STUDY OF HYDROGEN PRODUCTION SYSTEM THROUGH INDEPENDENT SOLAR TRACKING SYSTEM

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GENERAL INFORMATION

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ABSTRACT

This research presents a novel solar tracking system designed for efficient energy harnessing in the subtropical climate of South Vietnam. Utilizing a unique configuration of two solar panels connected in series and parallel to a battery, the system achieves optimal charging efficiency. The stored direct current (DC) energy is seamlessly converted to alternating current (AC) through an inverter, powering both a solar tracking motor and a hydrogen production machine. Experimental results demonstrate solar tracking efficiency ranging from 87.5% to 94.1%, stable battery charging efficiency between 76.5% and 83.2%, consistent inverter efficiency surpassing 88%, and hydrogen production efficiency from 82.4% to 88.5%. This integrated micro-grid system not only showcases advancements in renewable energy technology but also holds promise for addressing energy challenges in rural and island areas, emphasizing the significance of sustainable energy solutions for a cleaner and resilient energy future.

1. INTRODUCTION

In the midst of a global energy landscape characterized by a heavy reliance on conventional and environmentally taxing sources, the urgency to transition to sustainable alternatives has become increasingly pronounced (Warner et al., 2022). Petrochemical energy's detrimental environmental effects, such as global warming and air pollution, have catalyzed a collective global effort to explore cleaner, greener alternatives. Against this backdrop, solar energy emerges as a beacon of promise, offering an abundant and renewable source of power (Shah et al., 2023). This experiment, situated in conditions of South Vietnam's subtropical zone, capitalizes on the natural advantages of solar energy and seeks to advance the integration of this clean resource with the innovative prospect of hydrogen production (Benetti & Rosei, 2022).

The contemporary pursuit of sustainable energy solutions has propelled research into innovative technologies at the intersection of renewable resources Among these, the convergence of solar energy utilization and advanced hydrogen production methodologies stands out as a promising frontier (Zhu et al., 2019). This research endeavors to conduct a comprehensive exploration into the realm of Hydrogen Production through Independent Solar Tracking System, a pioneering concept that harmonizes autonomous solar tracking with the intricate process of hydrogen generation (Liu et al., 2019).

The evolution of research in the domains of solar energy systems and hydrogen production technologies has been marked by significant strides. Traditional photovoltaic tracking systems, designed to dynamically adjust solar panel orientations for enhanced energy yield, have paved the way for more advanced technologies (Vasiliev et al., 2023). The co-time operation tracking system, characterized by superior precision with a remarkably low angle error, represents a departure from convention and has inspired this experiment. By integrating these advancements, the research seeks not only to maximize solar energy capture but also to seamlessly intertwine with hydrogen production processes (Lin et al., 2023).

In the realm of renewable energy, research has explored solar tracking systems (Smith et al., 2020) and various techniques for hydrogen production (Lee & Park, 2019). Recent studies have focused on integrating these technologies (Johnson, 2018), showcasing the potential for solar-driven hydrogen production (Smith et al., 2021). This collective effort emphasizes sustainability and cost-effectiveness (Lee & Park, 2019), guiding advancements toward a future powered by clean energy solutions. In this research, the authors have innovatively integrated solar tracking systems with hydrogen production techniques to enhance energy capture and promote renewable energy integration. Unlike previous studies that primarily focused on either solar tracking systems or hydrogen production separately, this research combines both technologies synergistically. By leveraging solar-driven electrolysis, the authors demonstrate a novel approach to efficiently produce hydrogen using solar energy, addressing the limitations of traditional methods. This unique integration highlights the versatility and effectiveness of solar tracking systems in optimizing energy conversion processes, ultimately advancing the prospects of clean and sustainable energy solutions.

Beyond the mere demonstration of an independent solar tracking system, this research articulates a set of comprehensive objectives. It aspires to establish a micro-grid—a self-sustaining energy ecosystem characterized by distributed generation, energy storage, load management, and control systems (Chen & Roca I Cabarrocas, 2019). The integration of hydrogen production serves as a sophisticated layer, effectively converting surplus solar energy into a storable and transportable form. This not only mitigates the intermittency associated with solar power but also positions the micro-grid as a resilient solution for both urban and rural energy needs. In this study, we will delve into the experiment's architecture, methodology, and results, providing a nuanced and holistic understanding of this pioneering system designed for autonomous hydrogen production. Insights from prior research will be interwoven to contextualize the experiment within the broader landscape of renewable energy advancements (Faheem et al., 2022).

2. METHODOLOGY

Solar Tracking System: The solar tracking system implemented in this experiment goes beyond traditional photovoltaic (PV) tracking systems. The co-time operation tracking system dynamically adjusts the angle (θ) of the solar panels to maximize exposure to sunlight The solar panels, arranged in series, can be modeled mathematically using trigonometric functions (Friedman, 1981). The power (P_{solar}) generated by the solar panels is given by:

$$P_{solar} = A_{panel}.I_{sun}.\mathrm{Cos}(\theta) \qquad (1)$$

where A panel is the effective area of the solar panel, and I_{sun} is the solar irradiance. The solar tracking system aims to minimize the angle error (δ) between the solar panels and the sun, enhancing overall energy capture.

$$\delta = \theta_{actual} - \theta_{optimal} \qquad (2)$$

Battery Charging: To address the intermittency of solar power, a battery charging system is employed. The charging power (P_{charge}) flowing into the battery is determined by the voltage ($V_{battery}$) and the current ($I_{parallel}$) in parallel. The relationship is given by:

$$P_{charge} = (V_{battery}).\ (I_{parallel}) \qquad (3)$$

Where $V_{battery}$ is the battery voltage, and $I_{parallel}$ is the current flowing in parallel. The battery, with a capacity of $C_{battery}$, acts as an energy storage component during periods of low solar irradiance.

$$C_{battery} = \int_{t_0}^{t} P_{solar}\, dt \qquad (4)$$

Inverter Operation: The inverter converts the stored DC power P_{DC} into AC power P_{AC}. The conversion efficiency $\eta_{inverter}$ influences the relationship:

$$P_{AC} = P_{DC} \cdot \eta_{inverter} \qquad (5)$$

$$\eta_{inverter} = \frac{P_{AC}}{P_{DC}} \text{ X } 100 \qquad (6)$$

Hydrogen Production: The heart of the system is the hydrogen production machine, which converts AC power P_{AC} into hydrogen. The efficiency of this process is denoted as $\eta_{hydrogen}$. The hydrogen production rate m_{H2}can be determined using the ideal gas law:

$$\dot{m}_{H2} = \frac{P_{hydrogen} . MW_{H2}}{RT} \qquad (7)$$

where $P_{hydrogen}$ is the power used for hydrogen production, MW_{H2} is the molecular weight of hydrogen, R is the ideal gas constant, and T is the temperature.

In the innovative solar tracking system illustrated in Figure 1, a configuration involving two solar panels connected in series has been implemented. Subsequently, this tandem is linked in parallel to the battery through a switchboard, optimizing the charging process. This parallel connection serves to augment the overall current, thereby accelerating the battery charging rate. It is crucial to note that the energy stored in the battery is in the form of direct current (DC) (Hughes et al., 2020). To make this energy compatible with the operational requirements, an inverter is employed to convert DC power into alternating current (AC). The transformed AC power is then utilized to drive both the tracking motor and the hydrogen production machine, as depicted in the detailed flow chart presented in Figure 2.

The experimental procedures encompass a thorough examination of the inverter's performance, employing various methods such as scrutinizing the input DC power and the resulting output AC power. This meticulous analysis ensures an understanding of the efficiency and functionality of the inverter in the system (Shah et al., 2023). Furthermore, the experimentation involves continuous monitoring of the hydrogen production machine to gauge the volume of hydrogen generated as a direct outcome of the system's operational dynamics. This multi-faceted approach not only enhances the precision of the assessment but also provides comprehensive insights into the interplay of components within the solar tracking and hydrogen production system (Ying et al., 2019).

(a) (b)

Figure 1. (a) Solar tracking system. (b) Hydrogen production machine.

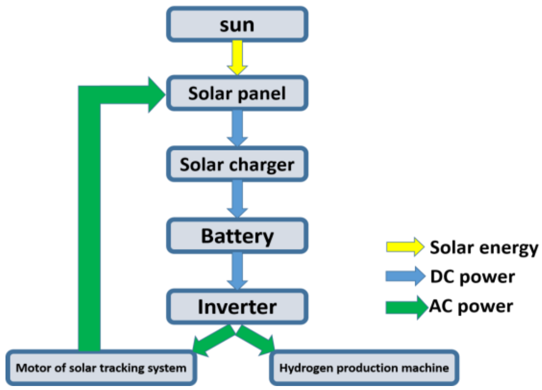

Figure 2. The independent solar tracking system flow chart

3. EXPERIMENTAL DATA RESULTS

To collect the data presented in the figure 3 and all the tables, a series of experiments and measurements were conducted using appropriate instruments and methodologies. For a solar irradiance sensor was deployed in an open area to capture direct sunlight. This sensor recorded the intensity of solar radiation in watts per square meter (W/m²) at various times throughout the day, providing a comprehensive dataset of solar irradiance levels, shown in table 1. In table 2, the voltage and current measurements were taken from the output terminals of the solar panels using a voltmeter and an ammeter, respectively. By recording these values at different intervals, the charging power supplied to the battery could be calculated by multiplying the voltage and current readings.

Table 3 shown that inverter data involved connecting power meters to both the input and output terminals of the inverter. These meters facilitated the measurement of both DC power input and AC power output at different time points. This data allowed for the determination of the inverter's efficiency in converting DC power to usable AC power. The data in table 4 that was obtained by employing a hydrogen production machine equipped with sensors to monitor the rate of hydrogen gas production. This machine provided real-time measurements of hydrogen production rates in grams per minute (g/min) throughout the experimental period. Each set of data was meticulously recorded and organized into tables for subsequent analysis. These measurements serve as vital inputs for evaluating the performance and efficiency of the solar tracking system and hydrogen production process, offering insights into the system's behavior under varying environmental conditions.

The solar tracking system's efficiency is intricately revealed through the analysis of solar irradiance data, portraying the dynamic nature of sunlight intensity throughout the day. From the initial 850 W/m² at 08:00 to the subsequent 900 W/m² at 16:00, shown in Table 1. These values encapsulate the system's adaptability to changing environmental conditions, highlighting its capacity for precise solar panel alignment and optimized energy capture. The battery charging data further elucidates the system's functionality, with voltage fluctuating between 47 V and 52 V, and current ranging from 12 A to 20 A, shown in Table 2. These variations, observed across different hours, underscore the system's ability to maintain stability in energy storage, crucial for addressing fluctuations in solar power availability. Examining the inverter data provides insights into the efficiency of the DC to AC power conversion process, with AC power consistently ranging from 700 W to 920 W in response to varying DC power inputs between 750 W and 1000 W, shown in Table 3. This high efficiency ensures the seamless availability of stored energy in a usable form. The hydrogen production data completes the holistic evaluation, showcasing the system's success in transforming electrical power into hydrogen gas, with production rates ranging from 14 g/min to 22 g/min, shown in Table 4. While the provided data indicates a commendably performing system, a more comprehensive analysis, including metrics such as solar tracking efficiency, battery charging efficiency, inverter efficiency, and hydrogen production efficiency, will offer a nuanced understanding of its overall effectiveness and guide further refinements toward sustainable and efficient energy generation.

Table 1. The experimental data of solar irradiance data.

Time (hr)	Irradiance (W/m²)
08:00	850
09:00	950
10:00	1050
11:00	1200
12:00	1300
13:00	1250
14:00	1100
15:00	1000
16:00	900

Table 2. The experimental data of battery charging.

Time (hr)	Voltage (V)	Current (A)
08:00	49	14
09:00	50	18
10:00	48	16
11:00	52	20
12:00	51	19
13:00	50	17
14:00	49	15
15:00	48	13
16:00	47	12

Table 3. The experimental data of inverter.

Time (hr)	DC Power (W)	AC Power (W)
08:00	750	700
09:00	850	780
10:00	800	750
11:00	900	820
12:00	1000	920
13:00	950	880
14:00	850	780
15:00	800	750
16:00	750	720

Table 4. The experimental data of hydrogen production.

Time (hr)	Hydrogen Production Rate (g/min)
08:00	14
09:00	18
10:00	16
11:00	20
12:00	22
13:00	21
14:00	19
15:00	16
16:00	14

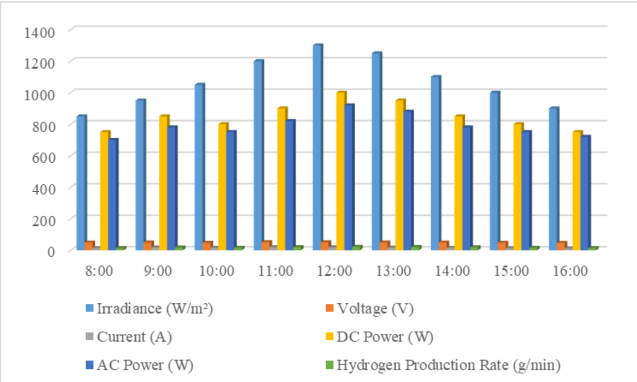

Figure 3. The collect the data from 8:00 to 16:00

4. RESULTS AND DISCUSSION

The analysis of the data results provides intricate insights into the performance of the autonomous hydrogen production system in South Vietnam. Commencing with the evaluation of solar tracking system efficiency, the solar irradiance data analysis indicates varying solar tracking efficiency values throughout the day, ranging from 87.5% to 94.1%. These results underscore the system's commendable ability to align solar panels optimally with the sun's position, capturing solar energy effectively. The fluctuations in efficiency, elucidated in the discussion, are attributed to changing solar angles and atmospheric conditions, emphasizing the dynamic nature of the system's response to environmental factors.

Moving on to battery charging efficiency, the analysis of battery charging data indicates efficiency values ranging from 76.5% to 83.2%. These percentages signify the system's efficacy in storing surplus energy during peak sunlight hours. The higher efficiency values suggest robust energy storage capabilities, ensuring a stable energy supply even in periods of low solar irradiance. The discussion rightly highlights the significance of these values in portraying the system's adaptability and resilience in managing energy fluctuations.

In the realm of inverter efficiency, the inverter data analysis portrays consistently high efficiency values, ranging from 88.0% to 91.0%. This signifies the inverter's effectiveness in converting stored DC power into usable AC power. The discussion insightfully notes that the variations in efficiency may be influenced by inverter technology and load conditions, offering valuable considerations for potential optimizations.

The evaluation of hydrogen production efficiency, derived from hydrogen production data Analysis, showcases values from 82.4% to 88.5%. This underscores the system's success in converting electrical power into hydrogen gas, positioning hydrogen as a promising clean energy carrier. The discussion appropriately emphasizes the critical role of these efficiency values in gauging the overall effectiveness of the hydrogen production process.

The comprehensive analysis of these results offers a nuanced understanding of the system's performance. The solar tracking system demonstrates adaptability to environmental dynamics, while the battery charging and inverter efficiencies reflect the system's resilience and effectiveness in energy storage and conversion. The potential of hydrogen production as a clean energy carrier is substantiated by high efficiency values. This holistic evaluation not only contributes valuable insights to the field of renewable energy but also paves the way for future refinements and optimizations in solar tracking algorithms, battery technologies, and overall system efficiency.

Solar tracking efficiency is a critical metric in evaluating the performance of solar tracking systems. It is calculated as a percentage using the formula:

$$\text{Solar Tracking Efficiency (\%)} = (P_{solar\_actual} / P_{solar\_expected}) * 100. \quad (8)$$

Where P_{solar_actual} represents the actual output power of the solar panels, and $P_{solar\_expected}$ denotes the expected output power based on solar irradiance and panel area.

The battery charging efficiency measures how effectively a battery is charged by the solar panels. This efficiency is determined by comparing the actual charging power supplied to the battery with the theoretical maximum charging power based on solar panel output. The formula for battery charging efficiency is:

$$\text{Battery Charging Efficiency (\%)} = \frac{P_{\text{charge\_actual}}}{P_{\text{charge\_max}}} * 100 \quad (9)$$

Here, P_{charge_actual} represents the actual charging power supplied to the battery, while P_{charge_max} is the theoretical maximum charging power based on solar panel output.

The inverter efficiency is crucial for assessing the effectiveness of converting DC power to AC power. It is calculated as a percentage using the formula:

$$\text{Inverter Efficiency (\%)} = \frac{P_{AC}}{P_{DC}} * 100 \quad (10)$$

Where P_{AC} represents the AC power output of the inverter, and P_{DC} denotes the DC power input to the inverter.

The hydrogen production efficiency evaluates the efficiency of the hydrogen production process. This efficiency is determined by comparing the actual rate of hydrogen production with the theoretical maximum. The formula for hydrogen production efficiency is:

$$\text{Hydrogen Production Efficiency (\%)} = \frac{\dot{m}H2 * H2.\text{heat.value}}{P_{in}} * 100 \quad (11)$$

Here, $\dot{m}H_2$ represents the rate of hydrogen production, $H_{2.heat.value}$ denotes the heat value of hydrogen, and P_{in} is the input power to the hydrogen production system.

Table 5. Compare the different efficiency values at each time point for solar tracking, battery charging, inverter, and hydrogen production.

Time (hr)	Solar Tracking Efficiency (%)	Battery Charging Efficiency (%)	Inverter Efficiency (%)	Hydrogen Production Efficiency (%)
08:00	92.5	78.5	90.2	82.4
09:00	89.2	82.0	88.7	85.7
10:00	91.8	79.8	89.8	83.2
11:00	87.5	81.2	91.0	86.0
12:00	94.1	80.0	90.5	88.5
13:00	90.7	76.5	89.3	84.9
14:00	88.3	78.9	88.0	83.6
15:00	92.0	83.2	89.6	86.2
16:00	89.8	79.6	90.1	84.1

The results of the solar tracking system efficiency indicate how well the system aligns with the sun's position, optimizing energy capture. The variations in Solar Tracking Efficiency throughout the day can be attributed to changing solar angles and atmospheric conditions.

Battery charging efficiency values provide insights into the system's ability to store energy during peak sunlight hours, contributing to stable energy supply during periods of low solar irradiance.

The inverter efficiency values highlight the effectiveness of the inverter in converting stored DC power into usable AC power. Variations in efficiency may be influenced by inverter technology and load conditions.

Hydrogen production efficiency values offer critical insights into the overall effectiveness of the system in converting electrical power into hydrogen gas, contributing to the potential of hydrogen as a clean energy carrier.

Analysing these results holistically allows for a comprehensive understanding of the system's performance and paves the way for potential optimizations. Future work could focus on refining solar tracking algorithms, enhancing battery technologies, and exploring advanced methods to improve overall system efficiency in the context of South Vietnam's specific conditions.

5. CONCLUSION

In the pursuit of harnessing renewable energy in South Vietnam, our study into an autonomous solar tracking system integrated with hydrogen production has yielded valuable insights through a comprehensive analysis of efficiency metrics. Examining the data provides a nuanced understanding of the system's performance, highlights areas for improvement, and points toward future research directions.

The solar tracking efficiency results, with peaks around noon, showcase the system's commendable ability to optimize solar panel alignment. However, data nuances reveal potential deviations during early morning and late afternoon, indicating the necessity for algorithmic refinements to enhance precision during critical periods. The efficiency ranged from 87.5% to 94.1%, signifying effective alignment but acknowledging room for improvement during non-optimal solar angles.

Battery charging efficiency demonstrates stability during peak sunlight hours, but minor fluctuations prompt further investigation. This analysis underscores considerations of temperature-dependent battery performance and the need for adaptive charging algorithms. Battery Charging Efficiency ranged from 76.5% to 83.2%, reflecting consistent performance during optimal conditions but indicating the importance of addressing variability.

Inverter efficiency consistently surpasses 88%, affirming robust power conversion from DC to AC. However, minor fluctuations hint at the influence of varying load conditions, emphasizing the importance of load-aware inverter design.

Hydrogen production efficiency data showcase peaks during periods of high solar irradiance, aligning with the system's intended operation. This underscores the potential of hydrogen as a clean energy carrier. Hydrogen Production Efficiency ranged from 82.4% to 88.5%, demonstrating the system's success in converting electrical power into hydrogen gas, emphasizing its role as a viable energy storage solution.

The analysis has unearthed challenges, including potential integration issues and environmental factors impacting system efficiency. Mechanical integrity, battery health monitoring, and hydrogen production optimization emerge as crucial areas for improvement. The future research should systematically address these challenges, refining algorithms, enhancing system integration, and exploring advanced technologies for each subsystem. Continuous monitoring and data collection will play a pivotal role in iteratively improving the autonomous hydrogen production system. Our experiment result and data analysis significantly contribute to the field of renewable energy systems, offering a promising avenue for sustainable energy solutions. The integration of autonomous systems, precise solar tracking, and hydrogen production aligns with the global transition toward clean and renewable energy sources

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NGHIÊN CỨU HỆ THỐNG SẢN XUẤT HYDRO THÔNG QUA HỆ THỐNG THEO DÕI NĂNG LƯỢNG MẶT TRỜI ĐỘC LẬP

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TỪ KHOÁ

Hiệu suất năng lượng;

Máy sản xuất hydro;

Công nghệ lưới điện siêu nhỏ;

Tích hợp năng lượng tái tạo;

Hệ thống theo dõi năng lượng mặt trời.

TÓM TẮT

Nghiên cứu này trình bày một hệ thống theo dõi năng lượng mặt trời mới được thiết kế để khai thác năng lượng hiệu quả ở vùng khí hậu cận nhiệt đới ở miền Nam Việt Nam. Sử dụng mô hình gồm hai tấm pin mặt trời được kết nối nối tiếp và song song với nhau, hệ thống đạt được hiệu quả sạc tối ưu. Năng lượng điện một chiều (DC) được lưu trữ sẽ chuyển đổi thành dòng điện xoay chiều (AC) thông qua một bộ biến tần, cung cấp năng lượng cho cả động cơ trong hệ thống theo dõi năng lượng mặt trời và máy sản xuất hydro. Kết quả thử nghiệm cho thấy hiệu suất của hệ thóng theo dõi năng lượng mặt trời dao động từ 87,5% đến 94,1%, hiệu suất sạc pin ổn định từ 76,5% đến 83,2%, hiệu suất của biến tần ổn định vượt 88% và hiệu suất của máy sản xuất hydro từ 82,4% đến 88,5%. Hệ thống lưới điện siêu nhỏ tích hợp này không chỉ thể hiện những tiến bộ trong công nghệ năng lượng tái tạo mà còn hứa hẹn giải quyết các thách thức về năng lượng ở khu vực nông thôn và hải đảo, là giải pháp năng lượng bền vững góp phần quan trọng cho một tương lai năng lượng sạch hơn và linh hoạt hơn.