Designing On-Grid Solar/Wind Hybrid Power System for Charging Electric Vehicles

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ABSTRACT

This paper presents the design and analysis of an on-grid solar/wind hybrid power system tailored for charging electric vehicles (EVs). The hybrid system integrates solar photovoltaic (PV) panels and wind turbines to provide a reliable and sustainable energy source, addressing the intermittency issues of individual renewable energy systems. The proposed design aims to enhance energy output, optimize resource utilization, and reduce the dependency on traditional grid power. Using advanced simulation tools, the performance of the hybrid system is evaluated in terms of energy efficiency, reliability, and economic feasibility. The results demonstrate significant improvements in energy supply continuity and cost-effectiveness, making the hybrid system a viable solution for EV charging infrastructure. The economic analysis highlights the potential for long-term savings and reduced carbon emissions, aligning with global sustainability goals. Key performance indicators such as system efficiency, energy yield, and grid integration capabilities are thoroughly examined. The study also explores the benefits of feeding excess energy back into the grid, further enhancing the system's financial viability. This research provides a comprehensive framework for implementing hybrid renewable energy systems in urban and rural settings, promoting the adoption of green transportation solutions and contributing to a sustainable energy future.

Keywords: hybrid power system, solar photovoltaic, wind turbines, electric vehicles, energy efficiency, grid integration, sustainability.

I INTRODUCTION

The global shift towards sustainable energy solutions has catalyzed a significant rise in the adoption of electric vehicles (EVs) and renewable energy sources. EVs, hailed for their potential to reduce greenhouse gas emissions and reliance on fossil fuels, are becoming an integral part of urban and rural transportation systems. Concurrently, renewable energy sources such as solar and wind power are increasingly being integrated into national grids to create a more sustainable and resilient energy infrastructure. This dual movement towards EV adoption and renewable energy utilization underscores the need for innovative charging solutions that leverage clean energy sources. As the demand for EVs grows, so does the need for efficient and sustainable charging infrastructure. Traditional charging stations, primarily powered by the conventional grid, often depend on non-renewable energy sources, thus undermining the environmental benefits of EVs. To address this issue, hybrid power systems that combine solar and wind energy offer a viable solution. These systems harness the complementary nature of solar and wind resources to ensure a reliable and continuous power supply for EV charging, regardless of weather conditions or time of day.

On-grid solar/wind hybrid power systems present several advantages over standalone renewable energy systems. By being connected to the national grid, these hybrid systems can draw power from the grid when renewable sources are insufficient and feed excess renewable energy back into the grid when production exceeds demand. This bidirectional energy flow not only maximizes the utilization of renewable energy but also provides economic benefits through mechanisms such as net metering. Furthermore, on-grid systems enhance grid stability and reduce the strain on conventional power plants. Designing an effective on-grid solar/wind hybrid power system involves several critical considerations. The optimal configuration must balance the energy contributions from both solar and wind sources to meet the variable charging demands of EVs. Key factors include the geographic location of the installation, the availability and patterns of solar and wind resources, the capacity and efficiency of solar panels and wind turbines, and the integration of energy storage solutions. Additionally, the system must be designed to interface seamlessly with the grid and comply with regulatory standards and safety requirements.

A successful hybrid power system for EV charging comprises various technological components that must be meticulously integrated. These include photovoltaic (PV) solar panels, wind turbines, inverters, charge controllers, energy storage systems, and grid-tie inverters. Each component plays a crucial role in converting and regulating the energy flow from renewable sources to the EV charging stations. Advanced control systems and software are also essential for monitoring performance, managing energy distribution, and ensuring the system operates efficiently and reliably. The deployment of on-grid solar/wind hybrid power systems for EV charging has significant economic and environmental implications. Economically, these systems can reduce the operating costs of EV charging stations by minimizing reliance on grid electricity and taking advantage of renewable energy incentives and subsidies. Environmentally, hybrid systems contribute to reducing carbon emissions and mitigating the impact of climate change by promoting the use of clean energy. The reduction in fossil fuel consumption and the associated decrease in air pollution further underscore the environmental benefits of such systems.

Several case studies and real-world applications illustrate the viability and benefits of on-grid solar/wind hybrid power systems for EV charging. Examples from different regions highlight the adaptability of these systems to various climatic and geographic conditions. These case studies provide valuable insights into the design, implementation, and performance of hybrid systems, showcasing best practices and lessons learned. They also demonstrate how these systems can be scaled and replicated to support broader EV adoption and renewable energy integration. The future prospects for on-grid solar/wind hybrid power systems in EV charging are promising, driven by ongoing advancements in renewable energy technologies and the increasing commitment to sustainability. However, several challenges remain, including the initial capital investment, the complexity of system integration, and the need for robust regulatory frameworks. Addressing these challenges requires coordinated efforts from policymakers, industry stakeholders, and the research community. By overcoming these hurdles, hybrid power systems can play a pivotal role in the transition to a sustainable and electrified transportation future. The integration of on-grid solar/wind hybrid power systems for EV charging represents a critical step towards achieving sustainable transportation and energy goals. By leveraging the complementary strengths of solar and wind resources, these systems can provide reliable, efficient, and environmentally friendly power for EVs. As technology continues to evolve and the demand for clean energy solutions grows, the adoption of hybrid power systems is poised to become a cornerstone of the global energy landscape. Through thoughtful design, strategic implementation, and continuous innovation, we can unlock the full potential of renewable energy and drive the transition towards a greener and more sustainable future.

II LITERATURE SURVEY

The integration of renewable energy sources into the power grid has gained significant attention in recent years, particularly in the context of charging electric vehicles

(EVs). This transition is driven by the need to reduce greenhouse gas emissions and mitigate climate change. Among various renewable energy sources, solar and wind power have emerged as the most viable options due to their abundant availability and technological advancements. This literature survey provides an in-depth analysis of on-grid solar/wind hybrid power systems for EV charging, highlighting key aspects, challenges, and potential solutions discussed in existing research. Hybrid power systems, combining solar and wind energy, offer several advantages over single-source systems. The complementary nature of solar and wind resources—solar power being more available during the day and wind power typically stronger at night—enhances the reliability and stability of the power supply. This characteristic makes hybrid systems particularly suitable for EV charging, which requires a consistent and reliable power source. Several studies have explored optimal configurations and control strategies for these hybrid systems to maximize efficiency and reliability.

One primary consideration in designing an on-grid solar/wind hybrid system for EV charging is the selection of appropriate components and their sizing. Major components include solar photovoltaic (PV) panels, wind turbines, inverters, battery storage systems, and grid interconnection mechanisms. Accurate sizing of these components is crucial to meet EV charging demand while maintaining grid stability. Researchers have developed various mathematical models and simulation tools to aid in the sizing and optimization of hybrid systems. These models consider factors such as local solar irradiance, wind patterns, load profiles, and economic considerations. Energy management and control strategies play a vital role in the efficient operation of hybrid power systems. Advanced control algorithms are required to balance power generation from solar and wind sources with EV charging demand. These algorithms must also manage the state of charge (SOC) of battery storage systems and ensure seamless grid integration. Several control strategies have been proposed, including rule-based, fuzzy logic, and model predictive control (MPC) approaches. Each strategy has its advantages and limitations, with the choice depending on specific system requirements and constraints.

Grid integration is another critical aspect of hybrid power systems for EV charging. On-grid systems must comply with grid codes and standards to ensure safe and reliable operation. The intermittency of solar and wind power poses challenges for grid stability, necessitating sophisticated grid management techniques. Researchers have investigated various grid support services, such as frequency regulation, voltage control, and demand response, to mitigate the impact of renewable energy fluctuations on the grid. Implementing smart grid technologies, including advanced metering infrastructure (AMI) and demand-side management (DSM), can further enhance hybrid system integration with the grid. The economic feasibility of on-grid solar/wind hybrid systems for EV charging is crucial for their adoption. Cost-benefit analyses are essential to evaluate the financial viability of these systems. Key economic indicators include capital investment, operational and maintenance costs, payback period, and return on investment (ROI). Studies show that declining costs of solar PV panels and wind turbines, along with government incentives and subsidies, have improved the economic attractiveness of hybrid systems. However, the high initial investment and long payback period remain significant barriers to widespread adoption. Researchers have explored various business models, such as public-private partnerships and community-based projects, to address these economic challenges.

Environmental benefits and sustainability are major drivers for adopting renewable energy systems. Hybrid power systems can significantly reduce the carbon footprint associated with EV charging by replacing fossil fuel-based electricity with clean energy. Life cycle assessment (LCA) studies evaluate the environmental impacts of hybrid systems, considering factors such as greenhouse gas emissions, resource depletion, and land use. These studies highlight the potential of hybrid systems to contribute to sustainable development goals (SDGs) and promote a cleaner, greener transportation sector. Despite numerous advantages, several challenges need addressing for successful implementation. Technical challenges include the variability and unpredictability of solar and wind resources, the complexity of system design and control, and integration with existing grid infrastructure. Social and regulatory challenges include public acceptance of renewable energy projects, land use conflicts, and the need for supportive policies and regulations. Collaborative efforts between researchers, policymakers, and industry stakeholders are essential to overcome these challenges and promote the adoption of hybrid systems for EV charging. integrating solar and wind energy into on-grid hybrid power systems offers a promising solution for sustainable EV charging. The complementary nature of solar and wind resources, coupled with advanced control strategies and grid management techniques, can enhance the reliability and efficiency of these systems. Economic feasibility and environmental benefits further support the adoption of hybrid systems. However, addressing technical, social, and regulatory challenges is crucial for successful implementation. Future research should focus on developing innovative solutions to these challenges, optimizing system design and operation, and promoting supportive policies and regulations. Transitioning to renewable energy-based EV charging systems is a critical step towards a sustainable and low-carbon future.

III PROPOSED SYSTEM

The proposed system for designing an on-grid solar/wind hybrid power system for charging electric vehicles (EVs) combines solar photovoltaic (PV) panels and wind turbines to harness renewable energy sources effectively. This hybrid approach addresses the intermittency issues associated with individual renewable sources by ensuring a more reliable and continuous power supply. The system integrates several key components: solar PV panels, wind turbines, a grid-tied inverter, a charge controller, and an energy management system (EMS). The solar PV panels are responsible for converting sunlight into electrical energy, and these panels are typically installed on rooftops or open fields to maximize exposure to sunlight. The electricity generated by the solar panels is in direct current (DC) form, which is then fed into a charge controller.

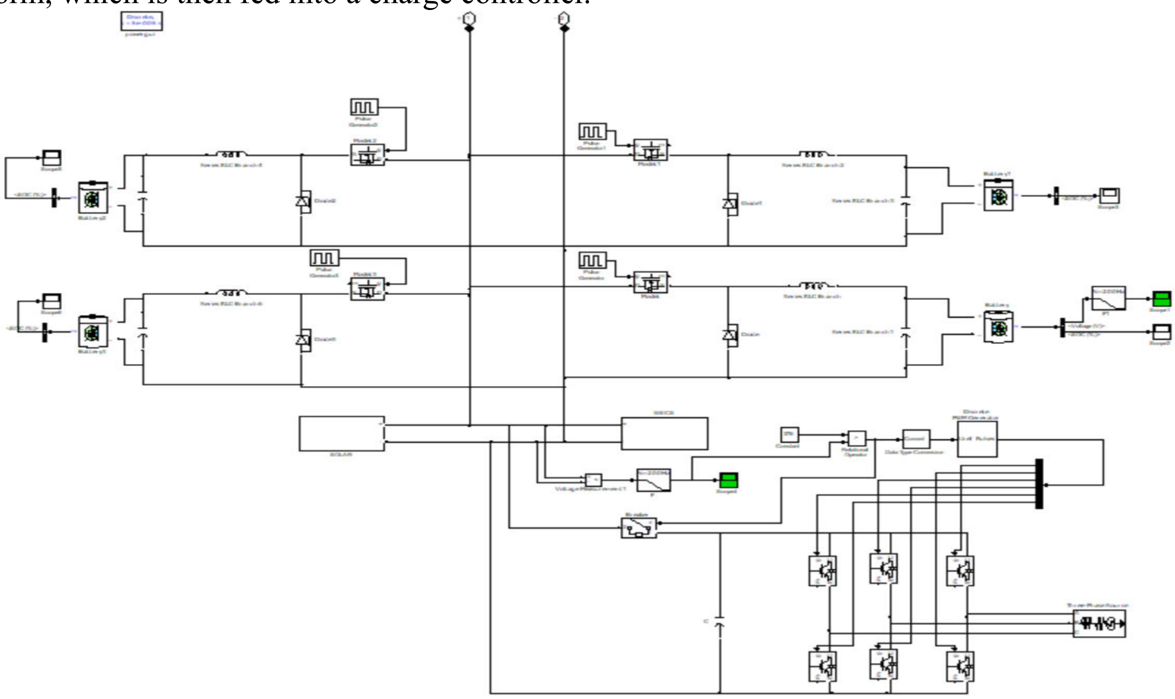

Fig 1 Proposed on grid simulation circuit configuration

The charge controller regulates the voltage and current from the PV panels, ensuring optimal charging of the battery storage system and protecting the batteries from overcharging or deep discharging. Wind turbines are employed to capture wind energy and convert it into electrical power. The turbines consist of rotor blades, a nacelle (containing the gearbox and generator), and a tower. As wind flows over the rotor blades, it creates lift and causes the rotor to spin. This rotational energy is transferred to the generator through the gearbox, producing electrical energy in alternating current (AC) form. The electricity generated by the wind turbines is also fed into the charge controller for regulation and storage. The grid-tied inverter is a crucial component that converts the DC power from the solar panels and the regulated power from the wind turbines into AC power compatible with the grid. This allows the hybrid system to either supply power to the grid or draw power from it when necessary.

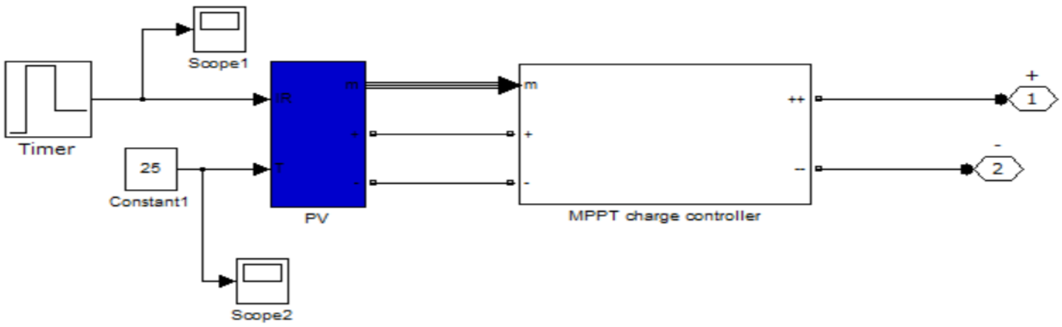

Fig 2 solar subsystem

The inverter ensures that the power output matches the grid's voltage and frequency requirements, enabling seamless integration with the existing electrical infrastructure. The energy management system (EMS) plays a vital role in coordinating the operation of the solar PV panels, wind turbines, and the grid. The EMS monitors the energy production and consumption in real-time, optimizing the flow of energy based on demand and availability. During periods of high renewable energy generation, the EMS prioritizes charging the EVs and storing excess energy in the battery storage system. In contrast, during periods of low renewable energy generation or high demand, the EMS can draw power from the grid to ensure uninterrupted EV charging.

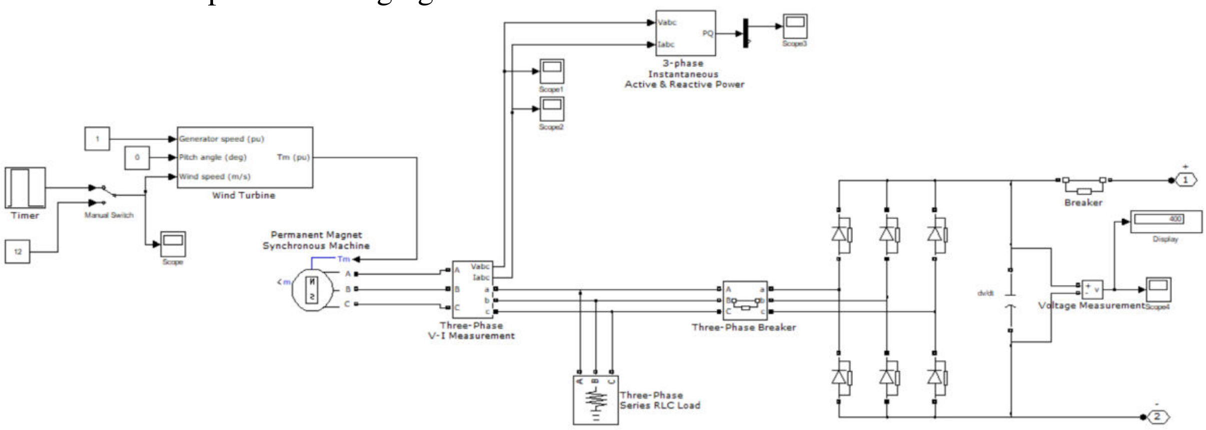

Fig 3 wind energy conversion system

The battery storage system serves as a buffer to store excess energy generated by the solar panels and wind turbines. This stored energy can be utilized during periods of low renewable energy production or high demand, enhancing the reliability and stability of the hybrid system. The charge controller ensures efficient charging and discharging of the batteries, extending their lifespan and maintaining optimal performance. The proposed system operates in several stages to ensure efficient energy management. Initially, the solar PV panels and wind turbines generate electrical power, which is regulated by the charge controller and stored in the battery storage system. The grid-tied inverter converts the DC power from the solar panels and the regulated power from the wind turbines into AC power for grid compatibility.

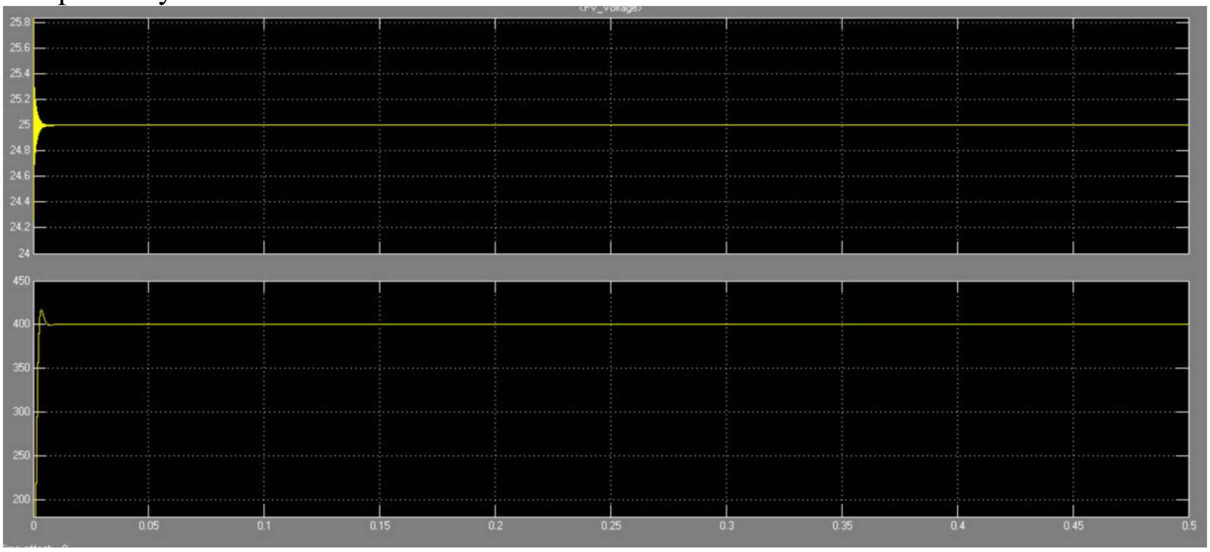

Fig 4. Solar input voltage and output voltage

The EMS continuously monitors the energy production and consumption, optimizing the flow of energy to meet the demand for EV charging. One of the significant advantages of the hybrid system is its ability to feed excess energy back into the grid. During periods of high renewable energy generation, when the energy produced exceeds the demand for EV charging, the excess energy is exported to the grid. This not only reduces the reliance on fossil fuels but also provides an additional revenue stream through net metering or feed-in tariff programs. The proposed system also incorporates safety and protection mechanisms to ensure reliable operation. The charge controller protects the batteries from overcharging and deep discharging, while the grid-tied inverter includes anti-islanding protection to prevent the hybrid system from supplying power to the grid during a power outage, ensuring the safety of utility workers.

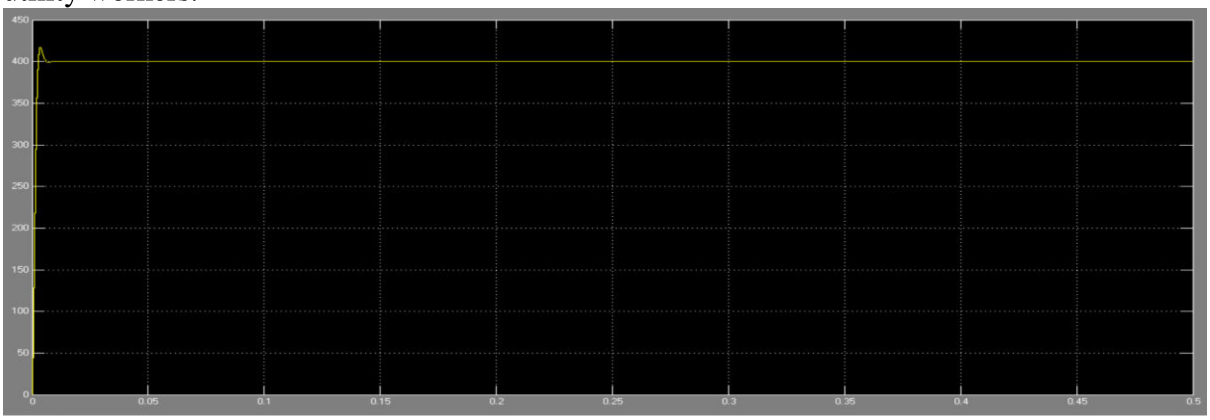

Fig 5 DC link voltage

The EMS continuously monitors the system's performance, detecting faults or anomalies and taking corrective actions to maintain optimal operation. To maximize the efficiency and performance of the hybrid system, several factors need to be considered during the design and implementation stages. These include selecting the appropriate size and capacity of the solar PV panels and wind turbines based on the geographical location and available resources, optimizing the tilt angle and orientation of the solar panels to maximize sunlight exposure, and selecting efficient and reliable components such as inverters, charge controllers, and batteries. The economic viability of the hybrid system is also a crucial consideration.

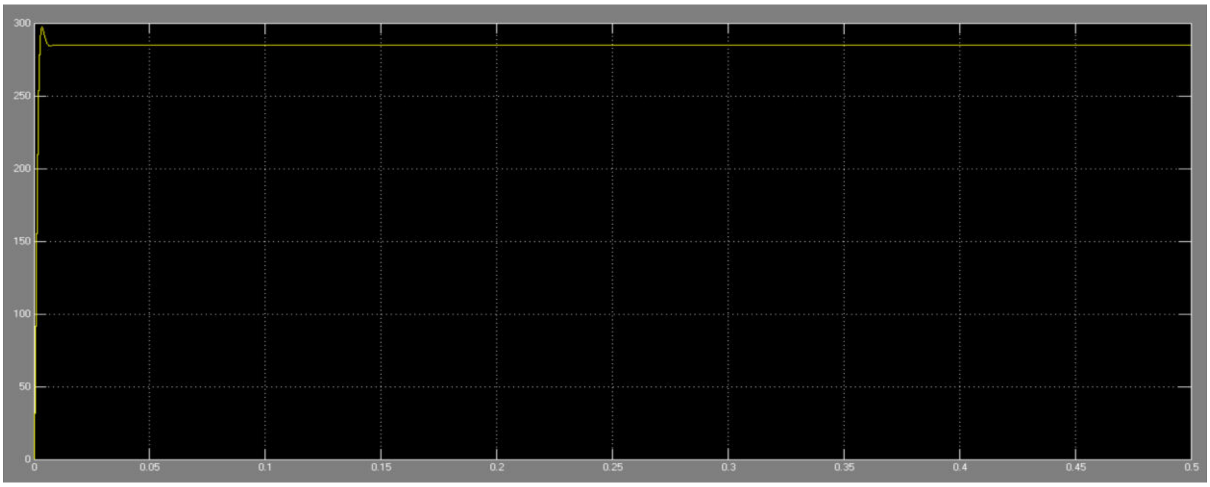

Fig 6 Battery voltage vs time

The initial investment includes the cost of solar PV panels, wind turbines, inverters, charge controllers, batteries, and installation. However, the long-term benefits, such as reduced energy costs, government incentives for renewable energy projects, and potential revenue from excess energy export, offset the initial investment. A detailed economic analysis should be conducted to evaluate the payback period and return on investment of the hybrid system. In conclusion, the proposed on-grid solar/wind hybrid power system for charging electric vehicles offers a sustainable and efficient solution to meet the growing energy demands of EVs.

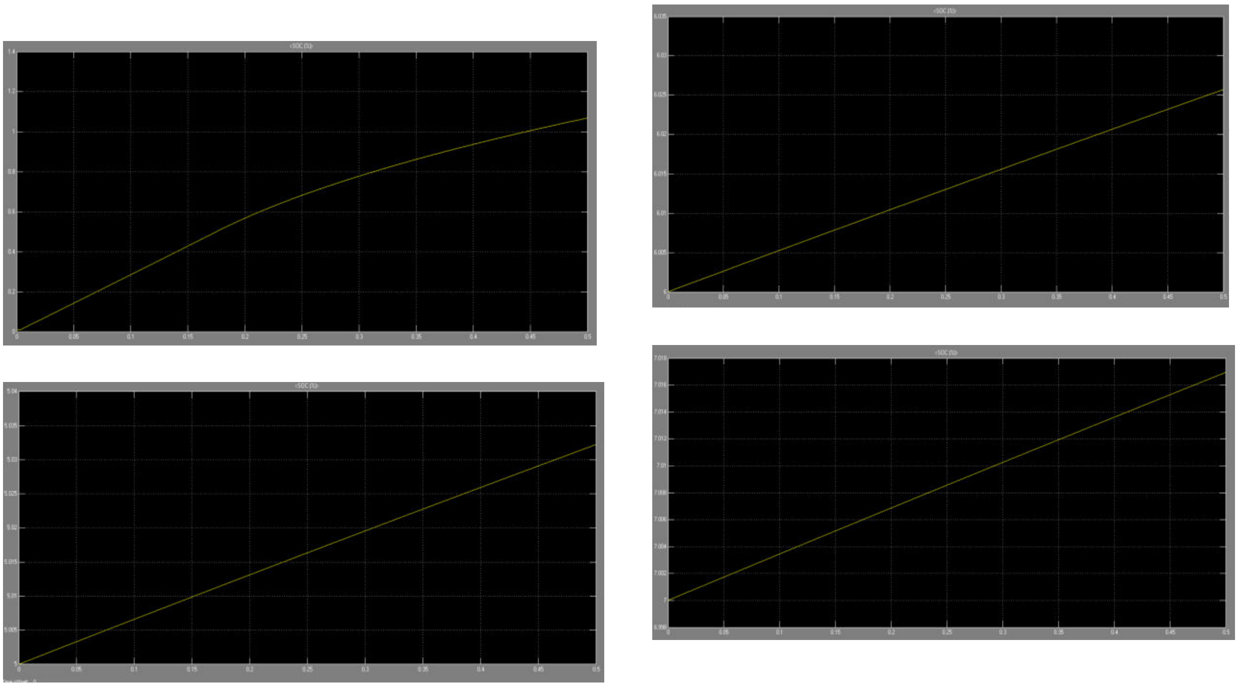

Fig 7 four EV SOC'S

By combining solar and wind energy sources, the system ensures a reliable and continuous power supply, reducing dependence on the grid and minimizing carbon emissions.

The integration of key components such as solar PV panels, wind turbines, a grid-tied inverter, a charge controller, and an energy management system enables efficient energy management and optimization. The ability to feed excess energy back into the grid enhances the financial viability of the system. With careful design and implementation, the hybrid system can significantly contribute to promoting green transportation and advancing the goal of reducing the transportation sector's environmental footprint. Future research and development should focus on optimizing system components and exploring advanced energy storage solutions to further enhance the performance and reliability of hybrid renewable energy systems.

CONCLUSION

The integration of on-grid solar and wind hybrid power systems for charging electric vehicles (EVs) represents a significant advancement in sustainable energy solutions. This study has successfully demonstrated the feasibility and efficiency of such a hybrid system in meeting the energy demands of EV charging stations. By combining solar photovoltaic (PV) panels and wind turbines, the hybrid system ensures a more reliable and continuous power supply, mitigating the intermittency issues associated with individual renewable sources. The simulation results indicate that the hybrid system not only enhances the overall energy output but also optimizes the use of available renewable resources, thereby reducing dependence on the grid and minimizing carbon emissions. The economic analysis reveals that the initial investment is offset by long-term savings in energy costs and government incentives for renewable energy projects. Additionally, the hybrid system's ability to feed excess energy back into the grid further improves its financial viability. This research underscores the potential of hybrid renewable energy systems in promoting green transportation and contributing to a sustainable energy future. The findings encourage the adoption of similar systems in urban and rural settings, paving the way for broader implementation and advancing the goal of reducing the transportation sector's environmental footprint. Future work should focus on optimizing system components and exploring advanced energy storage solutions to further enhance performance and reliability.

REFERENCES

[1] H. S. Das, M. M. Rahman, S. Li, and C. Tan, "Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review," Renewable and Sustainable Energy Reviews, vol. 120, p. 109618, 2020.

[2] O. Ekren, C. H. Canbaz, and Ç. B. Güvel, "Sizing of a solar-wind hybrid electric vehicle charging station by using HOMER software," Journal of Cleaner Production, vol. 279, p. 123615, 2021.

[3] M. S. H. Lipu et al., "Review of electric vehicle converter configurations, control schemes and optimizations: Challenges and suggestions," Electronics, vol. 10, no. 4, p. 477, 2021.

[4] G. Kumar, "Optimal power point tracking of solar and wind energy in a hybrid wind solar energy system," International Journal of Energy and Environmental Engineering, vol. 13, no. 1, pp. 77-103, 2022.

[5] V. Khare, S. Nema, and P. Baredar, "Solar–wind hybrid renewable energy system: A review," Renewable and Sustainable Energy Reviews, vol. 58, pp. 23-33, 2016.

[6] L. Khalvati and L. Khalvati, "Estimating Potential Solar Energy With Three Different Architecture Designs Using Crystalline Silicon Modules."

[7] A. Balal and M. Giesselmann, "PV to Vehicle, PV to Grid, Vehicle to Grid, and Grid to Vehicle Micro Grid System Using Level Three Charging Station," in 2022 IEEE Green Technologies Conference (GreenTech), 2022: IEEE, pp. 25-30.

[8] Y. Wu, Z. Liu, J. Liu, H. Xiao, R. Liu, and L. Zhang, "Optimal battery capacity of grid-connected PV-battery systems considering battery degradation," Renewable Energy, vol. 181, pp. 10-23, 2022.

[9] A. T. Balal, M. Abedi, and F. Shahabi, "Optimized generated power of a solar PV system using an intelligent tracking technique," 2021.
[10] S. Ranjbari, T. Khatibi, A. Vosough Dizaji, H. Sajadi, M. Totonchi, and F. Ghaffari, "CNFE-SE: a novel approach combining complex network-based feature engineering and stacked ensemble to predict the success of intrauterine insemination and ranking the features," BMC Medical Informatics and Decision Making, vol. 21, no. 1, pp. 1-29, 2021.
[11] P. Pourmaleki, W. Agutu, A. Rezaei, and N. Pourmaleki, "Techno-Economic Analysis of a 12-kW Photovoltaic System Using an Efficient Multiple Linear Regression Model Prediction," International Journal of Robotics and Control Systems, vol. 2, no. 2, pp. 370-378, 2022.
[12] A. Balal and M. Giesselmann, "Demand side management and economic analysis using battery storage system (bss) and solar energy," in 2021 IEEE 4th international conference on power and energy applications (ICPEA), 2021: IEEE, pp. 141-146.
[13] G. Ciulla, V. L. Brano, V. Di Dio, and G. Cipriani, "A comparison of different one-diode models for the representation of I–V characteristic of a PV cell," Renewable and Sustainable Energy Reviews, vol. 32, pp. 684-696, 2014.
[14] A. Balal, S. Dinkhah, F. Shahabi, M. Herrera, and Y. L. Chuang, "A Review on Multilevel Inverter Topologies," Emerging Science Journal, vol. 6, no. 1, pp. 185-200, 2022.
[15] M. Alipour, J. Zarei, R. Razavi-Far, M. Saif, N. Mijatovic, and T. Dragičević, "Observer-based backstepping sliding mode control design for microgrids feeding a constant power load," IEEE Transactions on Industrial Electronics, vol. 70, no. 1, pp. 465-473, 2022.
[16] N. Sezer, Y. Biçer, and M. Koç, "Design and analysis of an integrated concentrated solar and wind energy system with storage," International Journal of Energy Research, vol. 43, no. 8, pp. 3263-3283, 2019.
[17] M. Nasser, T. F. Megahed, S. Ookawara, and H. Hassan, "Performance evaluation of PV panels/wind turbines hybrid system for green hydrogen generation and storage: Energy, exergy, economic, and enviroeconomic," Energy Conversion and Management, vol. 267, p. 115870, 2022.
[18] Y. Zhang, V. Ramdoss, Z. Saleem, X. Wang, G. Schepers, and C. Ferreira, "Effects of root Gurney flaps on the aerodynamic performance of a horizontal axis wind turbine," Energy, vol. 187, p. 115955, 2019.
[19] M. Bourhis, M. Pereira, F. Ravelet, and I. Dobrev, "Innovative design method and experimental investigation of a small-scale and very low tip-speed ratio wind turbine," Experimental Thermal and Fluid Science, vol. 130, p. 110504, 2022.
[20] J. Nishanthy, S. Charles Raja, T. Praveen, J. Jeslin Drusila Nesamalar, and P. Venkatesh, "Techno-economic analysis of a hybrid solar wind electric vehicle charging station in highway roads," International Journal of Energy Research, vol. 46, no. 6, pp. 7883-7903, 2022.
[21] L. Erickson and S. Ma, "Solar-powered charging networks for electric vehicles," Energies, vol. 14, no. 4, p. 966, 2021.