International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

Check for updates

Optimal solution for PV integrated with smart grid connected fast charging EV station: A case study for Jaipur

Girish Kumar Dev * and Satyamwada Priyadarshi

Electrical Engineering, Jaipur Engineering College, Kukas, Jaipur, India.

International Journal of Science and Research Archive, 2024, 13(01), 549–555

Publication history: Received on 21 July 2024; revised on 09 September 2024; accepted on 11 September 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.13.1.1621

Abstract

Current research study investigates the optimal solution for integrating photovoltaic (PV) solar panels with a smart grid-connected fast-charging electric vehicle (EV) station in Jaipur, India, using HOMER software for simulation. The study aims to develop a cost-effective and sustainable charging infrastructure specifically designed for e-rickshaws and personal vehicles, targeting reduced electricity costs. The findings demonstrate that a hybrid Solar and Grid-integrated EV charging station significantly lowers operational costs while promoting renewable energy adoption. The optimized Solar + grid system, compared to a traditional grid-only model, achieves substantial savings, with an average annual energy bill reduction of ₹26,17,806. Despite an initial capital expenditure of ₹50,22,895, the system's financial viability is affirmed by a rapid payback period of 1.9 years (simple) or 2.1 years (discounted) and an impressive internal rate of return (IRR) of 51.3%. Over a 25-year project lifespan, the system is projected to generate total savings of ₹6,54,45,150. The analysis considers various financial metrics, including monthly and annual energy costs, demand charges, and fixed charges, providing a comprehensive overview of the economic benefits. The results underline the importance of incorporating solar power into EV charging stations to reduce overall energy expenses and enhance long-term sustainability. This study offers valuable insights for policymakers, energy managers, and stakeholders, highlighting the economic and environmental advantages of solar-integrated charging solutions in urban settings.

Keywords: EV charging; HOMER; PV-Grid integrated

1. Introduction

In recent years, the global energy landscape has been shifting towards more sustainable and renewable energy sources, with solar and wind power leading the way. This shift is driven by the urgent need to reduce carbon emissions and combat climate change. Solar photovoltaic (PV) systems have emerged as a critical component of renewable energy strategies, offering significant potential for enhancing the efficiency and reliability of energy supply when integrated with other renewable sources and advanced technologies. In countries like India, where the demand for energy is growing rapidly due to urbanization, industrialization, and an increasing population, the adoption of renewable energy is not just an environmental imperative but also an economic necessity. India's energy sector is primarily characterized by its reliance on coal, which contributes to high levels of pollution and greenhouse gas emissions. However, the country is also endowed with abundant solar energy resources, making solar PV systems an attractive alternative for clean energy generation. The integration of solar PV with other renewable energy sources, such as wind, and advanced storage solutions like Battery Energy Storage Systems (BESS), can play a pivotal role in meeting the country's energy needs sustainably. The government of India has set ambitious renewable energy targets to reduce its carbon footprint and achieve energy security, with solar power at the forefront of its energy strategy.

The transportation sector, particularly through the adoption of Electric Vehicles (EVs), represents another area where India can make significant strides towards sustainability. EVs offer a promising solution to reduce the nation's

* Corresponding author: Girish Kumar Dev

dependence on fossil fuels and decrease vehicular emissions, which are a major contributor to air pollution in Indian cities. However, the transition to EVs requires the establishment of a robust infrastructure for EV charging stations. This is where the integration of PV-BESS-grid systems comes into play. By utilizing renewable energy sources for EV charging, India can ensure that the shift to electric mobility is both environmentally friendly and economically viable. The integration of PV-BESS-grid systems in EV charging stations not only supports the growing demand for electric mobility but also enhances the reliability and efficiency of the energy supply. These integrated systems enable the storage of excess solar energy generated during the day, which can then be used for charging EVs during peak hours or when solar generation is low. This not only reduces the load on the grid but also ensures a continuous supply of clean energy for EVs. Additionally, the use of advanced energy management and control systems, powered by hybrid machine learning models, can optimize the operation of these integrated systems, ensuring that energy is used efficiently and costs are minimized. In the context of India, where energy availability and reliability are critical issues, developing optimal solutions for electric power control in PV-BESS-grid integrated fast EV charging stations is crucial. Leveraging hybrid machine learning models, this research aims to address the challenges associated with integrating renewable energy sources into the grid and managing the energy supply for EV charging stations. The focus is on developing strategies that ensure a reliable, efficient, and sustainable energy supply, which is vital for supporting India's transition to a low-carbon economy and achieving its energy security goals. The findings of this study are particularly relevant for India, as the country is committed to increasing its renewable energy capacity and reducing its carbon footprint. By optimizing the performance of PV-BESS-grid systems in EV charging stations, this research has the potential to make a significant impact on India's energy landscape and its efforts to combat climate change. The outcomes can contribute to the development of policies and technologies that support the widespread adoption of EVs and the integration of renewable energy into the national grid, ultimately leading to a more sustainable and resilient energy future.

India's renewable energy sector has witnessed remarkable growth over the past decade, driven by a combination of government initiatives, technological advancements, and a strong commitment to reducing carbon emissions. Among the various renewable energy sources, solar energy has emerged as a key player, with the country achieving an installed capacity of over 100 GW by 2022. This rapid expansion has positioned India as one of the global leaders in solar power, reflecting its vast potential in harnessing renewable energy to meet its growing energy demands. However, several challenges remain, including the variability of solar energy due to weather conditions and the integration of solar power into the existing grid infrastructure. The transition to renewable energy systems is crucial for addressing climate change, enhancing energy security, and fostering sustainable development. By focusing on improving grid infrastructure, energy storage, and financing mechanisms, India can significantly enhance the capacity utilization of its solar energy resources, ensuring a sustainable and reliable energy future for the country. This research aims to provide insights and strategies that can help optimize the integration of renewable energy systems with EV charging infrastructure, contributing to a cleaner, greener, and more sustainable energy landscape in India.

2. Literature Review

The integration of renewable energy sources, such as photovoltaic (PV) systems and battery energy storage systems (BESS), with grid-connected electric vehicle (EV) charging stations has emerged as a promising approach to enhance the efficiency, sustainability, and economic viability of charging infrastructure. Elsanabary et al. (2024) underscore the importance of optimized control strategies for balancing energy supply from various sources, which can significantly reduce operational costs and improve the long-term performance of EV charging stations. This study demonstrates the benefits of hybrid PV-BESS-grid systems in providing reliable and sustainable charging solutions. Machine learning (ML) techniques have also been widely studied for managing EV charging operations. Shibl, Ismail, and Massoud (2021) investigate the use of ML for optimizing charging schedules and grid integration, highlighting its potential to ensure efficient energy use and maintain grid stability amid increasing fast charging demands. Their later work (2023) expands this concept by introducing deep reinforcement learning (DRL) models that dynamically adjust charging strategies based on real-time data. The DRL approach not only enhances the efficiency of vehicle-to-grid (V2G) systems but also minimizes battery degradation, thereby lowering costs and extending battery life. Mazhar et al. (2023) provide a comprehensive analysis of various ML methods for smart grid-enabled EV charging systems. They emphasize the role of ML in forecasting energy demand and managing grid interactions, thereby improving the overall reliability and efficiency of the charging infrastructure. Reinforcement learning is further explored by Maeng, Min, and Kang (2023), who propose an approach for optimizing the bidirectional flow of energy in V2G systems, which is critical for grid stability and cost reduction.

Table 1 Summary of the research paper

Author(s)	Year	Focus Area	Methodology/Approach	Key Findings/Contributions
Elsanabary et al.	2024	Power management and optimization of hybrid PV-BESS-grid EV charging stations	Optimized control strategies for PV-BESS-grid systems	Proposed system improves performance, sustainability, and economic viability of EV charging stations by optimizing energy supply from different sources.
Shibl, Ismail, & Massoud	2021	Machine learning for managing EV charging and V2G operations	Machine learning techniques for optimizing charging schedules and grid integration	ML models effectively manage charging processes, balance grid stability, reduce impact on the grid, and support scalability of EV infrastructure.
Shibl, Ismail, & Massoud	2023	Deep reinforcement learning (DRL) for EV charging and V2G operations	DRL models for dynamic adjustment of charging strategies	DRL optimizes charging schedules, minimizes battery degradation, improves V2G efficiency, and reduces overall costs.
Mazhar et al.	2023	Machine learning methods in smart grid-enabled EV charging systems	Comparative analysis of ML algorithms	Identifies effective ML techniques for forecasting energy demand, optimizing charging schedules, and managing grid interactions, enhancing charging reliability.
Maeng, Min, & Kang	2023	Reinforcement learning for V2G systems	Reinforcement learning-based approach	Optimizes bidirectional energy flow between EVs and the grid, enhances grid stability, and reduces operational costs.
Ye, Gao, & Yu	2022	Optimization of EV charging station operations	Machine learning framework for charging station operations	ML model balances energy supply/demand, reduces costs, and enhances overall efficiency of charging stations.
Güven & Yücel	2023	Application of HOMER software in hybrid EV charging stations	HOMER software for optimizing renewable energy configurations	Demonstrates HOMER's effectiveness in optimizing design and operation of hybrid charging stations, leading to lower costs and improved sustainability.
Da Costa, Gomes, & Pereirinha	2024	Techno-economic evaluation of PV solar power systems for EV charging	HOMER Grid software for feasibility assessment	Highlights economic benefits of integrating solar energy with grid power, reducing operational costs and enhancing energy efficiency of EV charging stations.
Kumar & Channi	2024	Optimal site selection and scheduling for EV charging stations	Case study using HOMER software	Proposes an economically viable model for EV charging stations, emphasizing strategic location planning and cost optimization for sustainable deployment.

Research by Ye, Gao, and Yu (2022) introduces a machine learning framework to optimize operations of charging stations, considering dynamic factors like grid demand and energy prices. This study highlights the potential of ML in managing the complexity of EV charging infrastructure, improving cost efficiency and energy management. Software tools like HOMER have gained attention for their application in designing and controlling hybrid renewable energy systems for EV charging. Güven and Yücel (2023) demonstrate HOMER's effectiveness in optimizing hybrid configurations in Turkish cities, while Da Costa, Gomes, and Pereirinha (2024) provide a techno-economic evaluation of PV solar systems for EV charging at service buildings. Kumar and Channi (2024) explore the use of HOMER for optimal site selection and economic scheduling of EV charging stations, emphasizing strategic location planning and cost optimization. Collectively, these studies highlight the growing interest in using advanced simulation tools and AI-driven methods to enhance the planning, management, and sustainability of EV charging infrastructure.

3. Research Methodology

The research methodology in this study adopts a systematic and comprehensive approach to optimize the integration of renewable energy sources with grid power for an electric vehicle (EV) charging station in Jaipur, India. The methodology is divided into two primary phases: the simulation phase and the machine learning (ML) phase.

3.1. Step 1: HOMER Grid Simulation

The initial phase involves simulating the proposed hybrid energy system using the HOMER Grid software. This simulation models the energy system components, including grid electricity (JEC), photovoltaic (PV) panels (PVJEC), battery energy storage systems (JECBESS), and charging infrastructure for electric rickshaws (EVJEC_Eriksha) and electric cars (EVCars_B). The system is designed to meet a daily energy requirement of 1700 kWh with a peak demand of 245.77 kW, accurately reflecting the EV charging station's energy needs.

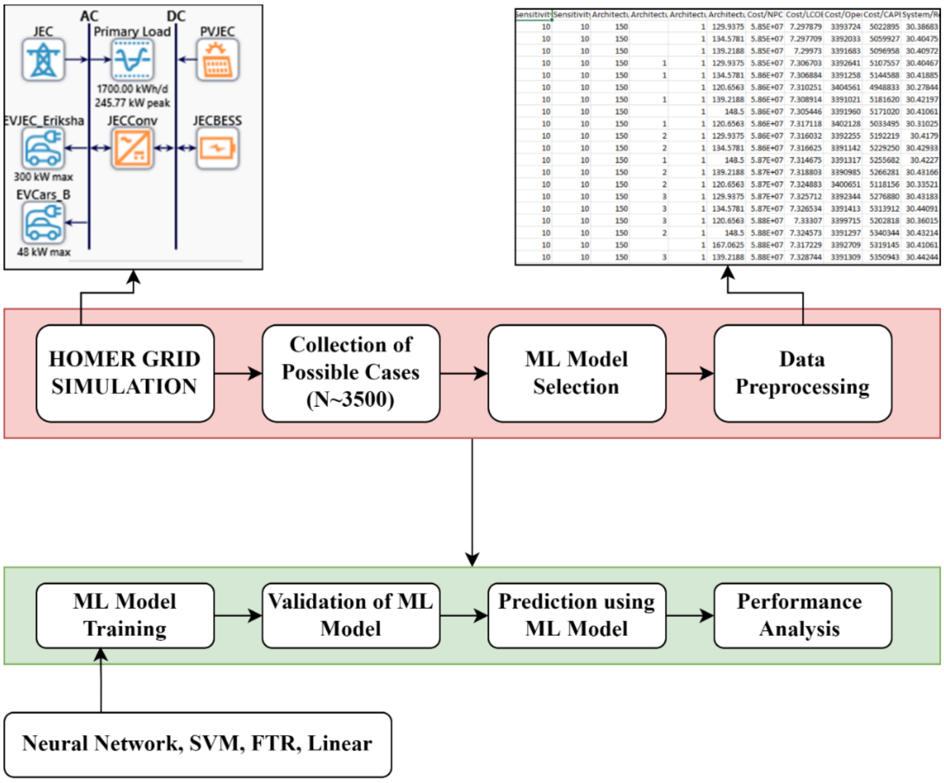


Figure 1 Research methodology adopted for present study

3.2. Step 2: Collection of Possible Cases (N ~ 3500)

HOMER Grid software generates approximately 3,500 potential configurations of the energy system, considering various combinations of component sizes, operational strategies, and other variables. This step creates a comprehensive dataset for evaluating different setups to determine the most optimal configuration.

3.3. Step 3: Performance Analysis

The final step includes a comprehensive analysis of the predicted configurations, evaluating economic, environmental, and technical aspects, such as cost of energy, system reliability, and carbon emission reduction, to determine the optimal solution for the EV charging station.

3.4. Study region selection

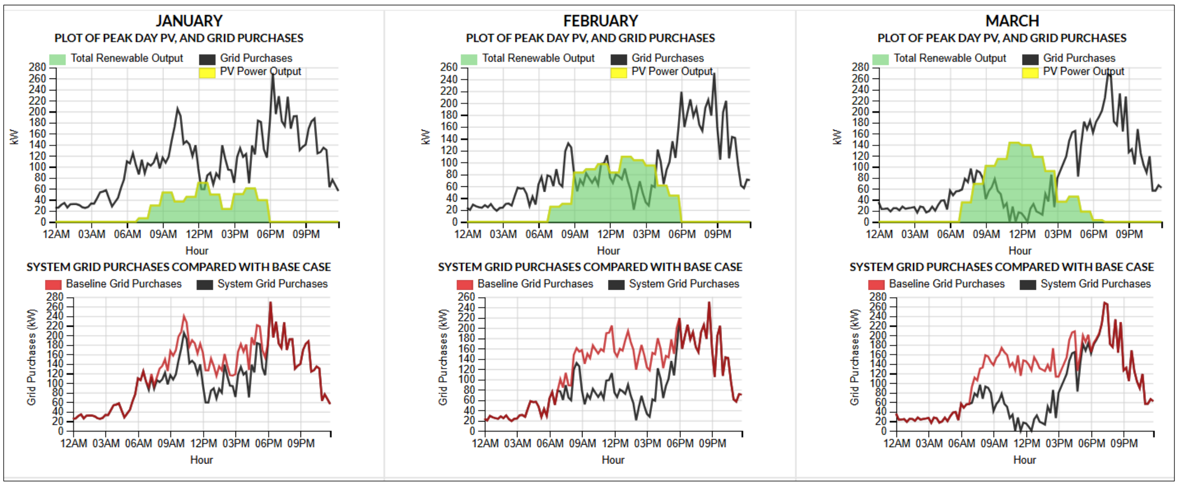
In this study, the Grid-PV integrated electric vehicle (EV) charging station was strategically planned for the Jaipur region, specifically focusing on the Sitapura Industrial Area. This area was chosen due to its concentration of key educational and medical institutions, which would greatly benefit from sustainable transportation solutions like electric rickshaws (E-rickshaws). The proposed charging infrastructure aims to support daily transportation needs for students, patients, and other passengers, promoting an environmentally friendly commute between significant institutions. Two locations within the Sitapura region were selected for installing EV charging stations: Location 1, near Vidhani Circle, and Location 2, near Mahatma Gandhi Hospital. These sites were chosen based on their proximity to important educational and medical facilities, ensuring convenient access to charging infrastructure for E-rickshaws and other electric vehicles. Prominent educational institutions which attract a large number of students, faculty, and staff, are expected to benefit significantly from the proposed EV charging stations. Additionally, major hospitals like Bombay Hospital and Mahatma Gandhi Hospital will find enhanced accessibility and reduced air pollution by using E-rickshaws for transporting patients, visitors, and healthcare workers. This strategic placement supports broader goals of reducing traffic congestion and promoting green transportation.

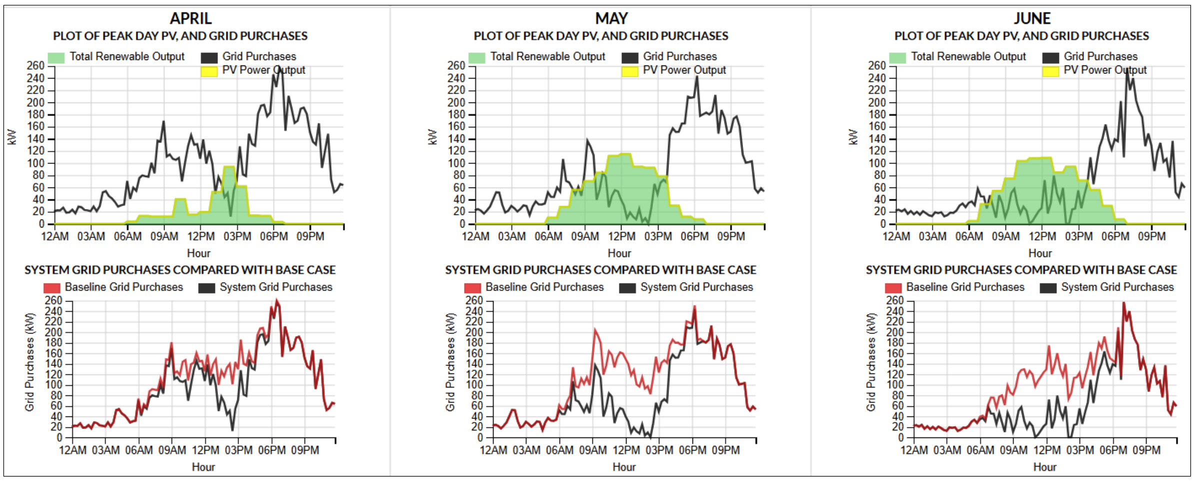
4. Result and Discussion

The optimized Solar and Grid-integrated EV charging station demonstrates a strong case for adopting renewable energy to minimize operational costs and boost sustainability. The analysis compared the Solar + JEC system against a traditional grid-only base case, with results heavily favoring the solar-integrated approach.

Financial Analysis and Savings: The Solar + JEC system yields significant financial savings. The average annual energy bill savings are ₹26,17,806, a notable reduction due to decreased reliance on grid electricity, which often incurs higher costs and demand charges. While the initial capital expenditure (CAPEX) for the Solar + JEC system is ₹50,22,895, the investment is offset by a rapid payback period of 1.9 years (simple) or 2.1 years (discounted), demonstrating its financial feasibility.

Performance Metrics: The internal rate of return (IRR) for this optimized system is 51.37%, suggesting a highly profitable investment. Over a 25-year project lifespan, the system is projected to generate total savings of ₹6,54,45,150, confirming its cost-effectiveness for long-term energy management. The JECSolar PV system, priced at ₹30.00 per watt, is installed at a capacity of 150 kW, with a total installation cost of ₹45,00,000. The annual maintenance expenses are modest, amounting to ₹37,500 per year.





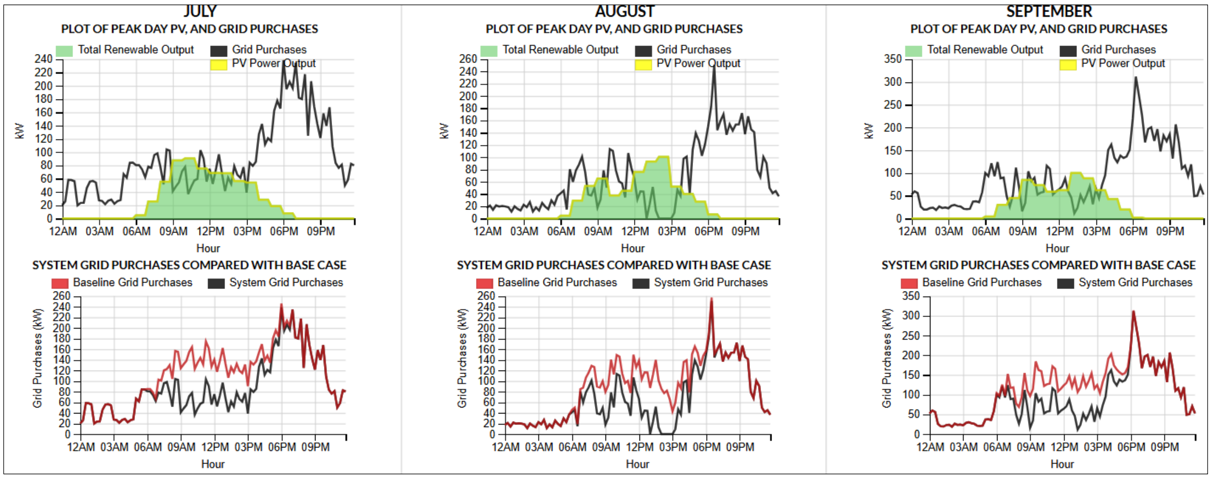


Figure 2 Performance summary of EV charging station for present study

Monthly and Seasonal Energy Analysis: The system's performance was evaluated on a monthly basis to account for seasonal variations in energy consumption and solar generation. For example, in January, the energy charges are ₹5,33,347 for a consumption of 54,123 kWh. This decreases in February to ₹4,25,374 due to reduced consumption of 43,549 kWh. Similar patterns continue throughout the year, with fluctuations reflecting varying energy demands and solar power outputs. In June, the consumption drops to 46,016 kWh, with corresponding charges of ₹4,53,834. By December, consumption rises slightly to 51,501 kWh, resulting in charges of ₹5,05,030.

Annual Energy Cost and Benefits: Overall, the annual total for the electric bill of this solar and grid-connected EV charging station amounts to ₹59,25,067. This highlights the financial benefits of solar integration, emphasizing its role in reducing energy costs and promoting sustainable energy consumption.

The results underscore the robustness of the Solar + JEC system in providing a cost-effective, sustainable solution for EV charging stations, with substantial long-term savings and environmental benefits.

5. Conclusion

The research confirms that integrating photovoltaic (PV) solar energy with a smart grid-connected fast-charging station for electric vehicles (EVs) provides a financially viable and sustainable solution for urban regions like Jaipur. By utilizing HOMER software for simulation, the study evaluates an optimized Solar + JEC system, demonstrating a compelling case for the adoption of renewable energy in EV infrastructure. The findings highlight significant financial benefits, including an average annual energy bill savings of ₹26,17,806 and a total projected savings of ₹6,54,45,150 over the 25-year project lifespan. The reduced dependency on grid electricity minimizes operational costs, with the system achieving a payback period of just 1.9 years (simple) or 2.1 years (discounted). Additionally, the internal rate of return (IRR) of 51.37% reflects the profitability and attractiveness of the investment. The comprehensive tariff utility analysis underscores the impact of seasonal variations on energy consumption and costs, with detailed monthly energy charges reflecting fluctuations due to both solar power generation and demand patterns. The system's total annual electric bill amounts to ₹59,25,067, showcasing the substantial cost savings achieved through solar integration. Moreover, the low annual maintenance expenses of ₹37,500 enhance the system's cost-effectiveness, making it an attractive option for long-term energy management.

The study demonstrates that a Solar + JEC system not only reduces the operational costs of EV charging stations but also contributes to environmental sustainability by promoting the use of renewable energy. The findings provide critical insights for policymakers, energy managers, and urban planners in developing regions to consider solar-integrated solutions for enhancing the efficiency and sustainability of EV charging infrastructure. This research highlights the potential of solar-powered EV charging stations as a strategic approach to advancing green mobility, reducing energy expenses, and fostering a sustainable urban environment.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Elsanabary, A., Khairullah, K., Ab Aziz, N. F., & Mekhilef, S. (2024). Power management and optimized control of hybrid PV-BESS-grid integrated fast EV charging stations. Journal of Energy Storage, 90, 111802.

[2] Shibl, M., Ismail, L., & Massoud, A. (2021). Electric vehicles charging management using machine learning considering fast charging and vehicle-to-grid operation. Energies, 14(19), 6199.

[3] Shibl, M. M., Ismail, L. S., & Massoud, A. M. (2023). Electric vehicles charging management using deep reinforcement learning considering vehicle-to-grid operation and battery degradation. Energy Reports, 10, 494-509.

[4] Mazhar, T., Asif, R. N., Malik, M. A., Nadeem, M. A., Haq, I., Iqbal, M., ... & Ashraf, S. (2023). Electric vehicle charging system in the smart grid using different machine learning methods. Sustainability, 15(3), 2603.

[5] Maeng, J., Min, D., & Kang, Y. (2023). Intelligent charging and discharging of electric vehicles in a vehicle-to-grid system using a reinforcement learning-based approach. Sustainable Energy, Grids and Networks, 36, 101224.

[6] Ye, Z., Gao, Y., & Yu, N. (2022). Learning to operate an electric vehicle charging station considering vehicle-grid integration. IEEE transactions on smart grid, 13(4), 3038-3048.

[7] Güven, A. F., & Yücel, E. (2023). Application of Homer in assessing and controlling renewable energy-based hybrid EV charging stations across major Turkish cities. International Journal of Energy Studies, 8(4), 747-780.

[8] Da Costa, L. M., Gomes, Á., & Pereirinha, P. G. (2024, June). Techno-Economic Evaluation of PV Solar Power Generation System and EV Charging for Services Building with HOMER Grid Software. In 2024 IEEE 22nd Mediterranean Electrotechnical Conference (MELECON) (pp. 412-417). IEEE.

[9] Kumar, P., & Channi, H. K. (2024, January). Optimal Site Selection and Economic Scheduling of Electric Vehicle Charging Station using HOMER: A Case Study of TOHANA, Haryana. In 2024 Fourth International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT) (pp. 1-6). IEEE. (base paper)

[10] Palanisamy, S., & Lala, H. (2024). Optimal Sizing of Renewable Energy Powered Hydrogen and Electric Vehicle Charging Station (HEVCS). IEEE Access.