Designing of Optimum Solar PV System with MPPT Techniques

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Abstract- In relation to photovoltaic (PV) systems, this work provides an extensive analysis of three well-known MPPT techniques: P&O, CV, and IC. Through the use of simulation circuits, IV and PV characteristics, and comprehensive output graphs, the paper investigates the effectiveness, stability, and suitability of every method. The goal of the study is to improve the overall performance of solar PV systems by clearly defining the ideal circumstances in which to apply each MPPT approach.

Keywords: *"MPPT, Photovoltaic Systems, Constant Voltage(CV), Incremental Conductance(IC), IV Characteristics, Perturb and Observe(P&O), PV Characteristics, Simulation."*

1.Introduction

The shift to renewable energy sources has become a critical goal for sustainable development as the world's energy consumption keeps rising. Photovoltaic (PV) systems have become a popular renewable energy technology because they can directly convert sunshine into electricity. PV systems reduce greenhouse gas emissions and reliance on fossil fuels greatly in addition to being scalable and versatile. The non-linear properties of the PV modules and the unpredictability of external elements like temperature and solar irradiation, however, are among the many factors that intrinsically restrict the efficiency of PV systems. These variables make it difficult to maintain operation at the MPP, the point at which the product of current and voltage is maximized, and the maximum power output is produced. They also cause the operating point of the PV modules to vary frequently. MPP approaches were created and are now commonly used to address this problem. Using dynamic operating point adjustments, MPPT algorithms enable PV systems to track the MPP as it varies over time. They guarantee that the PV system always runs at or close to maximum efficiency in this way, optimizing the amount of energy that is collected from the solar panels.

In order to assess these three MPPT approaches' performance under varied environmental conditions, this research aims to present a thorough comparison of each method. In order to determine the ideal circumstances for implementing each technique and to provide useful guidance for improving the design and performance of PV systems, this study will analyse important factors like convergence speed, stability, computing complexity, and overall efficiency. When aiming to optimize the performance of photovoltaic installations for residential, commercial, or utility-scale purposes, engineers and designers must be aware of the advantages and disadvantages of each MPPT approach. With its guidance on which MPPT approach is most suited for a given system given its requirements and operating conditions, this work adds to the increasing corpus of knowledge about solar energy research.

MPPT Techniques:

2.1 P&O Technique:

Because of its simplicity and ease of application, the P&O Technique is one of the most widely used MPPT approaches. This method modifies the PV module's operating voltage and tracks the change in power that occurs. The perturbation proceeds in the same direction if the power grows; the direction changes if the power falls. Under steady-state conditions, however, the P&O technique has a tendency to oscillation about the MPP, which might result in power losses.

Iteratively modifying the PV module's operating point and tracking the ensuing changes in power production are two of the most popular strategies for optimizing power output in solar systems. This technique is predicated on the idea that minute variations in the operating voltage can be utilized to detect changes in the power output.

A small voltage adjustment is made to the PV module to start the process. The algorithm keeps adjusting the voltage in the same direction if this disturbance results in a rise in power, which moves the operating point closer to the MPP. On the other hand, if the disturbance causes the power to drop, the algorithm reverses the direction of the change and shifts the operating point away from the initial configuration.

This strategy is very well-liked because it is straightforward and simple to use. Due to its simplicity and lack of need for intricate calculations or in-depth understanding of the features of the PV module, it is a well-liked option for a variety of PV systems, ranging from modest residential installations to more expansive commercial setups. Because of its simplicity, the approach can be quickly and simply integrated with current systems with little to no changes.

But even with its benefits, this strategy has certain built-in drawbacks. Its tendency to cause the operating point to oscillate around the MPP, especially in steady-state settings, is one of the main problems. tiny but cumulative losses in energy efficiency may arise from this oscillation's tiny but continual departures from the true MPP. Furthermore, the technique may be less successful in situations where the environment is changing quickly, such as abrupt changes in irradiance brought on by passing clouds. Under such circumstances, the algorithm can find it difficult to follow the fluctuating MPP, which could result in brief discrepancies between the ideal power point and the operational point of the PV module.

Furthermore, this approach operates on a trial-and-error basis, meaning it does not inherently possess predictive capabilities. It adjusts the operating point based solely on the immediate outcome of the previous perturbation, rather than anticipating future changes in environmental conditions. As a result, while it can achieve satisfactory performance in relatively stable environments, its effectiveness may be diminished in more dynamic settings where environmental variables fluctuate frequently.

2.2 ALGORITHM

STEP 1- Initialize values for operating voltage and current.

STEP 2- Calculate the power from initialized values.

STEP 3- Measure the initial voltage(V) and current(I).

STEP 4- Calculate initial power(P).

STEP 5- Perturb the voltage.

STEP 6- Measure new voltage and new current.

STEP 7- Calculate new power.

STEP 8- Compare new and old power.

STEP 9- Adjust voltage based on power comparison.

STEP 10- Update values.

STEP 11- Repeat the process.

2.3 P&O SIMULATION

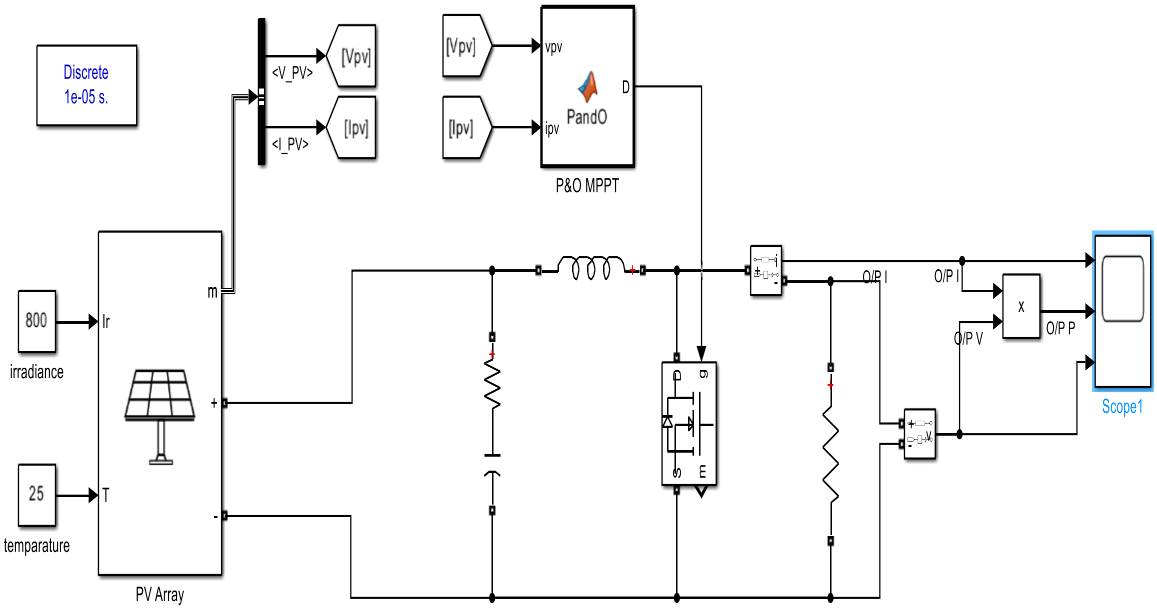

Figure 1 Simulation circuit of P&0 MPPT technique.

3. Constant Voltage Technique:

The Constant Voltage (CV) method maintains the PV module's voltage at a constant value, typically a fixed percentage of the V_{oc}. This method assumes that the MPP voltage is roughly constant and can be estimated as a fraction of V_{oc}. While straightforward and less computationally intensive, the CV method may not always track the true MPP, particularly under varying environmental conditions.

Another common approach to tracking the MPP in photovoltaic systems is based on the assumption that the optimal operating voltage remains relatively constant under varying environmental conditions. This method simplifies the task of maximizing power by keeping the PV module's voltage at a fixed level, which is typically chosen as a percentage of the V_{oc}.

In practice, this approach operates by continuously maintaining the operating voltage near a predefined set point, which is determined based on either previous experience or initial calculations of the module's behaviour. The assumption is that the voltage corresponding to the MPP does not vary significantly, even as irradiance and temperature conditions change. This assumption is particularly useful in systems where frequent fluctuations in environmental factors are minimal, allowing the system to operate efficiently with minimal adjustments.

One of the major advantages of this method is its simplicity. It eliminates the need for continuous adjustments or complex algorithms, as the voltage is held constant without requiring extensive real-time monitoring of the power output. This results in a lower computational burden, making it an attractive choice for PV systems with limited processing capabilities or in applications where simplicity is prioritized.

There are restrictions associated with this approach, though. It is predicated on the idea that the voltage and maximum power relationship is constant, which isn't necessarily the case. In actuality, variations in temperature or irradiance might cause the MPP to move, and in those cases, the fixed voltage set point might no longer match the true MPP. As a result, this method might not be able to get the most power out of the PV module, particularly in dynamic environments where things change regularly during the day.

This method is typically most effective in stable environments where irradiance and temperature changes are gradual or predictable. For instance, in regions with consistently clear skies or controlled settings, the variation in MPP voltage may be minimal, making this technique efficient enough to maintain reasonable performance. Additionally, in systems where computational resources are scarce or the cost of implementing more complex MPPT techniques is prohibitive, this approach offers a practical balance between simplicity and acceptable power output.

3.1 ALGORITHM

STEP 1- Set the reference voltage V_{ref} value.

STEP 2- Initialize the duty cycle.

STEP 3- Measure V_{pv} and I_{pv}

STEP 4- Compare V_{pv} with V_{ref}.

STEP 5- Adjust duty cycle

- Decrease if $V_{pv} > V_{ref}$
- Increase if $V_{pv} < V_{ref}$

STEP 6- Repeat steps 3 to 5 continuously.

3.2 CV SIMULATION

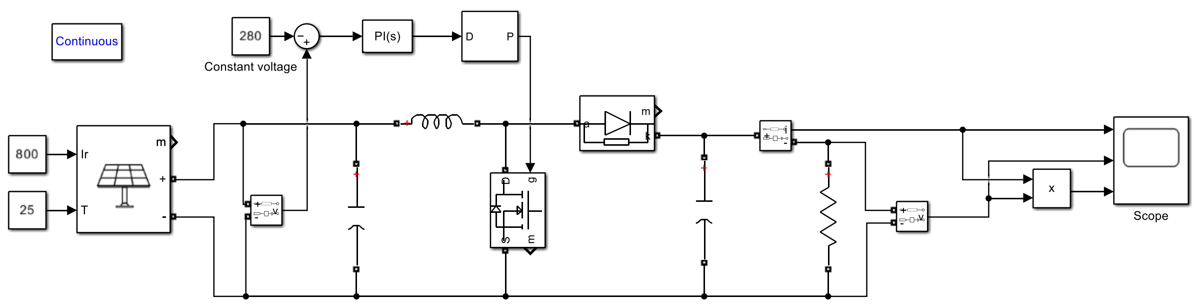

Figure 2 Simulation of Constant Voltage MPPT Technique

4.1 Incremental Conductance Technique:

To find the direction of the MPP, the incremental conductance (IC) technique computes the derivative of the power with respect to the voltage. Through a comparison between the instantaneous conductance (I/V) and the incremental conductance (ΔI/ΔV), the IC technique is able to track the MPP with accuracy and without oscillation. The IC approach is more accurate than P&O and CV, despite being more complicated, hence it is appropriate for systems where precision is crucial.

Using the derivative of power with respect to voltage to ascertain the ideal operating point is a more advanced technique for tracking the MPP in solar systems. In order to precisely locate and maintain the MPP even in the face of changing external conditions, this technique makes use of the relationship between the incremental changes in voltage and current.

This method's fundamental tenet is that the power's derivative with respect to voltage is zero at the MPP. The moment at which the incremental conductance (ΔI/ΔV) and the instantaneous conductance (I/V) added together equal zero is the mathematical expression for this condition. The system can determine whether it needs to raise or lower the operating voltage in order to meet or maintain the MPP by continuously computing these values and comparing them.

This method works especially well in places where temperature and light levels vary regularly. It can react fast to changes in the MPP since it measures current and voltage changes directly, ensuring that the PV system runs as efficiently as possible under a variety of circumstances. This approach produces more constant and dependable power production than simpler ones because it does not rely on presumptions about the stability of the MPP voltage and is less prone to oscillations around the MPP.

The accuracy of this approach is one of its main benefits. Even in the face of changing external variables, the system can stay in tight alignment with the MPP by precisely identifying the point at which the derivative of power with respect to voltage changes sign. Because of its accuracy, it is especially well-suited for applications where obtaining the maximum amount of energy harvest is essential, including large-scale solar farms or areas with extremely erratic weather patterns.

However, the complexity of this technique is also one of its main challenges. Implementing it requires more sophisticated hardware and software capable of performing real-time calculations of derivatives, which increases the computational load on the system. This can result in higher costs and more intensive maintenance requirements compared to simpler methods. Additionally, the increased complexity may lead to a longer development time and require more advanced technical expertise for proper implementation and troubleshooting.

Despite these challenges, the high accuracy and responsiveness of this method make it a preferred choice for PV systems where maximizing efficiency is a top priority. In scenarios where the additional cost and complexity are justified by the need for precise power tracking, with a wide range of working circumstances, this technology offers a reliable solution that can adjust to quickly changing environmental conditions and continue to function at its best.

4.2 ALGORITHM

Step 1- Measure the initial current (I_{pv}) and voltage (V_{pv}) from the PV panel.

Step 2- Compute the initial conductance ($G= I_{pv/}\ V_{pv}$).

Step 3- Measure the new current (I_{pv+1}) and voltage (V_{pv+1}).

Step 4- Find the difference in current ($\Delta I= I_{pv+1}- I_{pv}$) and the change in voltage ($\Delta V= V_{pv+1}- V_{pv}$).

Step 5- Compare conductances,

If $\Delta V \neq 0$:

- Calculate the incremental conductance $\Delta I/\Delta V$
- If $\Delta I/\Delta V= - (I_{pv}/ V_{pv})$, the MPP is reached.
- If $\Delta I/\Delta V > - (I_{pv}/ V_{pv})$, increase the voltage.
- If $\Delta I/\Delta V < - (I_{pv}/ V_{pv})$, decrease the voltage.

If $\Delta V = 0$:

- If $\Delta I=0$, the MPP is reached.
- If $\Delta I>0$, increase the voltage.
- If $\Delta I<0$, decrease the voltage.

Step 6- Based on the comparison's findings, adjust the PV panel's voltage.

Step 7- Continuously repeat the process to track the MPP as conditions change.

4.3 IC SIMULATION

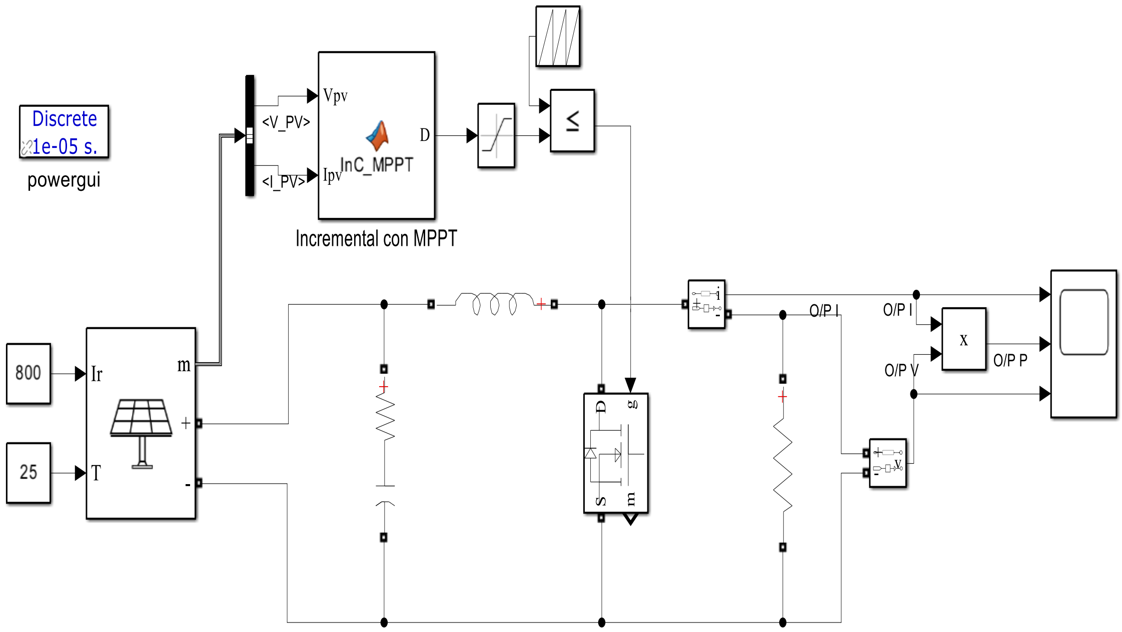

Figure 3 Simulation circuit of IC MPPT method

5. PV Module Description

The PV module used in the simulations is a standard silicon-based solar module. The key parameters include:

Parameters	Specifications
V_{oc}	36.3V
I_{sc}	7.84A
P_{output}	213.15W

MPP occurs at approximately 30V and 7.5A

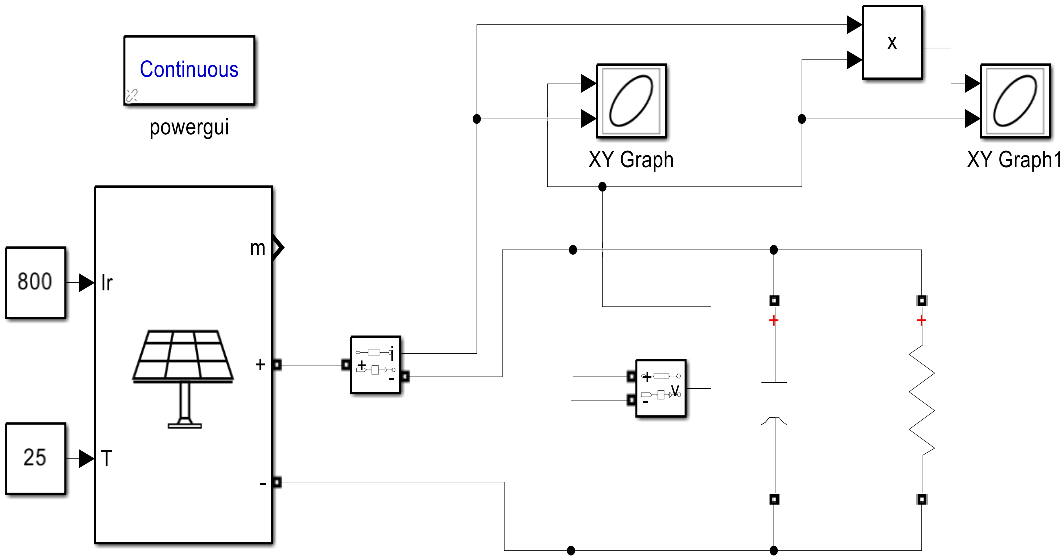

Figure 4 SIMULATION CIRCUIT OF SOLAR ARRAY

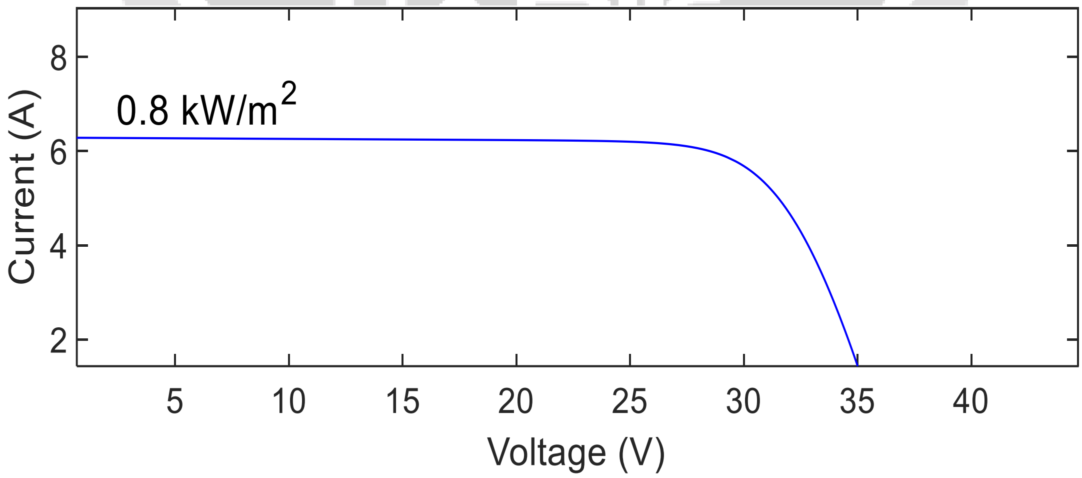

Figure 5 IV CHARACTERISTICS

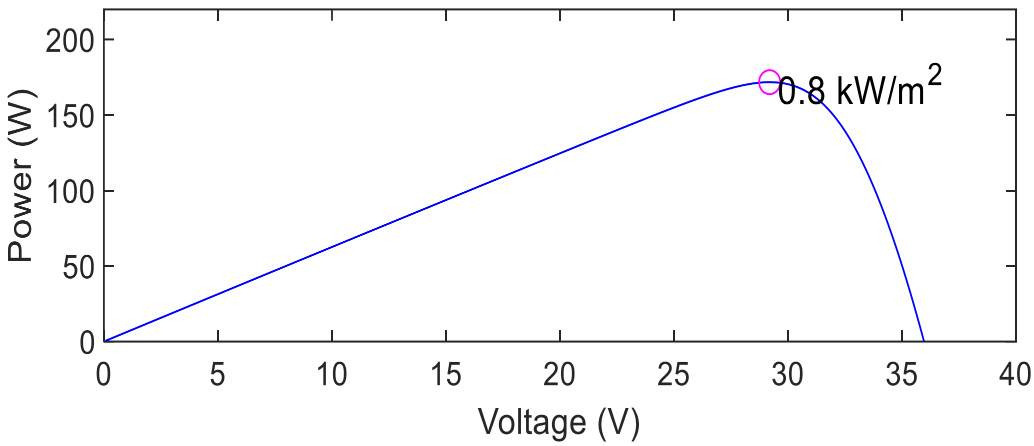

Figure 6 PV CHARACTERISTICS

6. MPPT Performance Comparison

The performance of the P&O, Constant Voltage, and Incremental Conductance MPPT techniques was evaluated through a series of simulations. The results for each method are summarized as follows:

6.1 P&O Technique:

- **Performance:** The P&O method shows a satisfactory performance under steady-state conditions, with minimal oscillations around the MPP. However, under rapidly changing irradiance, the method struggles to maintain accuracy, leading to potential energy losses.
- **Best Conditions:** The P&O method is best suited for environments with relatively stable irradiance and temperature. Its simplicity makes it ideal for low-cost applications where precision is not the highest priority.
- **Simulation Results:** Figures 7-9 illustrate the I_{output} , V_{output} and P_{output} over time using the P&O method.

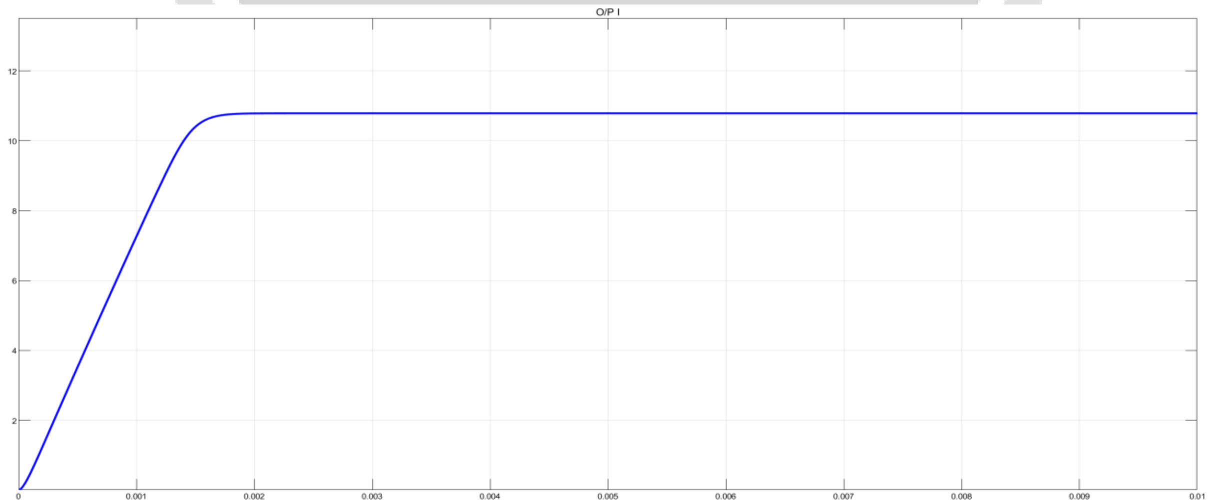

Figure 7 I_{output} vs Time using P&O method

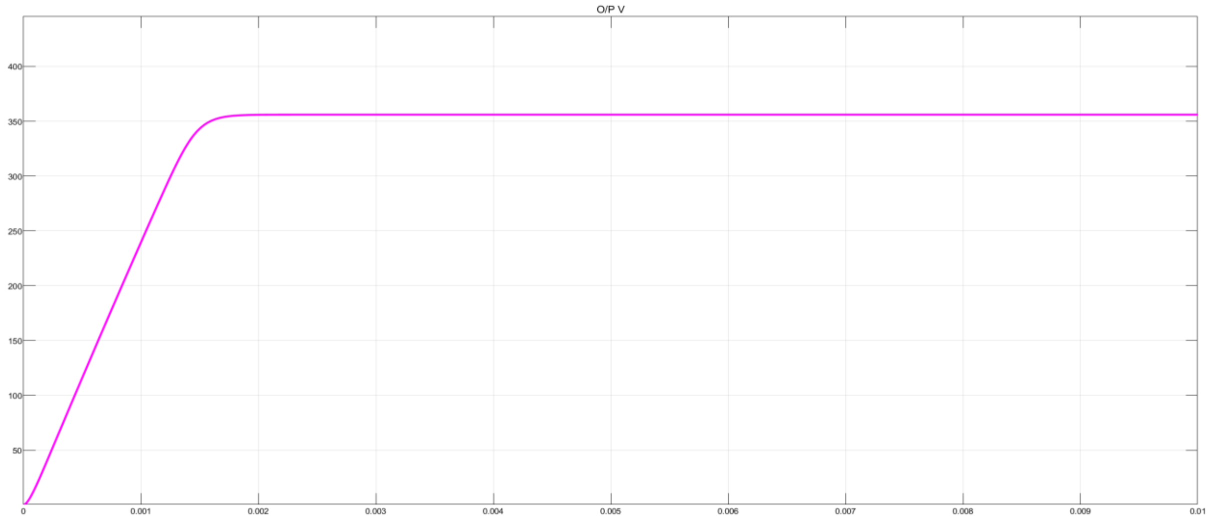

Figure 8 V_{output} vs Time using P&O method

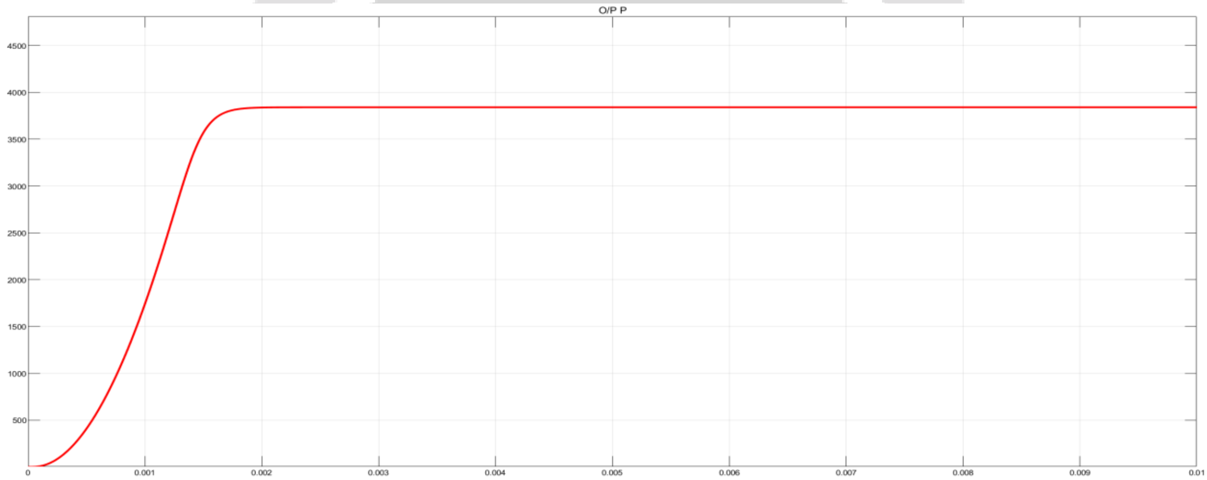

Figure 9 - P_{output} vs Time using P&O method

6.2 CV Technique:

- **Performance:** The CV method demonstrates moderate efficiency but lacks adaptability to changing environmental conditions. While it provides stable operation, its reliance on a fixed voltage set-point can result in suboptimal performance when the MPP voltage shifts.
- **Best Conditions:** The CV method is best used in systems where the PV module's operating conditions are relatively constant, such as in locations with minimal variation in irradiance and temperature. It is also useful in scenarios where computational resources are limited.
- **Simulation Results:** Figures 10-12 display the I_{output} , V_{output} and P_{output} over time using the CV method.

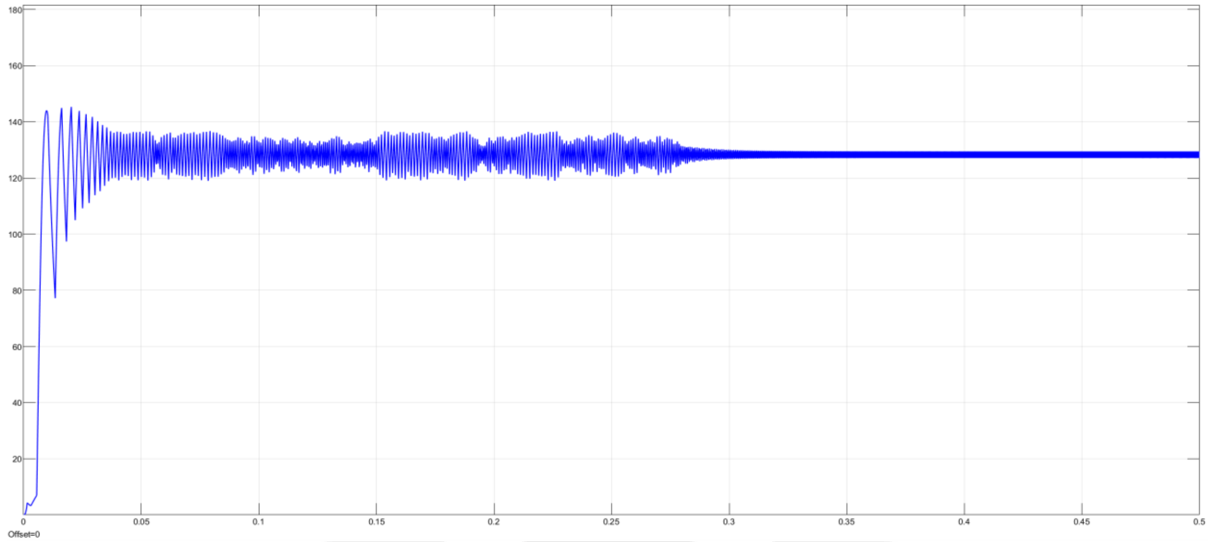

Figure 10 I_{output} vs Time using CV method

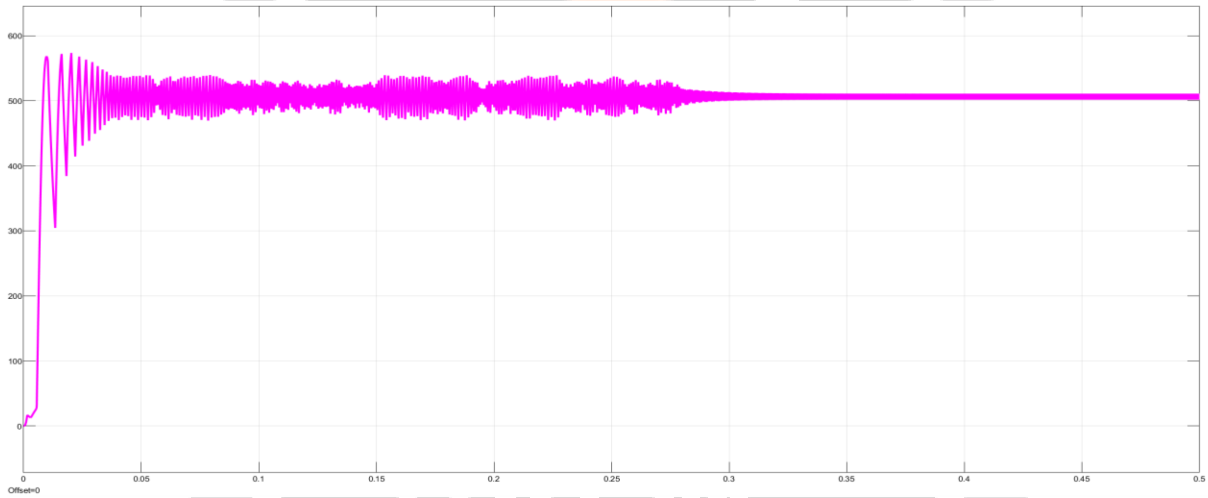

Figure 11 V_{output} vs Time using CV method

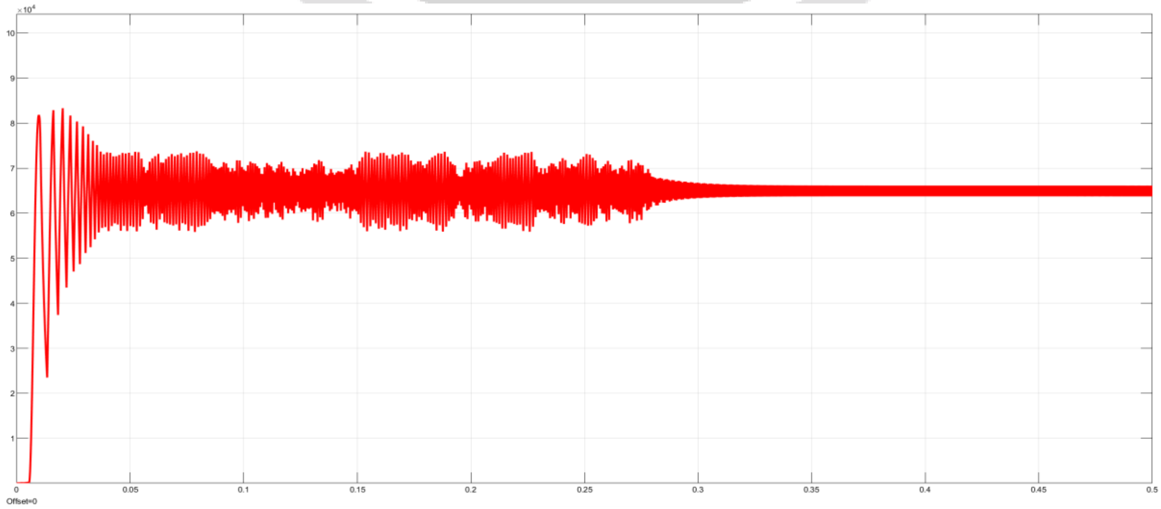

Figure 12 P_{output} vs Time using CV method

6.3 IC Technique:

- **Performance:** The IC method offers the highest accuracy among the three techniques, successfully tracking the MPP without oscillations. It quickly adapts to changes in irradiance and temperature, making it highly reliable in dynamic environments.
- **Best Conditions:** The IC approach works well in applications where precise power optimization is required, such as large-scale solar farms or systems where maximizing energy collection is essential. However, because of its complexity, more processing power is required.
- **Simulation Results:** Figures 13-15 show the I_{output} , V_{output} and P_{output} over time using the IC.

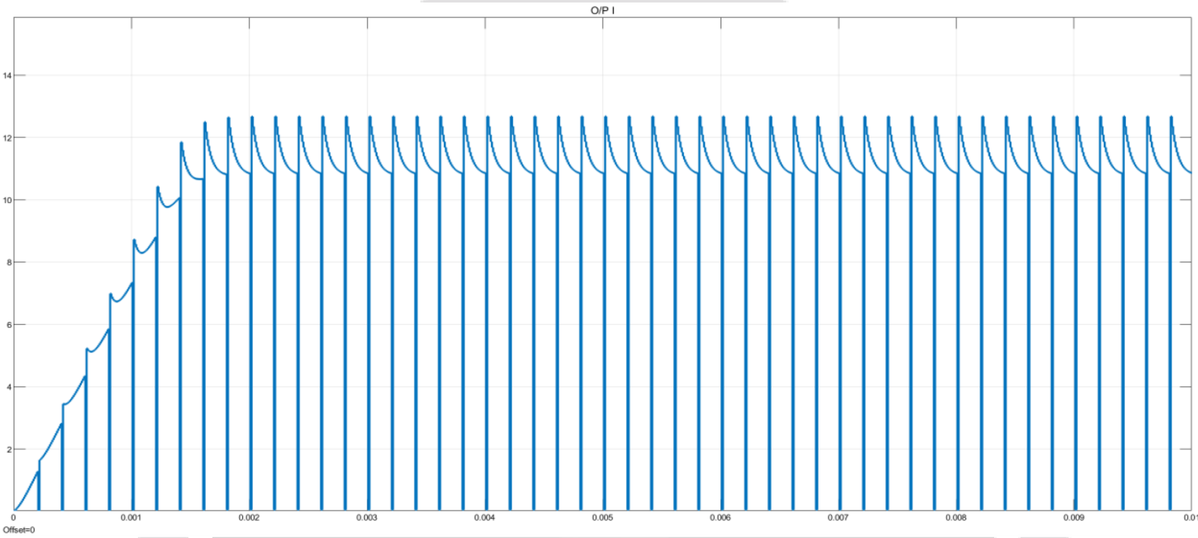

Figure 13 I_{output} vs Time using IC method

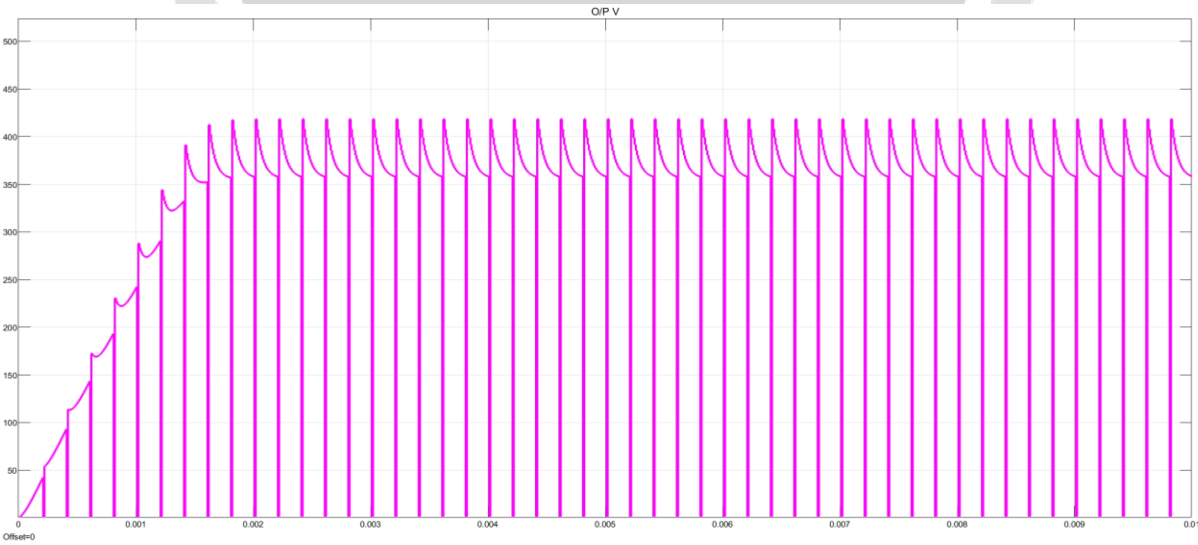

Figure 14 V_{output} vs Time using IC method

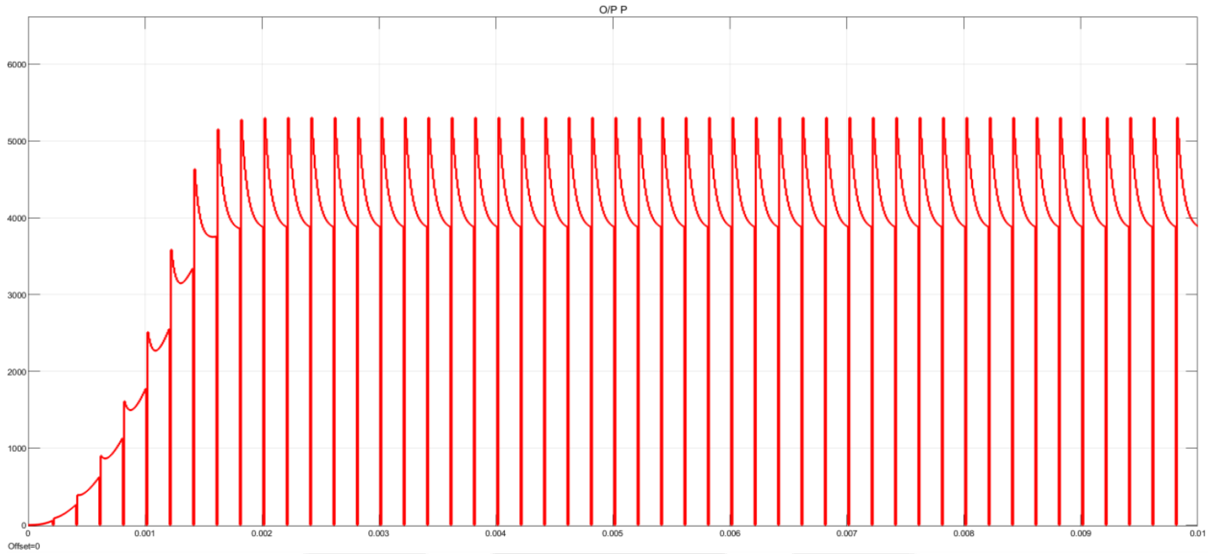

Figure 15 Poutput vs Time using IC method

7. Discussion

7.1 Comparison of Techniques:

Table 1 provides a summary of the three MPPT approaches' comparison. The P&O method, despite its simplicity, shows lower efficiency and requires periodic tuning to maintain performance. The Constant Voltage method, while stable, is not adaptable to environmental changes, leading to lower overall efficiency. The Incremental Conductance method, though complex, provides the highest efficiency and stability, making it the most suitable for environments with variable conditions.

	Convergence speed	**Stability**	**PV Array dependency**	**periodic tuning**	**complexity**	**efficiency**
P&0 method	Low	Not stable	No	No	Low	96.98% [4]
CV method	Medium	Not stable	Yes	Yes	Low	88-89.9% [4]
IC method	Low	Not stable	No	No	Medium	97% [4]

7.2 Analysis of MPPT Methods

The MPPT methods are compared based on their output graphs. These comparisons are made depending upon the V_{output}, I_{output} and P_{output} obtained from the solar panel while using these three different techniques. The curves on the graph will change the form according to used MPPT technique and depending on the amount of load, and varying conditions.

P&O MPPT Method:

- **Output Current vs Time:** The current fluctuates around the MPP as the algorithm adjusts the operating point, causing oscillations.
- **Output Voltage vs Time:** The voltage similarly oscillates around the MPP as the operating point is adjusted.
- **Output Power vs Time:** The output power initially increases when the algorithm perturbs towards the MPP. At the MPP, power may vary slightly due to minor adjustments by the algorithm.

IC MPPT Technique:

- **Output Current vs Time:** The algorithm continuously adjusts the operating point to track changes in load and environmental factors, resulting in variations in current.
- **Output Voltage vs Time:** Voltage fluctuates as the algorithm strives for maximum power.
- **Output Power vs Time:** As the algorithm dynamically adapts to variations in insolation and load conditions, output power is maximised over time, maintaining the system functioning at or near the MPP.

CV MPPT Technique:

- **Output Current vs Time:** The algorithm's fixed voltage and the characteristics of the load will determine how much current changes. Under certain circumstances, it might not consistently follow the MPP.
- **Output Voltage vs Time:** Voltage varies as the algorithm strives for maximum power, just like current does. Output Power vs. Time: The system operates at or very near the MPP by maximising output power over time because of the algorithm's dynamic adjustments to variations in insolation and load circumstances.
- **Output Power vs Time:** The output power is generally less than the maximum available at the MPP, depending on load and irradiance conditions.

8.CONCLUSION

The three various techniques to MPP tracking in solar systems are analysed, and the results show that each method has its own advantages and trade-offs, making it appropriate for a particular application based on the operational needs and environmental circumstances. The first method, characterized by its simplicity and widespread use, provides a straightforward approach to tracking the MPP by making iterative adjustments to the operating voltage. Its ease of implementation and low computational demands make it an attractive option for low-cost and small-scale PV systems. However, this method is prone to oscillations around the MPP, which can lead to efficiency losses, particularly in environments with stable conditions where such oscillations are unnecessary. The second approach, which maintains a fixed operating voltage, is particularly effective in stable environments where the relationship between voltage and power does not fluctuate significantly. Its simplicity and low computational requirements are its primary strengths, making it well-suited for systems with limited processing power or in scenarios where ease of use is prioritized over maximum efficiency. However, because it relies on the assumption of a constant voltage, it may not provide the best power tracking, particularly in dynamic situations where temperature or irradiance variations cause the MPP to move often. Out of the three techniques, the third one delivers the most precision and stability since it tracks the MPP precisely by using the derivative of power with respect to voltage. It can react to changes in the MPP fast and without oscillations, which makes it especially well-suited for applications with rapidly changing conditions. While this technique requires more sophisticated hardware and software, as well as greater computational resources, its ability to maintain optimal performance makes it ideal for large-scale or high-efficiency PV systems where maximizing energy harvest is critical.

The technology ultimately chosen will rely on the particular requirements of the PV system. In scenarios where the key concerns are affordability, simplicity, and ease of implementation, the first or second approach could be more suitable. The third approach, albeit more complicated, is the most efficient when it comes to situations when accuracy and flexibility are critical. The performance of solar energy systems may be maximized by comprehending the advantages and disadvantages of each technique, which has a role in the larger scheme of photovoltaic technology.

The needs of the PV system and its operational environment should thus be taken into consideration when choosing an MPPT approach. P&O or CV may be favoured in situations where cost-effectiveness and simplicity are crucial considerations. Nevertheless, despite its greater complexity, the incremental conductance approach is probably the best option in situations when maximal efficiency and dependability are crucial. Subsequent investigations may concentrate on creating hybrid strategies that integrate the advantages of many MPPT methodologies, therefore providing improved performance in an expanded array of operational scenarios. Additionally, a wider range of applications may be able to utilise sophisticated techniques like IC if current algorithms are optimised to minimise computing needs while retaining high accuracy. The efficiency and dependability of PV systems may be further increased, advancing the development of renewable energy sources, by further developing and innovating MPPT technology.

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