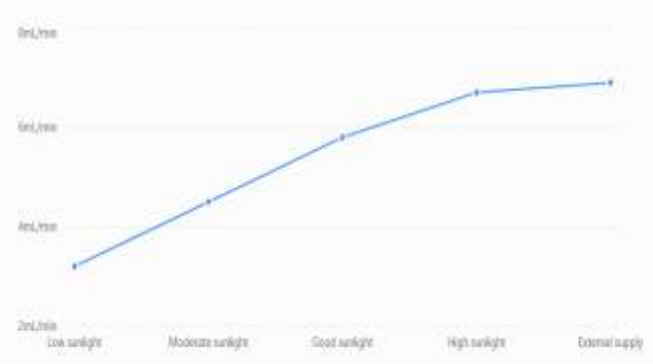
1. Electrical and Hydrogen Generation Results

Sr. No.	Test Condition	Solar Voltage (V)	Current (A)	Hydrogen Generated (mL/min)	Leakage Status	Buzzer
1	Low sunlight	10.2	0.42	3.2	No leakage	OFF
2	Moderate sunlight	11.0	0.55	4.5	No leakage	OFF
3	Good sunlight	11.8	0.68	5.8	No leakage	OFF
4	High sunlight	12.4	0.78	6.7	No leakage	OFF
5	External supply	12.0	0.80	6.9	No leakage	OFF

2. Analysis of Hydrogen Production

The results indicate that hydrogen production increases with the electrical power supplied to the electrolyzer. Under lower solar irradiance, the available voltage and current are reduced, resulting in lower hydrogen generation. As solar availability increases, the electrolyzer receives greater electrical input and hydrogen production correspondingly increases.

Hydrogen production under different operating conditions.



Hydrogen production under different operating conditions

3. Voltage and Current Analysis

Condition	Voltage (V)	Current (A)	Input Power (W)
Low sunlight	10.2	0.42	4.28
Moderate sunlight	11.0	0.55	6.05
Good sunlight	11.8	0.68	8.02
High sunlight	12.4	0.78	9.67
External supply	12.0	0.80	9.60

Input power is calculated using:

$P=V\times I$

For example, under good sunlight:

$P=11.8\times0.68$

$P=8.02W$

The analysis shows that the electrical input increases as solar conditions improve. This directly affects the operating condition of the electrolyzer.

4. Hydrogen Leakage Detection Results

Test	Hydrogen Leakage Condition	Gas Sensor Response	LCD Status	Buzzer
1	No hydrogen leakage	Normal	SAFE	OFF
2	Low leakage	Detected	WARNING	ON

3	Higher leakage	Detected	WARNING	ON
4	Normal operation	Normal	SAFE	OFF

The hydrogen gas sensor provides the safety-monitoring function. During normal operation, the buzzer remains OFF. When hydrogen leakage is detected, Arduino processes the sensor signal and activates the buzzer to alert the operator.

5. Overall Results

The prototype is expected to demonstrate the feasibility of solar-powered hydrogen generation using water electrolysis. The 12 V, 10 W solar panel provides the primary electrical energy, while the 12 V, 2 Ah lithium battery provides energy storage. Voltage and current sensors allow electrical performance to be monitored, while the hydrogen sensor and buzzer provide a basic leakage-warning mechanism. The uploaded project identifies hydrogen production and system efficiency as important performance parameters.

6. Discussion

The proposed system demonstrates the integration of solar photovoltaic energy with water electrolysis for hydrogen generation. The solar panel supplies DC electrical energy, while the DC-DC boost converter regulates the voltage required by the electrolyzer. The electrolyzer converts electrical energy into hydrogen and oxygen through the water-splitting process. The inclusion of a 12 V, 2 Ah lithium battery provides energy-storage support when solar availability varies. Arduino-based monitoring enables measurement of voltage and current through dedicated sensors, allowing the electrical operating condition to be observed during experimentation. The LCD provides a convenient local display of system parameters. In addition, the hydrogen gas sensor introduces an important safety-monitoring function by detecting possible gas leakage, while the buzzer provides an immediate warning to the operator. The system therefore combines renewable energy generation, electrolysis, energy storage, electrical measurement, and basic hydrogen safety monitoring within a compact prototype. However, actual hydrogen production rate and system efficiency must be established from experimental measurements rather than assumed values. The uploaded seminar similarly identifies hydrogen production, system efficiency, and operating conditions as important evaluation parameters.

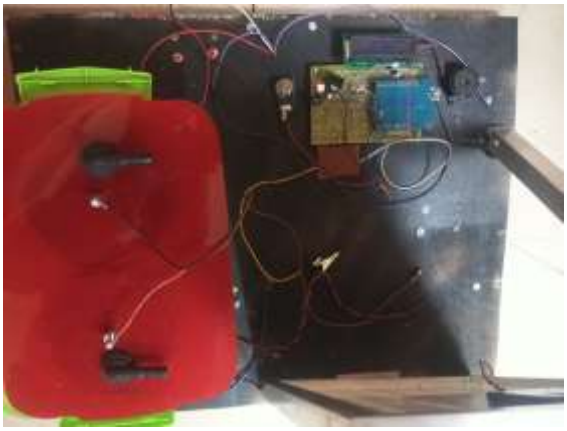


Figure 4: Project Model

VIII. CONCLUSION

The proposed project demonstrates a practical approach for generating hydrogen from water using solar energy through electrolysis. The system integrates a 12 V, 10 W solar panel, DC-DC boost converter, 12 V, 2 Ah lithium battery, external power supply, and electrolyzer to establish the required electrical and electrochemical process. Arduino UNO provides local monitoring of voltage, current, and hydrogen gas conditions, while the LCD displays the operating information. The hydrogen gas sensor and buzzer provide a basic safety mechanism by detecting possible hydrogen leakage and alerting the operator. The system therefore combines renewable energy utilization, hydrogen generation, electrical parameter monitoring, and safety indication within a compact prototype. Experimental evaluation can be used to determine hydrogen production rate, electrical power consumption, and overall system efficiency under different operating conditions. The project provides a useful platform for laboratory-scale investigation of solar-assisted hydrogen generation and supports further development of renewable hydrogen technologies. The uploaded seminar similarly identifies hydrogen production, system efficiency, and renewable-energy applications as the primary objectives of the work.

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