Vol 6, Issue 7, July 2026 www.ijesti.com E-ISSN: 2582-9734
International Journal of Engineering, Science, Technology and Innovation (IJESTI)

Machine Learning-Based Adaptive Power Tracking for Photovoltaic Systems

Dimpy Kumari
M. Tech in Electrical Power System, M.D.U Rohtak, Ganga Institute of Technology and Management, Jhajjar, Haryana.

Mr. Abhishake Jain
M.D.U Rohtak, Ganga Institute of Technology and Management, Jhajjar, Haryana.

Corresponding Author Email Id: manviraj418@gmail.com

ABSTRACT

The increasing adoption of photovoltaic (PV) systems has created a need for efficient control strategies to maximize energy extraction under dynamic environmental conditions. This study presents the development of a novel Maximum Power Point Tracking (MPPT) scheme for photovoltaic systems subjected to variations in solar irradiance, temperature, cloud movement, and partial shading conditions. The proposed MPPT controller was designed and evaluated using MATLAB/Simulink by integrating a PV model, DC–DC boost converter, and advanced control mechanism. The performance of the proposed method was compared with the conventional Incremental Conductance (INC) technique. Simulation results demonstrated that the proposed MPPT scheme achieved a maximum output power of 297.6 W with a tracking efficiency of 98.4%, faster settling time of 0.08 seconds, and reduced power ripple. The controller exhibited improved adaptability, voltage regulation, and converter stability under rapidly changing weather conditions. The developed approach provides an effective solution for enhancing PV system reliability and improving solar energy utilization in grid-connected, standalone, and renewable energy applications.

Keywords: *Photovoltaic System, Maximum Power Point Tracking, Dynamic Weather Conditions.*

1. INTRODUCTION

The growing demand for sustainable energy has increased the adoption of renewable technologies, particularly solar photovoltaic (PV) systems. PV technology converts solar radiation into electrical energy through semiconductor-based photovoltaic cells. However, PV performance is highly affected by environmental factors such as solar irradiance, temperature, cloud variations, and shading conditions. Due to nonlinear characteristics, PV systems operate at varying points on their power-voltage curve. The Maximum Power Point (MPP) changes continuously with environmental variations; therefore, efficient MPPT techniques are essential to maximize energy extraction, improve system efficiency, and ensure optimal utilization of solar energy resources.

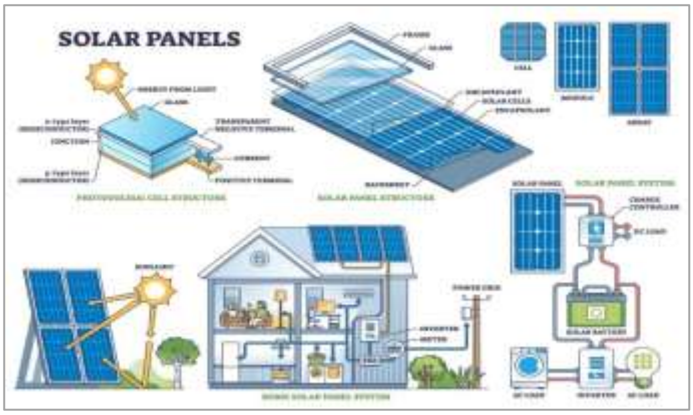


Fig. 1: Solar PV Modules (Solar Panels)

A complete photovoltaic (PV) system includes solar modules, mounting structures, wiring, inverters, charge controllers, storage systems, protection devices, and monitoring units. Solar modules generate DC electricity, while inverters convert it into AC power for practical applications. The MPPT controller optimizes energy extraction by continuously adjusting the operating point through a DC–DC converter. However, changing weather conditions such as fluctuating irradiance, temperature variations, and partial shading affect PV performance and shift the maximum power point. Therefore, advanced MPPT schemes are required to provide faster response, accurate tracking, reduced losses, and stable operation under dynamic environmental conditions.

1.1 Development of Conventional and Intelligent MPPT Techniques

Maximum Power Point Tracking (MPPT) techniques have developed significantly to enhance photovoltaic system efficiency and reliability. Early methods used simple voltage and current-based controls but showed limited performance under changing conditions. The Perturb and Observe (P&O) method became popular due to its simplicity and low cost; however, it suffers from oscillations around the maximum power point and inaccurate tracking during rapid weather changes. The Incremental Conductance (INC) method improved accuracy by using the slope of the power-voltage curve but required complex calculations. Both conventional techniques face limitations under dynamic conditions, encouraging the development of advanced MPPT approaches.

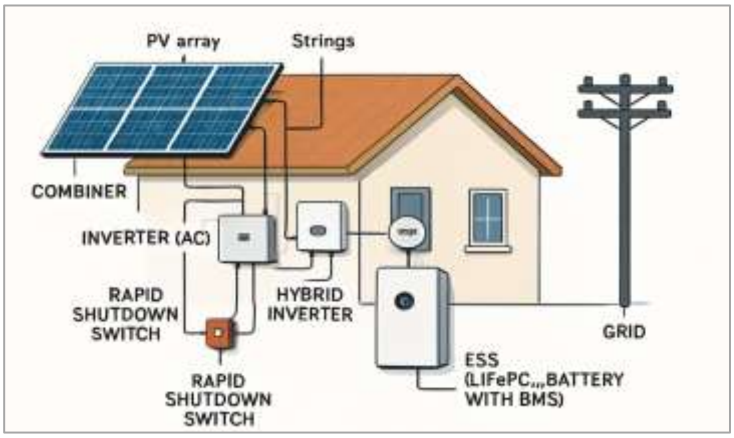


Fig. 2: Residential Hybrid Solar PV System with Energy Storage and Inverters

To overcome the limitations of conventional MPPT methods, advanced intelligent and optimization-based techniques have been developed. Artificial intelligence-based MPPT approaches improve performance by learning nonlinear PV characteristics and adapting to changing environmental conditions. Fuzzy Logic Control (FLC) provides faster response and reduced oscillations but requires expert rule development. Artificial Neural Network (ANN)-based methods accurately predict optimum operating points but need training data and higher computational resources. Optimization algorithms such as PSO, GA, GWO, and WOA effectively locate global maximum power points, especially under partial shading conditions. However, they involve greater computational complexity. Hybrid MPPT techniques, such as ANN-PSO and FLC-INC, combine advantages of multiple methods, offering improved accuracy, stability, and faster convergence. These advanced approaches enhance solar energy utilization and ensure reliable PV system operation under dynamic weather conditions.

1.2 Proposed Novel MPPT Scheme and Its Significance

The development of a novel MPPT scheme aims to overcome the limitations of conventional and existing intelligent tracking methods in photovoltaic systems. The proposed approach focuses on achieving efficient maximum power extraction under rapidly changing weather conditions by improving tracking speed, accuracy, stability, and reducing power losses. The controller continuously monitors PV parameters such as voltage, current, and output power to determine the operating condition relative to the maximum power point. Based on this analysis, appropriate switching signals are generated for the DC–DC converter to regulate voltage and current levels, ensuring operation near the optimal power region.

Dynamic weather variations, including sudden irradiance changes, temperature fluctuations, and partial shading, create complex operating conditions with multiple power peaks. Conventional MPPT methods may fail to identify the global maximum point, resulting in reduced energy generation. The proposed technique improves adaptability and search capability, enabling faster response and reliable operation under varying environmental conditions. The proposed MPPT method enhances PV system efficiency by maintaining operation close to the maximum power point, reducing steady-state oscillations, improving voltage regulation, and decreasing settling time. Its performance can be evaluated using MATLAB/Simulink simulations under different scenarios, including constant irradiation, variable irradiance, temperature changes, and partial shading conditions. Comparison with conventional P&O and INC techniques can be performed based on tracking efficiency, convergence speed, stability, and power losses. The advanced MPPT scheme supports applications such as grid-connected PV systems, standalone solar systems, EV charging stations, and hybrid renewable energy systems. Future integration with artificial intelligence, machine learning, IoT monitoring, and predictive control can further enhance PV system intelligence, reliability, and sustainability.

2. REVIEW OF LITERATURE

Manavaalan et al. (2026) had emphasized the importance of renewable energy adoption, particularly photovoltaic systems, for addressing sustainability and climate challenges. The study had proposed an ANN-ACO-based hybrid MPPT technique that improved tracking accuracy, voltage stability, and power quality. The proposed method had reduced limitations of conventional MPPT approaches and enhanced PV system reliability under varying conditions.

Fapi et al. (2024) had investigated advanced control strategies for solar energy conversion systems connected to DC bus applications. The study had introduced an FSCC-MPC-based MPPT approach for efficient energy harvesting. The proposed method had demonstrated simplicity, cost-effectiveness, and improved converter performance, making it suitable for smart-grid integration and photovoltaic systems operating under dynamic meteorological conditions.

Zaghba et al. (2023) had developed a fuzzy-PI-based MPPT controller for improving photovoltaic system performance under different climatic conditions. The study had compared fixed-angle and dual-axis solar tracking configurations using real-time climatic data from Algeria. Results had shown that dual-axis tracking significantly improved power generation, efficiency, and power quality compared with conventional fixed systems.

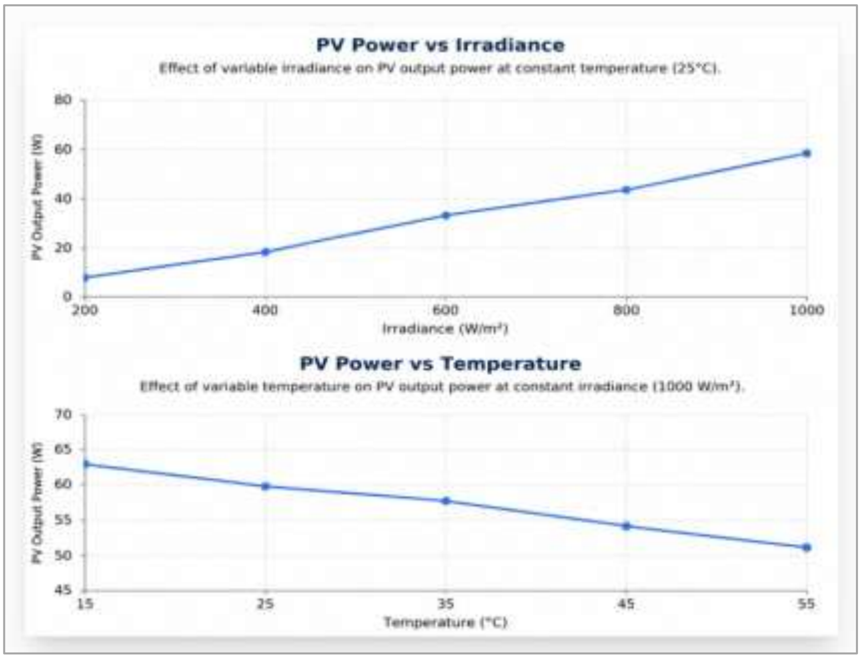
Almalaq et al. (2025) had proposed a sensor-based nonlinear MPPT controller for grid-connected photovoltaic systems exposed to rapidly changing weather conditions. The backstepping-based control strategy improved DC-link stability, power quality, and tracking speed. Simulation results using a 100 kW PV system had demonstrated reduced harmonic distortion, faster response, and superior performance compared with existing MPPT techniques.

Çelik et al. (2022) had focused on improving photovoltaic system performance under unpredictable atmospheric conditions. The study had proposed an advanced MPPT algorithm aimed at reducing oscillations, improving convergence speed, and increasing tracking efficiency. The proposed method had achieved reduced overshoot, faster transient response, and improved efficiency while maintaining lower control complexity and reliable operation.

Nkambule et al. (2021) had investigated machine learning-based MPPT techniques for photovoltaic systems under partial shading conditions. The study had evaluated nine ML-based algorithms through experimental analysis under different environmental conditions. The findings had demonstrated that machine learning approaches significantly improved maximum power extraction capability and provided a promising solution for enhancing PV system performance.

3. RESEARCH METHODOLOGY

The research methodology adopted in this study focused on the design, modelling, simulation, and evaluation of a novel Maximum Power Point Tracking (MPPT) scheme for photovoltaic (PV) systems operating under dynamic weather conditions. Since the power generation capability of photovoltaic systems varies significantly with solar irradiance and temperature, an efficient MPPT controller is required to continuously extract maximum available energy. The proposed methodology involved developing a mathematical PV model, designing an advanced MPPT control strategy, integrating the controller with a DC–DC converter, and comparing its performance with the conventional Incremental Conductance (INC) MPPT method. The research was based on a simulation-oriented approach, where the complete photovoltaic system was modelled mathematically to represent the real behaviour of solar cells under different environmental conditions. The PV system model consisted of a solar cell module, DC–DC converter, MPPT controller, and connected load. The research process included PV system development, analysis of electrical characteristics under different irradiance and temperature conditions, implementation of the proposed MPPT algorithm, integration with the converter system, and performance evaluation based on voltage, current, power output, tracking speed, and stability. The photovoltaic system was modelled using an equivalent electrical circuit consisting of a photo-current source, diode, series resistance, and shunt resistance. The mathematical model considered different parameters such as generated photocurrent, diode current, leakage current, reverse saturation current, open-circuit voltage, short-circuit current, and output power. These equations were used to generate the current-voltage (I–V) and power-voltage (P–V) characteristics of the PV module. The developed model helped in analysing the variation of PV output under different environmental conditions and identifying the maximum power operating region.



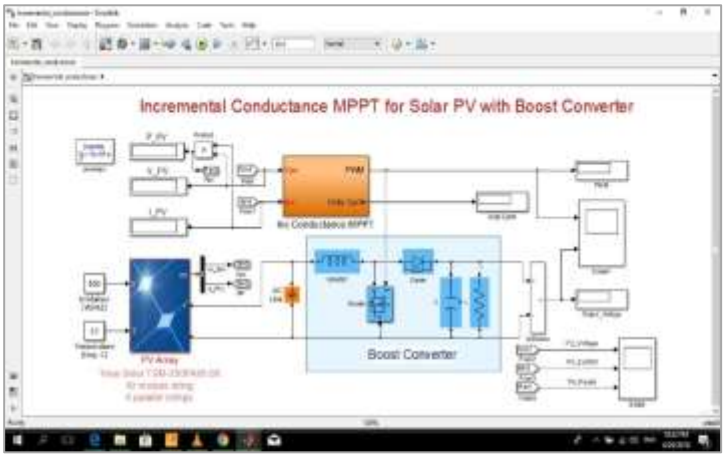
Solar irradiance and temperature were considered as the major environmental factors affecting PV performance. The increase in solar irradiation directly enhanced photo-generated current and increased the output power of the photovoltaic module. However, reduction in irradiation due to cloud movement or shading decreased current generation and power output. Similarly, temperature variations affected PV voltage and efficiency. Higher temperatures generally reduced the voltage output of PV modules, resulting in lower overall conversion efficiency. Due to continuous variations in these environmental parameters, the maximum power point of the PV system changed frequently, making dynamic MPPT control essential. The proposed MPPT scheme was developed to overcome the limitations of conventional tracking methods by improving tracking speed, reducing steady-state oscillations, and enhancing energy extraction capability. The controller continuously measured PV voltage and current values and calculated the corresponding output power. Based on the power variation, the MPPT controller adjusted the duty cycle of the DC–DC converter to maintain PV operation near the maximum power point. The duty cycle was continuously modified according to the change in operating conditions, allowing the system to respond effectively to sudden variations in solar irradiance and temperature. For performance comparison, the Incremental Conductance (INC) MPPT technique was implemented as a conventional reference method. The INC method determines the maximum power point based on the relationship between incremental conductance and instantaneous conductance. At the MPP, the slope of the power-voltage curve becomes zero, which provides the mathematical basis for tracking. Although INC provides better accuracy compared with traditional Perturb and Observe methods, it experiences limitations such as oscillation around the MPP and slower response during rapidly changing weather conditions.

A DC–DC boost converter was incorporated between the PV module and load to regulate the voltage and ensure efficient power transfer. The MPPT controller generated the required switching duty cycle for converter operation. By adjusting the duty cycle, the converter modified the voltage conversion ratio and allowed the PV system to operate at the optimum point. The converter therefore acted as an important component in improving energy harvesting efficiency and maintaining stable system performance. The complete PV system was implemented in MATLAB/Simulink for simulation and analysis. The simulation model consisted of PV modules, MPPT controller, DC–DC converter, load, and measurement blocks. Different irradiance and temperature variations were applied to examine the dynamic response of the proposed MPPT algorithm. The output parameters, including PV voltage, current, power, converter duty cycle, and ripple characteristics, were recorded and analysed. The same operating conditions were applied to the INC method for comparative evaluation. The simulation procedure involved developing the PV model, applying environmental input conditions, measuring voltage and current values, calculating PV output power, processing these parameters through the proposed MPPT algorithm, generating converter control signals, and analysing the resulting performance. The obtained results were compared with the INC method to evaluate improvements in tracking efficiency, convergence speed, power stability, and overall system reliability. This methodology provided a systematic framework for validating the effectiveness of the proposed MPPT scheme under dynamic weather conditions.

4. RESULT AND DISCUSSION

4.1 Simulation Model Development and PV System Performance Analysis

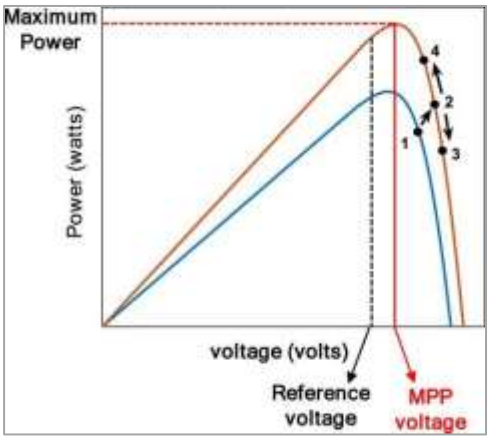
The results and discussion chapter presents the simulation outcomes of the developed Maximum Power Point Tracking (MPPT) scheme for photovoltaic (PV) systems under dynamic weather conditions. The performance evaluation was carried out using MATLAB/Simulink to analyse PV characteristics, converter response, voltage regulation, current variation, output power behaviour, and tracking efficiency. The proposed MPPT controller was compared with the conventional Incremental Conductance (INC) method to evaluate improvements in maximum power extraction, stability, and dynamic response.

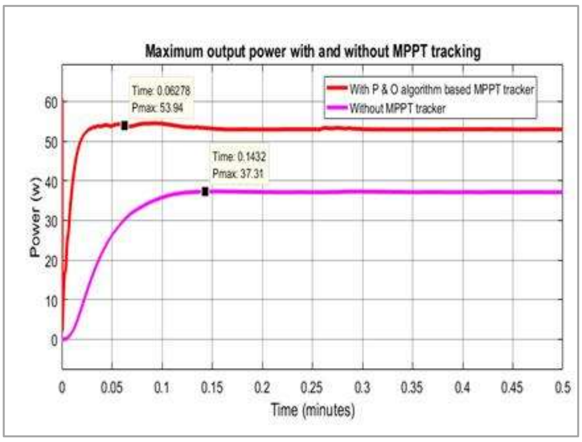


The developed PV-MPPT model included a photovoltaic source, MPPT controller, DC–DC boost converter, PWM switching unit, and measurement blocks to analyse system performance under practical operating conditions. The simulation was performed at 1000 W/m² irradiance and 25°C temperature with a 20 kHz switching frequency, 0.001 s sampling time, and 10 Ω load resistance. The PV model considered photocurrent, diode current, saturation current, series resistance, and shunt resistance to represent nonlinear PV behaviour. Under standard conditions, the PV module generated 21–24 V voltage, 2.4–2.5 A current, and approximately 50–60 W power. Results showed that increasing irradiance from 200 to 1000 W/m² increased current from 1.6 A to 8 A, while rising temperature from 20°C to 70°C reduced voltage from 31 V to 23 V. These variations confirmed the importance of an efficient MPPT controller for maintaining operation near the maximum power point.

4.2 Performance Evaluation and Comparative Analysis of Proposed MPPT Controller

The proposed MPPT controller was evaluated under different operating conditions to determine its effectiveness in extracting maximum power from the photovoltaic system. The controller continuously monitored PV voltage, current, and power signals and generated an optimized duty cycle for the DC–DC boost converter. The converter regulated the voltage and current levels to maintain stable operation near the maximum power point.

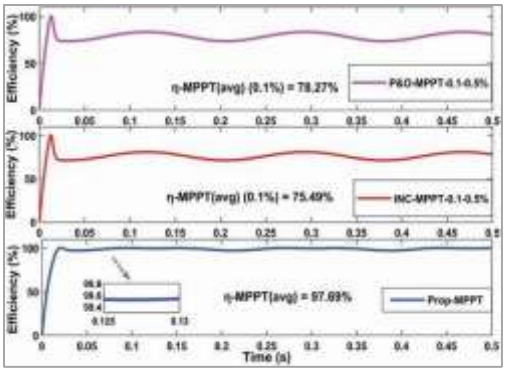




Under standard operating conditions, the proposed MPPT controller achieved an output voltage of 48–50 V and maximum power generation of 297.6 W with a tracking efficiency of 98.4%. The controller demonstrated a rapid settling time of 0.08 seconds and low power ripple of 1.8 W, indicating improved stability and reduced oscillations. Compared with the Incremental Conductance (INC) method, which achieved 285.2 W power, 94.8% efficiency, 0.16 seconds settling time, and higher ripple of 4.5 W, the proposed method showed superior performance. Under dynamic weather scenarios, including changing sunlight, cloud variations, heat waves, and monsoon recovery, the controller maintained efficiencies between 96.2% and 98.4%. The proposed MPPT scheme effectively adapted to environmental changes, restored maximum power extraction quickly, and provided better voltage regulation, tracking accuracy, and system reliability compared with conventional techniques.

4.3 Overall Findings and Significance of Proposed MPPT Scheme

The overall analysis demonstrated that the proposed MPPT technique significantly improved photovoltaic system performance under dynamic weather conditions. The developed controller successfully addressed the limitations of conventional MPPT methods by providing faster response, higher tracking efficiency, and improved system stability.



The comparative evaluation showed that the proposed MPPT controller achieved better performance than Incremental Conductance, PSO, GCSO, and ACO-based approaches. The extracted power values obtained using the proposed method were almost equal to the actual available PV power, with very small deviation. At 1000 W/m² irradiance and 25°C temperature, the proposed method achieved approximately 297.4 W compared with lower values obtained using PSO, GCSO, and ACO techniques.

The proposed controller maintained high tracking accuracy under different irradiance and temperature combinations. The efficiency remained within the range of 96.2% to 98.4% even under severe environmental variations. The low ripple characteristics and reduced oscillation level indicated improved converter stability and reliable operation.

The major findings of the study include:

1. The proposed MPPT controller increased PV output voltage from approximately 24–30 V to 48–50 V through efficient DC–DC boost converter operation.
2. The maximum output power achieved by the proposed method was 297.6 W, which was higher than the 285.2 W obtained using the Incremental Conductance method.
3. The tracking efficiency of the proposed controller reached 98.4%, demonstrating superior energy harvesting capability.
4. The proposed system achieved faster settling time of 0.08 seconds compared with 0.16 seconds for the conventional INC method.
5. Voltage ripple was reduced to approximately 0.5 V, while power ripple was maintained at only 1.8 W.
6. The controller demonstrated excellent adaptability under cloud movement, shading effects, temperature rise, and changing sunlight conditions.
7. The developed MATLAB/Simulink model successfully represented PV characteristics and provided a suitable platform for renewable energy system analysis.

The results confirm that the proposed MPPT scheme is highly suitable for practical photovoltaic applications, including grid-connected solar systems, standalone PV systems, solar-powered electric vehicle charging stations, and hybrid renewable energy systems. The improved tracking capability, reduced power losses, and stable operation make the proposed controller an effective solution for maximizing solar energy utilization under continuously changing environmental conditions.

5. CONCLUSION

The present study successfully developed a novel Maximum Power Point Tracking (MPPT) scheme for photovoltaic systems operating under dynamic weather conditions. The proposed controller effectively improved maximum power extraction by providing faster response, higher tracking accuracy, and reduced power fluctuations compared with the conventional Incremental Conductance method. Simulation results using MATLAB/Simulink demonstrated that the proposed MPPT achieved a maximum output power of 297.6 W with a tracking efficiency of 98.4%, while maintaining a lower settling time of 0.08 seconds and reduced power ripple. The controller showed excellent adaptability under varying irradiance, temperature changes, cloud movement, shading conditions, and other climatic variations. The developed approach enhanced voltage regulation, converter stability, and overall PV system reliability. Therefore, the proposed MPPT technique provides an efficient solution for grid-connected PV systems, standalone solar applications, and renewable energy-based power systems by maximizing solar energy utilization under continuously changing environmental conditions.

REFERENCES

1. Manavaalan, G., Thamatapu, E. R., Kumar, P. V., & Elango, S. (2026). A Novel Bat Algorithm-Optimized Quantum Neural Network-Based MPPT Techniques for Enhanced Photovoltaic in Grid Connected System Performance. *Journal of Circuits, Systems and Computers*, 2650017.
2. Almalaq, A., Annuk, A., Jin, T., & Mohamed, M. A. (2025). A reduced sensor-based efficient and robust MPPT nonlinear controller for grid-integrated photovoltaic energy systems operating under rapidly changing climatic conditions. *Scientific Reports*, *15*(1), 41473.
3. Fapi, C. B. N., Touré, M. L., Camara, M. B., & Dakyo, B. (2024, May). MPPT based fractional short-circuit current-model predictive control for PV system in real weather conditions for heat-pump applications. In *2024 International Conference on Intelligent Systems and Computer Vision (ISCV)* (pp. 1-6). IEEE.
4. Zaghba, L., Borni, A., Khennane, M., & Fezzani, A. (2023). Modeling and simulation of novel dynamic control strategy for grid-connected Solar Cell System under real outdoor weather conditions using Fuzzy–PI MPPT controller. *International Journal of Modelling and Simulation*, *43*(5), 549-558.
5. Çelik, Ö., Zor, K., Tan, A., & Teke, A. (2022). A novel gene expression programming-based MPPT technique for PV micro-inverter applications under fast-changing atmospheric conditions. *Solar Energy*, *239*, 268-282.
6. Nkambule, M. S., Hasan, A. N., Ali, A., Hong, J., & Geem, Z. W. (2021). Comprehensive evaluation of machine learning MPPT algorithms for a PV system under different weather conditions. *Journal of Electrical Engineering & Technology*, *16*(1), 411-427.