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Hybrid Renewable Energy System for Efficient Electric Vehicle Battery Charging Using Solar PV and Wind Integration

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ABSTRACT
The integration of renewable energy sources for electric vehicle (EV) battery charging has gained significant attention due to the increasing need for sustainable transportation solutions. This study presents the design and simulation of a hybrid energy system, combining rooftop solar photovoltaic (PV) and wind energy for efficient EV battery charging. The solar energy system is connected through a boost converter, with a duty cycle controller ensuring maximum power point tracking (MPPT) to optimize the energy harvested from the PV array. Simultaneously, the wind energy system is connected via a permanent magnet synchronous generator (PMSG) coupled to a wind turbine. The output from the PMSG is rectified using a three-phase diode bridge rectifier (DBR) and is also linked to a boost converter, controlled by a duty cycle controller, to stabilize the voltage and optimize the charging process. Both energy sources are integrated to charge the EV battery, ensuring a reliable and continuous energy supply. The boost converters in both subsystems are essential for managing voltage fluctuations and improving the charging efficiency of the EV battery. The system's performance is evaluated in MATLAB/Simulink, focusing on the control strategy of the duty cycle controllers and the interaction between the solar and wind subsystems. The results demonstrate the feasibility and effectiveness of the proposed hybrid system in delivering a stable and efficient EV battery charging solution, emphasizing the role of renewable energy in achieving sustainable electric mobility.
Keywords: Rooftop solar, wind energy, boost converter, duty cycle controller, PMSG, EV battery charging, hybrid energy system.

I INTRODUCTION

The integration of renewable energy into electric vehicle (EV) battery charging systems has emerged as a pivotal component in the global shift toward sustainable and eco-friendly transportation. With the rising popularity of EVs, efficient, reliable, and environmentally sustainable charging methods have become essential to reducing dependence on fossil fuels and mitigating greenhouse gas emissions[1]. Leveraging renewable energy sources, such as solar and wind power, for on-the-go EV battery charging not only aligns with global sustainability goals but also enhances the feasibility of widespread EV adoption. A hybrid system combining rooftop solar panels and wind turbines connected to permanent magnet synchronous generators (PMSG) offers a robust solution for ensuring continuous and reliable energy generation for EVs, even during motion. This approach harnesses the strengths of both solar and wind energy, optimizing power conversion through advanced power electronics like boost converters with duty cycle controllers[2]. The transportation sector is one of the largest contributors to global carbon dioxide (CO_2) emissions, primarily due to its reliance on fossil fuels. Transitioning to

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cleaner energy alternatives in transportation is crucial to combat climate change. EVs have emerged as a promising solution, offering a cleaner substitute to conventional internal combustion engine vehicles[3]. However, the environmental benefits of EVs largely depend on the source of the electricity used for charging. If this electricity is derived from fossil fuels, the overall environmental impact remains substantial. Integrating renewable energy sources, such as solar and wind, into the charging process is vital to unlocking the full potential of EVs in mitigating climate change. Solar energy, with its abundance and sustainability, presents an ideal candidate for this integration[4]. Photovoltaic (PV) systems installed on EV rooftops can provide supplementary charging while the vehicle is in motion, ensuring a steady energy supply during daylight hours[5].

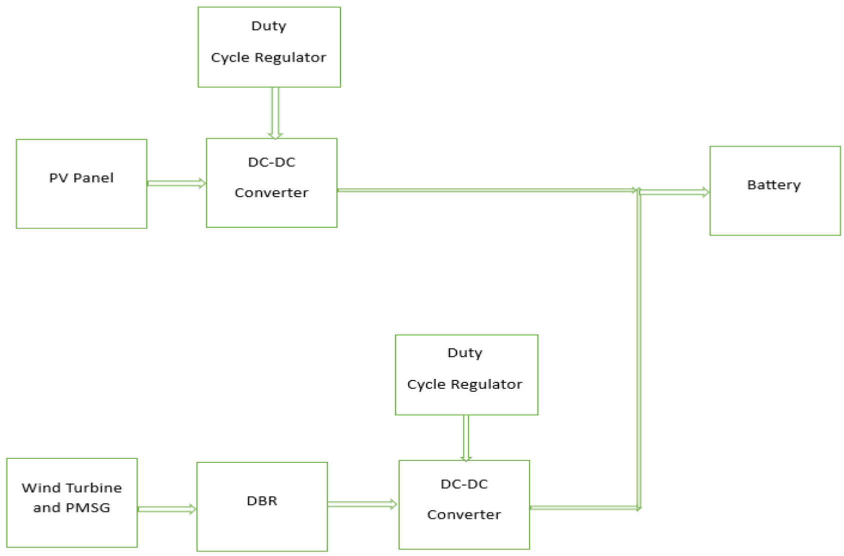

Fig 1. proposed system Block diagram

Solar PV systems convert sunlight directly into electrical energy, making them a highly suitable option for EV battery charging. However, environmental factors such as sunlight intensity, cloud cover, and shading can influence their performance. To address these challenges, a boost converter is employed to regulate the voltage generated by the solar panels. This converter steps up the solar output voltage to match the battery's charging requirements, ensuring efficient energy transfer. Furthermore, a duty cycle controller is used to optimize the converter's operation, maximizing energy conversion through maximum power point tracking (MPPT). This ensures that the solar panels operate at their most efficient point, regardless of environmental variations[6]. Complementing solar energy, wind power is another invaluable renewable resource for EV charging systems. By integrating wind turbines connected to PMSGs, EVs can harness wind energy to charge their batteries, especially during cloudy or nighttime conditions when solar energy is unavailable. Wind turbines convert kinetic energy from the wind into mechanical energy, which is subsequently transformed into electrical energy by PMSGs[7]. The alternating current (AC) generated by PMSGs is then converted into direct current (DC) using a three-phase diode bridge rectifier, enabling battery charging. Similar to the solar PV system, a boost converter and duty cycle controller are integral to regulating the voltage and optimizing energy conversion, ensuring seamless integration of wind energy into the hybrid system[8]. The integration of renewable energy sources into EV charging systems relies heavily on advanced power electronics to enhance efficiency and reliability. Boost converters play a critical role by stepping up the input voltage from renewable sources to levels compatible with EV batteries. They ensure optimal utilization of the energy generated by solar panels and wind turbines[9]. Additionally, duty cycle controllers regulate the boost converters, fine-tuning their performance to maximize power transfer. In the case of solar PV systems, duty cycle controllers implement MPPT algorithms to maintain the panels' operation at their maximum efficiency point. This not only increases energy conversion efficiency but also adapts to varying environmental conditions, ensuring a consistent power supply[10]. combining rooftop solar panels with wind turbines for EV battery charging represents a groundbreaking approach to sustainable transportation. By leveraging renewable energy sources and advanced power electronics, this hybrid system offers a viable solution for on-the-go EV

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charging, reducing reliance on fossil fuels and minimizing environmental impact. Although challenges such as energy generation variability, size constraints, and cost must be addressed, the benefits of this technology far outweigh the difficulties. As advancements in renewable energy and power electronics continue, the prospects for integrating solar and wind power into EV charging systems remain promising, paving the way for a greener and more sustainable future for transportation[11].

II LITERATURE SURVEY

The integration of renewable energy into electric vehicle (EV) battery charging systems has become a focus of research in the pursuit of sustainable transportation. Renewable energy sources such as solar and wind power are particularly appealing for this application, given their abundance and potential to reduce reliance on fossil fuels. Research has increasingly demonstrated the feasibility and efficiency of hybrid systems that combine solar photovoltaic (PV) and wind energy for EV battery charging. These systems capitalize on the complementary nature of the two energy sources, ensuring a consistent and reliable energy supply even under varying environmental conditions [11]. Solar PV technology is widely recognized for its ability to convert sunlight directly into electrical energy. When installed on the rooftops of vehicles, PV panels provide a viable source of energy for on-the-go charging. This approach reduces dependence on stationary charging infrastructure and enhances the mobility and convenience of EVs. However, the intermittent nature of solar energy poses challenges to its effective utilization. Variations in sunlight intensity, cloud cover, and shading affect the power output of PV systems, necessitating advanced power electronics to stabilize and optimize energy conversion [12]. Boost converters, combined with duty cycle controllers, play a crucial role in addressing these challenges. By stepping up the output voltage of the PV array and implementing maximum power point tracking (MPPT) algorithms, these devices ensure efficient energy harvesting, even under suboptimal conditions [13].

Wind energy, as a renewable resource, complements solar power by providing energy during periods when sunlight is unavailable, such as at night or during cloudy weather. Wind turbines connected to permanent magnet synchronous generators (PMSGs) are commonly used in hybrid systems to convert kinetic energy from the wind into electrical energy. The output from the PMSG, being alternating current (AC), must be rectified to direct current (DC) to be compatible with EV battery charging. This is achieved using three-phase diode bridge rectifiers (DBRs), which efficiently convert the AC output into DC. Like solar PV systems, wind energy systems also rely on boost converters and duty cycle controllers to regulate voltage and ensure efficient energy transfer to the battery [14]. Hybrid systems that integrate solar and wind energy offer several advantages over standalone renewable energy systems. By combining the strengths of both energy sources, these systems provide a more stable and reliable energy supply. For instance, during daylight hours, solar PV panels can generate sufficient energy to charge the EV battery, while wind turbines can take over during nighttime or when solar energy generation is reduced. This synergy minimizes energy generation variability, a common limitation of single-source renewable systems, and enhances the overall efficiency and reliability of the hybrid system [15].

The use of advanced power electronics is critical to the successful implementation of hybrid renewable energy systems. Boost converters are an essential component, as they allow the system to step up the input voltage from renewable energy sources to levels compatible with the EV battery. By regulating the voltage, these converters mitigate fluctuations caused by environmental variations and ensure a consistent charging performance. Duty cycle controllers further enhance the functionality of boost converters by dynamically adjusting their operation. This ensures that the system operates at optimal efficiency, maximizing power transfer from the renewable sources to the EV battery. In solar PV systems, the duty cycle controller is responsible for implementing MPPT algorithms, which adjust the operating point of the PV panels to achieve maximum power output under varying sunlight conditions [16]. Despite their potential, hybrid renewable energy systems face several technical challenges. One major issue is the variability of energy generation, which depends on environmental factors such as sunlight intensity and wind speed. To overcome this, sophisticated power management systems are required to coordinate the operation of solar and wind subsystems and ensure a consistent energy supply to the EV battery. The integration of energy storage solutions, such as lithium-ion batteries, is also crucial for storing excess energy generated during peak production periods for later use. This not only improves the reliability of the system but also enhances its ability to meet the dynamic energy demands of EVs [17]. Size and weight constraints are another challenge in the design of on-the-go charging systems for EVs. Rooftop solar panels and wind turbines must be compact and lightweight to avoid adding significant weight to the vehicle, which could reduce its overall efficiency. Moreover, the available surface area on the vehicle limits the size of the PV panels that can be installed. These constraints necessitate innovative designs that maximize energy generation while minimizing weight and space requirements [18].

The efficiency of power electronics, particularly boost converters and duty cycle controllers, is critical to the overall performance of hybrid renewable energy systems. Any losses in these components can significantly reduce the amount of energy available for charging the EV battery. Research has focused on developing high-efficiency power electronics to minimize energy losses and maximize system performance. For instance, advancements in semiconductor technology have enabled the development of highly efficient boost converters that operate with minimal energy loss, even under high load conditions [19]. Economic considerations also play a significant role in the feasibility of hybrid renewable energy systems. The cost of components such as solar panels, wind turbines, power electronics, and energy storage systems can be substantial, posing a barrier to widespread adoption. Ensuring the cost-effectiveness of these systems is therefore a key area of research. Innovative manufacturing techniques and the use of cost-effective materials have been explored to reduce the overall cost of system components without compromising performance [20].

III PROPOSED SYSTEM

The proposed hybrid renewable energy system is designed to address the challenges of efficient and sustainable electric vehicle (EV) battery charging by integrating rooftop solar photovoltaic (PV) and wind energy. This integration leverages the complementary characteristics of solar and wind resources to provide a reliable and consistent power supply. The system is built around advanced power electronics and control strategies to optimize the energy generation and charging process, ensuring maximum efficiency and stability.

The solar PV component is a cornerstone of the system, utilizing rooftop panels to convert sunlight into electrical energy. Solar PV technology is chosen due to its widespread availability, ease of deployment, and low environmental impact. However, solar energy generation is inherently variable, influenced by factors such as sunlight intensity, angle of incidence, shading, and weather conditions. To overcome these challenges, the solar PV subsystem is equipped with a boost converter connected to a duty cycle controller that employs a Maximum Power Point Tracking (MPPT) algorithm. The MPPT algorithm continuously adjusts the operating point of the PV array to ensure it operates at its maximum power output under varying conditions. This optimization is critical for harvesting the maximum amount of energy from the available sunlight.

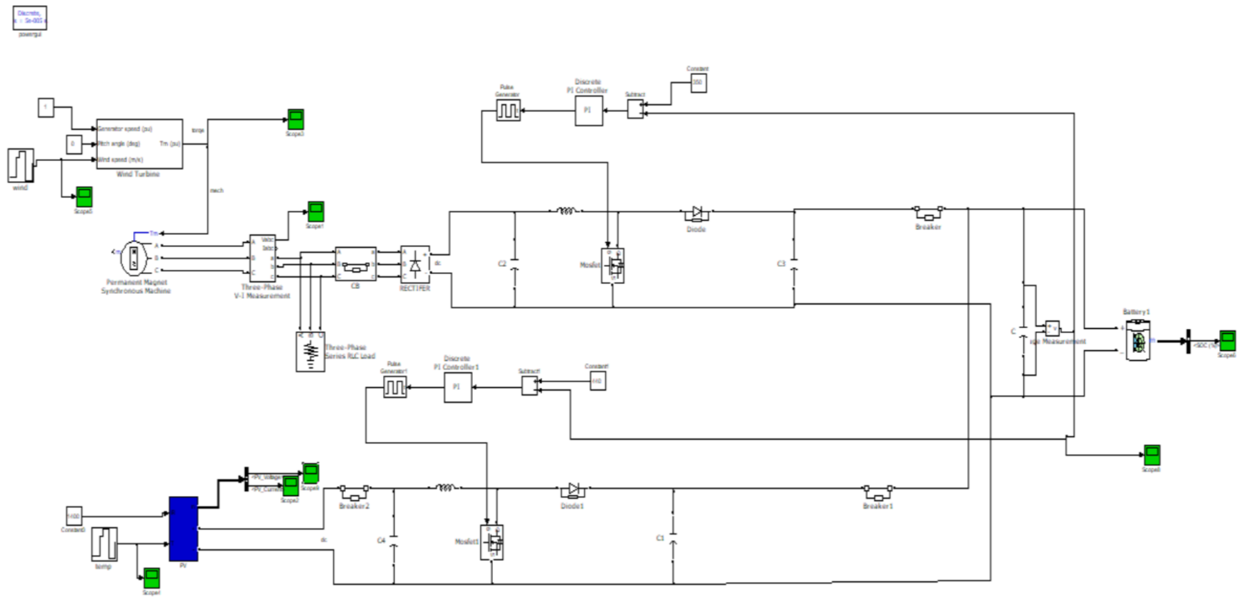

Fig 2. Proposed system simulation circuit

Complementing the solar PV system is the wind energy subsystem, which harnesses kinetic energy from wind using a turbine coupled to a Permanent Magnet Synchronous Generator (PMSG). Wind energy is chosen for its ability to generate power during periods when sunlight is unavailable, such as at night or during overcast conditions. The PMSG, known for its high efficiency and reliability, converts the mechanical energy of the wind turbine into electrical energy. However, the output from the PMSG is in alternating current (AC) form, which needs to be rectified into direct current (DC) for compatibility with EV battery charging. This is achieved using a three-phase diode bridge rectifier (DBR),

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which ensures a smooth and consistent DC output. To stabilize the rectified output and enhance the energy transfer efficiency, the wind subsystem also includes a boost converter controlled by a duty cycle controller.

The integration of the solar and wind subsystems is a crucial aspect of the proposed system. The output from both energy sources is combined in a common DC link, which serves as the input for the EV battery charging unit. The hybrid design ensures that energy from either source, or a combination of both, can be used to charge the battery, providing a continuous and reliable power supply. This redundancy is particularly beneficial in maintaining system stability and ensuring uninterrupted charging, even when one of the energy sources is unavailable or underperforming due to environmental conditions.

One of the key innovations of the proposed system lies in its control strategy, which is implemented through the duty cycle controllers of the boost converters in both subsystems. These controllers dynamically adjust the duty cycle of the converters to regulate the voltage levels, ensuring compatibility with the battery's charging requirements. The duty cycle controllers also coordinate the operation of the solar and wind subsystems, optimizing energy utilization and minimizing losses. For instance, when solar energy generation is at its peak, the system prioritizes the use of solar power, while wind energy takes precedence during periods of high wind speeds. This dynamic management of energy sources enhances the overall efficiency and performance of the system.

IV PROPOSED SYSTEM MODELLING

The EV battery charging process is another critical component of the proposed system. The charging unit is designed to handle the variable input from the hybrid energy sources while maintaining the charging characteristics required for the battery. Lithium-ion batteries, commonly used in EVs, require precise charging protocols to ensure safety, efficiency, and longevity. The proposed system incorporates advanced charging algorithms that regulate the charging current and voltage, preventing overcharging and overheating while maximizing the battery's capacity. The combination of stable power input from the hybrid energy sources and intelligent charging algorithms results in a highly efficient and safe charging process.

Power electronics play a central role in the proposed system, not only in energy conversion but also in addressing voltage fluctuations and ensuring the stability of the DC link. Boost converters are employed to step up the voltage levels from both the solar and wind subsystems, enabling seamless integration into the charging unit. The design of these converters emphasizes high efficiency and low energy losses, leveraging advanced semiconductor technology and innovative circuit designs. Additionally, the system incorporates filters to minimize electromagnetic interference and improve the quality of the power delivered to the battery.

The control output u(t) for the PI controller is given by:

$$u(t) = K_P e(t) + K_i \int_0^t e(\tau)d\tau$$

Where:

- $u(t)$: Control signal or controller output.
- K_P: Proportional gain, which determines the strength of the response to the current error.
- K_i: Integral gain, which determines the response based on the accumulation of past errors.
- e(t): Error signal, defined as:

$$e(t) = V_{ref} - V_{actual}$$

Here, V_{ref} is the reference voltage and V_{actual} is the actual voltage.

$\int_0^t e(\tau)d\tau$: The integral term that accumulates the error over time.

To evaluate the performance and feasibility of the proposed system, a detailed simulation is conducted using MATLAB/Simulink. The simulation focuses on several key parameters, including the efficiency of energy conversion, the stability of the DC link voltage, and the effectiveness of the control strategy. It also examines the interaction between the solar and wind subsystems, assessing their ability to complement each other and provide a consistent power supply. The results from the simulation demonstrate the system's capability to achieve high efficiency and reliability, validating its potential as a sustainable solution for EV battery charging.

The hybrid system's design also considers scalability and adaptability, making it suitable for various applications and scenarios. For instance, the capacity of the solar PV and wind subsystems can be adjusted based on the energy demand and availability of resources. Similarly, the system can be adapted to integrate additional energy sources, such as energy storage units or grid connections, to further enhance its reliability and flexibility. This adaptability ensures that the proposed system can cater to a wide range of user requirements and environmental conditions.

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Another important aspect of the proposed system is its environmental impact. By relying on renewable energy sources, the system significantly reduces greenhouse gas emissions and dependence on fossil fuels. This aligns with global efforts to combat climate change and promote sustainable development. The integration of rooftop solar panels also makes efficient use of existing infrastructure, minimizing land use and associated environmental impacts. Additionally, the wind subsystem's compact and efficient design ensures minimal disruption to the surrounding environment.

The proposed system also has significant implications for the broader adoption of EVs and renewable energy. By providing a reliable and efficient charging solution, it addresses one of the key barriers to EV adoption: the availability and convenience of charging infrastructure. The integration of renewable energy into EV charging not only enhances the sustainability of transportation but also contributes to the decentralization and diversification of the energy supply. This, in turn, supports the transition to a more resilient and sustainable energy system.

V SIMULATION RESULTS

The proposed hybrid renewable energy system represents a comprehensive and innovative approach to EV battery charging. By integrating rooftop solar PV and wind energy, it leverages the complementary characteristics of these renewable resources to provide a reliable and efficient power supply. The use of advanced power electronics and intelligent control strategies ensures the system's stability, efficiency, and adaptability, making it a viable solution for sustainable transportation. Through detailed simulation and evaluation, the proposed system demonstrates its potential to meet the growing demand for EV charging while contributing to global efforts to reduce carbon emissions and promote renewable energy adoption.

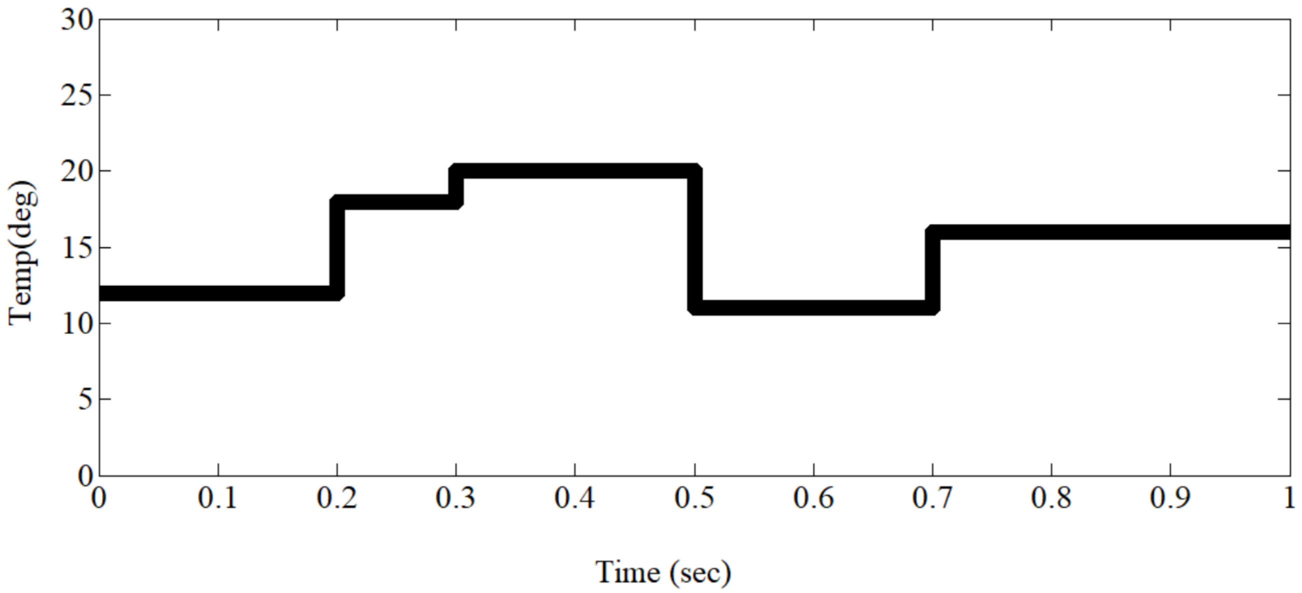

Fig 3.PV Input Temperature vs Time

The simulation illustrates the variation of PV module temperature over time, influenced by environmental conditions. An increase in temperature typically reduces the PV efficiency by decreasing the open-circuit voltage. The results validate the system's capability to adapt to these fluctuations, ensuring consistent MPPT operation for optimal energy harvesting. This parameter is crucial in assessing how effectively the system manages thermal impacts on solar energy generation.

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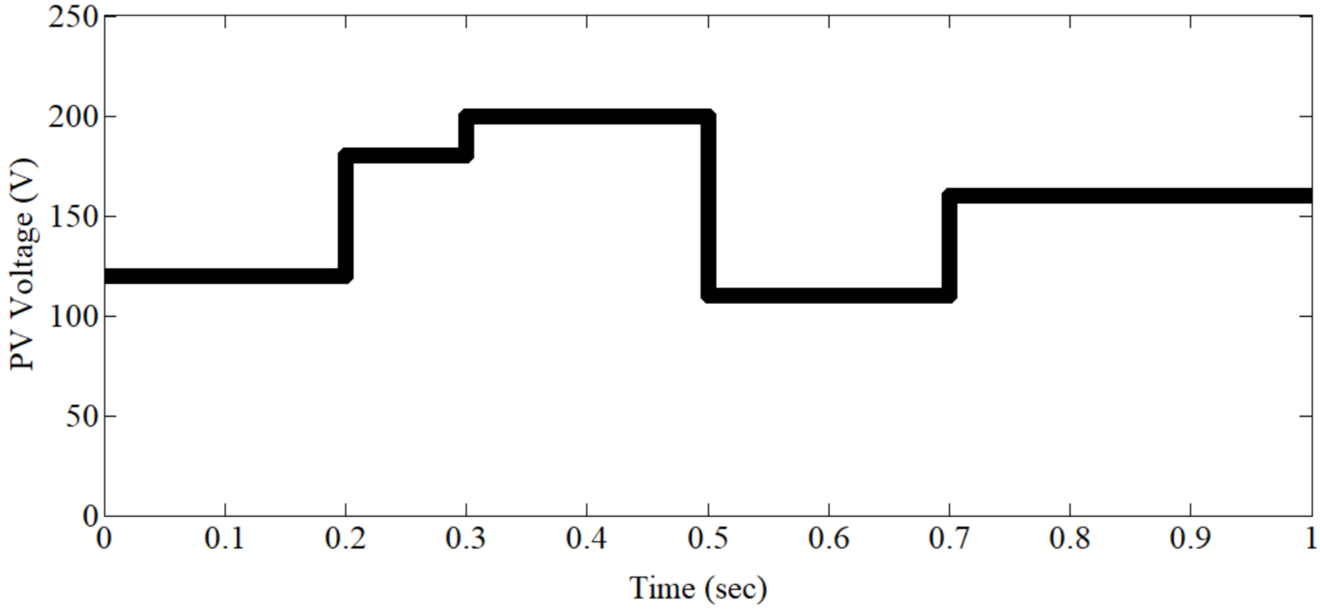

Fig 4. PV Voltage vs Time

PV voltage over time reflects the system's ability to maintain consistent output despite changing solar irradiance levels. The MPPT algorithm dynamically adjusts the voltage to operate the PV array at its maximum power point. This ensures stability and reliability in energy production, even under varying sunlight conditions, emphasizing the system's efficiency in solar energy conversion.

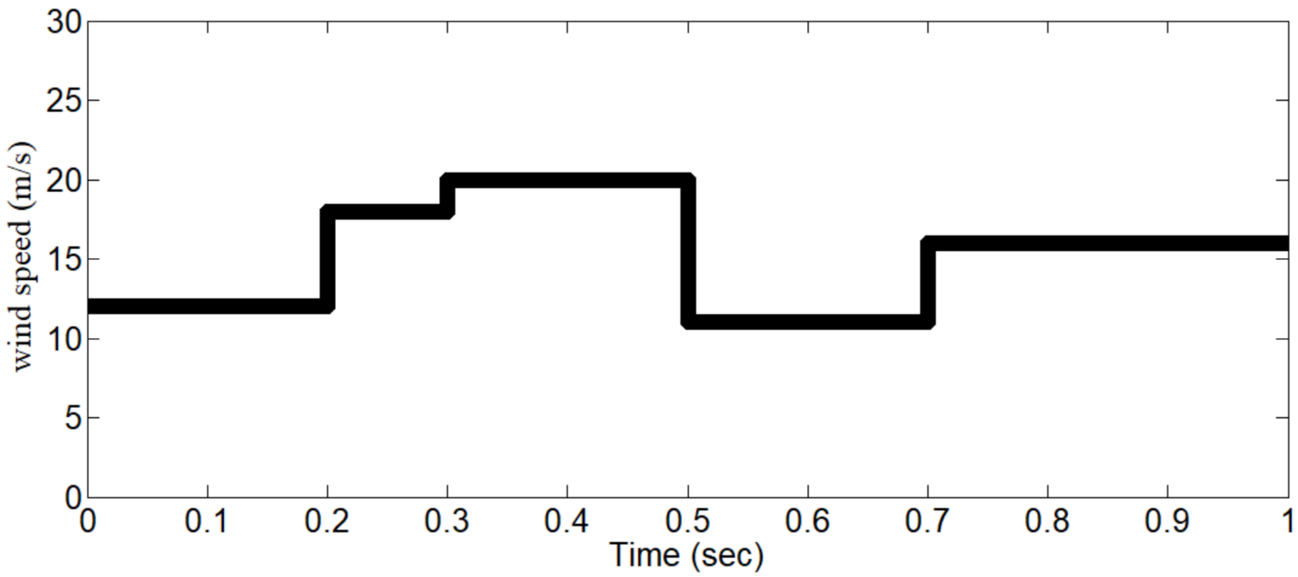

Fig 5.Wind Speed vs Time

Wind speed versus time showcases the intermittent and variable nature of wind energy. The system's PMSG effectively converts mechanical energy from fluctuating wind speeds into electrical energy. The results confirm the wind subsystem's robustness in accommodating these variations, providing a complementary energy source to the solar PV for continuous EV charging.

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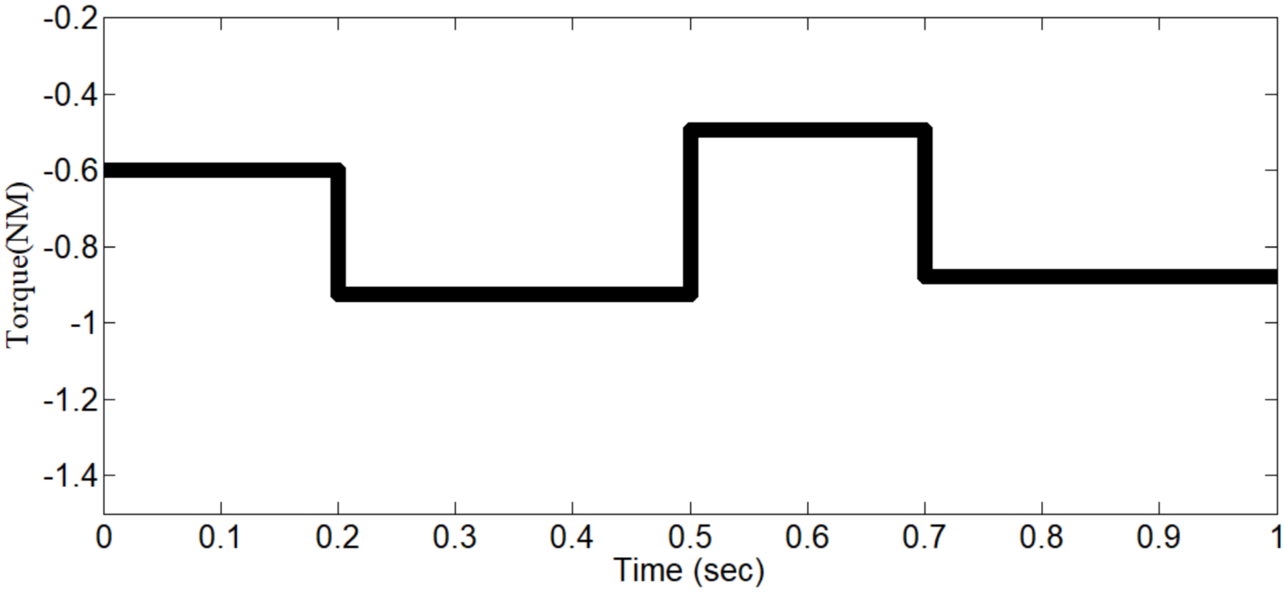

Fig 6. Torque vs Time

Torque generated by the wind turbine demonstrates its direct relationship with wind speed. The simulation highlights the system's ability to manage variations in turbine torque, ensuring smooth energy transfer to the PMSG. This stability is critical for maintaining consistent energy production from wind resources.

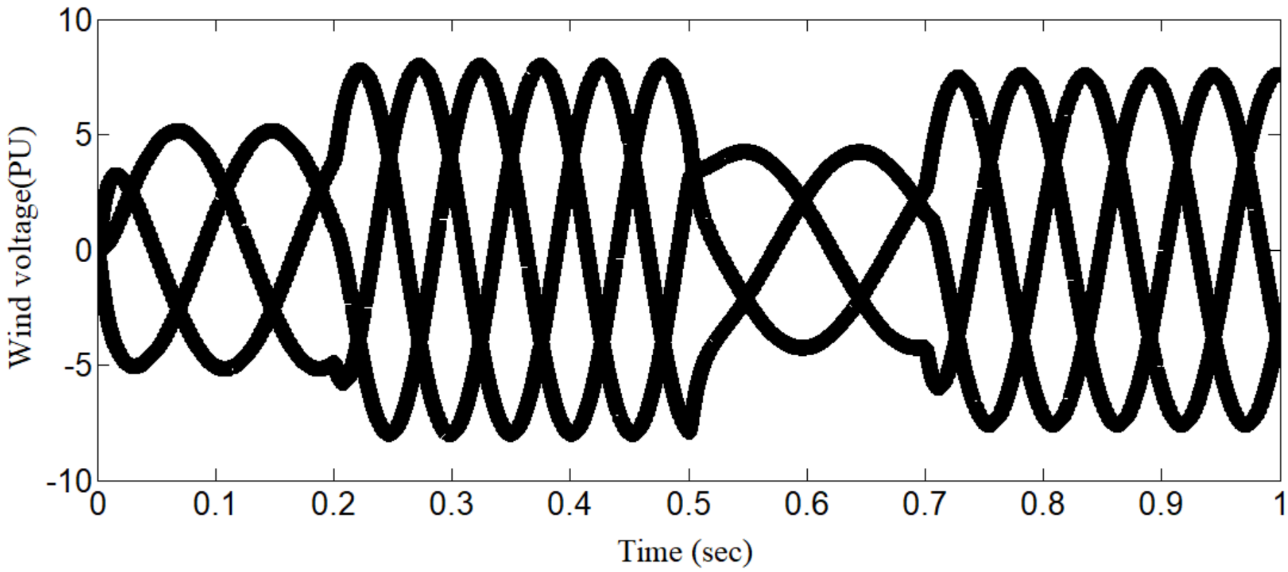

Fig 7. PMSG Output Voltage in PU

The PMSG output voltage in per unit (PU) represents its stability across different wind speeds. The rectified voltage from the PMSG remains steady due to the integration of the boost converter, which regulates fluctuations. This ensures a reliable DC output for the hybrid system, crucial for EV battery charging.

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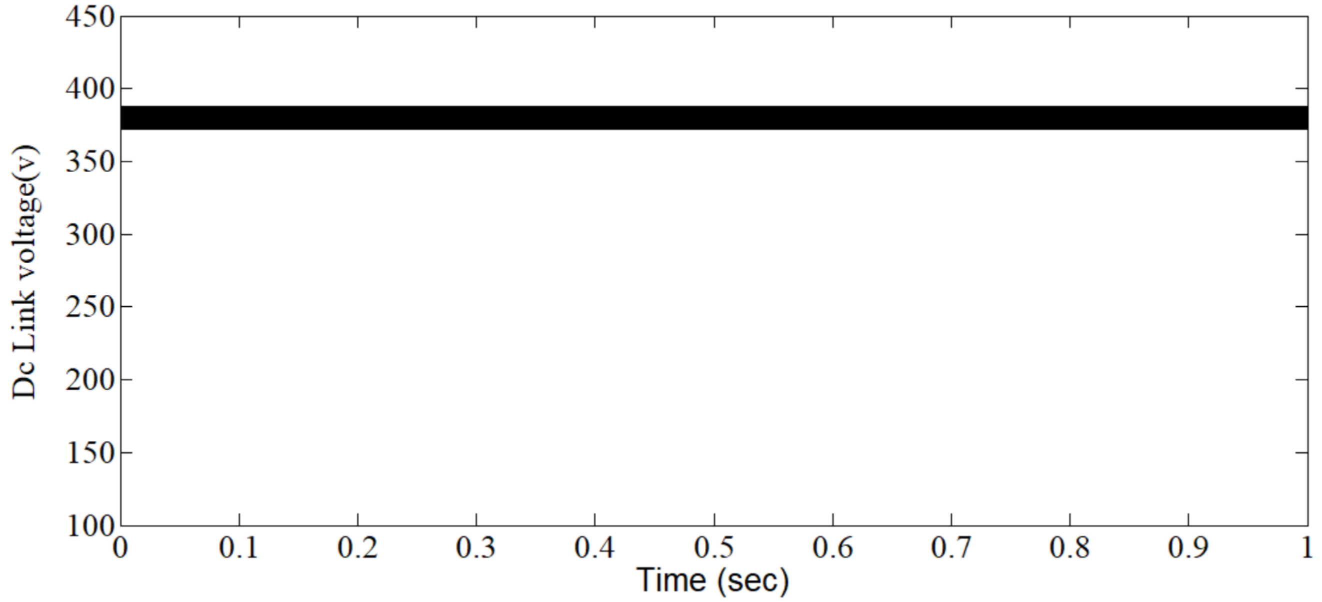

Fig 8.DC Link Voltage vs Time

The DC link voltage graph illustrates the seamless integration of solar and wind energy sources. The boost converters in both subsystems stabilize the DC link voltage, ensuring a consistent and efficient power supply to the EV battery. This result confirms the system's ability to handle input variations and provide reliable charging.

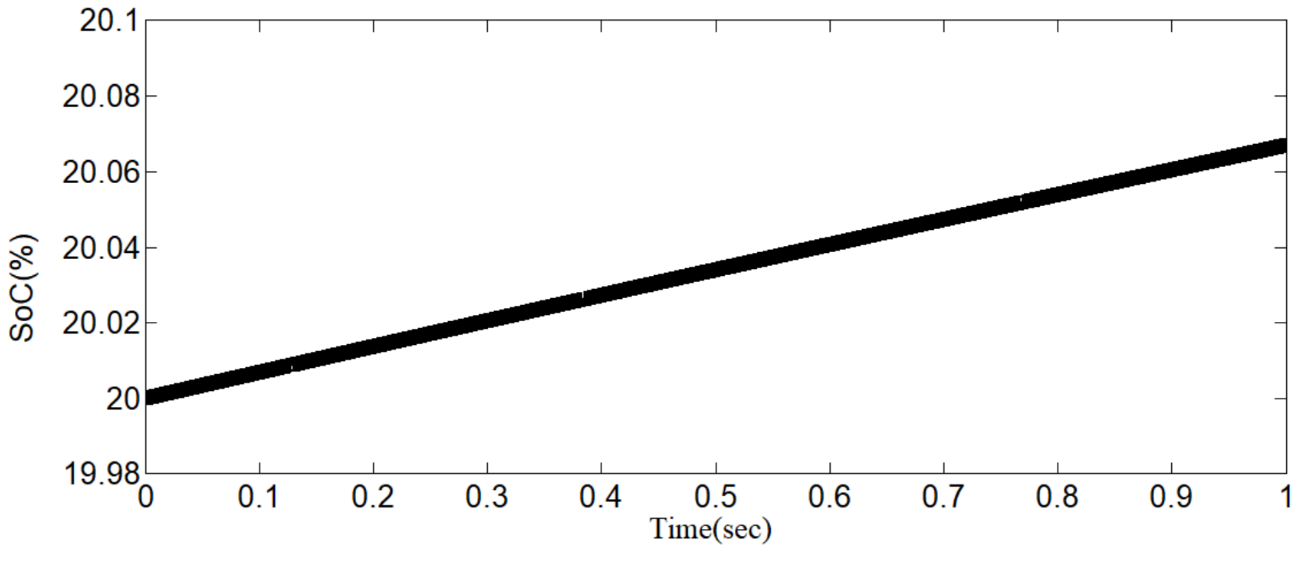

Fig 9. SoC vs time

The simulation results of the hybrid renewable energy system for electric vehicle (EV) battery charging demonstrate the State of Charge (SoC) versus time behavior under varying conditions. The SoC increases steadily, reflecting the effective integration of solar PV and wind energy sources. The boost converters and MPPT algorithms optimize energy utilization, ensuring continuous charging despite fluctuations in solar irradiance or wind speed. The results validate the system's ability to maintain a reliable energy supply, with minimal interruptions or inefficiencies. The SoC curve highlights the hybrid system's capacity to achieve efficient energy transfer, supporting EV charging demands while ensuring sustainability.

CONCLUSION

The proposed hybrid EV charging system combining rooftop solar and wind energy presents a sustainable and efficient solution to the challenges posed by renewable energy intermittency. By integrating boost converters and duty cycle controllers, the system ensures optimal voltage regulation, improving the reliability and efficiency of the charging process. The dual-source approach reduces grid dependency, promotes the use of clean energy, and contributes to the global transition toward greener transportation. Additionally, the system is scalable and can be adapted for a wide range of applications, from residential charging units to public EV infrastructure. Overall, this project demonstrates the potential of hybrid renewable energy systems in revolutionizing EV charging technology and supporting sustainable energy goals.

REFERENCES

1. T. Markvart and L. Castaner, Solar Cells: Materials, Manufacture and Operation, Elsevier, 2005.
2. S. P. Sukhatme and J. K. Nayak, Solar Energy: Principles of Thermal Collection and Storage, 3rd ed., Tata McGraw-Hill Education, 2008.
3. A. Luque and S. Hegedus, Handbook of Photovoltaic Science and Engineering, 2nd ed., Wiley, 2011.
4. D. Yogi Goswami, F. Kreith, and J. F. Kreider, Principles of Solar Engineering, 3rd ed., CRC Press, 2015.
5. T. Esram and P. L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, " IEEE Transactions on Energy Conversion, vol. 22, no. 2, pp. 439-449, 2007.
6. W. Li and X. He, "Review of Non isolated High-Step-Up DC/DC Converters in Photovoltaic Grid-Connected Applications, " IEEE Transactions on Industrial Electronics, vol. 58, no. 4, pp. 1239-1250, April 2011.
7. A. Kwasinski, "Quantitative Evaluation of DC Microgrids Availability: Effects of System Architecture and Converter Topology Design Choices, "IEEE Transactions on Power Electronics, vol. 26, no. 3, pp. 835-851, March 2011.
8. R. Teodorescu, M. Liserre, and P. Rodriguez, Grid Converters for Photovoltaic and Wind Power Systems, Wiley-IEEE Press, 2011.
9. Y. Zhou and W. Huang, "Simulation and Experiment of Maximum Power Point Tracking (MPPT) Strategy for PV Generation System, " IEEE Power Electronics and Motion Control Conference, 2004.
10. A. Iqbal and S. Islam, "A Review on Renewable Energy Systems for Electric Vehicles Charging Applications, " Renewable and Sustainable Energy Reviews, vol. 69, pp. 1014-1027, March 2017.
11. A. Hussein, A. Radwan, and A. Gabbar, " Modeling and Optimization of a Solar/Wind Hybrid Energy System, " International Journal of Renewable Energy Research, vol. 4, no. 2, pp. 213-220, 2014.
12. C. G. Hochgraf and R. M. Nelms, "Battery Charging Algorithms for Electric Vehicles, "IEEE Transactions on Vehicular Technology, vol. 42, no. 3, pp. 337-344, August 1993.
13. S. K. Kollimalla, M. K. Mishra, and M. F. AlHajri, "Optimal Sizing of Hybrid Wind/PV/Battery Systems Using Genetic Algorithm, " Renewable Energy, vol. 103, pp. 629-640, April 2017.
14. M. S. ElNozahy and M. M. A. Salama, "Technical Impacts of Grid-Connected Photovoltaic Systems on Electrical Networks—A Review, " Journal of Renewable and Sustainable Energy, vol. 6, no. 5, 2014.
15. Y. Shi, Y. Li, and H. Wu, "Research on Adaptive Fuzzy Logic Controller of Boost Converter for Maximum Power Point Tracking of Photovoltaic Systems, " Journal of Renewable Energy, vol. 2014, Article ID 345916, 2014.
16. H. S. Rauschenbach,Solar Cell Array Design Handbook: The Principles and Technology of Photovoltaic Energy Conversion, Van Nostrand Reinhold, 1980.
17. S. Mekhilef, R. Saidur, and A. Safari, "A Review on Solar Energy Use in Industries, "Renewable and Sustainable Energy Reviews, vol. 15, no. 4, pp. 1777-1790, May 2011.
18. M. A. Elgendy, B. Zahawi, and D. J. Atkinson, "Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications, " IEEE Transactions on Sustainable Energy, vol. 3, no. 1, pp. 21-33, Jan. 2012.
19. S. J. Park, S. Han, and H. Ahn, "Hybrid Solar and Wind Energy Systems for Electric Vehicles Charging—A Review, " Journal of Electrical Engineering & Technology, vol. 13, no. 3, pp. 1536-1545, 2018.
20. R. C. Bansal, T. S. Bhatti, and D. P. Kothari, "On Some of the Design Aspects of Wind Energy Conversion Systems, " Energy Conversion and Management, vol. 43, no. 16, pp. 2175-2187, November 2002.