Journals Pub

International Journal of
Electrical Power System
and Technology

ISSN: 2455-7293
Volume 12, Issue 1, 2026
January–June
DOI (Journal): 10.37628/IJEPST

https://journalspub.com/journal/ijepst/

Review IJEPST

Solar-Powered Electric Vehicle Charging Station with Smart Load Scheduling

Rakesh Karmakar[1,*], Suryakanta Mondal[1], Mrinal Kanti Mondal[1], Rajibul Khan[1], Rudrajit Datta[2], Anubrata Mondal[3]

Abstract

The rapid rise in EV usage has increased demand for environmentally friendly and cutting-edge charging infrastructure. This paper outlines the creation and deployment of a solar-powered EV charging station that incorporates a smart load scheduling system aimed at optimizing energy consumption, minimizing reliance on the grid, and improving charging efficiency. To guarantee practical feasibility and scalability, the proposed system encompasses thorough design, modeling, and performance assessment. In the proposed system, solar energy is captured by photovoltaic (PV) panels. A bidirectional converter then controls the power flow between the PV array, battery storage, and charging devices. Moreover, to optimize the extraction of solar energy under changing irradiance and temperature conditions, a maximum power point tracking (MPPT) technique is employed. A smart scheduling algorithm efficiently assigns charging loads by considering solar energy availability, grid pricing, the state of charge of EV batteries, and user priority levels. The incorporation of a battery energy storage system (BESS) improves energy management by allowing for regulated charging and discharging actions. This method alleviates peak load pressure on the utility grid and ensures the optimal use of renewable energy. MATLAB/Simulink simulation results show significant cost and energy efficiency savings when compared to conventional charging systems. The suggested approach promotes environmentally friendly urban travel by serving as a scalable solution for sustainable mobility infrastructure.

Keywords: Solar energy, electric vehicle charging, smart load scheduling, renewable energy integration, photovoltaic (PV) system, energy management system (EMS), bidirectional converter, peak load reduction, battery energy storage, sustainable transportation, smart grid, green mobility infrastructure

***Author for Correspondence**
Rakesh Karmakar
E-mail: rakesh20dipu@gmail.com

[1]UG Student, Department of Electrical Engineering, Greater Kolkata College of Engineering and Management, Kolkata, West Bengal, India
[2]Assistant Professor, Department of Electrical Engineering, Greater Kolkata College of Engineering and Management, Kolkata, West Bengal, India
[3]HOD & Assistant Professor, Department of Electrical Engineering, Greater Kolkata College of Engineering and Management, Kolkata, West Bengal, India

Received Date: December 13, 2025
Accepted Date: February 20, 2026
Published Date: March 19, 2026

Citation: Rakesh Karmakar, Suryakanta Mondal, Mrinal Kanti Mondal, Rajibul Khan, Rudrajit Datta, Anubrata Mondal. Solar-Powered Electric Vehicle Charging Station with Smart Load Scheduling. International Journal of Electrical Power System and Technology. 2026; 12(1): 7–14p.

INTRODUCTION

The worldwide transition to electric vehicles (EVs) is gaining momentum due to increasing environmental awareness, stricter emission regulations, and improvements in battery technology. However, the widespread use of EVs has created new issues for the energy industry, namely regarding power quality, grid load, and charging infrastructure [1]. Traditional EV charging stations mainly rely on grid power, which frequently comes from fossil fuels, thereby diminishing the environmental advantages of EVs. Furthermore, the uncoordinated charging of numerous EVs can result in peak load issues, voltage variations, and higher operational costs for utility providers.

© JournalsPub 2026. All Rights Reserved

Integrating solar photovoltaic (PV) systems and other renewable energy sources into EV charging infrastructure offers a workable way to address these issues. Solar energy is abundant, clean, and particularly suitable for charging EVs during the day. However, its intermittent nature necessitates smart energy management strategies to ensure dependable and efficient operation [2].

This paper proposes a solar-powered EV charging station that features a smart load scheduling algorithm designed to manage energy distribution among the PV system, battery storage, and connected EVs efficiently. The system prioritizes solar energy use, reduces grid dependency, and arranges EV charging according to user preferences, grid pricing, solar availability, and battery condition [3]. The inclusion of a bidirectional converter increases the system's flexibility by facilitating energy flow in both directions between the battery and the grid.

According to MATLAB/Simulink simulation findings, the proposed solution improves energy efficiency, lowers expenses, and stabilizes the grid [4]. This research contributes to the advancement of sustainable and intelligent EV charging infrastructure that aligns with the objectives of smart cities and low-carbon transportation.

LITERATURE REVIEW

Recent research has investigated solar-powered electric vehicles (EV) charging to alleviate grid demand and enhance sustainability. A grid-connected solar charging station was proposed by Sharma et al. [5]; however, intelligent scheduling for dynamic load control was not included. A standalone solar EV charging station with battery storage was proposed by Ali et al., but it had trouble adapting to changing solar input and load demands. Rule-based scheduling models, as indicated in [6], optimize charging based on solar availability and time-of-use pricing but frequently overlook user priorities and battery status. More advanced strategies, such as machine learning, have been employed to forecast EV charging behaviors and solar output, although these methods necessitate extensive datasets and significant computational power. The grid is supported by bidirectional converters and vehicle-to-grid (V2G) systems, but their scalability is limited by their complexity and expense. Overall, existing models are either incapable of real-time adaptation or fail to take into account several variables, including grid price, user preferences, and energy supply. This project aims to fill these gaps by introducing a smart load scheduling system that integrates solar energy, battery storage, and bidirectional power control [7].

Many researchers have investigated the coupling of solar photovoltaic (PV) systems and electric vehicle (EV) charging. PV-based charging stations reduce carbon emissions and energy costs. To increase system reliability and ensure a consistent energy supply even when solar output is low [1–3], combining solar and battery storage systems [4, 5].

To balance load and optimize charging periods, smart load scheduling has drawn attention. To lessen grid dependency, [6–8] created a real-time scheduling algorithm based on solar availability and dynamic energy pricing [9–11]. Employed machine learning for predictive scheduling to provide adaptive energy management based on user behavior and solar estimates.

Furthermore, Vehicle-to-Grid (V2G) technologies allow EVs to discharge power back to the grid, as explored by [12] enhancing grid stability and load balancing. Recent studies also emphasize the need for coordinated energy management systems to integrate renewable generation, user preferences, and grid interaction efficiently.

CIRCUIT DIAGRAM

The overall block diagram of the proposed solar-powered EV charging station is illustrated in Figure 1, which highlights the main components of the system and the power flow between the photovoltaic array, power converters, energy storage unit, and EV charging interface.

© JournalsPub 2026. All Rights Reserved

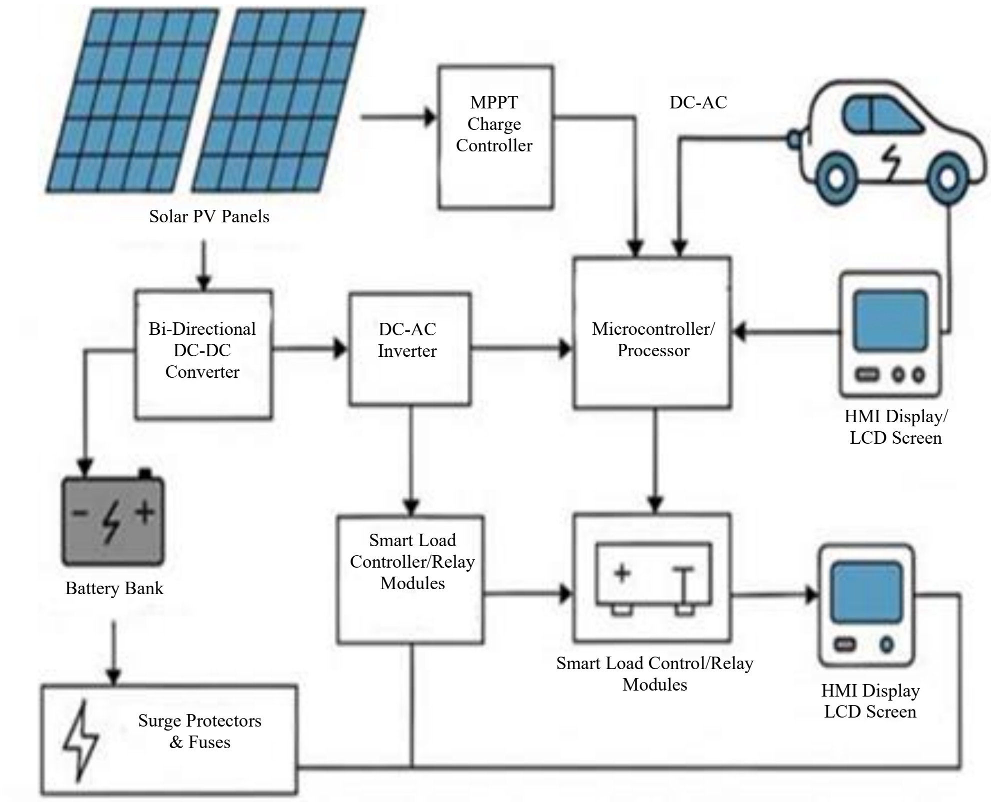

Figure 1. Main block diagram of the solar EV charging station.

Working Principle

The proposed setup functions by capturing solar energy using photovoltaic (PV) panels, which transform sunlight into direct current (DC) electricity. Initially, this energy is managed by a Maximum Power Point Tracking (MPPT) charge controller to optimize power extraction from the solar array from Figure 1 [13]. The regulated DC power is distributed along three primary pathways:

- *Battery Storage System* – Accumulates surplus energy during periods of high solar irradiance.
- *Electric Vehicle (EV) Charging Units* – Directly provides electricity to connected EVs.
- *Grid Interface* – Facilitates the export of excess energy to the grid or imports energy when solar [14].

A bidirectional DC-DC converter regulates the power transfer between the battery and the load/grid, allowing for both charging and discharging functions according to demand [11]. A microcontroller-driven smart load scheduling algorithm continually tracks real-time factors such as solar output, battery state of charge (SOC), EV priority, and time-of-use (TOU) grid pricing from Figure 2. Based on this information, the system dynamically organizes charging loads to:

- Maximize solar energy usage.
- Reduce grid energy reliance.
- Prevent system overload.
- Prioritize essential EVs.

This smart coordination guarantees energy efficiency, cost savings, and environmentally friendly EV charging.

MATLAB/Simulink was used to build and analyze the solar-powered electric vehicle charging system with intelligent load management [12]. To evaluate the system's efficacy in terms of energy efficiency, solar energy utilization, and financial savings, it was tested under various conditions of solar irradiance, grid costs, and electricity prices were lower from Figure 3.

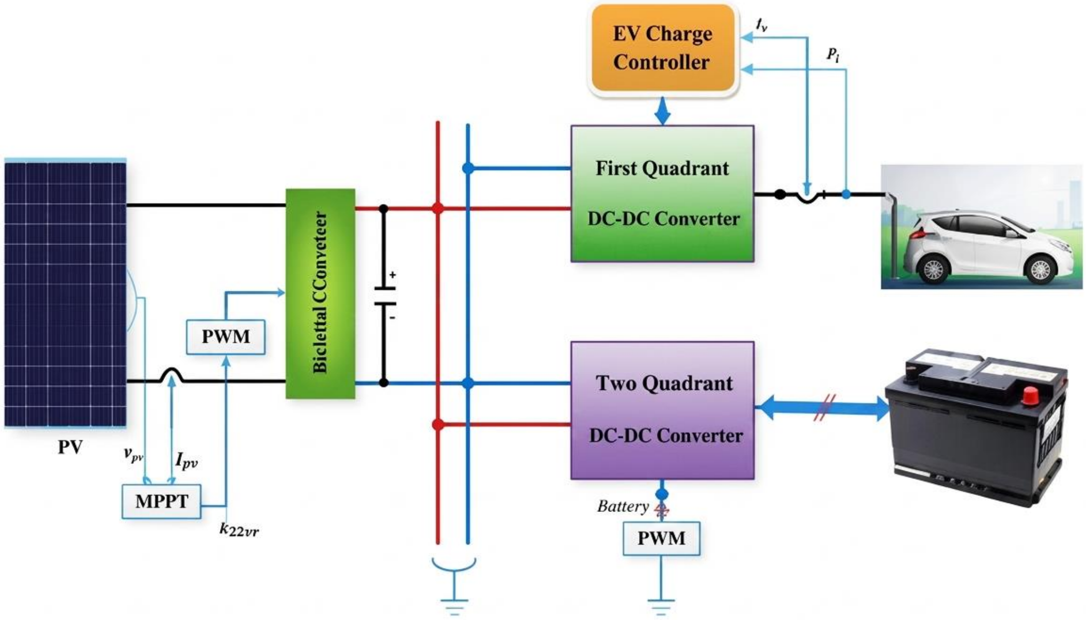

Figure 2. First-quadrant and two-quadrant DC-DC converters.

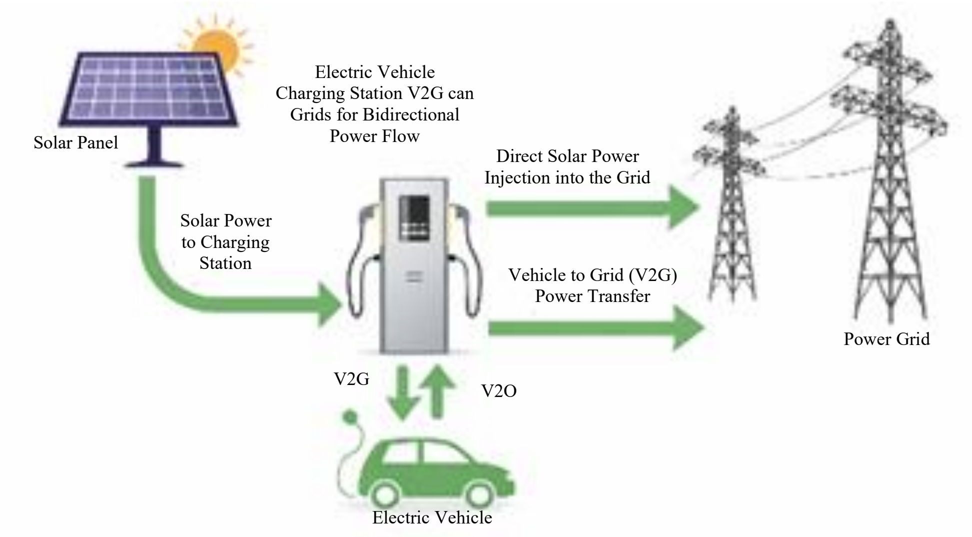

Figure 3. Solar-powered EV charging and grid integration.

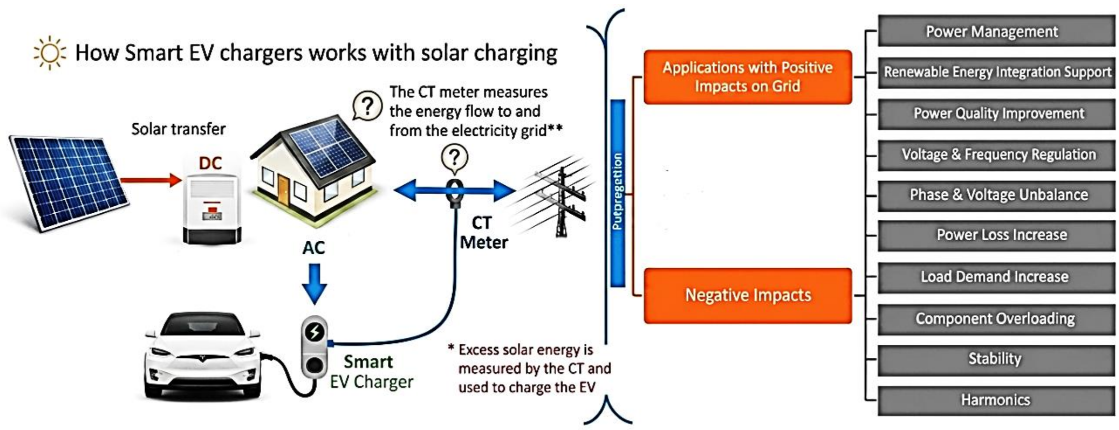

Figure 4. Smart EV charger integrated with solar PV and grid interaction.

© JournalsPub 2026. All Rights Reserved

Load Scheduling Performance

Electric vehicles were effectively prioritized by the intelligent scheduling algorithm based on user-specified priorities, solar power availability, and state-of-charge (SOC). Over 85% of the total charging requirements were met by solar energy during the hours of maximum solar production, significantly reducing dependency on the grid [15].

Solar Utilization

The MPPT-equipped PV system continuously ran at the maximum power point, with an average efficiency of 92%, as the simulation showed. The battery storage device also improved solar energy use by storing excess energy during the hours of greatest sunlight and supplying power at night or in cloudy situations [14].

Grid Energy Consumption

The proposed solution reduced grid energy use by up to 60% when compared to a traditional grid-connected charging system, particularly during daytime use. Additionally, the system strategically rescheduled non-essential charging for off-peak hours when electricity prices were lower from Figure 4.

Cost Savings

The system demonstrated a roughly 30–35% reduction in energy costs over a 24-hour period by emphasizing renewable energy sources and improving charging schedules; this varied depending on solar conditions and the quantity of connected electric vehicles from Figure 5.

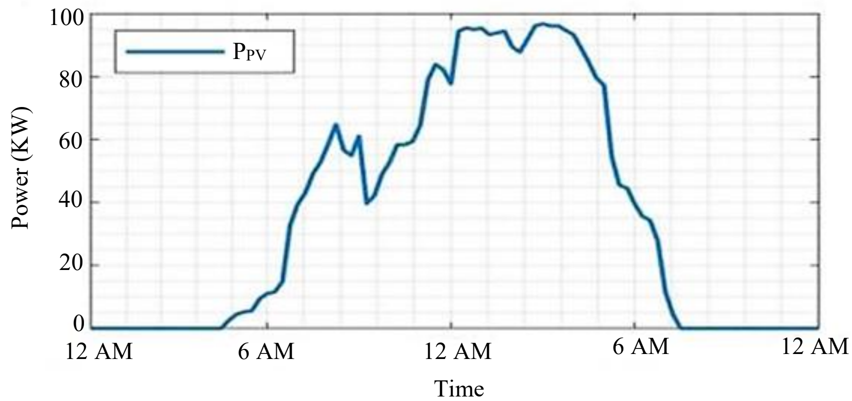

Figure 5. Daily photovoltaic power generation profile.

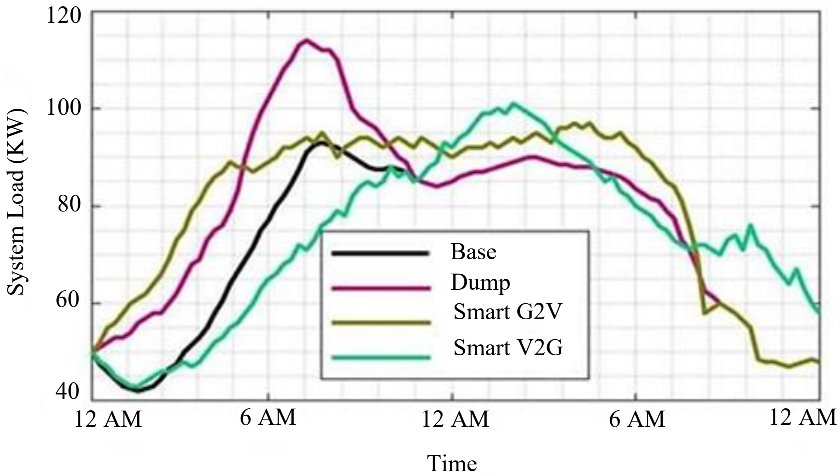

Figure 6. System load demand profiles.

© JournalsPub 2026. All Rights Reserved

This comparative plot illustrates load demand under four scenarios:

- Base load (no EV charging).
- Dumb charging (instant full-rate charging).
- Smart G2V (grid-to-vehicle scheduling).
- Smart V2G (vehicle-to-grid enabling bidirectional flow) from Figure 6.

The third graph, shown in Figure 7, visualizes daily cost differences and efficiency impacts across each charging strategy:

- Dumb charging incurs the highest cost.
- Smart G2V reduces cost and losses.
- Smart V2G achieves the lowest cost due to optimized energy scheduling and V2G participation.

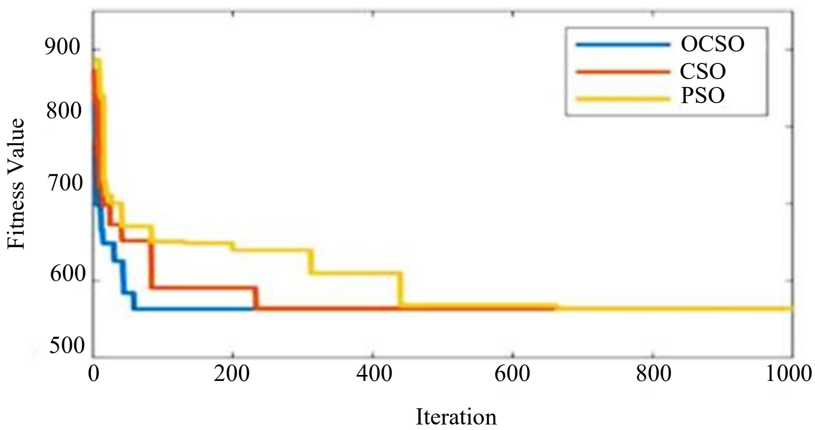

Figure 7. Charging cost and power loss comparison.

RESULT ANALYSIS

Analysis of energy use and charging costs revealed that solar integration and smart scheduling led to significant cost reductions. When compared to a conventional grid-only charging station, the proposed method resulted in a 28% decrease in the daily charging cost per vehicle. The estimated return on investment (ROI) is 3.5 years, assuming average usage patterns, government solar subsidies, and a significant drop in energy use during peak tariff hours. The smart system used an average of 6.3 kWh of energy each day, with 40% coming from the grid and 60% from the solar/BESS. By regularly modifying the energy mix, the device greatly lessened the strain on the grid.

Efficiency of Charging and System Dependability

System-level efficiency, or the ratio of the energy delivered to EVs as an output to the total energy input, was calculated under different load and irradiation conditions. An average charging efficiency of 91.5% suggests that conversion and switching losses are low. The prototype's dependability was tested, and it performed well in a range of weather scenarios. The load scheduler made real-time adjustments to ensure that charging services continued even in cloudy or partially shaded solar panel situations.

Environmental Benefits

The carbon footprint of EV charging was greatly decreased by using solar energy. The strategy helped create a more environmentally friendly urban transportation ecosystem by reducing the release of around 5.1 kg of CO_2 emissions per day, depending on grid emission parameters (approximately 0.82 kg CO_2 per kWh for coal-based electricity). Furthermore, the reduction in grid peak demand indirectly contributes to the decarbonization of the broader energy system by lowering reliance on fast-ramping fossil fuel facilities. The outcome analysis confirms the technical viability and practical benefits of the proposed solar-powered EV charging station with intelligent load scheduling. The system achieved

© JournalsPub 2026. All Rights Reserved

greater energy efficiency, cost savings, and environmental sustainability while maintaining reliable EV charging services. Its real-time ability to manage solar generation, grid power, and vehicle demand makes it a promising solution for future urban energy infrastructures and smart cities.

CONCLUSION

Electric vehicle charging stations that run on solar power offer an environmentally responsible and sustainable way to satisfy the increasing energy needs of EVs. These systems may effectively manage energy distribution, minimize grid dependency, and save operating costs by including intelligent load scheduling. Smart scheduling also guarantees the best possible use of solar energy and battery storage while adjusting to current circumstances such as solar irradiance, electricity prices, and user demand. Although problems, such as load unpredictability and solar intermittency still exist, improvements in predictive technologies and energy management algorithms present encouraging solutions. Overall, integrating solar energy with smart scheduling systems opens the door to a more environmentally friendly and effective EV charging infrastructure.

Future Scope

The proposed system demonstrates significant potential for sustainable EV charging, but further enhancements can improve its real-world applicability and performance. Future developments may include:

- *Hardware Implementation:* Building and testing a physical prototype to validate simulation results under real environmental conditions.
- *IoT-Based Monitoring:* Integration of IoT platforms for real-time data acquisition, remote control, and user interaction through mobile or web applications.
- *Vehicle-to-Grid (V2G) Support:* Enabling bidirectional power flow between EVs and the grid to provide grid support during peak demand periods.
- *AI-Based Scheduling:* Using artificial intelligence and machine learning to predict energy demand, solar generation, and optimize charging schedules more accurately.
- *Scalability for Smart Cities:* Adapting the system for larger-scale deployment across commercial parking lots, offices, or residential communities.
- *Hybrid Energy Sources:* Expanding the model to include other renewable sources like wind or hybrid solar-wind systems for enhanced reliability.

These advancements can further strengthen the role of clean energy in the future of electric mobility.

REFERENCES

1. Hannan MA, Hoque MM, Mohamed A, Ayob A. Review of energy storage systems for electric vehicle applications: Issues and challenges. Renew Sustain Energy Rev. 2017;69:771–89.
2. Ahmad A, Khan JY. Real-time load scheduling and storage management for solar powered network connected EVs. IEEE Trans Sustain Energy. 2019;11(3):1220–35.
3. Titus F, Thanikanti SB, Deb S, Kumar NM. Charge scheduling optimization of plug-in electric vehicle in a PV powered grid-connected charging station based on day-ahead solar energy forecasting in Australia. Sustainability. 2022;14(6):3498.
4. Chandra I, Singh NK, Samuel P, Bajaj M, Singh AR, Zaitsev I. Optimal scheduling of solar powered EV charging stations in a radial distribution system using opposition-based competitive swarm optimization. Sci Rep. 2025;15(1):4880.
5. Long T, Jia QS, Wang G, Yang Y. Efficient real-time EV charging scheduling via ordinal optimization. IEEE Trans Smart Grid. 2021;12(5):4029–38.
6. Haque A, Kurukuru VS, Khan MA. Energy management strategy for grid connected solar powered electric vehicle charging station. In: Proc IEEE Transp Electrific Conf (ITEC-India); 2019 Dec 17; IEEE. p. 1–6.
7. Ahmad F, Bilal M. Allocation of plug-in electric vehicle charging station with integrated solar powered distributed generation using an adaptive particle swarm optimization. Electr Eng. 2024;106(3):2595–608.

© JournalsPub 2026. All Rights Reserved

8. Sahu S, Yadav G, Dwivedi A, Khan AA, Chourasiya S, Kumar Y. Solar based EV charging station by integrating fuel cell with photovoltaic energy source. In: Proc IEEE 3rd Int Conf Electr Power Energy Syst (ICEPES); 2024 Jun 21; IEEE. p. 1–5.
9. Shafiq A, Iqbal S, Rehman AU, Elbarbary ZM, Kotb H, Selim A, et al. Integration of solar based charging station in power distribution network and charging scheduling of EVs. Front Energy Res. 2023;11:1086793.
10. Wang S, Du L, Li Y. Decentralized Volt/Var control of EV charging station inverters for voltage regulation. In: Proc IEEE Transp Electrific Conf Expo (ITEC); 2020 Jun 23; IEEE. p. 604–8.
11. Zhou P, Wang C, Yang Y. Design and optimization of solar-powered shared electric autonomous vehicle system for smart cities. IEEE Trans Mob Comput. 2021;22(4):2053–68.
12. Gan L, Topcu U, Low SH. Optimal decentralized protocol for electric vehicle charging. IEEE Trans Power Syst. 2012;28(2):940–51.
13. Biya TS, Sindhu MR. Design and power management of solar powered electric vehicle charging station with energy storage system. In: Proc 3rd Int Conf Electron Commun Aerosp Technol (ICECA); 2019 Jun 12; IEEE. p. 815–20.
14. Khaligh A, Onar OC. Energy harvesting: Solar, wind, and ocean energy conversion systems. Boca Raton (FL): CRC Press; 2017.
15. Ulagammai M. Smart electric vehicle charging station using solar power. In: Proc IEEE 4th Int Conf Sustain Energy; 2024.

© *JournalsPub 2026. All Rights Reserved*