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An AI-Driven MPPT Algorithm for Enhanced Performance of Solar-Powered Electric Vehicle Charging Stations

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Abstract

The fast-tracked implementation of electric vehicles (EVs) has prompted the development of effective, secure, and sustainable charging systems. Solar powered EV charging stations assure that renewable energy is utilized while minimizing the need of traditional grid energy in the process. However, because of the nature of solar radiation and temperature changes, the PV operating point varies continuously, which makes the need for maximum power point tracking (MPPT) in order to gain the highest available amount of power crucial. Although traditional MPPT methods such as perturb and observe (P&O) and incremental conductance (INC) can be characterized as straightforward and inexpensive, they are likely to cause oscillations while remaining close to the maximum power point and experience lower efficiency in the process of adapting to the environmental variations. Artificial intelligence-based MPPT approaches, including artificial neural networks, fuzzy logic, adaptive learning, and hybrid methods can provide better intelligence in the process of adapting since they can learn the non-linear behavior of the PV system. The fast-tracked implementation of electric vehicles (EVs) has prompted the development of effective, secure, and sustainable charging systems. Solar powered EV charging stations assure that renewable energy is utilized while minimizing the need of traditional grid energy in the process. However, because of the nature of solar radiation and temperature changes, the PV operating point varies continuously, which makes the need for maximum power point tracking (MPPT) in order to gain the highest available amount of power crucial. Although traditional MPPT methods such as perturb and observe (P&O) and incremental conductance (INC) can be characterized as straightforward and inexpensive, they are likely to cause oscillations while remaining close to the maximum power point and experience lower efficiency in the process of adapting to the environmental variations. Artificial intelligence-based MPPT approaches, including artificial neural networks, fuzzy logic, adaptive learning, and hybrid methods can provide better intelligence in the process of adapting since they can learn the non-linear behavior of the PV system.

Keywords: Artificial Intelligence, MPPT, Solar Photovoltaic, Electric Vehicle Charging, DC–DC Converter, Renewable Energy.

I. Introduction

The increasing popularity of electric vehicles (EVs) necessitates the need for reliable and efficient charging infrastructure. Traditional EV charging stations primarily depend on electricity from the utility grid, which leads to high peak demand, with an indirect contribution to greenhouse gas emissions derived from fossil fuels in electricity generation. The alternative of producing clean electricity directly at the EV charging station using renewable energy, namely solar photovoltaic (PV) energy, is thus appealing. PV systems can function autonomously, connect to the grid, or take

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advantage of a combination of these two modes, and these systems may employ battery energy storage [1]. However, the irregular nature of solar energy is a significant disadvantage as far as PV-based EV charging is concerned. Solar irradiance and temperature are in constant motion, resulting in continuous variation of voltage and current, thus implicating the need for an appropriate control mechanism to extract maximum power from PV. Typically, an MPPT controller is integrated with a DC–DC converter to regulate the PV operating point and transfer the maximum available solar power toward the DC link, battery, or EV charger.

Conventionally, various Maximum Power Point Tracking (MPPT) algorithms such as perturb and observe (P&O), incremental conductance (INC), and constant voltage method have demonstrated their effectiveness due to their simple construction, low computational complexity, and ease of implementation. However, these techniques may have problems such as steady-state oscillation, slow response to changes, and poor tracking efficiency in rapidly changing environmental conditions. These limitations are further aggravated by partial shading that results in the occurrence of multiple local maxima on the PV power-voltage curve. Hence, in such situations, conventional algorithms get stuck at a local maximum, while failing to locate the global maximum power point (GMPP) [2]. Therefore, applying Artificial Intelligence (AI) has been suggested as a promising solution to improve MPPT performance. Various AI techniques such as artificial neural networks (ANN), fuzzy logic algorithms, adaptive algorithms, evolutionary optimization, and hybrid techniques can grasp the non-linear relationship between the PV operating conditions and MPP thereby enabling a faster convergence time, lower oscillation, and better performance under changing environmental conditions. Recent reviews indicate that AI-based MPPT methods can achieve improved tracking accuracy and dynamic performance compared with several conventional approaches, although computational complexity, training requirements, real-time implementation, and hardware resources remain important challenges [3].

For solar-supported EV charging stations, the role of MPPT is significant because fluctuations in the amount of energy collected from PV will cause variations in efficiency of charging, duration of battery charging, energy utilization, and the overall operation of charging station. Thus, the choice of MPPT strategy should take into account several important aspects like tracking performance, speed of convergence, stability of the output signal, computational complications, reliability, working under partial shadow conditions, and the feasibility of its real-time usage. In this review, the authors concentrate on AI-based MPPT algorithms for solar-supported EV charging stations. The authors systematically describe the working principles of the considered algorithms, their advantages and disadvantages, and some of their characteristics in terms of performance. They also draw a comparison between traditional and AI-based techniques and present the current issues and prospects in this field. As it is shown in Figure 1, solar energy obtained from PV array is processed through DC-DC boost converter, while the algorithm based on LSTM processes the voltage and current of PV array to define PWM signal and get an effective battery charging.

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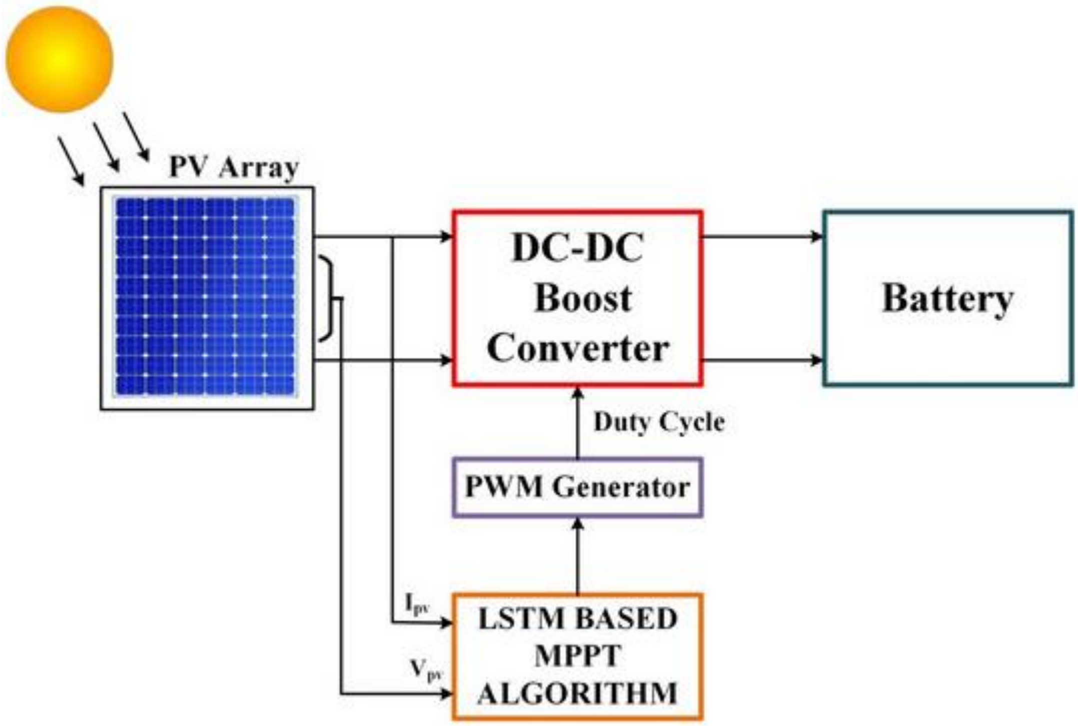

Figure 1: Block Diagram of LSTM-Based MPPT-Controlled Solar PV Battery Charging System. [21]

II. Solar PV-Based Electric Vehicle Charging Systems

The solar photovoltaic electric vehicle charging systems utilize renewable energy from the sun combined with EV charging stations to provide a greener option than conventional electricity grid-based charging for electric vehicles. An example of a solar electric vehicle charging station includes the solar photovoltaic array, maximum power point tracking (MPPT) controller, DC–DC converters, DC link, batteries, electric vehicle charging station, and electric vehicle interface. The solar PV array converts the solar power into electrical energy while converters condition the generated energy into the right format that can meet the EV's charging needs. Additionally, AI, machine learning, and IoT technology integration will help improve the process of managing the energy supply, keeping the energy constant, and optimizing the charging process as well [4]. The efficiency of the solar-powered electric vehicle charging stations depends highly on how much energy is being harvested from the existing solar photovoltaic energy source due to the continuous change in both solar irradiance and temperature. A complete artificial intelligence and machine learning structure that exhibited a valuable combination of smart optimization and IoT-based supervision of solar-fueled electric vehicle charger networks [5]. Intelligent systems are capable of utilizing real-time data about solar generation, charging demand, batteries' status, and weather conditions for optimizing energy distribution and charging process. Moreover, the usage of MPPT based on neural networks has been considered for DC fast chargers powered by solar energy. The combination of model predictive control (MPC) and the neural network-based MPPT controller represents a sophisticated solution for capturing the greatest amount of solar energy while ensuring stable operation of the converter and charger systems. In addition, AI-based Random Forest and hybrid intelligent MPPT solutions have proven high efficiency of energy capture under different solar irradiation scenarios, which is further evidence of the potential of machine learning in the area of adaptive MPPT performance [6].

III. Fundamentals of Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) is a control technique that has substantial importance for solar photovoltaic (PV) systems and that enables harvesting the maximum amount of electrical power from PV modules regardless of the varying environmental conditions and loads. PV modules exhibit a nonlinear behavior in their electric parameters largely influenced by solar irradiance and temperature. The changes in temperature and irradiance bring changes in voltage and current values of the maximum power point, which means that if one were to operate the PV system at certain fixed voltage or current it would continuously lose a chance of getting the maximum available power. An MPPT controller monitors the conditions of operation of the PV modules and shifts the operation point in order to achieve maximum power from the solar module. This function is crucial for the solar EV charging stations because efficient utilization of solar energy has direct importance for the charging efficiency of the stations. The basic principle of operation of MPPT is based on the power-voltage characteristics of the PV array. At small voltages, low voltages correspond to a small power produced. As the voltage increases, the power of the PV array also changes until the maximum.

Generally, the power electronic converter is used between the PV array and the load or the EV charging station. The MPPT controller sends an appropriate switching signal to the converter, altering the electrical working point of the PV array. Depending on the configuration of the charging system, different configurations of the converter can be used, such as boost, buck, buck-boost, or others. For instance, in the architecture of the charging station based on the boost converter, the duty cycle is adjusted so as to maintain the PV voltage at the required level and deliver the solar energy to the DC-link or EV battery. Thus, the MPPT controller and the converter control coordinate their operation in order to make the energy conversion process as efficient as possible.

The effectiveness of the MPPT controller can be evaluated by such important indicators as tracking efficiency, time of convergence, oscillation in steady state, accuracy of tracking, response in dynamic conditions, and complexity of computation. Tracking efficiency refers to how well the controller manages to extract the maximum possible power from the PV array. A controller with high efficiency should be able to reach the maximum power point fast and keep it stable.

Solar irradiance plays a significant role in PV power production. Irradiance increase increases the current levels available for use and therefore maximum power output achievable from PV array. At the same time, temperature variations affect the voltage output of PV modules and as a result lead to MPP changes. Thus, an efficient MPPT algorithm should be able to follow the changes of irradiance and temperature. It becomes harder when the PV unit is integrated with an EV charging station because of variable electric load. Adoption of traditional MPPT techniques is explained by their simplicity, low computational intensity and ease of implementation. However, traditional methods have their drawbacks when used in case of significant changes in operating conditions. Among these challenges is excessive oscillations around the MPP leading to power loss, as well as usage of additional control devices to strike a balance between efficiency and speed of tracking.

Therefore, explorations in the field of intelligent and adaptive MPPT techniques for modern PV systems have become research priorities [8].
Adaptive fuzzy-based MPPT is another intelligent approach that can provide flexible control under uncertain and changing PV conditions. Recent research has investigated explainable AI-enabled adaptive fuzzy MPPT together with energy management for bifacial PV and battery-supported EV charging systems [10]. Such approaches extend the role of MPPT beyond simple maximum power extraction by coordinating solar generation, battery storage, and EV charging requirements. The incorporation of explainability can also improve understanding of the decision-making process of intelligent controllers [9]. Partial shading is another important issue with MPPT systems.PV power-voltage characteristics may have several peaks since different modules may receive different amounts of solar irradiance. These peaks can be classified as local either the global maximum power points. Conventional MPPT systems can get stuck in local maxima sometimes, which means that they do not fully utilize solar energy. AI-based and hybrid optimization techniques can have advantages in such cases. Integration of MPPT and energy storage can also be useful for solar-powered EV charging stations. During peak solar generation periods, surplus energy can be stored in batteries, and battery energy can be used when solar energy production is insufficient. For this reason, MPPT is combined with battery management, DC-link voltage stability, and charging control in such systems. Recent studies of hybrid solar-powered EV charging stations show the role of advanced MPPT and converter technologies in energy use efficiency. [11].

IV. Conventional MPPT Techniques For Solar Pv Systems

Traditional maximum power point tracking methods are commonly used in solar PV systems in order to enable them to harness the maximum available energy in different conditions of irradiance and temperature. These methods usually monitor PV voltage and current and modify the operating point through power electronic devices. Their popularity can be explained primarily by the simplicity of their control system and low computational requirements. However, the overall performance may decrease due to sudden environmental changes or partial shading. The method known as perturb and observe can be mentioned as the most frequently used method for MPPT. It operates by perturbing the voltage or duty cycle and monitoring the change in the output power and if it increases, the controller continues its perturbation in the same direction while in the opposite case it changes the direction. Despite its simple algorithm, low cost of implementation, and applicability to digital controllers, this method is not without disadvantages. Continuous perturbation results in fluctuations around the maximum power point. In addition, fluctuations may be misinterpreted in case of fast changes of irradiance.
The method of Incremental Conductance (INC) allows to find the maximum power point by analyzing the both instantaneous and incremental values of conductance for photovoltaic arrays. The monitoring capabilities of the INC method allow to identify if the working point is located before/at/after the maximum power point. It has been proven that INC is better than P&O in terms of tracking performance during irradiance changes, but INC is much more complex in terms of control and the choice of sampling intervals and accuracy of measurement will affect overall performance [12]. The method of Hill Climbing (HC) also allows to find the maximum power point, since it makes use of constant change in the duty cycle or operating voltage of the system. The method of HC, similar to the P&O method, does not have to be complicated in terms of

applying and does not require very deep understanding of the PV system. Meanwhile, the method may have oscillations at steady states and the tracking accuracy would be poor in case of rapid changes of environmental situation. Another conventional approach is the constant-voltage method, which maintains the PV operating voltage near a predetermined reference value. Although this method is easy to implement, it cannot accurately follow MPP variations caused by temperature, irradiance, and aging of PV modules. Under partial-shading conditions**,** conventional MPPT methods face additional difficulties because multiple peaks can occur in the PV power-voltage characteristic. Basic P&O and INC algorithms may converge to a local maximum rather than the global maximum, reducing the amount of solar energy extracted. Therefore, several improved and hybrid conventional approaches have been developed to enhance global MPP detection [13].

For solar-powered EV charging stations, the selection of a conventional MPPT technique involves a trade-off between simplicity, tracking efficiency, dynamic response, and computational requirements. P&O remains attractive for cost-sensitive applications, while INC provides improved adaptability to changing operating conditions. Nevertheless, the limitations of conventional techniques have encouraged the development of intelligent MPPT methods capable of providing faster and more adaptive tracking under complex PV operating conditions.

V. AI-Driven MPPT Algorithms

MPPT algorithms that rely on artificial intelligence represent a new technological frontier when it comes to tracking methods and their application to maximum power extraction in solar cells. Unlike traditional tracking methods, AI-based systems can figure out the nonlinear dependence of PV operating conditions on maximum power. The intelligent controller receives information from parameters like PV voltage, current, irradiance, and temperature in order to create a correct signal for the converter.

Approaches based on artificial neural networks (ANNs) enable power management through trained neural models. The main advantage is the speed of response to environmental changes. ANNs are able to instantly determine the required operating point without having to go through many trials, although their performance highly depends on training data quality and requires advanced computing facilities. [14].

Fuzzy logic controller (FLC) based MPPT approaches utilize linguistic rules to decide the best control action based on the operating conditions of photovoltaic systems. Fuzzy logic controllers don’t depend on a precise mathematical model for the PV system and they provide robust performance under nonlinear and uncertain conditions. Adaptive fuzzy systems enhance the functionality of FLCs as they adjust the controller response in accordance with the changing operating environment.

Other AI-based approaches comprise such techniques as machine learning, Random Forest, adaptive neuro-fuzzy inference systems, reinforcement learning, and hybrid optimization methods that help improve tracking efficiency and decrease oscillations when conditions change rapidly. In addition, research efforts in this area combined AI-based MPPT with electric vehicle (EV) charging, battery storage, and energy management systems in order to determine the power generated from the sun and the charging requirements. In Table 1 below a comparison is made between conventional and AI techniques based on efficiency rates, speed of response, level of complexity, adaptability, and relevancy for solar energy stations used for charging EVs.

Table 1: Comparative Analysis Of Mppt Techniques For Ev Charging Stations

Ref.	System / Application	Method / Technique	MPPT / Control Strategy	Key Parameters / Focus	Major Findings / Contribution	Limitation / Research Gap
[7]	Solar-powered EV system	Hybrid AI	Hybrid AI-driven MPPT	PV power extraction, EV charging	Improved MPPT performance and charging efficiency under varying operating conditions.	Hybrid AI implementation may require higher computational resources.
[8]	Bifacial PV and battery-powered EV charging	Explainable AI	Adaptive fuzzy MPPT	MPPT, battery management, energy management	Integrated explainable AI with adaptive fuzzy control for intelligent PV and battery energy management.	Requires further validation under diverse real-time operating conditions.
[9]	Hybrid solar-powered EV charging station	Review of advanced technologies	Advanced MPPT and converter control	MPPT, converters, charging efficiency	Reviewed advanced MPPT and converter technologies for improving energy conversion and EV charging performance.	Provides review-level analysis rather than experimental validation of a new controller.
[10]	Hybrid solar-wind energy system	Artificial intelligence	AI-based MPPT	Solar-wind energy harvesting, off-grid operation	Demonstrated the potential of AI-based MPPT for	Focuses mainly on hybrid renewable generation

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					improved renewable-energy extraction in off-grid applications.	rather than EV charging.
[11]	Off-grid solar EV charging station	Artificial intelligence	AI-assisted MPPT with DAB converter	DAB converter, MPPT, EV charging	Applied AI-assisted optimization to converter control for improving solar-powered EV charging performance.	Further investigation is required for different charging loads and operating conditions.
[12]	Solar-powered DC fast-charging station	Neural Network and MPC	Neural-network-based MPPT	DC fast charging, converter control, PV generation	Combined neural-network MPPT with model predictive control for efficient PV power extraction and fast EV charging.	Neural-network training and real-time implementation increase system complexity.
[13]	Solar PV energy system	Machine learning	Random Forest MPPT	Irradiance, PV voltage/current, energy extraction	Developed an AI-driven Random Forest MPPT architecture for improved solar-energy extraction under variable conditions.	Computational requirements and real-time hardware implementation need further investigation.
[14]	IoT-enabled solar EV charging	Machine Learning and IoT	Intelligent performance analysis	IoT monitoring, charging	Demonstrated the application	Greater integration of real-time AI-

	station			performance, energy management	of machine learning for intelligent monitoring and performance assessment of solar EV charging systems.	based MPPT and predictive energy management is required.
[15]	EV battery management system	Fuzzy Logic and AEO	Intelligent battery control	Battery management, optimization, EV performance	Investigated fuzzy logic and optimization-based battery management for improved EV battery operation.	Primarily focuses on battery management rather than PV MPPT.
[16]	Solar PV systems	Conventional and AI techniques	Conventional and AI-based MPPT	MPPT efficiency, tracking performance	Compared conventional and AI-based MPPT techniques and highlighted the benefits of intelligent approaches.	Further application-specific evaluation for EV charging is needed.
[17]	Electric transportation	Energy-management techniques	Advanced energy management	Sustainable transportation, energy management	Reviewed emerging energy-management strategies and challenges associated with sustainable electric transportation.	Does not specifically develop an AI-based MPPT controller for PV-EV charging.

[18]	Hybrid renewable-energy systems	Solar-wind and green hydrogen	Renewable-energy management	Energy integration, hydrogen production	Investigated integration of solar and wind energy with green hydrogen systems for sustainable energy utilization.	Limited focus on direct EV charging and MPPT optimization.
[19]	Grid-connected solar PV	Hybrid ZOA-SNN	Intelligent inverter control	Multilevel inverter, grid integration, power quality	Developed a hybrid intelligent control technique for a 15-level inverter in a grid-connected PV system.	Primarily addresses inverter control rather than AI-based MPPT for EV charging.
[20]	Modern renewable power grid	Renewable energy and storage	Grid modernization and energy management	Renewable integration, storage, grid stability	Discussed renewable-energy integration, storage technologies, and modernization of future power grids.	Does not specifically address intelligent MPPT control for solar EV charging stations.

VI. Conclusion

The review emphasizes the significance of Maximum Power Point Tracking (MPPT) in enhancing solar power utilization and charging efficacy of electric vehicle (EV) charging systems. Traditional techniques such as Perturb and Observe, Incremental Conductance, and Hill Climbing are easy to implement and have low costs of computation but may be subject to oscillations, slow responses, and low level of precision when irradiance is quickly varying or during partial shading. AI-based techniques like neural networks, fuzzy logic, Random Forest and hybrid intelligent techniques enhance adaptability and speed by learning the nonlinear patterns of photovoltaic systems in such a way. Researchers should concentrate on developing lightweight AI models with high degree of efficiency that can work instantly, adaptive hybrid MPPT for partial shading purposes, and reinforcement-learning approaches for controlling constantly changing environments. Connections with advanced converters, battery infrastructures, IoT monitoring, and predictive energy management should be studied as well. Lastly, experiments have to be conducted in order to test MPPT systems in practice and confirm their reliability and efficiency.

References

[1] Gedam, Rohit, and Abhimanyu Kumar. "AI-Driven MPPT and Power Quality in Renewable Energy EV Charging Stations." 2026 3rd International Conference on Advancements and Key Challenges in Green Energy and Computing (AKGEC). IEEE, 2026.

[2] Manikandan, S., et al. "A Comprehensive Review of Hybrid Solar-Powered EV Charging Stations: Advanced MPPT and Converter Technologies." 2026 Second International Conference on Multi-Agent Systems for Collaborative Intelligence (ICMSCI). IEEE, 2026.

[3] Ananthasaravanan, N., and V. Megala. "IoT-Based Hybrid Power System with an AI-Driven MPPT Controller for Z-Source Boost Converters." Iranian Journal of Science and Technology, Transactions of Electrical Engineering 50.1 (2026): 551-571.

[4] Manikandan, T., G. Madhu Mitha, and S. Sharmila. "AI in Machine Learning-Based Optimization of Solar-Powered EV Charging Networks Using IoT: A Comprehensive Framework." AI-Driven Solutions for Solar Energy Efficiency, Irradiance Modeling, and PV Forecasting. IGI Global Scientific Publishing, 2026. 1-36.

[5] Senthil Kumar, C., et al. "Implementation of solar-powered DC fast charging stations for electric vehicles using neural network-based maximum power point tracking and model predictive control." Journal of the Chinese Institute of Engineers 49.1 (2026): 157-173.

[6] Rao, J. Viswanatha, et al. "A next-generation AI-driven random forest MPPT control architecture for solar energy extraction." Discover Energy (2026).

[7] Govindarajan, Vinothbabu, and Saravanakumar Raju. "Design & modelling of a hybrid AI-driven MPPT controller for electric vehicle." Results in Control and Optimization (2026): 100729.

[8] Tiwari, Vineet Kumar, et al. "Explainable AI-enabled adaptive fuzzy MPPT and energy management for bifacial PV and battery-powered electric vehicle charging system." Scientific Reports 16.1 (2026): 4813.

[9] Manikandan, S., et al. "A Comprehensive Review of Hybrid Solar-Powered EV Charging Stations: Advanced MPPT and Converter Technologies." 2026 Second International Conference on Multi-Agent Systems for Collaborative Intelligence (ICMSCI). IEEE, 2026.

[10] Eze, Val Hyginus Udoka. "AI-advanced MPPT for optimized hybrid solar-wind energy harvesting in off-grid rural electrification: Fabrication and performance modeling." KIU J. Sci. Eng. Technol 4 (2025): 262-282.

[11] Pal, Subhabrata, and Avik Bhattacharya. "Artificial intelligence assisted optimization control of dab converter in mppt-based off-grid solar ev charging station." 2025 IEEE 2nd International Conference on Green Industrial Electronics and Sustainable Technologies (GIEST). IEEE, 2025.

[12] Senthil Kumar, C., et al. "Implementation of solar-powered DC fast charging stations for electric vehicles using neural network-based maximum power point tracking and model predictive control." Journal of the Chinese Institute of Engineers 49.1 (2026): 157-173.

[13] Rao, J. Viswanatha, et al. "A next-generation AI-driven random forest MPPT control architecture for solar energy extraction." Discover Energy (2026).

[14] Uddin, Md Shihab, et al. "Machine learning-enhanced performance analysis of an iot-enabled solar ev charging station." 2026 5th International Conference on Electrical, Computer & Telecommunication Engineering (ICECTE). IEEE, 2026.

[15] Justin Raj, P., V. Vasan Prabhu, and V. Krishna Kumar. "Optimal battery management system utilized in electric vehicle using fuzzy logic controller (FLC) and artificial eco-system algorithm (AEO)." Cybernetics and Systems 55.5 (2024): 1230-1254.

[16] Khan, Malhar, et al. "Conventional and artificial intelligence based maximum power point tracking techniques for efficient solar power generation." Engineering Reports 6.12 (2024): e12963.

[17] Rahman, Tuhibur, et al. "Empowering fuel cell electric vehicles towards sustainable transportation: An analytical assessment, emerging energy management, key issues, and future research opportunities." World Electric Vehicle Journal 15.11 (2024): 484.

[18] Nnabuife, Somtochukwu Godfrey, et al. "Innovative strategies for combining solar and wind energy with green hydrogen systems." Applied Sciences 14.21 (2024): 9771.

[19] Anusuya, M., R. Geetha, and R. Ilango. "Design of a 15-level non-modular multilevel-inverter in a grid-connected solar PV system: a hybrid ZOA-SNN technique." IETE Journal of Research 70.2 (2024): 2120-2132.

[20] Ertugrul, Nesimi. Reinventing the Power Grid: Renewable Energy, Storage, and Grid Modernization. CRC Press, 2024.

[21] Fkirin, M.A.; Gowaly, Z.M.; Elsheikh, E.A. Dynamic Controller Design for Maximum Power Point Tracking Control for Solar Energy Systems. Technologies **2025**, 13, 71. https://doi.org/10.3390/technologies13020071