

Performance Comparison of MPPT algorithm using P&O, INC and ANN Based Tracking

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ABSTRACT

Introduction: The increasing demand for electricity underscores the necessity of renewable energy sources in enhancing electric grid stability, with solar and wind energy being prominent contributors. This study focuses on maximising solar power extraction through Maximum Power Point Tracking (MPPT) techniques. This research offers the comparative study of different MPPT algorithms with machine learning technique. To compare with machine learning technique this research has taken the prominent MPPT techniques of perturb and observe method and incremental conductance method. the above said two methods exhibits the higher volatile and oscillations in the peak point of power. To reduce the oscillations this research employs the higher adaptable Radial Basis Function (RBF) networks. These networks typically feature a single layer radial function, contributing to the versatility and adaptability of ANN in addressing complex tasks. The results are exhibiting the higher performance when compare to other techniques.

Objectives: Compare the Performance Maximum Power Point Tracking algorithm using P&O, INC and ANN Based Mechanism.

Conclusions: The simulation results highlight the superior performance of the ANN method in tracking the Maximum Power Point (MPP) under both rapidly changing and stable solar irradiation conditions. Its ability to quickly and accurately locate the MPP ensures optimal power extraction, outperforming the P&O and INC methods. While the P&O method demonstrates significant limitations, including poor performance under rapid irradiation changes and notable oscillations around the MPP under constant conditions, the INC algorithm shows moderate improvement. Although the INC method reduces oscillations compared to the P&O, it still incurs some power loss. Overall, the ANN approach emerges as the most reliable and efficient technique for maximizing power output in dynamic and steady solar environments.

Keywords: MPPT, P&O, PSO

I. INTRODUCTION

The rapid escalation in global electricity consumption has intensified the search for sustainable and efficient energy solutions [1][2][3][4]. As efforts to curb carbon emissions and address climate change intensify, renewable energy sources like solar and wind have become essential elements in the shift toward a more sustainable energy future [5][6][7]. Among these, solar energy stands out due to its abundance and the technological advancements that have made photovoltaic (PV) systems increasingly viable for widespread use [8]. Amidst the various drawbacks of PV systems, this research has taken on the challenge of achieving higher energy cultivation. The solution of reaching higher efficiency is maintaining the operating point PV system in maximum point [9]. MPPT is a critical technology developed to augment the efficiency of solar PV systems by continuously adjusting the electrical operating point to maintain the higher power harnessing [10]. The power voltage curve brings the higher power at certain point (MPP) and it always dependent of the irradiance and temperature of the solar panel. So operating the solar panel in the optimal point is essential, rather the system will lead to

loss of energy cultivation with consecutive reduced economic benefits. MPPT techniques, which rely on temperature and irradiance values, tuned automatically to reach the optimal point ie.MPP. Various MPPT algorithms have been developed to address the challenges to locate the optimal point of MPP with different conditions [11]. These algorithms range from simple, heuristic methods [12] to more sophisticated techniques like artificial intelligence [13] and machine learning. There are some fundamental methods to locate the MPP are Perturb and Observe (P&O) model [14], Incremental Conductance (INC) model, and in recent years the advanced methods of Artificial Neural Networks (ANN) and Particle Swarm Optimization (PSO)used[15][16][17][18]. In this study, we provide a comprehensive analysis of these MPPT algorithms, evaluating their performance across different operational scenarios and environmental conditions. By examining both traditional and cutting-edge approaches, we aim to enhance the understanding of MPPT technology and explore new opportunities for improving the efficiency and reliability of solar PV systems [19]. Our research specifically focuses on leveraging machine learning techniques to develop a data-driven MPPT algorithm that adapts to dynamic environmental conditions to enhance the energy cultivation [20].

II. SYSTEM DESCRIPTION

The investigative system comprises of power source of solar panel along with DC buck convertor and maximum power point tracking controller. The investigation is done by the resistive load. The schematic diagram of the investigative system is illustrated in figure 1. The power rating of the panel is 1200 W. As per the standard operating procedure the investigation is done under the nominal conditions of irradiance 1000 W/m² and the standard temperature of 25°C. The other parameter rating of the solar panel is given in table no 1.

Table 1: PV System parameters

Electrical Parameters	Value
Temperature coefficient of $V_{oc}(Kv)$	-0.291
MPP Voltage (V_{mpp})	60 V
Panel's Open circuit voltage (V_{oc})	66 V
Panel's Maximum power(P_{mpp})	1200 W
MPP Current at (I_{mpp})	20 A
Panel's Short circuit current (I_{sc})	25
I_{sc} Coefficient of Temperature (Ki)	0.013301

The sample PV curve of the solar panel is given in figure 2. The PV curve of a solar panel represents the relationship between its power output (P) and voltage (V). Under varying solar irradiance, the shape of the PV curve changes significantly. Higher irradiance levels result in increased power output and a steeper curve, while lower irradiance reduces the maximum power point (MPP). The MPP shifts along the curve depending on the irradiance, requiring precise tracking to optimize energy harvest. As irradiance decreases, both the short-circuit current and the maximum power diminish. Understanding these variations is crucial for designing efficient Maximum Power Point Tracking (MPPT) systems.

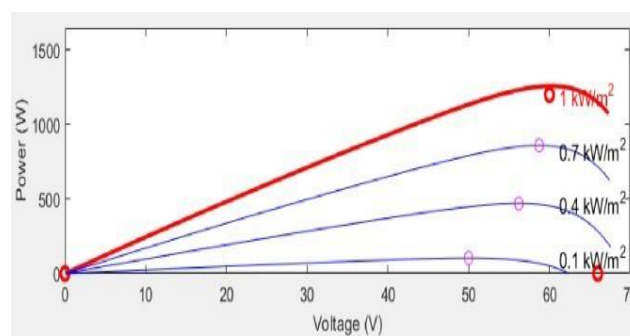


Fig. 1: Sample PV Characteristics of Solar Panel

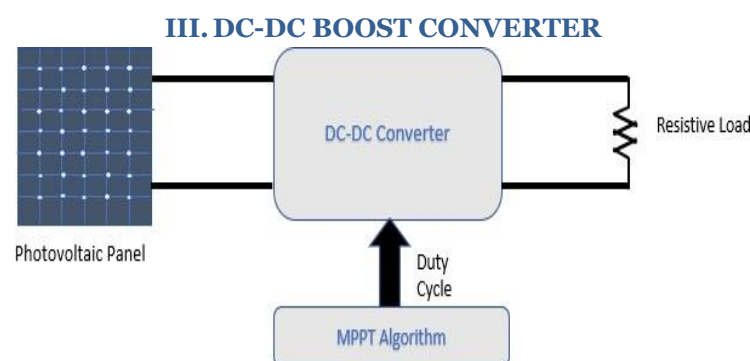


Fig. 2 DC-DC Boost Converter

The output of solar panel cannot be categorised in any of the specific form. But the waveform in DC nature with low voltage [21]. Since the output section requires higher voltage, it become necessary to convert the low voltage to higher voltage. The DC nature is not allowing the usage transformer to boost the voltage. So that power electronic converters are required and to boost the voltage boost converter is used in this research. These converters typically incorporate with switching devices such as IGBTs or MOSFETs, along with inductors and capacitors [22]. To switch the devices a standard Pulse Width Modulation (PWM) technique is used in this research [23]. And this signal controls the switching of these devices, allowing them to turn on and off as required as per maximum power point tracking (MPPT) systems. The simulation diagram of the boost converter is given in figure 3. The boost converter receives the input voltage form solar panel. The PWM controller produces the pulses to activate the operation of converter. The generation of control pulses is the key factor in this research [24]. The command of the generation of pulses is from various algorithms. As seen before this research deals with the pulse generation with P&O, IC and ANN methods.

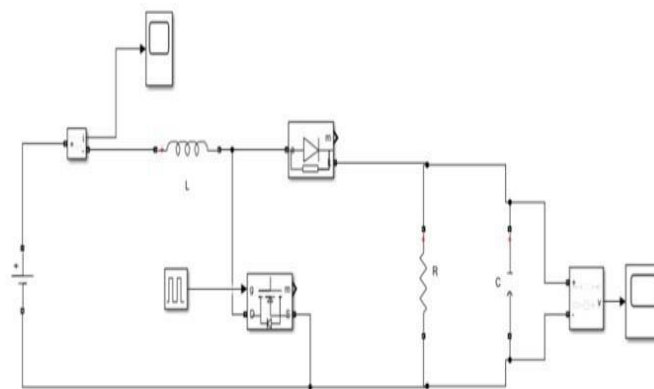


Fig 3: Simulation of DC-DC Boost Converter.

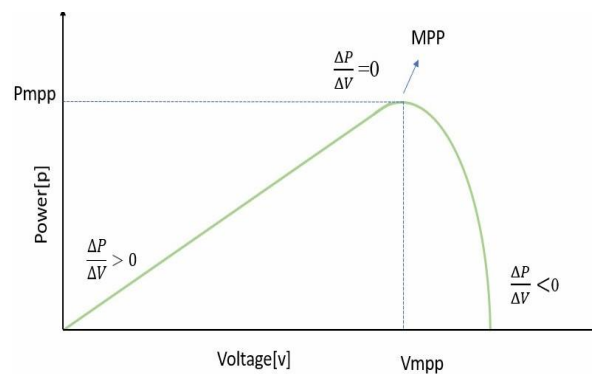


Fig 4: Behaviour of Solar Panel Indicating MPP

As the outcome this research aim to find the optimal point as per the figure 4. This research aims to assess which algorithm yields the best outcomes through this comparison. Additionally, we need to identify the most appropriate converter for MPP tracking, ensuring compatibility with the chosen algorithm and achieving high efficiency and accuracy in the operation of the solar PV system.

A. PERTURB AND OBSERVE(P&O)

P&O is one of the popular algorithm used in solar energy as MPPT as well as it is used in wind energy also[21]. It is having several advantages like cheaper to operate, higher effectiveness and sustainability under higher irradiance. But this algorithm is having certain disadvantages like limitations is high power operation, complex operation during multiple voltage peaks. Moreover it having partial operation during shading. Figure 5 shows the schematic diagram of P&O algorithm and its work [22][23]. The process is begin with the measurement of voltage and current from solar panel. Based these values the active power is calculated by multiplying two values. Then the algorithm locate the maximum power point by checking zero value of active power. The zero value denotes the attainment of MPP. If not the algorithm checks the sign of the voltage further. Positive sign means denote the location of MPP in left side otherwise right side. In summary, when the ratio of power to voltage is positive, the perturbation should be minimal, which indicates an increase in power generation. This approach allows the system to efficiently track and maintain the Maximum Power Point, optimizing the overall energy output of the PV system.

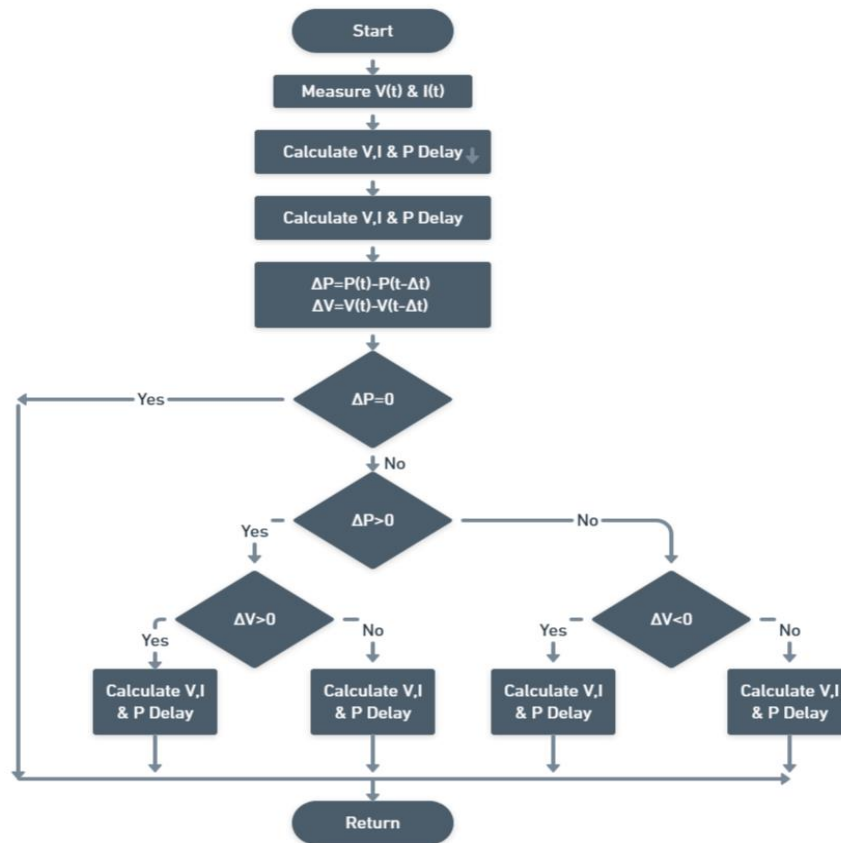


Fig 5: Flowchart of P&O Algorithm.

B. INCREMENTAL CONDUCTANCE (I&C)

The Incremental Conductance algorithm is the best suit algorithm for minor fluctuations of voltage and current. In addition to it this algorithm helps to predict the fore coming voltage changes[24]. The major drawback this system is higher computational when compare to other techniques. In addition to that, as like P&O method this method also creates more oscillations in output power. Unlike other methods, INC method examines the ratio of power to voltage by leveraging the ratio of current to voltage of solar panel. This method identify the MPP by continues monitoring the comparison of the incremental conductance of solar panel array and the conductance of solar panel[25]. The INC controller maintains the MPP even if the changes in the irradiance. The INC controller takes the input from current and voltage sensors. The execution of INC algorithm is depicted in schematic form in figure 6. The output power can be represented by the equation $P_{out} = V_{out} I_{out}$ succinctly reflecting how the INC method defines the source's output power. The equation $P = V \cdot I$ along with the chain rule for derivatives of products concerning voltage further supports this representation[26].

$$\Delta P / \Delta V = \Delta(VI) / (\Delta(V)) = I \Delta V / \Delta V + V \Delta I / \Delta V \quad \text{-----} > (1)$$

$$(1/V) \nabla P / \nabla V = I/V + \Delta I / \Delta V \quad \text{-----} > (2)$$

The sign of the exhibited voltage from the solar panel is always positive.

The output voltage from a source is generally positive. The prime objective of this method is to locate the voltage operating point where the conductance and incremental is same and equal. The slope of the PV curve of solar panel is very much crucial in INC algorithm. To the right of the maximum power point

(MPP), the slope is negative; to the left, it is positive; and at the MPP, the slope is zero. Below are the key equations that govern this algorithm:

$$\Delta P/\Delta V > 0 \text{ Left side of the MPP} \text{ -----} > (3)$$

$$\Delta P/\Delta V = 0 \text{ At the MPP} \text{ -----} > (4)$$

$$\Delta P/\Delta V < 0 \text{ Right side of the MPP} \text{ -----} > (5)$$

The immediate instantaneous conductance and the incremental conductance can be derived based on the following equations 6, 7 and 8.

$$\Delta I/\Delta V = (-I)/V \text{ At the MPP} \text{ -----} > (6)$$

$$\Delta I/\Delta V \geq (-I)/V \text{ Left side of the MPP} \text{ -----} > (7)$$

$$\Delta I/\Delta V \leq (-I)/V \text{ Right side of the MPP} \text{ -----} > (8)$$

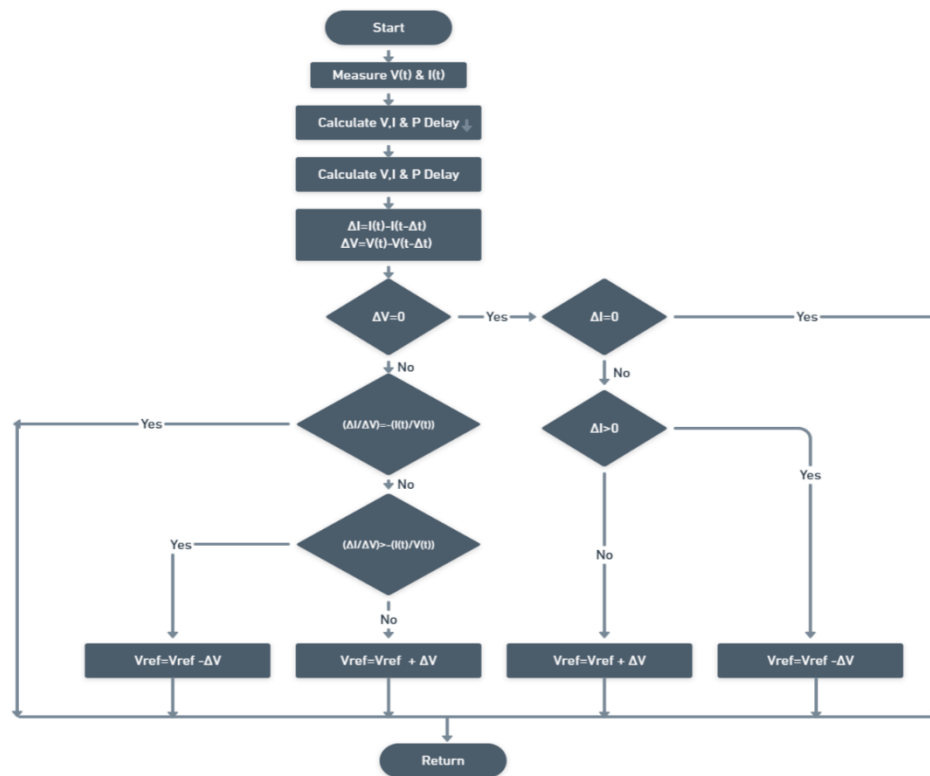


Fig 6: Flowchart of I&C Algorithm.

C. ARTIFICIAL NEURAL NETWORK (ANN)

This advanced Artificial Neural Network (ANN) offers a highly effective solution for tackling complex problems without requiring extensive system knowledge or mathematical modelling [27]. By accurately mapping input-output relationships, these ANN applications can handle intricate issues with ease. Leveraging its inherent learning mechanism and mimicking the biological structure of neurons, ANN serves as an advanced Maximum Power Point Tracking (MPPT) technique for intelligence based systems. Represented in its fundamental form as a directed graph, an ANN's nodes and edges correspond to neurons and synapses, respectively. Radial Basis Function (RBF) networks, a simple class of functions, can be employed within ANN architectures [28]. These networks typically feature a single

layer radial function, contributing to the versatility and adaptability of ANN in addressing complex tasks.

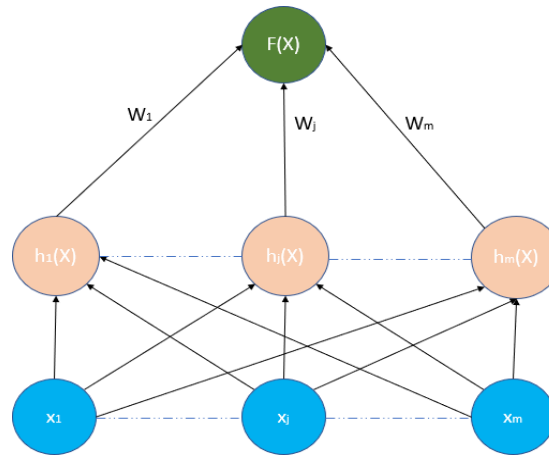


Fig 7: Basic formulation of ANN

$$f(X) = \sum_{j=1}^m w_j * h_j(X)$$

Moreover, $x_1, x_2, \dots, x_n$ are the n incoming signals, $w_1, w_2, \dots, w_m$ are the related synapse weights, and $h_j(X)$ represents the hidden layers in the whole network. Generally speaking, $f(X)$ is a nonlinear function composed of a hyperbolic tangent and log sigmoid that converts a linear function to a nonlinear function. Figure 7 shows the formulation of the ANN. A multi-layer feed-forward system contains the ANN, which has as its primary building components input, hidden, and output layers with three layers each. The characteristics of the PV module, such as VOC and ISC, environmental data such as irradiance and temperature, or any combination of these two, can be used as input to this technique. VMPP, V_{ref} , or GMPP will also be the output. The process is carried out at the crucial hidden layer by adjusting the weights and bias to estimate the best-targeted value or GMPP with the available input sets. Depending on the MPP, it will produce the D signal that powers the converter.

The learning process and ANN's structure determine how well this technology (ANN) can identify real GMPP. The probability that the P-V curve approaches the GMPP increases with the number of data sets (VPV, IPV) at which the P-V curve is evaluated. In contrast to previous methodologies, ANN neurons can process information in parallel. Weights are updated in accordance with the function used in the hidden layers. Additionally, all weights are reset, resulting in quick responses (faster in the process). The technique's accuracy, however, depends on the volume of data used. Figure 8 shows detailed implementation of ANN.

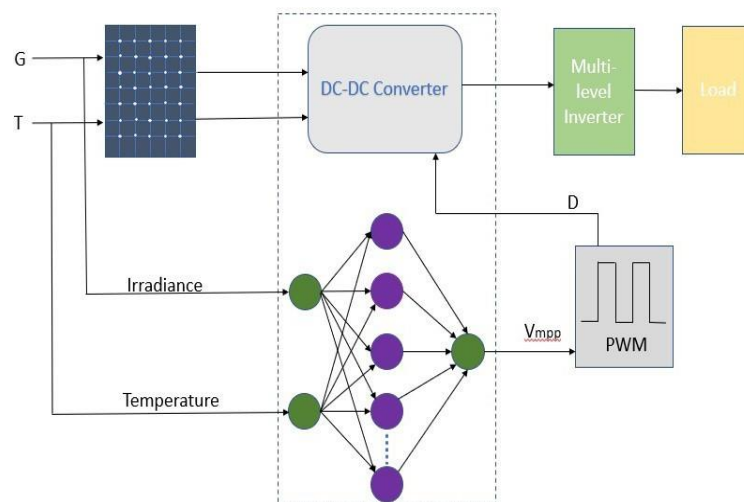
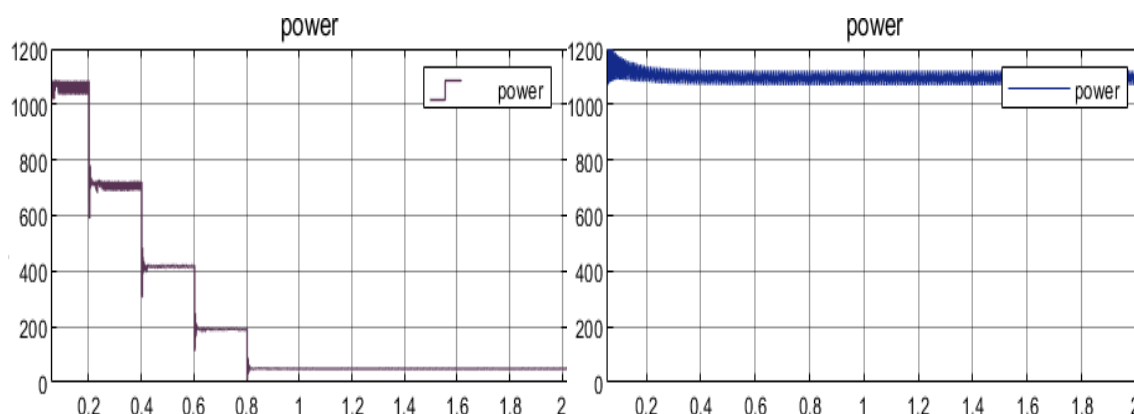


Fig 8: Development of ANN for MPPT

IV. COMPARISON OF ANN AND P&O METHOD UNDER VARIABLE IRRADIATION

Figure 10 presents a comparative analysis of the Perturb and Observe (P&O), Incremental Conductance (INC), and Artificial Neural Network (ANN) methods under conditions of constant irradiation. The P&O technique, while commonly used for its simplicity, demonstrates significant oscillations around the maximum power point (MPP), which result in notable power losses during steady-state operation. This drawback is particularly evident in scenarios requiring consistent energy output, as oscillations compromise overall efficiency. The INC method, offering a more refined tracking approach, reduces these oscillations to some extent but still falls short of achieving optimal stability. In contrast, the ANN method exhibits remarkable performance, with minimal oscillations and superior accuracy in tracking the MPP. This stability allows for enhanced energy harvesting efficiency, making the ANN approach highly suitable for conditions requiring precise and steady power output. The results underscore the limitations of traditional methods like P&O and highlight the potential of ANN-based algorithms for improving solar energy system performance.



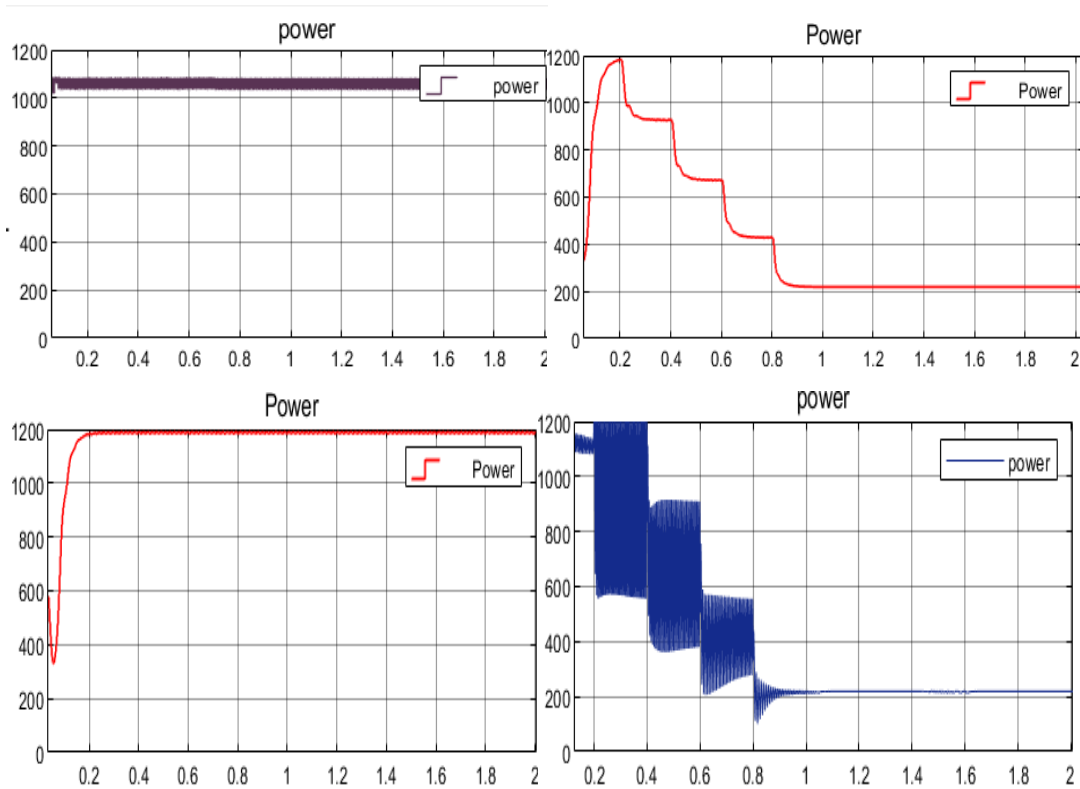


Fig. 9. Comparison of (a) P&O MPPT, (b) INC MPPT, and (c) ANN MPPT under Variable irradiation and constant temperature of 25°.

Fig. 10. Comparison of (a) P&O MPPT, (b) INC MPPT, and (c) ANN MPPT under constant irradiation and constant temperature of 25°.

V. COMPARISON OF ANN AND P&O METHOD UNDER VARIABLE IRRADIATION

The outcome of all the above methods are compared and we can inherit the higher performance from ANN method. To ensure the stability of the ANN system, analysis of system response under disturbance is required. The disturbance is created with the support of matlab disturbance function. The response of the disturbance is shown in figure no 11. Soon after introducing the disturbance the ANN algorithm system reaches to the stability to say in 0.1 second itself. This study infers that the ANN algorithms are more stable than P&O and INC algorithms

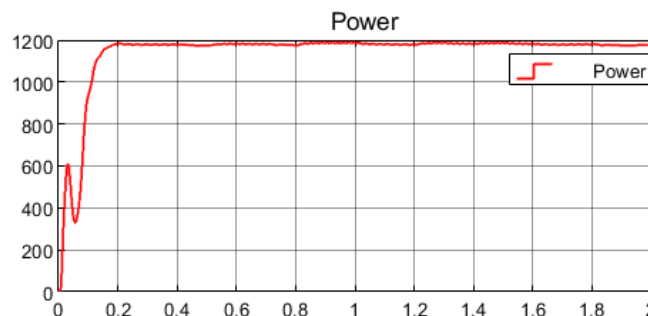


Fig. 11. ANN algorithm after adding disturbance at the input

VI. CONCLUSION

The simulation results highlight the superior performance of the ANN method in tracking the Maximum Power Point (MPP) under both rapidly changing and stable solar irradiation conditions. Its ability to quickly and accurately locate the MPP ensures optimal power extraction, outperforming the P&O and INC methods. While the P&O method demonstrates significant limitations, including poor performance under rapid irradiation changes and notable oscillations around the MPP under constant conditions, the INC algorithm shows moderate improvement. Although

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