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Comparative Study of different Types of MPPT Algorithm for Efficient Battery Charging

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***Abstract*— The solar power generation plays a crucial role in energy generation in commercial and industrial areas, in order to get maximum boosted power from solar is a challenging task. There are different MPPT methods to harvest the peak power available from a solar panel such as perturb and observe (PO), Incremental conductance (Inc)this are traditional MPPT algorithms. The advanced MPPT algorithm are (ANN) artificial neural network and (PSO) practical swarm optimization which can perform better than traditional MPPT. This paper presents a comparative analysis of four widely used MPPT (Maximum Power Point Tracking) algorithms. Each algorithm is implemented and evaluated using MATLAB/Simulink under constant irradiance and temperature conditions. Simulation results show that while P&O and INC provide reliable performance with moderate accuracy and ANN provieds good performance than other MPPT methods.**

***Index Terms*— Maximum Power Point Tracking (MPPT), P&O, Incremental Conductance, ANN, PSO, MATLAB/Simulink, Solar Energy.**

I. INTRODUCTION

Sunlight can be harnessed as a renewable form of energy, which is easily available and it is most encouraging renewable energy sources because it is clean, widely available, and requires minimal maintenance. Among various renewable energy technologies, photovoltaic (PV) generation is a preferred choice due to its environmental and economic benefits. PV modules harness solar energy and convert it into direct current for electricity generation.[1]. However, since most electrical appliances and power grids operate on alternating current (AC), PV systems need power converters to convert DC to AC and ensure proper power delivery. One major challenge in photovoltaic systems, a discrepancy arises between the PV panel's power output and the load's requirements. When a panel is linked directly to a load, it does not always operate at its maximum efficiency.[1]

This issue is addressed using Maximum Power Point Tracking (MPPT) technology, which enables the PV system to operate at its optimal power point. The exact location of this Maximum Power Point (MPP) shifts based on factors such as varying sunlight intensity and temperature, making it difficult to determine in advance. Several MPPT methods have been developed to address this issue. The traditional methods like Perturb and observe and incremental conductance are having simplicity but have steady state oscillation disturbance and slower response under varying condition [2],[9]. The advance methods like Particle Swarm Optimization (PSO) and Artificial Neural Networks, have been introduced to improve tracking efficiency and response time [3], [8].

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The [3] showed that ANN has improved and enhanced adaptability and reduce power disturbance or fluctuations. Similarly, Koad and Zobaa [2] demonstrated that PSO is better than traditional methods in terms of accuracy. MPPT plays a crucial role for battery charging system . [4] compared several MPPT for charging battery and showed the INC offered better efficiency and stability,[7] also evaluated P&O, ANN, and fuzzy logic algorithms in a MATLAB-based simulation and concluded that ANN provided the most consistent results under variable irradiance. Motivated by these studies this paper presents a simulation based comparative study of four widely used MPPT P&O, INC, PSO, and ANN — implemented using MATLAB/Simulink. The goal is to evaluate their performance under standard conditions and identify the most efficient method for extracting power from PV modules.

II. METHODOLOGY

Solar panel produces fluctuating output power due to the change in environment conditions this further may affect to the loads connected to the PV panel. The MPPT (maximum power tracking) algorithms are implemented in order to generated stable output from the PV panel. The panel at standard temperature and irradiance is connected to boost converter, the MPPT algorithm is implemented in MATLAB function block, output of this is duty cycle which is given to MOSFET of the converter and workspace to store the data. The comparative study of traditional MPPT strategies that are P&O (Perturb and Observe) and INC (incremental conductance) algorithm is carried in MATLAB software.
The PSO (particle swarm optimization) MPPT algorithm is modified compare to the generic PSO algorithm and simulated in MATLAB, and these algorithms are compared with ANN (Artificial Neural Network) MPPT algorithm. As the ANN subset of AI, which is intended to produce stable and efficient output power compare to other three MPPT algorithm and in is suitable for real time application for solar panel to extract maximum power

A. System Block Diagram

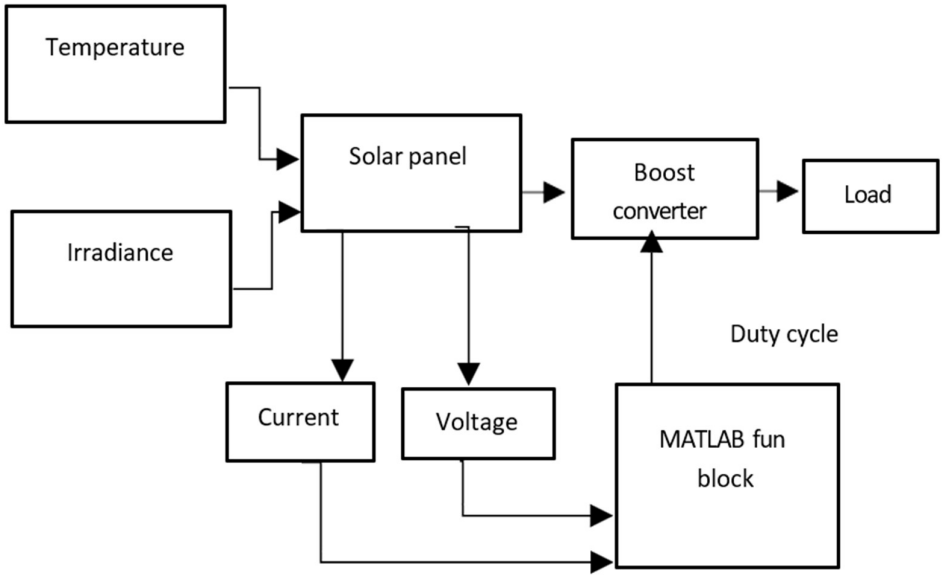

Figure 1 Simulation Block Diagram of PV System used for Comparing MPPT Algorithms

Figure 1 represents the block diagram used for simulating an MPPT system aimed at improving the use of solar energy in an efficient manner. The simulation model takes temperature and irradiance as inputs, which in turn influence the power generated by the solar PV. The electrical voltage and current of the panel are fed into a MATLAB function block where different MPPT algorithms are implemented. A comparative study is conducted between algorithms to determine the maximum power output that can be transferred. Hence, P&O algorithm, INC algorithm, PSO algorithm, and ANN algorithm were considered for output generation. Each algorithm works in such a manner that it determines the best duty cycle to ensure the panel operates at its maximum power point. The duty cycle is then sent to a boost converter. This setup is used to compare how efficiently each algorithm enables the solar energy system to deliver maximum power.

B. Solar Panel Specification

TABLE I: SOLAR PANEL SPECIFICATION

Characteristics	Valus
Maximum power	210 Watt
Voltage at MPP	21 Volts
Current at MPP	10Amps
PV Short Circuit Current	12Amps
PV Open circuit voltage	21 Volts
Temperature Coefficient Voc	-0.36099
Light generated Current	12.804
Diode Ideality factor	1.0529

III. MPPT ALGORITHMS

A. Traditional MPPT

The renewable energy source is used for power generation and other application, the renewable energy as different forms which are used for different types of application and it provides the benefit of eco-friendly, not effecting environment, no cause of pollution. Solar energy is type of renewable energy source which produce dc output and used for power generation and in industrial application. Solar PV Power changes due to the change in the environment conditions that are temperature, irradiance this effect the power output from the pv panel this fluctuation in power output from the pv cause damage to loads connected. The PO algorithm is the frequently employed for MPPT techniques for PV systems. It functions by making a small change to the PV module's voltage and monitoring the corresponding change in output power. If the power increases following a voltage change, the algorithm maintains the same adjustment direction; otherwise, it switches direction to keep in track the maximum power point more effectively.[1]Inc is intented to give better accuracy as shown in [4] and achieved higher power efficiency compared to another traditional methods.

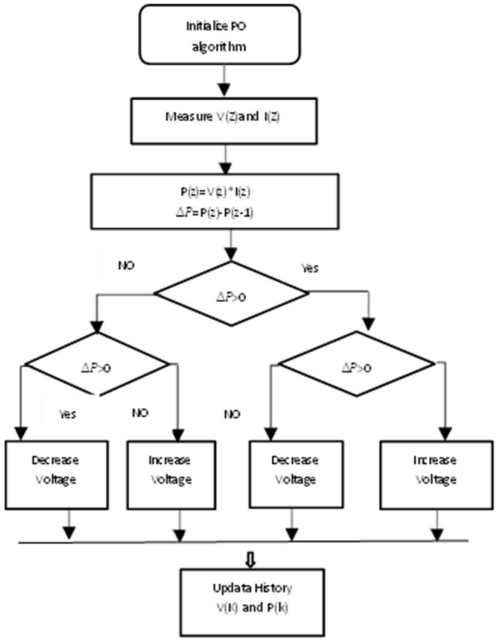

Figure 2 P&O flowchart

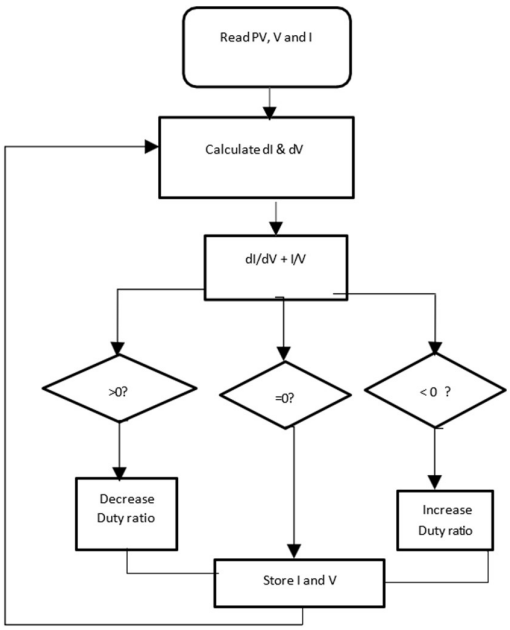

Figure 3 INC Flowchart

The Incremental Conductance (InC) algorithm is also a widely adopted MPPT method, known for addressing certain drawbacks of the Perturb and Observe (PO) approach, especially in scenarios with rapidly fluctuating solar irradiance. The InC method determines the direction of voltage adjustment by evaluating the difference between dI/dV and the ratio of current to voltage (I/V). When the incremental conductance equals the

instantaneous conductance (dI/dV = -I/V), the system reaches at the Maximum Power Point (MPP). If dI/dV is more than -I/V, the operating point is to the left of the MPP, requiring an increase in voltage. Conversely, if dI/dV is less than - I/V, the operating point is to the right of the MPP, necessitating a decrease in voltage. This approach enables the InC method to accurately track the MPP without continuous oscillations, unlike the P&O algorithm [1]

B. Modified PSO

The Normal PSO (particle swarm optimization) algorithm from [5] is slightly modified for batter performance and result from PV panel. The modified PSO algorithm shown in the flowchart differs from the standard PSO algorithm in several key aspects, particularly in its application to MPPT. In the basic PSO algorithm treats particles as candidate solutions that explore the search space by updating their positions based on velocity, which is updated.

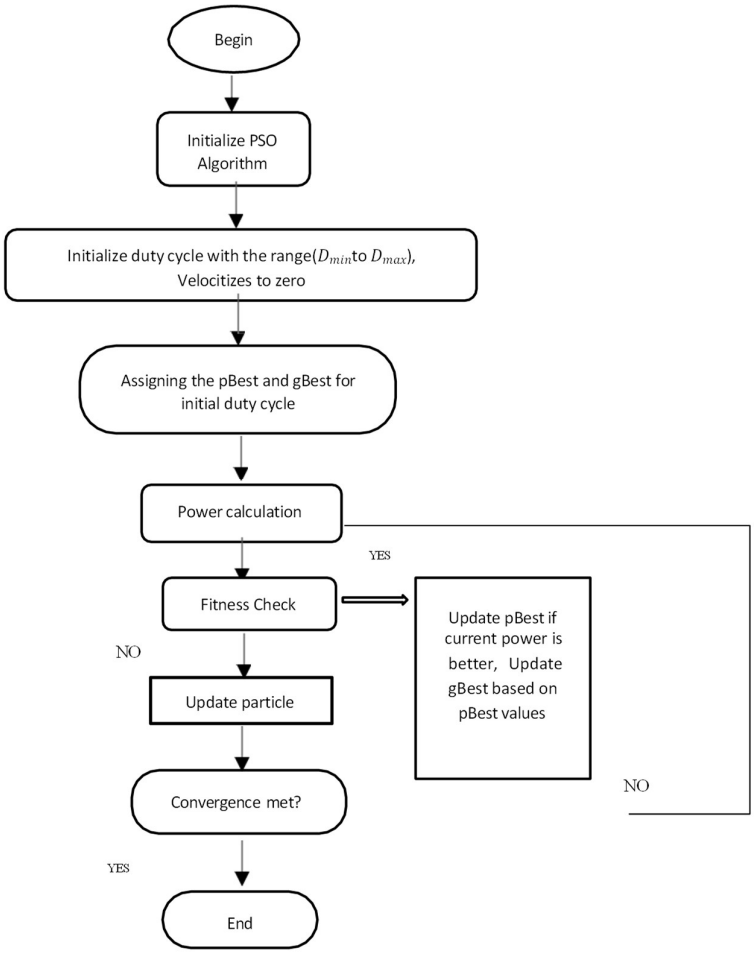

Figure 4 Modified PSO Flowchart

Using both individual (pBest) and global (gBest) best values. However, in the modified PSO, the particles represent different duty cycle values for the power converter, making the optimization problem more specific to power electronics. Instead of using a generalized velocity update, the modified PSO initializes velocities to zero, reducing unnecessary fluctuations and improving stability in tracking the MPP. Additionally, the fitness function in the modified PSO directly evaluates power levels to update pBest and gBest, streamlining the tracking process and avoiding unnecessary computations. The modified algorithm also includes a convergence check based on power, ensuring that once the MPP is reached, further oscillations are minimized. This modification slightly improves tracking speed and accuracy, with fewer steady-state oscillations, making it better suited for real-time MPPT than the standard PSO method.

C. ANN MPPT

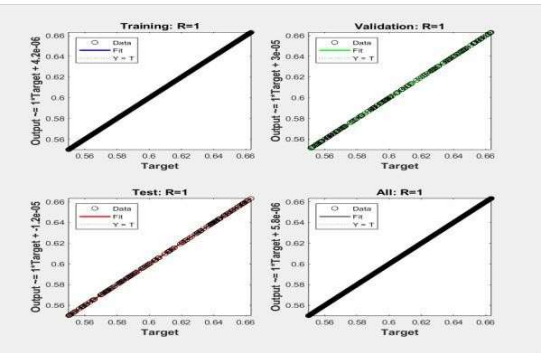

Figure 5 Regression plots

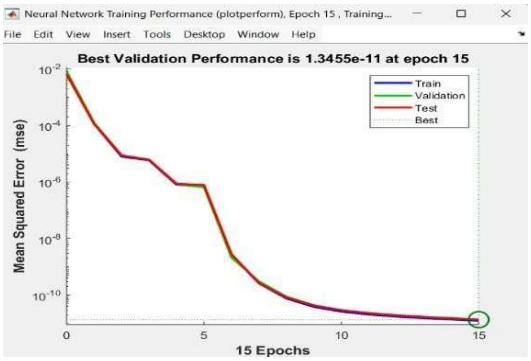

Figure 6Neural network training performance

ANN MPPT is based on neural network, the ANN structure as the different layers that are input layer, output layer and hidden layer. An Artificial Neural Network (ANN)-based Maximum Power Point Tracking system is an efficient control technique used to optimize power extraction from photovoltaic (PV) systems. Unlike traditional MPPT's methods ANN-MPPT learns from historical data and adapts to varying climatic conditions like solar irradiation and temperature. The input layer captures parameters like PV voltage, current, and sometimes irradiance or temperature. The hidden layers process this data using activation function, and the last layer generates the duty cycle for the power converter, ensuring maximum power transfer. By training the neural network with a dataset of PV characteristics, ANN-MPPT achieves faster tracking with reduced oscillations and improved efficiency under dynamic conditions. The structure of an ANN-MPPT system involves three key components: data acquisition, neural network processing, and control signal generation. The data acquisition unit collects real-time PV parameters using sensors. This data is fed into the trained ANN model, which performs pattern recognition and regression to predict the optimal duty cycle for the DC-DC converter. The trained network adapts to environmental changes, enabling better tracking performance even in rapidly changing conditions. Compared to traditional methods, ANN-based MPPT offers enhanced accuracy and robustness, making it suitable for complex and non-linear PV characteristics. However, the efficiency of ANN-MPPT relay on the actual training data, network architecture, and computational resources.[6] The Figure 4.4.2 represents the regression plots of an ANN model. The four subplots show the model's performance in Training, Validation, Testing, and Overall phases. Each plot also includes a small equation showing the relationship between the output and the target, with very small error values. This means the ANN model is providing almost exact predictions across all phases.

As shown in Figure 6, the network achieved a rapid and smooth convergence of mean squared error (MSE) across training, validation, and testing datasets. The best validation performance of 1.3455×10^{-11} was achieved at epoch 15, demonstrating the model's strong generalization ability and low prediction error. This confirms the suitability of the ANN for accurately estimating the maximum power point in solar PV systems.

IV. MATLAB SIMULATION AND RESULTS

A. TRADTIONAL MPPT simulation and results

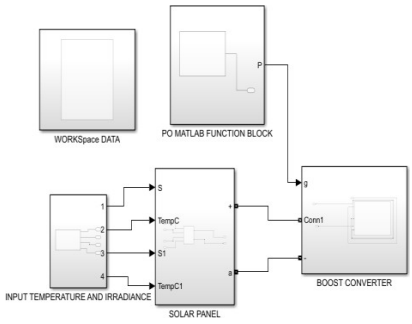

Figure 7 P&O Simulation

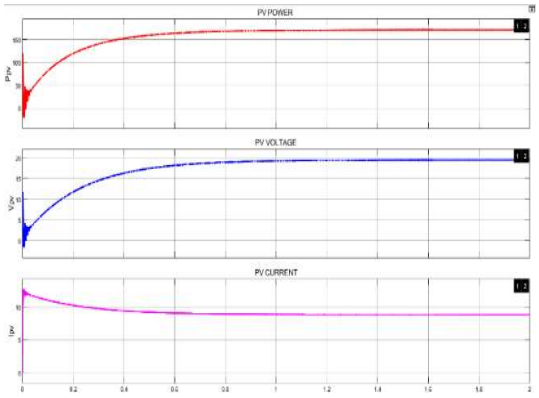

Figure 8 P&O simulation result

Simulation of four different algorithm is conducted in MATLAB Simulink; the solar panel connection is given to the boost converter, algorithm for MPPT is implemented in MATLAB function block as the output of MPPT is duty cycle or pulse which is given to the switch of boost converter. The solar panel is operated at a particular temperature and irradiance (25°C, 1000 W/m²) and the inputs of solar panel such as voltage and current is given to the MATLAB function block in which MPPT algorithm is implemented these inputs of solar panel is used to calculated the pwm duty cycle that is given to the switching element. MPPT is used to get a proper and efficient output from the solar panel in order to avoid the causes and effects due to irregular power supply that may cause damage to the components and device connected to panel.

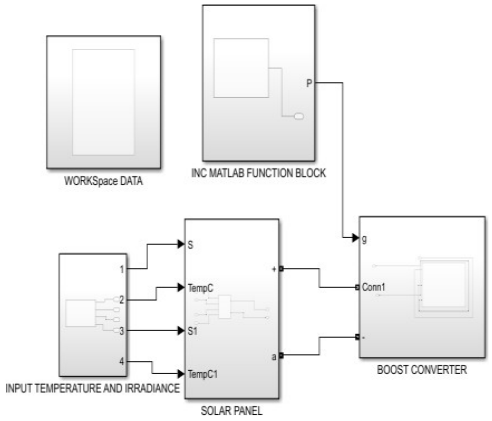

Figure 9 Inc simulation

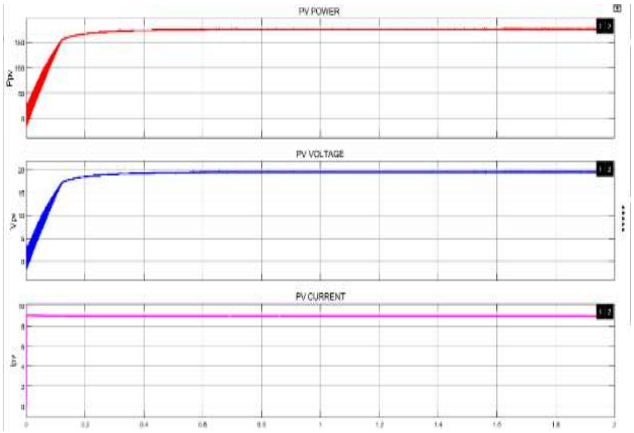

Figure 10 INC simulation result

B. PSO AND ANN MPPT Simulation and Results

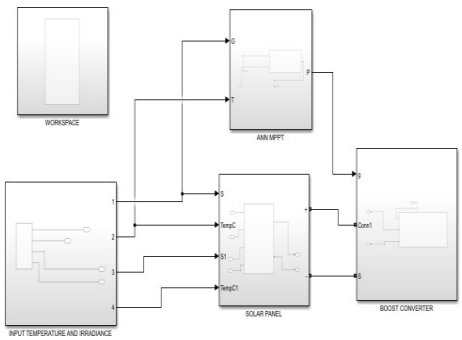

Figure 11 Modified Pso

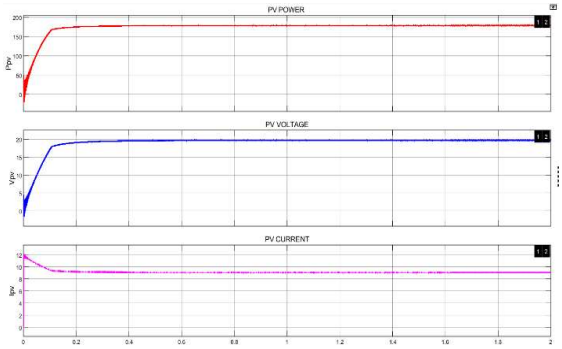

Figure 12 Pso simulation result

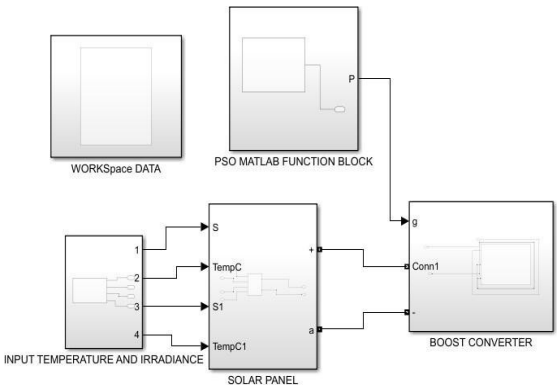

Figure 13 Ann simulation

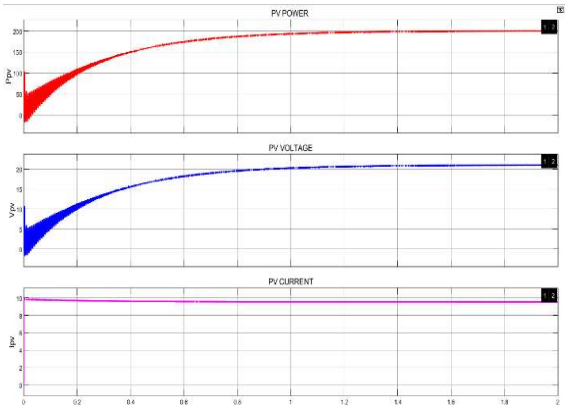

Figure 14 Ann simulation result

The Figure 7 shows the simulation of PO and figure 8 is PO simulation result in this pv voltage is shown in red line that is 170 watts and is having some oscillations, when see the figure 10 Inc simulation has less oscillation in power graph and has the power of 170 watts. The figure 11 shows the simulation result of PSO, in this power of 190 watts is generated and compare to Inc it is more efficient and other traditional methods the oscillations are also reduced, when compare to pv voltage that is maintained constant 20 volts, the current changes. The small change in current leads to change in the pv power for traditional methods and PSO.when compare to ANN simulation results from the figure 14 it achieved the power of 200 watts and voltage of 21volts and current of 9.5 amps that makes it give more pv power as it depends on the training of the data. The table 2 shows the comparsion of the pv power achieved for different mppt's from MATLAB simulation.

TABLE II: COMPARISON TABLE BASED ON SIMULATION RESULTS

MPPT Algorithm	PV Power (W)	Remarks
P&O	170	Simple, widely used
INC	170	Simple
Modified PSO	190	Slightly modified, efficient
ANN	200	Best performance overall

V. CONCLUSION

Simulation of various MPPT algorithms was successfully performed under Nominal testing environment (25°C, 1000 W/m²). While traditional methods like P&O, INC, and modified PSO delivered under 200 W, the ANN-based technique is efficient. This demonstrates the effectiveness of AI-based methods in enhancing MPPT efficiency. Future work can explore fuzzy logic, ANFIS, and machine learning to further boost adaptability and performance.

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