

## PERFORMANCE ANALYSIS OF MPPT ALGORITHMS IN A GRID- CONNECTED SOLAR SYSTEM

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### ABSTRACT:

The growing need for sustainable energy solutions, combined with rising global electricity demand, has accelerated the development of solar photovoltaic (PV) systems. The efficiency of a PV system is closely tied to environmental factors such as solar irradiance and temperature, both of which fluctuate continuously throughout the day. These variations shift the operating point of PV modules away from their maximum power output, necessitating effective control strategies. Maximum Power Point Tracking (MPPT) algorithms address this challenge by dynamically adjusting the operating point of the PV array to ensure optimal power extraction under all conditions. In grid-connected solar systems, MPPT plays a pivotal role in sustaining both system efficiency and grid stability. This research examines and compares the performance of three widely employed MPPT techniques—Perturb and Observe (P&O), Incremental Conductance (INC), and Fuzzy Logic-based MPPT—within a grid-connected photovoltaic framework. The evaluation covers tracking accuracy, response speed, oscillation behaviour, and overall power delivery. The system was modelled and simulated using MATLAB/Simulink, and the results demonstrate that while conventional methods offer simplicity, intelligent algorithms such as Fuzzy Logic provide superior efficiency and stability. This study provides guidance for selecting the most appropriate MPPT method for practical grid-connected PV deployments.

**KEYWORDS:** *Maximum Power Point Tracking, Photovoltaic Systems, Grid-Connected Solar System, MPPT Algorithms, Renewable Energy, MATLAB/Simulink*

## I. INTRODUCTION

The rapid depletion of conventional fossil fuel reserves and their significant environmental impact have intensified global interest in renewable energy technologies. Among these, solar photovoltaic (PV) systems have emerged as a leading alternative, owing to their abundant resource base, scalability, and minimal environmental footprint. PV systems function by directly converting solar radiation into electrical energy through the photovoltaic effect, and their applications span residential, commercial, and utility-scale installations.

Grid-connected PV systems have gained considerable traction due to their ability to deliver generated electricity directly to the utility network, thereby supplementing conventional power sources and reducing dependency on carbon-intensive generation. A typical grid-connected PV system comprises solar panels, a DC-DC converter, an inverter, an MPPT controller, and grid interface components.

One of the fundamental challenges in PV system operation is the continuous variation of solar irradiance and ambient temperature throughout the day. These environmental changes directly influence the voltage and current characteristics of PV modules, causing the maximum power point (MPP) to shift continuously. The MPP refers to the specific operating condition at which the product of output voltage and current reaches its maximum, delivering peak power. Without an effective tracking mechanism, a PV system can operate far from this optimum point, resulting in significant energy losses.

MPPT algorithms are control strategies designed to continuously adjust the duty cycle of a DC-DC converter, thereby steering the PV array's operating point toward its MPP under varying environmental conditions. Conventional MPPT methods, such as Perturb and Observe (P&O) and Incremental Conductance (INC), are widely adopted owing to their simplicity and ease of implementation. However, these methods can suffer from oscillations around the MPP and sluggish response under rapidly changing irradiance. To overcome these limitations, intelligent approaches based on fuzzy logic, artificial neural networks, and optimization algorithms have been proposed.

This research investigates the performance of three MPPT algorithms—P&O, INC, and Fuzzy Logic—within a MATLAB/Simulink model of a grid-connected photovoltaic system. Each algorithm is assessed on the basis of tracking accuracy, response speed, oscillation magnitude, and power extraction capability under varying irradiance and temperature conditions. The

outcomes of this study serve as a practical reference for engineers and researchers seeking to optimize MPPT strategy selection in grid-tied solar applications.

## II. Literature Review

Research on MPPT algorithms for photovoltaic systems has evolved significantly over the past two decades. Early investigations concentrated on simple, easily implementable methods that could be deployed with minimal computational resources.

Al-Majidi, Abbod, and Al-Raweshidy [1] introduced a fuzzy logic-based MPPT technique for PV systems, combining fuzzy reasoning with the P&O principle to reduce oscillations and enhance tracking accuracy. Simulation results confirmed tracking efficiencies exceeding 99.6%, demonstrating the superiority of intelligent control over conventional methods.

Kumar and Sharma [2] proposed an enhanced INC- based MPPT technique for grid-connected PV systems. Their work demonstrated that a modified INC algorithm could achieve faster convergence and reduced steady-state error compared with the standard INC implementation, particularly under fluctuating atmospheric conditions.

Mallat et al. [3] explored an optimised Genetic Algorithm (GA)-based MPPT method for off-grid PV systems. The GA-based approach was shown to outperform conventional techniques in terms of convergence speed and tracking precision, indicating the potential of evolutionary algorithms for MPPT applications.

Sravankumar et al. [4] examined soft computing- based MPPT methods, demonstrating that adaptive and intelligent optimisation techniques could provide enhanced tracking performance over a broad range of environmental conditions compared with rule-based methods.

Soumana, Saulo, and Muriithi [5] conducted a comparative study of MPPT techniques with respect to their effect on Total Harmonic Distortion (THD) in grid-connected PV systems. Their findings established that the choice of MPPT method significantly influences grid power quality, highlighting the importance of algorithm selection in grid-integrated applications.

Ramjee, Kumar, and Rao [6] developed a single- phase grid-tied inverter with integrated MPPT functionality, demonstrating that efficient power transfer to the grid could be maintained through careful controller design and MPPT implementation. Sharma, Nigam, and Sharma [7] further analysed PV system behaviour using MPPT controllers in hybrid energy contexts, while Mochi [8] provided a comprehensive review of MPPT method selection and inverter sizing for grid- connected PV installations.

### Research Objectives

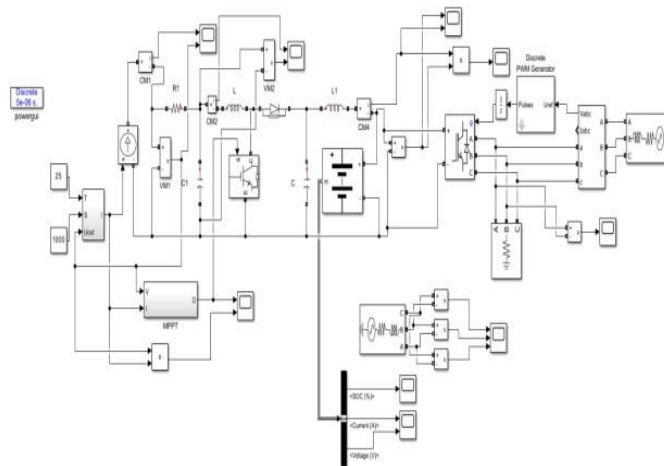
- To analyse the working principles of P&O, Incremental Conductance, and Fuzzy Logic MPPT algorithms.
- To evaluate algorithm performance within a grid-connected MATLAB/Simulink PV simulation.
- To compare tracking efficiency, response time, and steady-state stability across the three methods.
- To identify the most effective MPPT technique for maximising power extraction in grid-connected PV systems.

### A. Research Gap

Despite the extensive body of literature on MPPT techniques, comparative studies that specifically evaluate multiple algorithms within a grid-connected photovoltaic context—considering both steady-state and dynamic irradiance conditions—remain limited. Existing works often focus on isolated algorithm analysis or system configurations that do not account for grid interface dynamics. Furthermore, performance under rapidly changing environmental conditions requires deeper investigation to establish robust algorithm selection criteria.

### III. Methodology

The proposed methodology centres on the design, modelling, and simulation of a grid-connected solar photovoltaic system incorporating MPPT control. The system comprises a solar PV array, a DC-DC boost converter, an MPPT controller, a DC link capacitor, a three-phase voltage source inverter, and a grid/load interface. The entire architecture was implemented and tested using the MATLAB/Simulink simulation environment.



**Fig. 1: MATLAB/Simulink Simulation Model of the Grid-Connected PV System.**

**A. Solar PV Module Modelling**

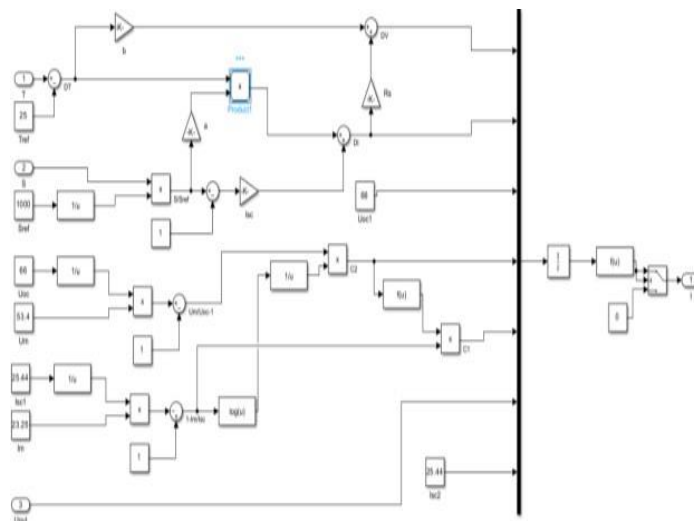
A solar PV cell converts incident sunlight into electrical energy through the photovoltaic effect. Its behaviour is represented by an equivalent circuit consisting of a photocurrent source, a diode, a series resistance, and a shunt resistance. The fundamental output current equation of the PV cell is:

$$I = I_{ph} - I_d$$

where I is the output current,  $I_{ph}$  is the photo-generated current, and  $I_d$  is the diode current governed by the Shockley equation. The photocurrent depends on solar irradiance (S) and cell temperature (T), while the diode saturation current is derived from the open-circuit voltage. The following solar module parameters were used in the simulation model:

**Table 1: Solar PV Module Parameters.**

Parameter	Value
Reference Temperature	25 °C
Reference Irradiance	1000 W/m <sup>2</sup>
Open Circuit Voltage (Voc)	66 V
Short Circuit Current (Isc)	25.44 A
Voltage at MPP	53.4 V
Current at MPP	23.25 A

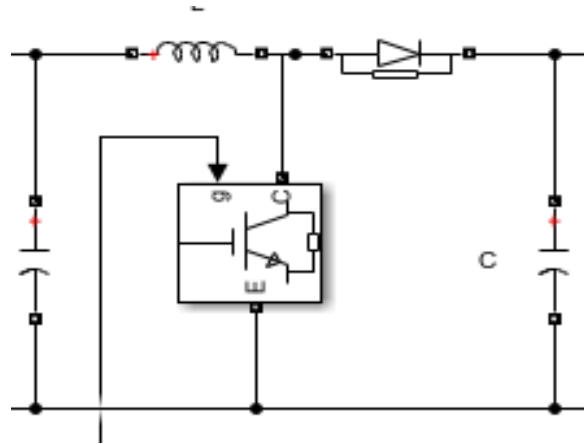


**Fig. 2: Solar PV Module Configuration in MATLAB/Simulink.**

**B. DC-DC Boost Converter**

A boost converter is employed to step up the PV panel output voltage to the required DC bus level. Operating in continuous conduction mode (CCM), the ideal voltage conversion relationship is given by  $V_o = V_{in} / (1 - D)$ , where  $V_o$  is the output voltage,  $V_{in}$  is the PV panel input voltage, and D is the duty cycle of the switching device. The MPPT controller

regulates  $D$  to maintain operation at the maximum power point. The converter's inductor and capacitor are dimensioned to minimise current ripple and output voltage ripple respectively.



*Fig. 3: DC-DC Boost Converter Topology.*

### C. MPPT Controller and Inverter

The MPPT controller continuously samples PV voltage and current, computes instantaneous power, and adjusts the converter duty cycle according to the chosen algorithm. The regulated DC output feeds a three-phase voltage source inverter (VSI), which converts the DC power to AC. Sinusoidal PWM techniques are used to generate gate signals for the inverter switches, ensuring synchronisation with the utility grid. A DC link capacitor stabilises the intermediate bus voltage and decouples the PV side dynamics from the inverter stage.

## IV. Analysis of MPPT Algorithms

Three MPPT algorithms are analysed in this study: Perturb and Observe (P&O), Incremental Conductance (INC), and Fuzzy Logic-based MPPT. Each is implemented within the MATLAB/Simulink grid-connected PV model and evaluated under varying irradiance and temperature conditions.

### A. Perturb and Observe (P&O) Algorithm

The Perturb and Observe method is among the most widely adopted MPPT techniques owing to its straightforward implementation. The algorithm introduces a small periodic perturbation to the PV operating voltage and monitors the consequent change in output power. If a voltage increase yields a power increase, the perturbation continues in the same direction; otherwise, it is reversed. This iterative process progressively drives the operating point toward the MPP.

The algorithm is defined by the condition  $dP/dV = 0$  at the MPP. For regions to the left of the MPP,  $dP/dV > 0$  (power increases with voltage), while to the right,  $dP/dV < 0$ . By comparing

current power  $P(k)$  with the previous sample  $P(k-1)$  and current voltage  $V(k)$  with  $V(k-1)$ , the duty cycle is adjusted accordingly.

Despite its simplicity, the P&O method has a notable drawback: it induces sustained oscillations around the MPP under steady-state conditions. Additionally, under rapidly changing irradiance, it may misinterpret power changes and momentarily steer the operating point in the wrong direction, causing transient power losses.

### B. Incremental Conductance (INC) Algorithm

The Incremental Conductance algorithm addresses the oscillation weakness of P&O by exploiting the mathematical relationship between incremental and instantaneous conductance at the MPP. Since  $P = V$

$\times I$ , differentiating with respect to  $V$  yields  $dP/dV = I + V(dI/dV)$ . At the MPP, this derivative equals zero, giving the fundamental INC condition:  $dI/dV = -I/V$ .

The algorithm evaluates three cases: when  $\Delta I/\Delta V$  equals  $-I/V$  the system is at the MPP and no adjustment is required; when  $\Delta I/\Delta V > -I/V$  the operating point lies to the left of the MPP and voltage must be increased; when  $\Delta I/\Delta V < -I/V$  the operating point is to the right and voltage must be reduced. This explicit determination of MPP position eliminates the need for continuous perturbation and substantially reduces steady-state oscillations. The INC method demonstrates superior tracking accuracy and faster dynamic response compared with P&O, particularly under rapidly varying irradiance, though it requires greater computational resources.

### C. Fuzzy Logic-Based MPPT Algorithm

Fuzzy Logic Control (FLC) is an intelligent control paradigm that uses linguistic variables and rule-based inference to manage system behaviour without requiring a precise mathematical model. The fuzzy MPPT controller employs two input variables: the error term  $E(k) = [P(k) - P(k-1)] / [V(k) - V(k-1)]$ , which represents the slope of the power-voltage curve, and the change in error  $\Delta E(k)$

$= E(k) - E(k-1)$ , which captures the rate of change of this slope.

The controller consists of three stages. In the fuzzification stage, the crisp numerical values of  $E$  and  $\Delta E$  are converted into fuzzy linguistic variables such as Negative Big (NB), Negative Small (NS), Zero (ZE), Positive Small (PS), and Positive Big (PB). The rule evaluation stage applies a set of IF- THEN rules that map combinations of input linguistic variables to the

appropriate change in duty cycle. Finally, the defuzzification stage— typically using the centroid method—converts the fuzzy output into a precise duty cycle adjustment value.

Fuzzy Logic MPPT offers several advantages over conventional methods: it handles the nonlinear characteristics of PV systems effectively, responds rapidly to environmental changes, and produces minimal oscillations around the MPP. However, it demands greater design expertise for membership function tuning and higher computational overhead compared with P&O.

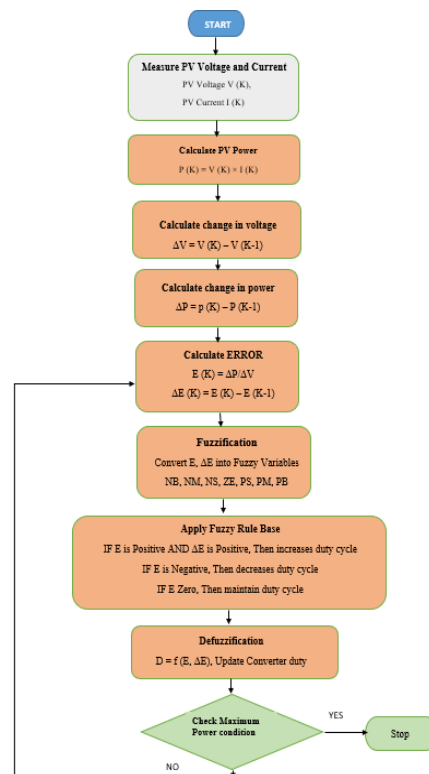


Fig. 6: Flowchart of the Fuzzy Logic-Based MPPT Algorithm.

## V. RESULTS AND DISCUSSIONS

### A. Perturb and Observe Method

#### A.1 PV Output Characteristics

The PV system output obtained using the P&O MPPT algorithm exhibits a brief transient response upon startup, after which the system converges to steady-state operation. As shown in Fig. 7, the PV current stabilises in the 9–10 A range and the voltage settle between 90 and 110 V. Nevertheless, small but persistent oscillations are visible in both waveforms even after steady-state is reached. These oscillations are an inherent consequence of the continuous perturbation applied by the P&O algorithm, which prevents the system from settling precisely at the MPP.

### ***A.2 Boost Converter Output***

The boost converter output voltage initially shows a slight overshoot associated with switching transients, before stabilising at approximately 450 V as illustrated in Fig. 8. While the DC link voltage is maintained near the target level, small ripples persist due to the continuous perturbation mechanism of the P&O controller. Despite these minor fluctuations, the converter successfully provides the required DC bus voltage throughout operation.

### ***A.3 Effect of Irradiance on System Performance***

Table 2 presents the measured PV and boost converter output parameters under varying irradiance conditions at different temperatures. As irradiance decreases from 1000 W/m<sup>2</sup> to lower levels, the PV output current drops noticeably, causing a corresponding reduction in output power. The boost converter output voltage remains nearly constant at 449–450 V across all irradiance levels, confirming stable DC link regulation. However, due to the P&O algorithm's oscillatory nature, slight power losses and instability are observed, particularly during irradiance transitions.

### ***A.4 Performance Summary***

- Fast initial transient response to reach steady-state operation.
- Persistent oscillations present around the MPP under steady-state conditions.
- Tracking accuracy lower than INC and Fuzzy Logic methods.
- Minor power losses result from continuous voltage perturbation.

## **B. Incremental Conductance Method**

### ***B.1 PV Output Characteristics***

The INC algorithm demonstrates markedly improved PV output behaviour compared with P&O. Following a brief startup transient, the system rapidly reaches steady-state, with the PV voltage stabilising in the 90–100 V range and current reaching 9–10 A at full irradiance (Fig. 9). Crucially, oscillations around the MPP are significantly reduced compared with the P&O method, as the INC algorithm explicitly determines the MPP location rather than relying on continuous perturbation. This leads to smoother waveforms and more stable power output.

### ***B.2 Boost Converter Output***

The boost converter output under INC control shows a minor overshoot during startup, followed by rapid stabilisation at approximately 449–450 V as shown in Fig. 10. The output voltage exhibits minimal ripple under all tested irradiance conditions, indicating efficient

voltage regulation and proper converter component design. This stable DC output benefits the downstream inverter and grid interface stages.

### ***B.3 Effect of Irradiance on System Performance***

Table 3 summarises the system response under varying irradiance and temperature conditions using the INC method. The data confirm a proportional relationship between irradiance and both output current and power, while the boost converter voltage remains nearly constant at 449– 450 V, demonstrating stable DC link regulation across the full irradiance range.

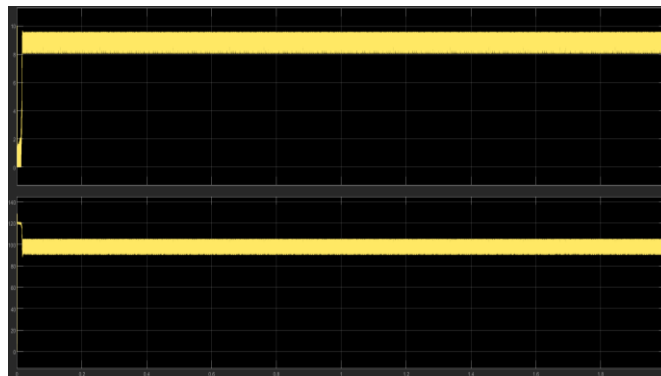
### ***B.4 Performance Summary***

- Rapid convergence to steady-state with minimal startup transient.
- Substantially reduced MPP oscillations compared with P&O.
- Higher tracking accuracy and improved dynamic response under changing irradiance.
- Stable voltage output and efficient energy conversion maintained throughout.

## **C. Fuzzy Logic MPPT Method**

### ***C.1 PV Output Characteristics***

The Fuzzy Logic MPPT controller produces the smoothest PV output characteristics among all three methods evaluated. The system exhibits a clean transient response at startup and converges rapidly to steady-state operation, with current stabilising at 9–10 A and voltage settling in the 90–110 V range (Fig. 11). The output waveforms are markedly smoother than those observed with either P&O or INC, with negligible ripple under steady-state conditions. The fuzzy controller's rule-based decision mechanism allows it to anticipate required duty cycle changes rather than relying on reactive perturbation, resulting in highly stable and efficient MPP tracking.



***Fig. 11: Solar PV Output Characteristics Using the Fuzzy Logic MPPT Method.***

### C.2 Boost Converter Output

The boost converter output under Fuzzy Logic control stabilises at approximately 450 V with very low ripple, as shown in Fig. 12. Compared with the P&O and INC methods, the Fuzzy Logic controller provides the most stable DC output, minimising voltage fluctuations across the DC link. This superior voltage regulation ensures efficient operation of both the inverter and grid interface components.



*Fig. 12: Boost Converter Output Voltage Using the Fuzzy Logic MPPT Method.*

### C.3 Effect of Irradiance on System Performance

Under varying irradiance conditions, the Fuzzy Logic controller adapts quickly and maintains efficient operation throughout. As shown in Table 4, output current and power scale proportionally with irradiance, while the boost converter voltage remains stable at 449–450 V. Importantly, unlike the P&O method, no significant oscillations are observed in the output parameters, even during irradiance transitions. The system demonstrates the most consistent and reliable performance across the full tested range of conditions.

*Table 4: Effect of Irradiance on Fuzzy Logic Method Performance*

### C.4 Performance Summary

- Very fast MPP tracking with minimal transient response time.
- Negligible oscillations around the MPP under all tested conditions.
- Smooth and stable output waveforms throughout operation.
- Superior efficiency compared with both P&O and INC methods.

## VI. CONCLUSION

This research presented a systematic performance evaluation of three MPPT algorithms—Perturb and Observe (P&O), Incremental Conductance (INC), and Fuzzy Logic—within a

MATLAB/Simulink model of a grid-connected photovoltaic system incorporating a DC-DC boost converter, a DC link capacitor, a three-phase VSI, and a grid interface. The simulation results demonstrate that all three methods successfully maintain a boosted DC link voltage of approximately 450 V, confirming correct converter and voltage regulation operation. The P&O algorithm, while easy to implement, exhibits persistent oscillations around the MPP, leading to measurable power losses and reduced tracking precision. The INC method improves upon P&O by reducing oscillations and providing more accurate

MPP tracking, particularly under dynamic irradiance conditions. The Fuzzy Logic MPPT controller achieves the best overall performance, delivering the smoothest output waveforms, the fastest convergence to the MPP, and the highest power extraction efficiency across all tested conditions.

Based on these findings, the Fuzzy Logic MPPT technique is recommended as the most suitable algorithm for grid-connected photovoltaic systems where high efficiency, stability, and robustness under varying environmental conditions are required. Future research directions include the exploration of hybrid MPPT strategies, deep learning-based controllers, and hardware-in-the-loop validation to further advance the performance and practical applicability of intelligent MPPT systems.

## REFERENCES

1. Al-Majidi, S. D., Abbod, M. F., & Al-Raweshidy, H. S. (2018). A novel maximum power point tracking technique based on fuzzy logic for photovoltaic systems. *International Journal of Hydrogen Energy*, 43(31), 14158–14171.
2. Kumar, M., & Sharma, K. C. (2025). An enhanced incremental conductance based MPPT technique for grid connected photovoltaic system. *IEEE*, 1–6.
3. Mallat, M., Kechiche, O. B. H. B., Ezzeddine, K., & Hamouda, M. (2023). An optimized genetic algorithm (GA)-based MPPT for off-grid solar photovoltaic system. *IEEE*.
4. Sravankumar, K., Ramireddy, K. V., Boddepalli, S. R., Chenniappan, S., Kumar, P., & Prasad, K. D. S. (2024). Soft computing techniques based MPPT for solar photovoltaic system. *IEEE*.
5. Soumana, R. A., Saulo, M. J., & Muriithi, C. M. (2022). Comparison of MPPT techniques on THD current in a grid-connected photovoltaic system. *IEEE*, 95–100.
6. Ramjee, T., Kumar, K. K., & Rao, S. C. K. (2025). Building a single-phase grid-tied inverter with maximum power point tracking (MPPT). *IEEE*, 1– 8.

7. Sharma, H., Nigam, A., & Sharma, K. K. (2023). Modeling & simulation analysis of solar PV system using MPPT controller for study of hybrid energy system. IEEE, 1–6.
8. Mochi, P. (2018). Primary review on MPPT method and size of grid connected solar photovoltaic inverter. IEEE, 20, 1–6.