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Performance of Solar Panel-Based Electric Motor Charger System at Variations in Sunlight Intensity

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ABSTRACT

This study aims to analyze the performance of electric motorcycle charging systems that use solar panels as the main energy source. The research method used is an experiment by testing the charging system on various conditions of sunlight intensity and ambient temperature. The system tested consisted of a series assembled solar panel, Maximum Power Point Tracking (MPPT), a Sealed Lead Acid (SLA) battery, and a supporting measuring instrument. The parameters observed included battery voltage, solar panel voltage, current, power, light intensity, and temperature. The results showed that the variation in sunlight intensity had a significant influence on the solar panel's output power and battery charging rate. Sunny weather conditions result in optimal charging performance, while high ambient temperatures tend to lower the efficiency of solar panels.

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INTRODUCTION

The increasing demand for electrical energy, particularly in the transportation sector, has accelerated the development of electric vehicle technology as a more environmentally friendly alternative to conventional fossil fuel–based vehicles. Electric vehicles are widely recognized for their potential to reduce exhaust emissions, minimize air pollution, and decrease dependence on finite fossil fuel resources. However, despite these advantages, the widespread adoption of electric vehicles still faces significant challenges, especially those related to the availability and sustainability of energy sources for the battery charging process. Reliance on conventional electricity generated from fossil fuels may reduce the overall environmental benefits of electric vehicles and weaken their role in supporting long-term energy sustainability.

To address these challenges, the integration of renewable energy sources into electric vehicle charging systems has become an important research focus. Renewable energy offers a pathway to decarbonize the charging infrastructure while enhancing energy security. Among various renewable energy sources, solar energy is considered one of the most promising options due to its cleanliness, abundance, and continuous availability throughout the year, particularly in tropical regions such as Indonesia. The high solar irradiation levels in these regions provide favorable conditions for utilizing solar energy as an alternative power source to support electric vehicle charging systems on both small and medium scales (1–3).

The application of solar panels for charging electric vehicle batteries also offers several additional advantages. From an economic perspective, solar-based charging systems can reduce operational costs by minimizing dependence on grid electricity. From an energy management standpoint, such systems enhance energy independence, especially in remote or rural areas where access to the power grid is limited or unreliable (4,5). These advantages highlight the potential role of solar energy not only as a supplementary power source but also as a primary solution for decentralized electric vehicle charging infrastructure.

Previous studies have demonstrated that solar panels can be effectively used to charge electric vehicle batteries with satisfactory performance levels. However, it has also been reported that the performance of solar panel–based charging systems is highly dependent on environmental conditions (6–8). Key environmental factors influencing system performance include sunlight intensity and ambient temperature(9–11). Higher solar irradiance generally leads to increased power output from photovoltaic modules, thereby improving charging performance. Conversely, elevated ambient and module temperatures may reduce energy conversion efficiency due to the inherent thermal characteristics of solar cells, which can negatively affect voltage output and overall system efficiency (12–14).

These environmental influences indicate that the real-world performance of solar-powered charging systems cannot be fully characterized through theoretical analysis alone. Instead, experimental investigations under actual operating conditions are required to obtain a comprehensive understanding of system behavior. Such experimental analysis is essential for evaluating system reliability, efficiency, and feasibility when subjected to natural variations in sunlight intensity and temperature.

Based on this background, the present study focuses on analyzing the performance of a solar panel–based electric motor charger system under varying sunlight intensity conditions. The system utilizes a solar panel configuration integrated with a Maximum Power Point Tracking (MPPT) controller and Sealed Lead Acid (SLA) batteries. Field experiments are conducted to observe the system's response to changes in sunlight intensity and ambient temperature. Electrical parameters, including voltage, current, and power, are systematically measured and analyzed to assess the effectiveness and stability of the charging process.

The findings of this research are expected to contribute scientifically to the development of renewable energy–based charging technologies for electric vehicles. Furthermore, the results may serve as a technical reference for future research and practical implementation of solar-powered charging systems. In a broader context, this study supports ongoing efforts to promote the utilization of solar energy as an environmentally friendly, sustainable, and practical solution for electric vehicle charging applications.

LITERATURE REVIEW

Solar Energy for Electric Vehicle Charging Systems

Solar energy stands out as one of the most promising renewable energy sources for powering EV charging stations. The utilization of photovoltaic (PV) systems can significantly enhance energy sustainability by allowing direct conversion of sunlight into electricity for charging EV batteries. Studies have emphasized the effectiveness of solar energy in reducing emissions associated with traditional electricity generation. For instance, Alkawsi et al. highlight that integrating renewable energy sources, including solar, can alleviate pressure on local electricity networks due to the increasing number of EV charging points (15). Additionally, the feasibility of integrating such systems within charging infrastructure has been supported by research indicating that it can supply a reliable and cleaner energy source for EVs, promoting a shift towards environmentally friendly transportation (16).

The development of smart grids plays a crucial role in incorporating renewable energy into EV charging systems. Smart grids facilitate the integration of diverse technologies such as solar panels and energy storage systems (ESS), optimizing electricity generation and distribution. Elbouchikhi et al. assert that smart grid technologies are essential for managing the complexity of new energy demands, particularly in the context of EV charging (17). Furthermore, studies suggest that optimizing the placement and operation of EV charging stations in tandem with PV and battery solutions can minimize overall development costs while ensuring efficient energy use (18,19).

Several studies have reported that photovoltaic-based charging systems can be effectively implemented for electric vehicles, particularly for small-scale applications such as electric motorcycles and electric bicycles. These systems are commonly designed as off-grid or hybrid configurations, allowing flexibility in deployment, especially in remote or rural areas. The feasibility of solar-based charging systems is strongly influenced by local solar irradiation conditions, system configuration, and energy management strategies.

Photovoltaic System Performance under Environmental Conditions

The performance of photovoltaic systems is inherently affected by environmental factors, particularly solar irradiance and ambient temperature. Solar irradiance directly determines the amount of energy that can be converted into electrical power by photovoltaic modules. Higher irradiance levels generally result in increased output power and improved charging performance.

However, temperature variations also play a significant role in photovoltaic system efficiency. Elevated ambient temperatures can lead to an increase in cell temperature, which may cause a reduction in open-circuit voltage and overall conversion efficiency. This thermal effect is especially critical in tropical regions, where high solar irradiance is often accompanied by high ambient temperatures. Consequently, understanding the combined influence of solar irradiance and temperature is essential for evaluating the real-world performance of solar-powered charging systems.

Maximum Power Point Tracking (MPPT) in Solar Charging Systems

Maximum Power Point Tracking (MPPT) technology is widely used to enhance the efficiency of photovoltaic systems by ensuring that solar panels operate at their optimal power point under varying environmental conditions. MPPT controllers continuously adjust the operating voltage and current to maximize power output despite fluctuations in solar irradiance and temperature.

In solar-based charging systems for electric vehicles, MPPT plays a crucial role in stabilizing the charging process and improving energy utilization efficiency. Previous studies have shown that MPPT-based charging systems outperform conventional charge controllers, particularly under dynamic environmental conditions such as partial shading or rapidly changing sunlight intensity. The integration of MPPT is therefore considered a key factor in improving the reliability and effectiveness of solar-powered electric vehicle chargers.

Battery Characteristics in Solar Charging Applications

The selection of battery type is an important consideration in solar-powered charging systems. Sealed Lead Acid (SLA) batteries are commonly used due to their relatively low cost, robustness, and ease of integration with photovoltaic systems. SLA batteries are also known for their stable performance and minimal maintenance requirements, making them suitable for small- to medium-scale electric vehicle applications.

However, the charging performance and lifespan of SLA batteries are influenced by charging voltage, current regulation, and temperature conditions. Improper charging strategies may lead to reduced battery efficiency or accelerated degradation. Therefore, appropriate charge control and monitoring are necessary to ensure safe and efficient battery operation in solar-powered charging systems.

Research Gap and Contribution

Although numerous studies have investigated solar-powered charging systems and photovoltaic performance, limited research has focused specifically on the experimental evaluation of electric motorcycle charger systems under varying sunlight intensity conditions. Many existing studies rely on simulations or controlled laboratory environments, which may not fully represent actual operating conditions. This study addresses this gap by conducting field-based experimental testing of a solar panel–based electric motorcycle charging system. By analyzing system performance under real-time variations in sunlight intensity and ambient temperature, this research provides practical insights into the feasibility and effectiveness of solar energy utilization for electric vehicle charging applications, particularly in tropical environments.

METHODOLOGY

This study uses an experimental method with the aim of evaluating the performance of a solar panel-based electric motor charger system at variations in sunlight intensity. The experimental approach was chosen because it allows direct observation of the charging system's response under real operational conditions, so that the results obtained can represent the actual performance of the system (20–23).

The test system consists of four solar panels connected in a series configuration to produce a nominal voltage of 48 V, which matches the voltage requirements of the electric motor battery used in this study. The series configuration was selected to ensure sufficient voltage levels for effective battery charging while maintaining system simplicity. The solar panels are integrated with a Maximum Power Point Tracking (MPPT) controller, which plays a crucial role in optimizing the power output of the photovoltaic modules under varying environmental conditions. The MPPT continuously adjusts the operating point of the solar panels to maximize energy harvesting and to maintain the stability and safety of the battery charging process. The electrical energy generated by the solar panels is stored in a Sealed Lead Acid (SLA) battery, which is commonly used in electric motor applications due to its robustness, stable performance, and compatibility with photovoltaic charging systems.

To support the experimental measurements, several measuring instruments were employed to ensure accurate data acquisition. A multimeter was used to measure voltage and current at key points within the system, allowing real-time monitoring of electrical parameters during the charging process. A watt meter was utilized to determine the output power generated by the solar panels and delivered to the charging system. In addition, a luxmeter was used to measure sunlight intensity, providing quantitative data on solar irradiance levels corresponding to system performance. The combination of these measuring devices enabled comprehensive monitoring of both environmental conditions and electrical responses throughout the experiment.

The experimental testing was conducted in the Banjarbaru area, South Kalimantan, where environmental conditions allow for natural variations in sunlight intensity throughout the day. This location was selected to represent realistic operating conditions in a tropical region. Data collection was carried out over several days, with each test session lasting approximately four hours. During the testing process, measurements were recorded periodically at 30-minute intervals to capture temporal variations in system performance resulting from changes in sunlight intensity and ambient temperature. This measurement interval was chosen to balance data resolution and experimental practicality while providing sufficient insight into performance trends.

In this study, the research variables were classified into independent, dependent, and control variables. The independent variable is sunlight intensity, measured using a luxmeter, as solar irradiance is the primary factor influencing the electrical output of photovoltaic panels. The dependent variable is the performance of the electric motor charging system, which is represented by the solar panel output power and the increase in battery voltage during the charging process. Control variables include the type of battery used, the solar panel configuration, the charging system components, as well as the duration and procedures of the experiment. These control variables were maintained consistently throughout the testing period to ensure that observed changes in system performance were predominantly caused by variations in sunlight intensity rather than by external or uncontrolled factors.

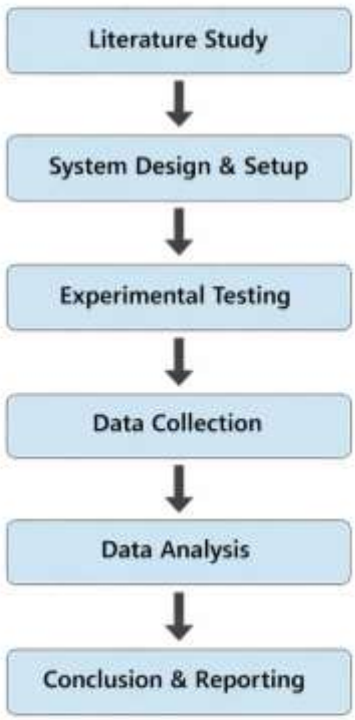

Figure 1. Research flow diagram of the experimental procedure

The research stages in this study are systematically arranged and follow an experimental research flow consisting of several main stages, namely literature study, system design and preparation, system testing and data recording, data collection, data analysis, as well as drawing conclusions and reporting research results. These stages are in line with the research flow chart shown in figure 1.

The test results data were then analyzed descriptively by comparing the relationship between sunlight intensity, solar panel output power, and battery voltage increase. This analysis was used to identify the performance patterns of electric motor charger systems as well as evaluate the effectiveness of the use of solar panels as an alternative energy source for electric vehicle charging

RESEARCH RESULT AND DISCUSSION

The experimental results indicate that from the morning until the period before noon, the increase in sunlight intensity is directly proportional to the increase in solar panel output power and battery voltage. During this time interval, solar irradiance gradually rises, allowing the photovoltaic modules to generate higher electrical power that can be effectively utilized for battery charging. Under conditions of high solar irradiance combined with relatively stable ambient temperatures, the charging system operates optimally and delivers a considerable charging current. This condition demonstrates that sufficient and stable solar radiation plays a crucial role in ensuring efficient energy conversion and reliable charging performance.

Nevertheless, when ambient temperature increases significantly, a noticeable decrease in the output power of the solar panels is observed, even though the sunlight intensity remains relatively high. This phenomenon is associated with the thermal characteristics of photovoltaic cells, where elevated cell temperatures lead to a reduction in voltage and overall conversion efficiency. As a result, part of the potential electrical energy generated by high irradiance cannot be fully utilized for the charging process. These findings highlight that, in addition to sunlight intensity, ambient temperature is a critical environmental parameter that influences the performance and stability of solar-based charging systems.

Overall, the solar panel–based electric motor charging system is capable of gradually increasing the battery voltage until it approaches a fully charged condition. The most optimal system performance is achieved during periods characterized by high sunlight intensity and moderate ambient temperatures, where the balance between irradiance and thermal conditions is favorable. These results are consistent with previous studies reporting that the performance of photovoltaic systems is strongly affected by environmental factors, particularly solar irradiance and temperature variations (24,25).

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, it can be concluded that the electric motor charging system utilizing solar panels can operate effectively as an alternative renewable energy source. The experimental findings indicate that sunlight intensity plays a dominant role in determining the output power of the solar panels and the battery charging rate. Higher levels of solar irradiance result in increased electrical output and improved charging performance, while variations in environmental conditions significantly influence overall system behavior.

In addition, high ambient temperatures were observed to reduce the efficiency of the charging system due to the thermal characteristics of photovoltaic modules. Despite this limitation, the proposed system demonstrates considerable potential for further development as an environmentally friendly electric vehicle charging solution. Its application is particularly suitable for regions with high solar energy availability, where solar-based charging systems can contribute to sustainable transportation and reduced dependence on conventional electricity sources.

ADVANCED RESEARCH

Future research may extend this study by integrating adaptive control strategies and intelligent energy management systems to further enhance the performance of solar-powered electric vehicle charging systems. The implementation of real-time monitoring combined with machine learning or optimization algorithms could enable dynamic adjustment of charging parameters based on solar irradiance, temperature, and battery state of charge. In addition, the use of alternative battery technologies, such as lithium-ion or hybrid energy storage systems, may be investigated to improve charging efficiency, energy density, and system lifespan. Expanding the experimental scope to include long-term performance evaluation, seasonal variations, and hybrid grid–solar configurations would also provide a more comprehensive assessment of system reliability and scalability for broader electric mobility applications.

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