Hindawi
International Journal of Energy Research
Volume 2024, Article ID 7095461, 14 pages
https://doi.org/10.1155/2024/7095461

Research Article

An Enhanced MPPT Approach Based on CUSA for Grid-Integrated Hybrid Electric Vehicle Charging Station

Debabrata Mazumdar,[1] **Pabitra Kumar Biswas**,[1] **Chiranjit Sain**,[2] **Furkan Ahmad**,[3] **and Luluwah Al-Fagih**[3]

[1]*Department of Electrical Engineering, National Institute of Technology Mizoram, Aizawl 796012, India*
[2]*Department of Electrical Engineering, Ghani Khan Chowdhury Institute of Engineering and Technology, Narayanpur, Malda 732141, India*
[3]*Divison of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar*

Correspondence should be addressed to Furkan Ahmad; fuahmad@hbku.edu.qa

Received 15 November 2023; Revised 6 December 2023; Accepted 11 March 2024; Published 3 April 2024

Academic Editor: Muhammad Ahsan Saeed

 The publication of this article was funded by Qatar National Library.

Because of the fluctuating demands for electricity and the growing awareness of the need to protect the environment from global warming and the depletion of nonrenewable natural resources, battery-powered electric vehicles, or EVs, are being used in the transportation sector as an alternative to internal combustion engine vehicles. However, charging these EVs with conventional fossil fuels is neither economically sustainable nor structurally viable. Therefore, this manuscript proposes a renewable energy-powered EV charging station featuring a combination of solar energy, standby battery systems, sophisticated control techniques such as neural network-integrated grids, the enhanced Cuckoo Search Algorithm for Maximum Power Point Tracking, and the Proportional-Integral-Derivative controller. This idea beats current methods and presents a viable way to drive the EV revolution while lessening environmental effects. It maximizes energy management and guarantees a steady power supply even in erratic weather. Grid integration ensures the consistency of power supplies at charging terminals. When compared to other algorithms that have been investigated in the literature, the designed algorithm exhibits excellent performance. Grid integration, in addition to the standby battery, is essential in ensuring that the charging station has a constant power supply, even during unpredictable weather.

1. Introduction

Historically, fuel has been essential to the development of transportation infrastructure. During the nineteenth decade, fossil fuels constituted the main source of fuel, though their negative environmental effects necessitated the development of other modes of mobility. Electric vehicles (EVs) are one viable substitute, which has prompted the development of these automobiles. Electric-powered vehicles are defined as those that primarily rely on electricity for propulsion.

1.1. Motivations. Due to the massive global EV implementation that has occurred recently, scientists are examining whether grid integration could enhance the electrical infrastructure. Parked grid-connected electric vehicles (EVs) can be compared to enormous batteries. Grid-connected EVs that are parked could be thought of as massive batteries. The amount of grid current utilized during periods of elevated electrical demand typically reflects the increased consumption of electricity by consumers and businesses, placing greater stress on the power grid infrastructure. Broad parking frames, generally found in commercial buildings and educational institutions, can be used to lower power costs when the energy produced by distributed generation like solar or wind is limited and costly.

The ability of microgrids to supply appropriate and dependable power to the service area has been extensively researched in recent years [1]. Microgrids are made up of distributed generating units (DEUs), energy storage technologies, and controllable or unpredictable demands. The DEUs integrated with the microgrid typically consist of

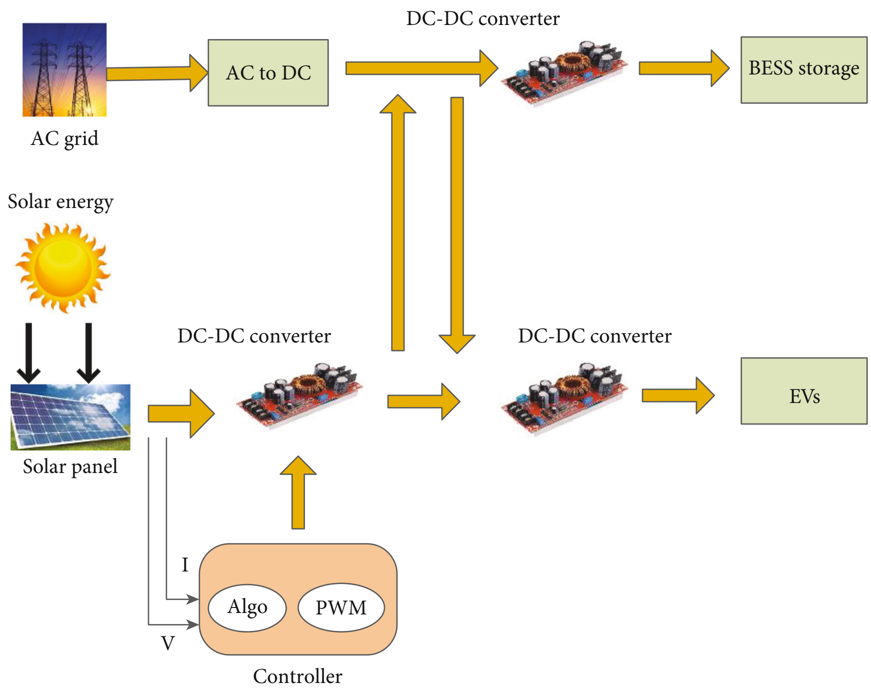


Figure 1: Schematic layout of the proposed scheme with grid interpretation.

devices with power electronic circuits and capacities under 100 kW [2]. Electrically powered vehicles are steadily increasing in the transportation industry as an additional measure to reduce environmental pollution. By 2030, the International Energy Agency expects to sell 30% of all new EVs [3]. When the number of electric vehicles (EVs) increases, the process of charging them with grid electricity will become more intricate [4]. When a lot of electrically driven vehicles were using the grid, it would eventually lose control and functionality.

Additionally, there are no benefits to using conventional energy sources to charge EVs via the electrical grid. Thus, a dependable network is required for the purpose of charging EVs that are fueled by renewable energy sources. Using a standby battery to act as a buffer between the utility and the EV charging station is an excellent technique [5–7].

1.1.1. Literature Review. The goal of the proposed study is to provide a dependable and effective power supply facility that uses grid integration to meet the excessive power demand of EVs at a specific station. Generating pollution-free power can only be possible through nonconventional resources like solar energy. Thus, we need to incorporate a solar PV array structure as well. Through MPPT techniques, utmost power can be achievable. A PV system's energy efficiency is increased by an MPPT controller, which follows the maximum power point of a PV array [8]. The literature has reported on a number of MPPT strategies [9]. By altering the DC/DC chopper's settings, which are commonly used in PV systems, MPP can be generated [10]. In recent years, innovative MPPT algorithms have been invented by researchers for solar power systems [11–13]. Particle-swarm optimization- (PSO-) focused MPPT algorithms have been proposed by numerous scholars [14, 15]. Examples of such algorithms are the Cuckoo Search Algorithm (CUSA) [16], grey wolf optimization (GWO) [17], ant colony optimization (ACO) [18], artificial bee colony (ABC) [19], slap swarm optimization (SSO) [20, 21], grasshopper optimization [22], and teaching-learning driven optimization [23].

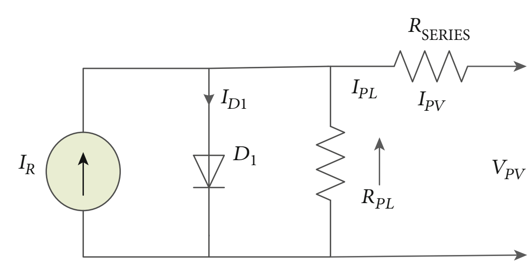
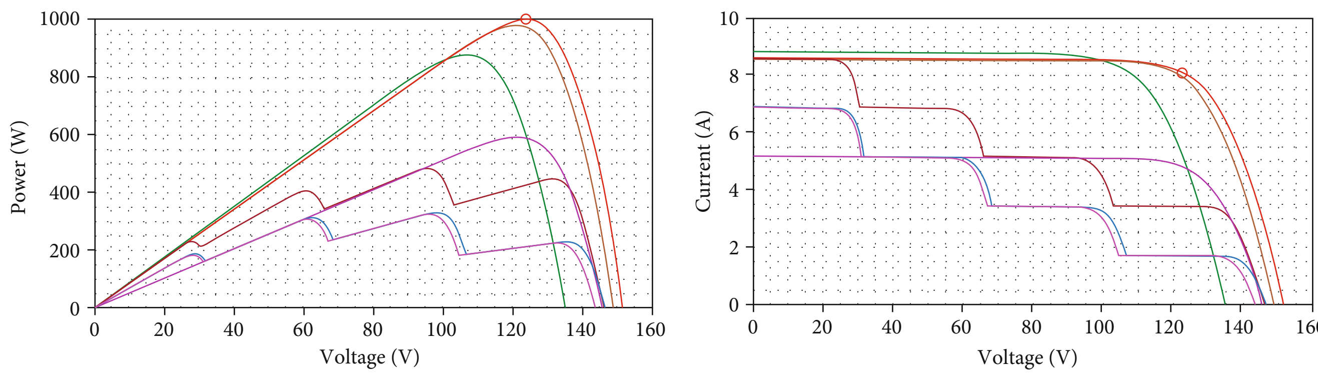


Figure 2: PV cell's analogous circuit diagram.

The authors of [23] employed three coordinated strategies for balancing wind and stored energy in PEVs using vehicle-to-grid (V2G) technology. This covers energy dispatching with variable supply, intermittent power, and valley seeking. First outlined in [24–26], the energy management system for smart households includes a PV system, PEV, and smart devices. The grid, a single voltage source converter, a diesel generator, a solar PV array, an SBB, and an EV vehicle charging system comprise the power components in [27]. An illustration of how to scale green energy resources incorporated into electric vehicle charging terminals using particle swarm optimization and the genetic algorithm was given by Singh et al. [28]. An integrated power system platform is also used in the construction of infrastructure for commercial EV charging [29].



(a) (b)

Figure 3: Properties of a solar cell for (a) V-P and (b) I-V curve.

A compact, reasonably priced charging system combined with an efficient design for lightweight PEVs [30] voltage controller design for interleaved boost converters and dual-input DC-DC converters employing optimization techniques for hybrid electric car applications has been covered in some studies [31–34]. A robust design of a PV-powered wireless charging system for EVs using an inductively coupled power transfer topology can be found in [35]. In [36], a fuzzy logic algorithm-based MPPT controller is recommended for an EV charging terminal that is battery-supported and solar-powered. An efficient algorithm is offered to achieve an efficient and successful coordination system for EV charging and discharging [37]. The authors in [38] look into the feasibility of creating an EV charging station for security bikes powered by solar photovoltaic technology. According to [39], a brand-new, highly coordinated method for frequency regulation using electric cars (EVs) in changeable power system operation states is suggested.

The literature review presents significant issues and disagreements that this article should address and look further into. Research on theoretical studies that look into optimization applications for renewable energy sources appears to have many advantages and stability. When interacting with the interface of many modules, there are a few considerations to make in contrast to well-known conventional methods. Unfortunately, soft computing-based MPPT algorithms require more time and money to build than more conventional methods [14–23]. Neural network-based MPPT controllers, already introduced in the literature, show good performance. Still, they require a large dataset of information like solar irradiance and atmospheric temperature, and their implementations are also very complicated.

1.1.2. Research Contributions and Significance. Summarizing the literature review, for solar-powered EV charging stations, it can be argued that an effective MPPT controller is necessary. It needs to be able to monitor GMPP as quickly as possible while exhibiting the least amount of oscillation, overshoot, and ripple in the grid integration. SBB is also crucial because it ensures the vehicles' continuous power supply. These study's objectives—optimal modelling for every EV fleet—align with the noted research void. Researchers have put forward numerous solutions, such as energy storage and standby power generators [40]. This article proposes a way to manage integrated generating equipment that uses solar-powered photovoltaic panels and solar-block batteries in a grid-connected state. Here, the major objective of the SBB is to keep the electricity delivered to the customer through charging and discharging in balance. In this way, the SBB draws power from the grid during periods of high photovoltaic energy output and feeds it back into the system during periods of low supply. The recommended control technique achieves the intended performance even when the system uses PSCS in a range of weather scenarios. A 2 kW single-phase photovoltaic system that can run in both PSCS and standard test scenarios is presented in this research. Duty cycle optimization uses a boost converter that uses the Cuckoo Search Algorithm (CUSA) as MPPT. Figure 1 depicts a schematic of a proposed solar-powered charging station with an AC grid and a battery for energy storage.

Table 1: Parameters of converter used in simulation.

Sl no.	Parameter	Value
1	Output capacitance (C_{OUT})	4.0704 μF
2	Switching frequency	10 KHz
3	Inductance	0.0153 H

The following is a sketch of the main achievements made by this article:

(i) To assess how the size of the power supply for charging stations is affected by the scaled average EV session that occurs every day

(ii) The design and construction of a grid-tied photovoltaic (PV) transportation charging structure which is dependable and capable of carrying on with charging even in less-than-ideal scenarios

Here is how the article is organized: Section 2 reveals a detailed illustration of the intended PV system. Section 3 addresses DC-DC restrictions' limits. This section describes the boost converter in detail as well as the effects of partial shading. The battery system's illustration is covered in

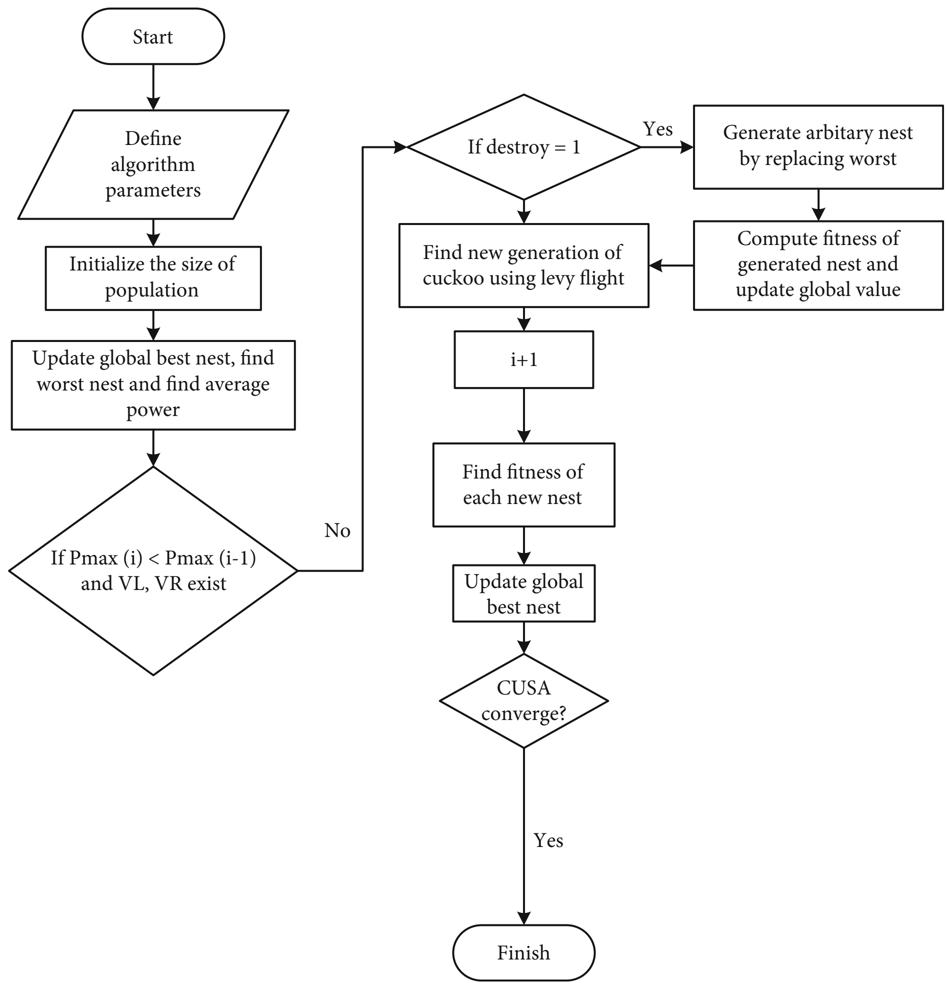


Figure 4: Flow chart of CUSA MPPT method.

Section 4. A recommended MPPT control framework and structure are given in Section 5. A brief summary of the simulation results for the recommended approach is given in Section 6, Section 7 offers a conclusion.

2. Model and Features of PV Systems

There are numerous PV system configurations available in literature [31]. An array of resistors connected in parallel and series, a current source, and a diode make up the most common configuration of a photovoltaic cell, as seen in Figure 2. One possible application of the PV cell's output current is as follows:

$$I_{PV} = I_R - I_{D1} - I_{PL}, \tag{1}$$

where I_{PV} and V_{PV} are discretely output current and voltage from photovoltaic cells. I_{PL}, I_{D1} (Eq. (2)), I_R are parallel resistance R_{PL}, diode, and photovoltaic current, respectively. Series resistance is noted as R_{SERIES}.

$$I_{D1} = I_{RSC} + e^{q((V_{PV+}I_{PV*}R_{SERIES})/(nKT))-1}. \tag{2}$$

The reverse saturation current is I_{RSC}. The symbols q, T, n, and K represent the electron charge, ambient temperature, diode factor, and Boltzmann constant, correspondingly. Equation (3) indicates the current generated in the photovoltaic cell.

$$I_R = \frac{W}{W_0}\left(I_{SCN} + \lambda(T - T_0)\right). \tag{3}$$

A short circuit current is represented by I_{SCN}, whereas temperature and reference irradiance are represented by T_0 and W_0, respectively. It was found that λ and W stood for the irradiation coefficient and ambient temperature, respectively.

$$I_{PV} = I_R - I_{RSC}\left[e^q \frac{V_{PV+}I_{PV*}R_{SERIES}}{nKT} - 1\right] - \frac{V_{PV} + I_{PV} * R_{SERIES}}{R_{PL}}. \tag{4}$$

The power voltage and voltage-current nature of the photovoltaic array are shown in Figures 3(a) and 3(b) in STC and PSCS conditions.

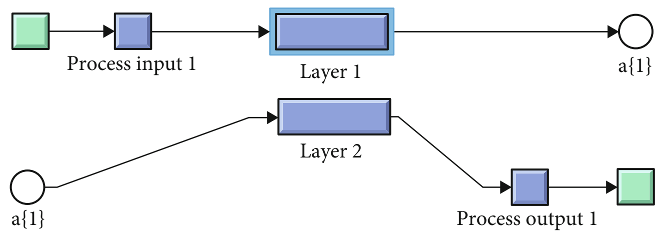


Figure 5: Schematic diagram of neural network.

Table 2: Specification of solar panel.

Specification	Values
Open circuit voltage (V_{OC})	37.30 volts
Short circuit current (I_{SCN})	8.66 A
Coefficient of temperature at V_{OC}	-0.36901 (V/°C)
Coefficient of temperature at I_{SC}	0.086998 (A/°C)
Cell for each module	60
Maximum power	250.205 W

3. Proposed System Components

3.1. DC-DC Boost Converter. Under specific weather and irradiance conditions, the solar array may function in line with MPP because of its DC-DC converter connection to load. The duty ratio of the boost converter switch is adjusted using MPPT techniques to maintain the solar array running at its maximum power point. In Table 1, the boost converters used in the present task are given along with their specifications. This is an illustration of how the DC-DC converter used for the investigation was modified.

3.2. The Bidirectional Converter. This paper outlines the advantages of employing a bidirectional boost converter. This converter manages the electricity storage and transfer between a battery bank and a solar system [41–46]. The main benefits are as follows: (i) It provides the most affordable option with the fewest external components. (ii) Its duty cycle is lowered while it is in operation. (iii) This converter is very much cost-effective.

SBB delivered its excess and stored solar energy for charging the EVs after sunset. This article describes how to charge or drain the standby battery (SBB) using a bidirectional converter. The SBB, with a capacity of 240 V and 40 Ah, serves as the energy storage unit. In this configuration, determining the SBB's minimum 20% SOC discharge rate is crucial. This strategic discharge rate ensures efficient storage energy utilization, making the entire charging system reliable and sustainable.

3.3. Grid Setup Using an Inverter Module. To meet the increased power requirements of the charging station, a thorough analysis of the 230 V, 50 Hz AC grid is conducted. In the MATLAB/Simulink environment, the grid is represented as a 230 V AC source linked to a 500 V DC bus through an inverter. A neural network model is developed to manage this system efficiently. This model utilizes the energy output from the PV array and the Smart Battery Bank's SOC percentage as input data to generate pulses for controlling the inverter switches. By ensuring a smooth integration of battery storage and renewable energy sources, this creative strategy maximizes the performance of the charging station.

4. Representation of the Battery System

As intermittent energy sources advance and become more prevalent, the necessity of building storage systems will become more and more evident. Because of their high power and energy densities, batteries have attracted interest among the numerous electrical storage devices that have been developed. The battery that will be used in the charging station is a 240 V, 7 Ah battery. A 500 V DC bus, a DC-DC boost converter, and a PI controller are utilized in the electrically powered vehicle's battery charging process. It is expected for modelling reasons that the approaching EV's battery will have a minimum SOC of 10%. The battery's amp-hour rating (Ah_r), lowest voltage (V_{no}), and lasting percentage state of charge (SOC_{re}) can all be utilized to determine the amount of energy needed (E_{ev}) to charge the EV battery.

$$E_{ev} = \frac{V_{no} * SOC_{re} * Ah_r}{100}. \quad (5)$$

The model indicates that it is possible to maintain a consistent internal resistance in the battery throughout the cycles of charge and discharge.

5. MPPT Methodology

5.1. Cuckoo Search Algorithm-Based MPPT Controller. Yang and Deb introduced the CUSA in 2009. The CUSA is a metaheuristic approach that is influenced by traits of cuckoo birds in their reproductive process. The parasitic cuckoo lays its eggs inside the nests of different species rather than building its own. There are three novel characteristic regulations for using this method [47]. The flow chart of Figure 4 illustrates how the CUSA controls the MPPT method.

5.2. Current Control Technique Employed in AC Grid. Output from the PV array under uncertain atmospheric conditions and standby batteries SOC (%) are utilized to create a functionally adequate neural network in MATLAB/

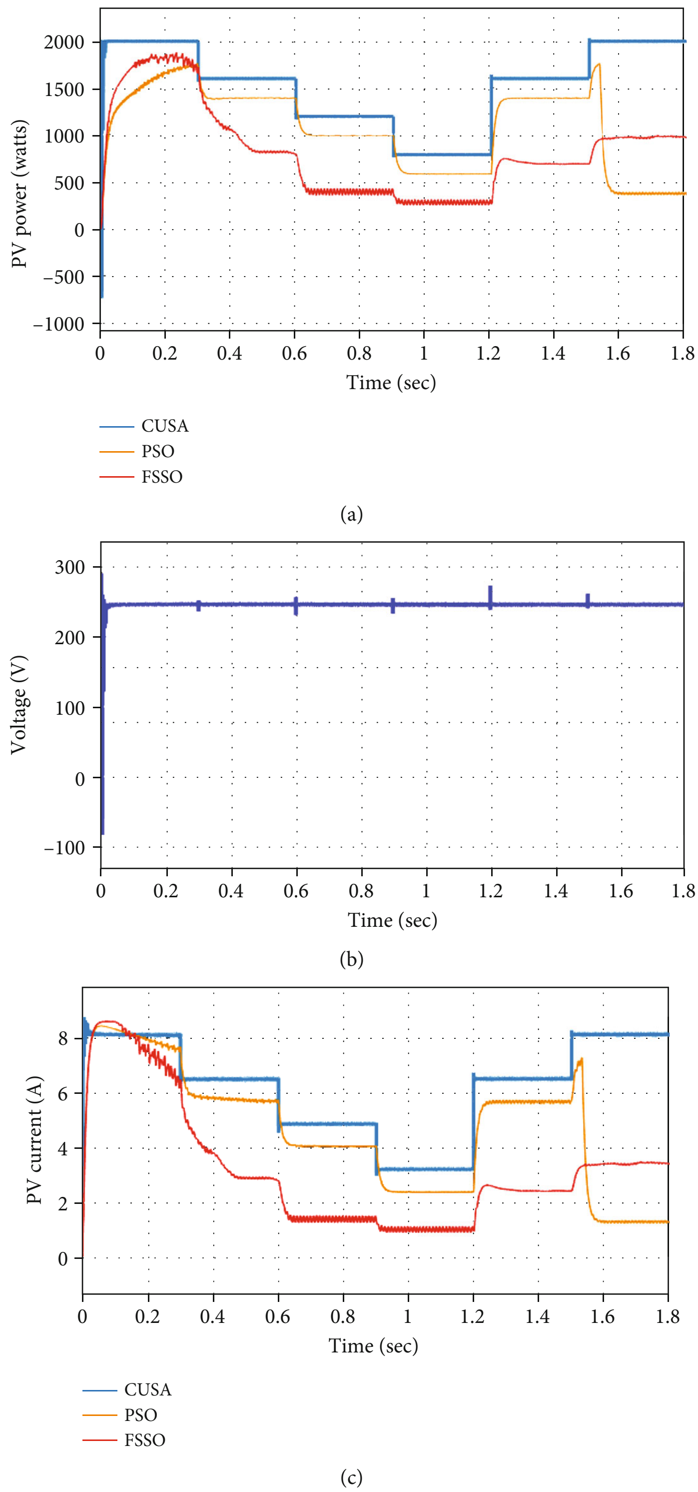
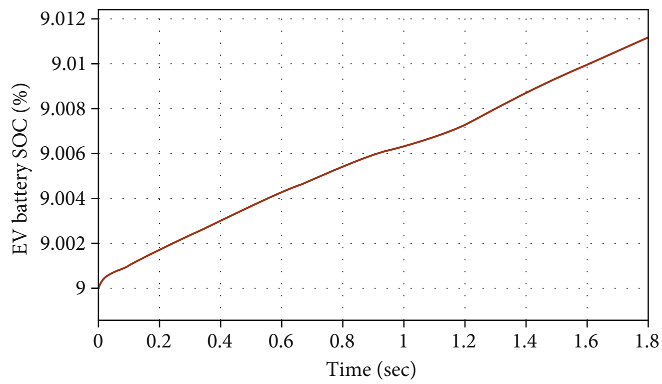


Figure 6: (a) PV power, (b) voltage, and (c) current under uncertain irradiance conditions.

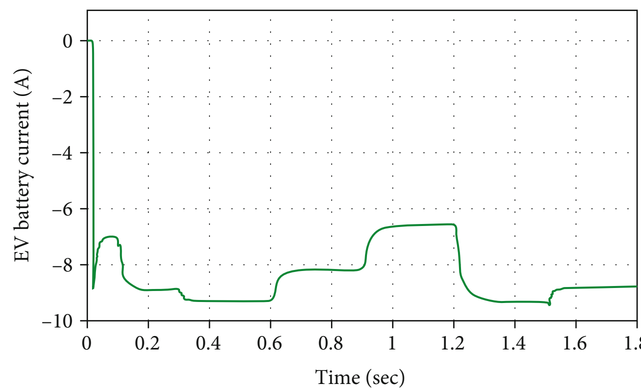
Simulink. To find the fault current, the input current from the AC grid and the current from the neural network simulation are compared. When the PI controller has assessed the fault current, it produces a duty cycle for the inverter. Figure 5 shows input-output and intermediate layers for the neural network used in the AC grid.

5.3. Operational Mode of Charging Units. The charging terminals can function in the following five different modes:

(i) The photovoltaic array provides the battery of electric vehicles with independent power. Here, the varied irradiance and constant 25°C temperature for



(a)



(b)

Figure 7: (a) % SOC of EV battery and (b) EV battery current.

the PV panels are maintained while the CUSA-regulated technique aims to collect as much energy as feasible from the PV array

(ii) Solar energy is only used to charge an EV's battery when connected to a DC bus. The CUSA approach can be used to obtain MPP

(iii) With varying irradiance, EV batteries are charged utilizing solar power and SBB. CUSA ensures the solar panel array can provide the most possible power

(iv) After dusk, when one of the input parameters, i.e., solar irradiance, is absent at night, the standby battery and EV battery both take charge from the AC grid

(v) Both the atmospheric temperature and solar irradiance can be changed. When an AC grid, SBB, and solar PV array are all connected, EV batteries can be charged. The AC grid gets infused with more electricity

6. Simulation Outcome

In this section, the simulation's findings are displayed and analyzed. MATLAB/Simulink 2018 includes an implementation of a 2 kW single-phase grid-connected inverter system. Eight series-connected 1Soltech 1STH-250-WH 250 W panels are used to produce 2 kW of output. Table 2 contains a list of the module specs we discussed earlier. A blend of industry standards, application requirements, and practical considerations drives the choice of a 2 kW single-phase inverter. Standardization contributes to compatibility and cost-effectiveness, while the 2 kW rating aligns well with typical power needs in residential solar and EV charging applications. Cost efficiency, ease of installation, and compliance with relevant standards further support the rationale behind this selection. The 2 kW inverter, with its commonality and availability, emerges as a practical and well-suited choice for meeting the project's specific demands.

6.1. Case 1. In the first scenario, when the temperature is held nearly constant, irradiance fluctuates under partial shade conditions. To produce PSCS-like conditions, a stair generator was used. The irradiance fluctuates at intervals of every 0.3 seconds up to 1.5 seconds of simulation time, and the total simulation time is taken as 1.8 seconds. Comparable irradiances fluctuate every 0.3 seconds, as previously mentioned, going from 1000 w/m^2 to 800-600-400-800 w/m^2 and back every 1.8 seconds. In the first case, irradiance varies in PSCS, but atmospheric temperature remains almost constant. PV voltage is constant and photovoltaic power swings with changes in irradiation. Figure 6 demonstrates that the PV array can provide the maximum amount of power that is reached to the MPP rapidly within the least amount of settling time. For modelling reasons, the initial consideration is 9% SOC of EV. As seen in Figure 7, the EV battery current is negative, meaning that the battery is taking charge. Using data from the PV array that shows variations in the SOC (%) of the SBB and irradiance, a functionally sufficient neural network model is built into the model. After analyzing the fault current with the help of input current and reference current from the neural network as stated previously, the duty cycle for the inverter is set by the PI controller.

Table 3: Result analysis and efficiency calculation.

Algorithm	Settling time (s)	Power received avg. (W)	Efficiency
CUSA	0.05	1998.60	99.26
FSSO	0.42	1625.80	81.29
PSO	0.32	1746.80	87.32

The efficiency and settling time of the proposed CUSA MPPT algorithm compared with existing literature is shown in Table 3.

6.2. Case 2. This section has looked at the impact of temperature fluctuation on the operational point of the photovoltaic system under the assumption that the irradiance value also keeps changing. Take temperature readings every 0.4 seconds. Authors here choose a 0 to 1.8 sec time range, which denotes irradiance variations at 0.4, 0.8, 1.2, and 1.6 sec. As previously discussed, the corresponding temperature changes from 25°C to 38°C every

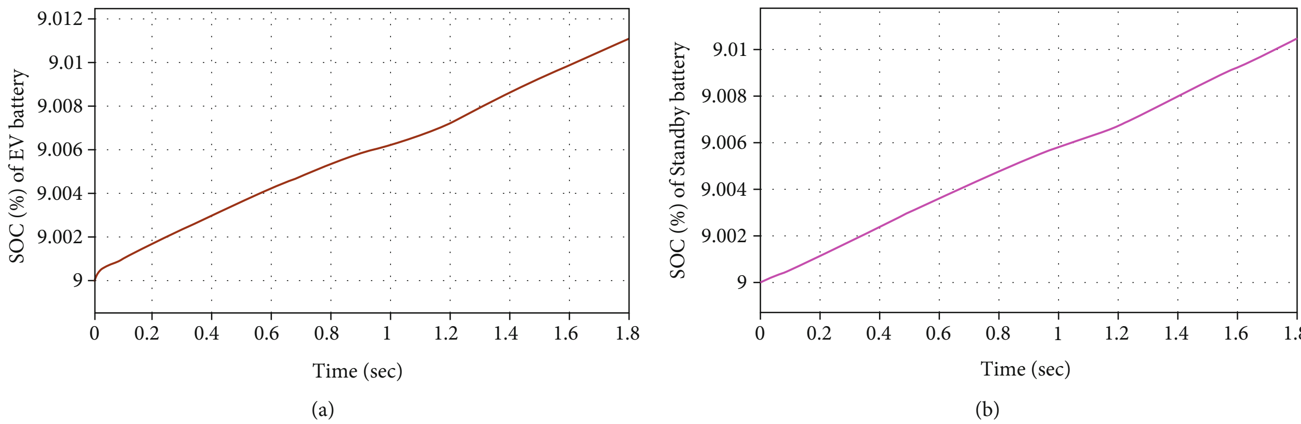


FIGURE 8: % SOC of (a) EV battery and (b) standby battery.

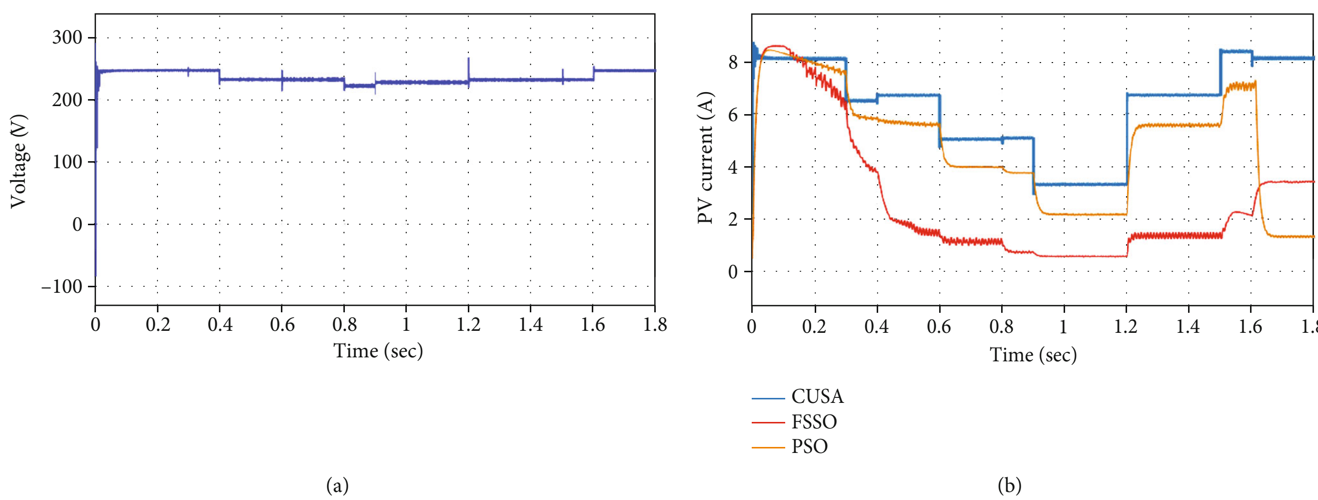


FIGURE 9: (a) Output voltage and (b) current from the photovoltaic array.

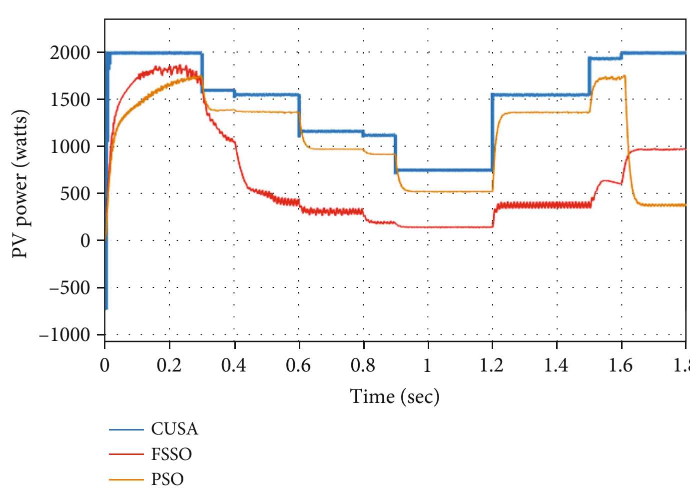
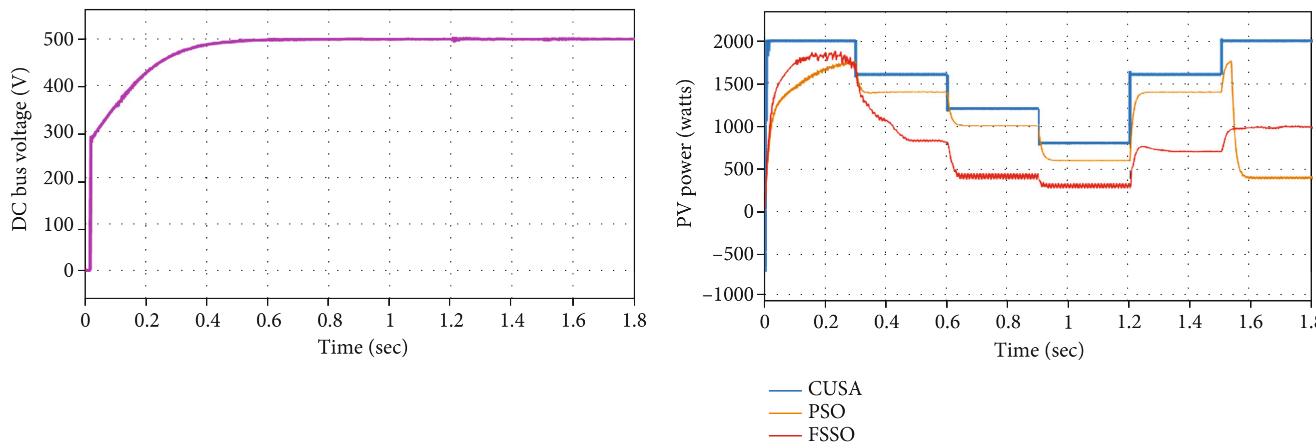


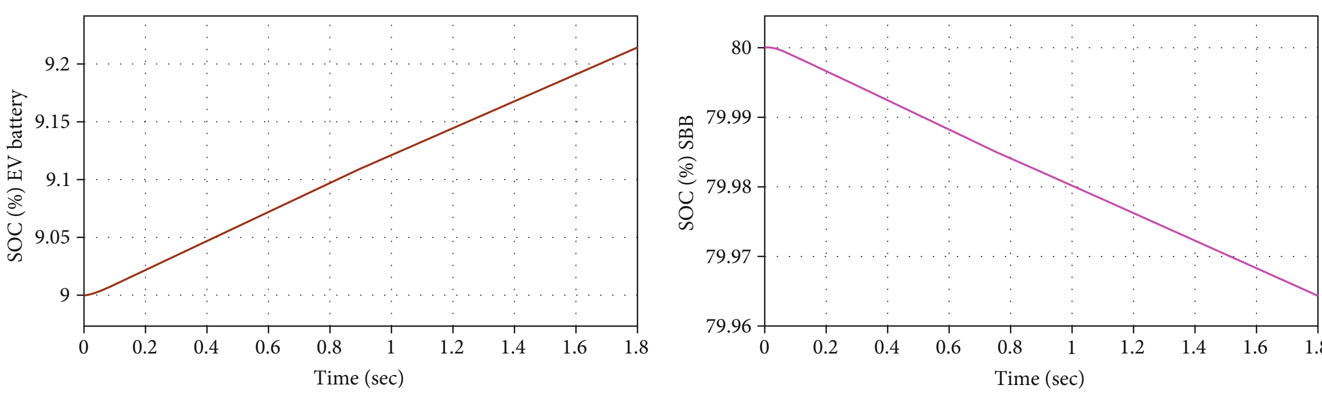
FIGURE 10: Photovoltaic array output power.

0.4 seconds, and it then instantly returns to 25°C after 1.8 seconds, whether irradiance varies according to case no. 1. In accordance with Figure 8, both SBB and EV batteries are charged in this complex scenario. At a variety of temperatures and irradiances, the PV array's maximum voltage, current, and power are retrieved, as depicted in Figures 9 and 10, which are far more stable and reach MPP very quickly compared with preexistence methods like particle swarm optimization or flying squirrel search optimization.



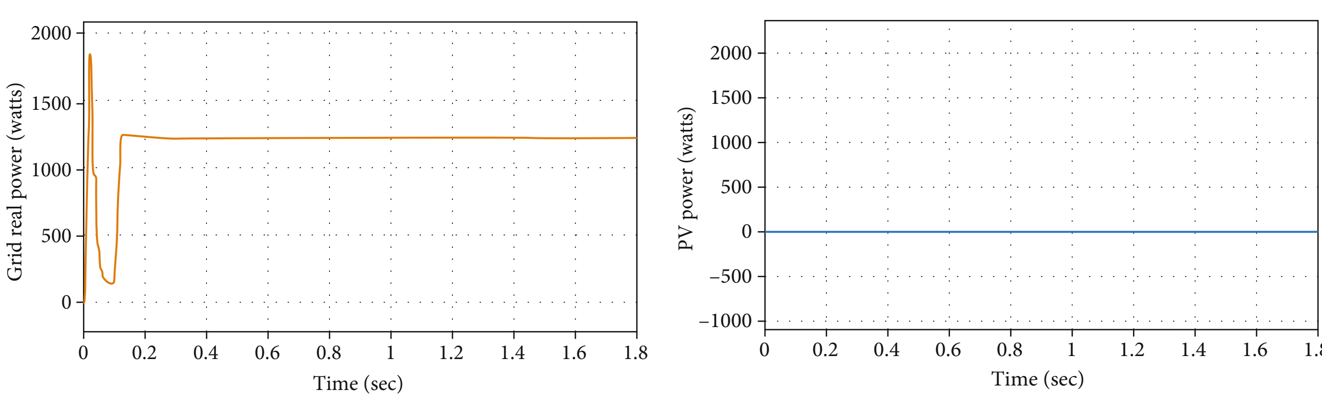
(a) (b)

Figure 11: (a) Bus voltage and (b) output power from the photovoltaic array.



(a) (b)

Figure 12: % SOC of (a) electric vehicle's battery and (b) standby battery.



(a) (b)

Figure 13: (a) Grid real power and (b) PV power at night.

6.3. Case 3. The SBB, PV array, and EV battery are interconnected through a DC bus. This DC bus operates at a constant voltage of 500 V and facilitates power transfer, particularly during variations in the PV array's irradiance and temperature conditions, as depicted in Figure 11.

Figure 12 shows how energy flows through this system in a dynamic manner. The DC bus and the SBB contribute electrical energy to fulfill the charging requirements of the EV battery. This process involves discharging the SBB, causing a decrease in its SOC percentage, while simultaneously

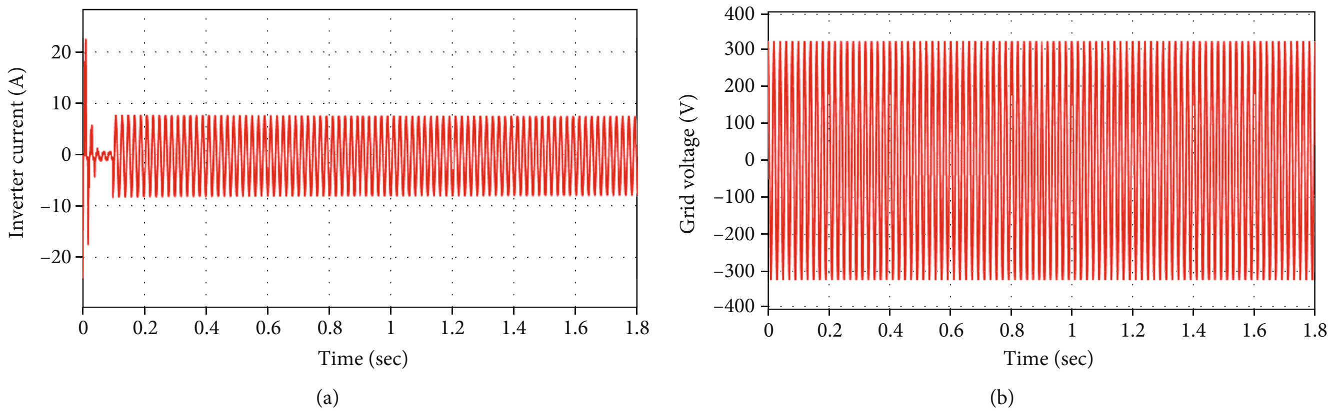


Figure 14: (a) Grid current and (b) grid voltage.

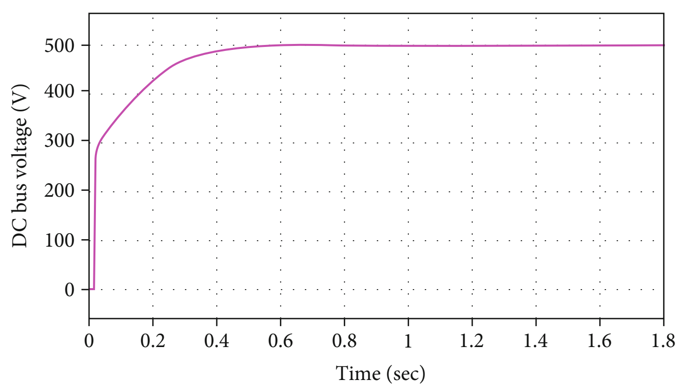


Figure 15: DC bus voltage.

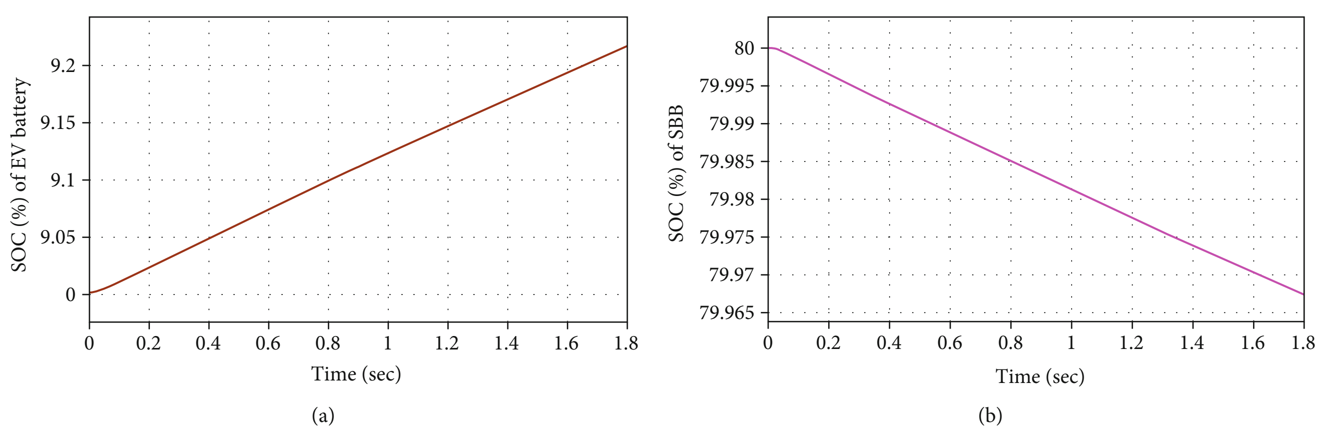


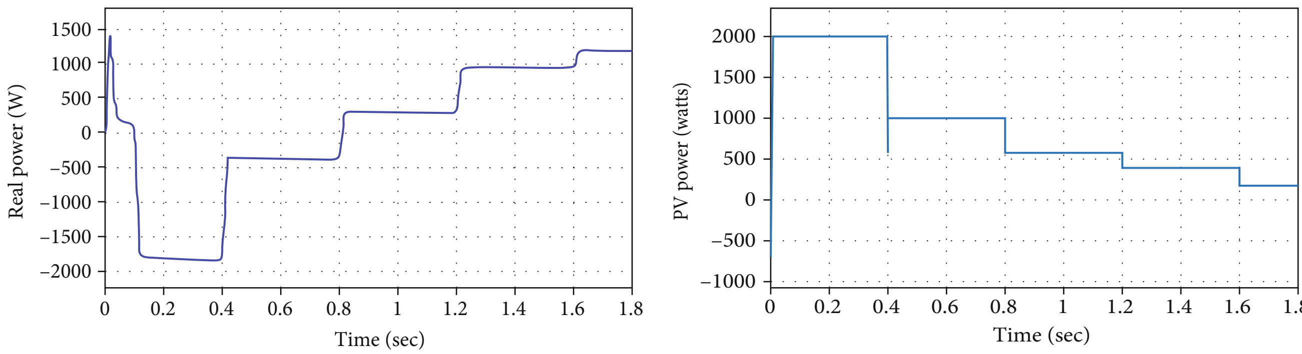
Figure 16: SOC (%) of (a) electric vehicle's battery and (b) standby battery.

charging the battery of an electric vehicle, increasing its SOC percentage.

6.4. Case 4. In Figure 13, we observe the power flow management within the grid through a functional fitting neural network. This occurs at a simulation time of 0.1 seconds, specifically during nighttime when the PV array generates no power. The DC bus and the AC grid are connected by means of an inverter.

Figure 14 shows inverter current and grid voltage, whereas Figure 15 represents DC bus voltage.

Furthermore, in Figure 16, there is a comprehensive visual representation that elucidates the intricate steps involved in charging an EV battery directly from the DC bus. This figure not only captures the dynamic aspects of the charging process but also provides a granular breakdown of the standby battery's SOC throughout the entirety of this operation. The detailed insights presented in the figure serve



(a) (b)

Figure 17: (a) Grid active power and (b) photovoltaic power supplied.

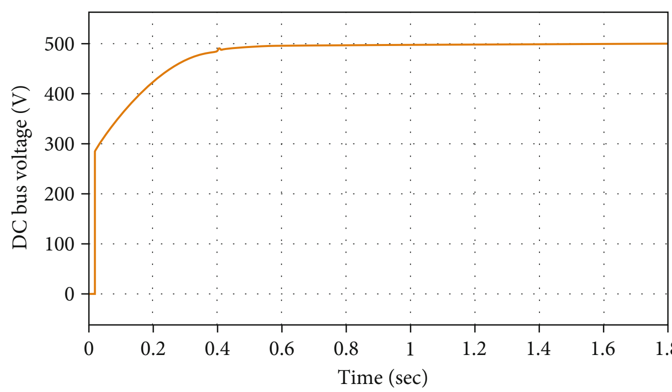
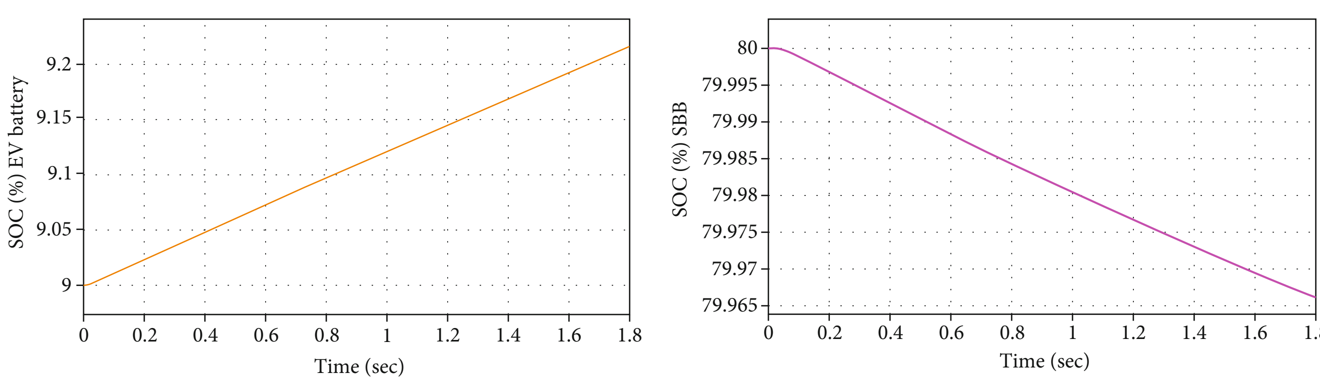


Figure 18: DC bus voltage in DC bus.



(a) (b)

Figure 19: (a) SOC (%) of electric vehicle's battery and (b) SOC (%) of SBB.

to enhance the understanding of the charging dynamics and the corresponding variations in the standby battery's SOC, contributing valuable information for a comprehensive analysis.

6.5. Case 5. At 0.1 seconds into the simulation, the functional fitting neural network starts to control the amount of electricity going to the AC grid. Between simulation periods of 0.1 and 0.8 seconds, the real power of the grid is negative, indicating that electricity enters the AC grid via a DC bus, as seen in Figures 17 and 18. As seen in Figure 19, SBB powers the DC bus, which then charges the electrically empowered conveyance's battery.

6.6. Comparative Analysis. In the context of the considered methods, various performance metrics have been evaluated to gauge their effectiveness. A thorough examination of each method is given in the paragraphs that follow, taking into account factors including performance, accuracy, tracking speed, steady-state error, maximum overshoot,

Table 4: Detailed comparison of the proposed method's performance.

Procedure	Execution	Maximum overshoot	Interpretation	Tracking speed	Accuracy	Steady-state error
Considered	Easy	Low	Outstanding	Outstanding	Outstanding	Poor
FSSO	Complex	High	Moderate	Moderate	Moderate	Moderate
PSO	Simple	Low	Very good	Average	Moderate	Less
GWO	Complex	Low	Very good	Outstanding	Moderate	Less

and implementation complexity. The FSSO method presents a more complex implementation, accompanied by a higher maximum overshoot. Its overall performance is considered average, with moderate tracking speed, accuracy, and a noticeable steady-state error. While it may not excel in certain aspects, depending on the particular needs of the application, it is still a feasible solution.

On the other hand, the PSO method is associated with an easy implementation process, resulting in a low maximum overshoot. Its performance is classified as good, with an average tracking speed, moderate accuracy, and a comparatively lower steady-state error. This method proves to be a practical choice for applications where simplicity and reasonable performance are crucial. While GWO method, in contrast, involves a complex implementation, paired with a low maximum overshoot. Its performance is labeled as very good, with excellent tracking speed, accuracy, and a moderate steady-state error. Despite its complexity, the GWO method showcases impressive attributes, particularly in applications that prioritize high-performance outcomes, while the considered CUSA is characterized by an easy implementation process, resulting in a low maximum overshoot. Its performance is deemed excellent, with superior tracking speed, accuracy, and minimal steady-state error. Overall, this method exhibits commendable attributes across multiple performance metrics.

In a nutshell, Table 4 contrasts existing traditional MPPT methods with the suggested CUSA MPPT method. Each method exhibits unique characteristics, making them suitable for specific applications based on factors such as implementation ease, performance metrics, and overall effectiveness in addressing particular optimization goals.

7. Conclusion

In conclusion, the escalating presence of electrically powered motor conveyances on our roadways has unequivocally elevated the significance of the charging infrastructure.

The proposed research has delved into a multifaceted strategy that addresses the immediate needs of EV charging and lays a strong foundation for future enhancements. Charging station power can be effectively achieved by combining grid support, solar panel power, and a backup battery energy storage system. The orchestration of this system through advanced control mechanisms such as the Cuckoo Search Algorithm-based Maximum Power Point Tracking controller, PI controller, and neural network has showcased its adaptability to accommodate the diverse charging requirements of a wide array of electrically powered conveyances.

One of the most important aspects of this research has been emphasized: maintaining a steady DC bus voltage at the recharging terminal. This voltage stability is necessary to ensure the charging process's dependability and efficacy. We thoroughly investigated and verified the station's effectiveness across five distinct scenarios using MATLAB/Simulink research, thereby enhancing its robustness and usefulness. The grid integration discovered in this study enhances the stability of the power supply for electric vehicle charging terminals.

In future versions, this research can be refined and built upon. Higher-rating EV charging stations may be built up in the near future. These stations may be part of a large infrastructure of charging stations or found in offices. More sophisticated control algorithms and creative energy storage techniques are two more cutting-edge technologies that can be added to EV charging stations to further improve its sustainability and efficacy. Further diversifying the energy mix and bolstering the resilience of the system could be achieved by incorporating nonsolar renewable energy sources like wind and hydropower. In the future, this research can be developed and refined even more. The most important thing to accomplish next is to scale up the suggested layout to meet the increasing demand for charging stations and the expanding number of electric vehicles. This may include installing high-capacity vehicle charging terminals. These stations may be placed in offices or on public charging networks. Modern technology such as enhanced control algorithms and novel energy storage solutions can be incorporated to further maximize the sustainability and effectiveness of the infrastructure for EV charging. Furthermore, incorporating renewable energy sources other than solar, like wind or hydropower, into the mix could increase system resilience and diversify the energy source mix. Therefore, our effort contributes to a viable and ecologically conscious future in mobility by providing an adequate foundation for the expansion of EV charging terminals.

Data Availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflicts of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Acknowledgments

Open Access funding is provided by the Qatar National Library.

References

[1] S. M. Malik, X. Ai, Y. Sun, C. Zhengqi, and Z. Shupeng, "Voltage and frequency control strategies of hybrid AC/DC microgrid: a review," *IET Generation, Transmission & Distribution*, vol. 11, no. 2, pp. 303–313, 2017.

[2] P. Shrivastava, M. S. Alam, and M. S. J. Asghar, "Design and techno-economic analysis of plug-in electric vehicle-integrated solar PV charging system for India," *IET Smart Grid*, vol. 2, no. 2, pp. 224–232, 2019.

[3] P. Shrivastava, P. A. Naidu, S. Sharma, B. K. Panigrahi, and A. Garg, "Review on technological advancement of lithium-ion battery states estimation methods for electric vehicle applications," *Journal of Energy Storage*, vol. 64, article 107159, 2023.

[4] M. A. H. Rafi and J. A. Bauman, "A comprehensive review of DC fast-charging stations with energy storage: architectures, power converters, and analysis," *IEEE Transactions on Transportation Electrification*, vol. 7, no. 2, pp. 345–368, 2021.

[5] M. Yilmaz and P. T. Krein, "Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles," *IEEE Transactions on Power Electronics*, vol. 28, no. 5, pp. 2151–2169, 2013.

[6] J. Francfort, S. Salisbury, J. Smart, T. Garetson, and D. Karner, *Considerations for corridor and community DC fast charging complex system design*, Idaho National Lab. (INL), Idaho Falls, ID, USA, 2017.

[7] R. Srivastava, M. Amir, F. Ahmad, S. K. Agrawal, A. Dwivedi, and A. K. Yadav, "Performance evaluation of grid connected solar powered microgrid: a case study," *Frontiers in Energy Research*, vol. 10, article 1044651, 2022.

[8] H. Fathabadi, "Lambert W function-based technique for tracking the maximum power point of PV modules connected in various configurations," *Renewable Energy*, vol. 74, pp. 214–226, 2015.

[9] H. Rezk and A. M. Eltamaly, "A comprehensive comparison of different MPPT techniques for photovoltaic systems," *Solar Energy*, vol. 112, pp. 1–11, 2015.

[10] Y. Li, S. Q. Mohammed, G. S. Nariman, N. Aljojo, A. Rezvani, and S. Dadfar, "Energy management of microgrid considering renewable energy sources and electric vehicles using the backtracking search optimization algorithm," *Journal of Energy Resources Technology*, vol. 142, no. 5, article 052103, 2020.

[11] F. Ahmad, L. Al-Fagih, S. A. Qadir, and M. Khalid, "EV charging station placement using nature inspired optimisation algorithms," in *IEEE International Conference on Power, Instrumentation, Energy, and Control*, Aligarh, India, February 2023.

[12] N. Khanam, B. H. Khan, and T. Imtiaz, "Maximum power extraction of solar PV system using meta-heuristic MPPT techniques: a comparative study," in *2019 International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, pp. 1–6, Aligarh, India, 2019.

[13] L. T. Omine, M. A. G. de Brito, J. O. P. Pinto, and R. C. García, "Hybrid MPPT algorithms for photovoltaic systems," in *2018 IEEE 4th Southern Power Electronics Conference (SPEC)*, pp. 1–8, Singapore, 2018.

[14] W. A. Ibrahim, M. B. Shafik, M. Ding et al., "PV maximum power-point tracking using modified particle swarm optimization under partial shading conditions," *Chinese Journal of Electrical Engineering*, vol. 6, no. 4, pp. 106–121, 2020.

[15] K. Ishaque, Z. Salam, M. Amjad, and S. Mekhilef, "An improved particle swarm optimization (PSO)–based MPPT for PV with reduced steady-state oscillation," *IEEE transactions on Power Electronics*, vol. 27, no. 8, pp. 3627–3638, 2012.

[16] D. A. Nugraha, K. L. Lian, and Suwarno, "A novel MPPT method based on cuckoo search algorithm and golden section search algorithm for partially shaded PV system," *Canadian Journal of Electrical and Computer Engineering*, vol. 42, no. 3, pp. 173–182, 2019.

[17] S. Mohanty, B. Subudhi, and P. K. Ray, "A grey wolf-assisted perturb & observe MPPT algorithm for a PV system," *IEEE Transactions on Energy Conversion*, vol. 32, no. 1, pp. 340–347, 2017.

[18] K. Sundareswaran, V. Vigneshkumar, P. Sankar, S. P. Simon, P. S. R. Nayak, and S. Palani, "Development of an improved P&O algorithm assisted through a colony of foraging ants for MPPT in PV system," *IEEE Transactions on Industrial Informatics*, vol. 12, no. 1, pp. 187–200, 2016.

[19] S. Padmanaban, N. Priyadarshi, M. S. Bhaskar, J. B. Holm-Nielsen, V. K. Ramachandaramurthy, and E. Hossain, "A hybrid ANFIS-ABC based MPPT controller for PV system with anti-islanding grid protection: experimental realization," *IEEE Access*, vol. 7, pp. 103377–103389, 2019.

[20] A. F. Mirza, M. Mansoor, Q. Ling, B. Yin, and M. Y. Javed, "A salp-swarm optimization based MPPT technique for harvesting maximum energy from PV systems under partial shading conditions," *Energy Conversion and Management*, vol. 209, article 112625, 2020.

[21] B. Yang, L. Zhong, X. Zhang et al., "Novel bio-inspired memetic salp swarm algorithm and application to MPPT for PV systems considering partial shading condition," *Journal of Cleaner Production*, vol. 215, pp. 1203–1222, 2019.

[22] M. Mansoor, A. F. Mirza, Q. Ling, and M. Y. Javed, "Novel grass hopper optimization based MPPT of PV systems for complex partial shading conditions," *Solar Energy*, vol. 198, pp. 499–518, 2020.

[23] F. Ahmad, M. Khalid, and B. K. Panigrahi, "An enhanced approach to optimally place the solar powered electric vehicle charging station in distribution network," *Journal of Energy Storage*, vol. 42, article 103090, 2021.

[24] T. Wu, Q. Yang, Z. Bao, and W. Yan, "Coordinated energy dispatching in microgrid with wind power generation and plug-in electric vehicles," *IEEE Transactions on Smart Grid*, vol. 4, no. 3, pp. 1453–1463, 2013.

[25] L. Chandra and S. Chanana, "Energy management of smart homes with energy storage, rooftop PV and electric vehicle," in *2018 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*, pp. 1–6, Bhopal, India, 2018.

[26] F. Huang, P. Sarikprueck, Y. Cheng, and W. J. Lee, "Design optimization of PHEV charging station," in *48th IEEE Industrial & Commercial Power Systems Conference*, pp. 1–7, Louisville, KY, USA, 2012.

[27] B. Zhang, Q. Yan, and M. Kezunovic, "Placement of EV charging stations integrated with PV generation and battery storage," in *2017 Twelfth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, pp. 1–7, Monte Carlo, Monaco, 2017.

[28] B. Singh, A. Verma, A. Chandra, and K. Al-Haddad, "Implementation of solar PV-battery and diesel generator based electric vehicle charging station," *IEEE Transactions on Industry Applications*, vol. 56, no. 4, pp. 4007–4016, 2020.

[29] M. Rezaeimozafar, M. H. Moradi, and M. H. Amini, "A simultaneous approach for optimal allocation of renewable energy sources and electric vehicle charging stations in smart grids based on improved GA-PSO algorithm," *Sustainable Cities and Society*, vol. 32, pp. 627–637, 2017.

[30] A. K. Mishra and T. Kim, "An economical light plug-in electric vehicle (LPEV) with on-board single-stage battery charging system," *IEEE Transactions on Industry Applications*, vol. 59, no. 5, pp. 6568–6579, 2023.

[31] N. K. Saha and S. K. Panda, "Adaptive grid-supportive control for solar-power integrated electric-vehicle fast charging station," *IEEE Transactions on Energy Conversion*, vol. 38, no. 3, pp. 2034–2044, 2023.

[32] N. Kumar, H. K. Singh, and R. Niwareeba, "Adaptive control technique for portable solar powered EV charging adapter to operate in remote location," *IEEE Open Journal of Circuits and Systems*, vol. 4, pp. 115–125, 2023.

[33] S. Deb, K. Tammi, K. Kalita, and P. Mahanta, "Charging station placement for electric vehicles: a case study of Guwahati city, India," *IEEE Access*, vol. 7, pp. 100270–100282, 2019.

[34] M. Ibrahim, L. Bernard, L. Pichon et al., "Inductive charger for electric vehicle: advanced modeling and interoperability analysis," *IEEE Transactions on Power Electronics*, vol. 31, no. 12, pp. 8096–8114, 2016.

[35] N. Sivanantham, P. Pugazhendiran, R. Revathy, and M. Sathiya, "PV-powered MPPT controlled smart parking system using inductive coupling charging technique for electric vehicle," in *2023 2nd international conference on Smart technologies and Systems for Next Generation Computing (ICSTSN)*, pp. 1–6, Villupuram, India, 2023.

[36] V. Jayasree, M. Sruthi, O. V. Asokan, and P. Jayaprakash, "Fuzzy logic algorithm based MPPT controller for solar PV powered electric vehicle charging station," in *2022 International Conference on Futuristic Technologies in Control Systems & Renewable Energy (ICFCR)*, pp. 1–6, Malappuram, India, 2022.

[37] S. Iqbal, S. Habib, M. Ali et al., "The impact of V2G charging/discharging strategy on the microgrid environment considering stochastic methods," *Sustainability*, vol. 14, no. 20, article 13211, 2022.

[38] A. Shafiq, S. Iqbal, S. Habib et al., "Solar PV-based EV vehicle charging station for security bikes: a techno-economic and environmental analysis," *Sustainability*, vol. 14, no. 21, article 13767, 2022.

[39] S. Iqbal, S. Habib, N. H. Khan, M. Ali, M. Aurangzeb, and E. M. Ahmed, "Electric vehicles aggregation for frequency control of microgrid under various operation conditions using an optimal coordinated strategy," *Sustainability*, vol. 14, no. 5, p. 3108, 2022.

[40] S. R. Das, P. K. Ray, A. K. Sahoo, S. Ramasubbareddy, T. S. Babu, and N. M. Kumar, "Performance of hybrid filter in a microgrid integrated power system network using wavelet techniques," *Applied Sciences*, vol. 10, no. 19, p. 6792, 2020.

[41] S. A. Gorji, H. G. Sahebi, M. Ektesabi, and A. B. Rad, "Topologies and control schemes of bidirectional DC–DC power converters: an overview," *IEEE Access*, vol. 7, pp. 117997–118019, 2019.

[42] S. Adhikary, P. K. Biswas, and C. Sain, "Comprehensive review on charging solution of electric vehicle-an internet of things based approach," *International Journal of Electric and Hybrid Vehicles*, vol. 15, no. 1, pp. 40–66, 2023.

[43] D. Chatterjee, P. K. Biswas, C. Sain, A. Roy, and F. Ahmad, "Efficient energy management strategy for fuel cell hybrid electric vehicles using classifier fusion technique," *IEEE Access*, vol. 11, pp. 97135–97146, 2023.

[44] A. Ganguly, P. K. Biswas, C. Sain, and T. S. Ustun, "Modern DC–DC power converter topologies and hybrid control strategies for maximum power output in sustainable nanogrids and picogrids–a comprehensive survey," *Technologies*, vol. 11, no. 4, p. 102, 2023.

[45] T. Barker, A. Ghosh, C. Sain, F. Ahmad, and L. Al-Fagih, "Efficient ANFIS-driven power extraction and control strategies for PV-BESS integrated electric vehicle charging station," *Energy Conversion and Management*, vol. 48, article 100523, 2024.

[46] D. Mazumdar, P. K. Biswas, C. Sain, and T. S. Ustun, "GAO optimized sliding mode based reconfigurable step size Pb& O MPPT controller with grid integrated EV charging station," *IEEE Access*, vol. 12, pp. 10608–10620, 2024.

[47] X. S. Yang and S. Deb, "Multiobjective cuckoo search for design optimization," *Computers and Operations Research*, vol. 40, no. 6, pp. 1616–1624, 2013.