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Improved Perturb and Observe (P&O) MPPT Algorithm for Solar PV Systems with MATLAB/SIMULINK Simulations

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Abstract
This study employs the Perturb and Observe (P&O) method, where the Maximum Power Point Tracking (MPPT) process is based on evaluating the power output of a photovoltaic (PV) system by measuring both current and voltage. A modified P&O algorithm is proposed in this work for optimizing the performance of PV modules. PV panels exhibit nonlinear voltage-current characteristics, which are significantly influenced by sunlight and temperature variations. Therefore, developing an effective strategy to extract maximum power from PV systems has been a key focus in recent years. Initially, the PV system is designed using the observation and perturbation technique. The system's performance under varying irradiance levels is then analyzed. However, a limitation of this approach is its inability to handle abrupt changes in irradiance and temperature effectively. To address this issue, an improved P&O algorithm, also acknowledged as the mutable step size P&O method, was presented and realized to overawed the shortcomings of the traditional scheme. The performance of the complete solar system with MPPT was evaluated using simulations conducted in MATLAB/Simulink. Additionally, comparisons were made between the improved algorithm and the conventional P&O method, highlighting that the enhanced approach reaches the maximum power point more rapidly. The entire system was modeled and implemented in MATLAB/Simulink.

Keywords: Solar PV, MPPT, P&O.

Introduction
Renewable energy resources, unlike conventional energy sources, are distributed across diverse geographical regions. This widespread availability makes them crucial for addressing the ever-increasing global energy demands and combating pressing environmental challenges. As nations grapple with the twin imperatives of energy security and climate change mitigation, the rapid adoption of renewable energy and energy efficiency measures emerges as a transformative solution. Global surveys consistently reveal strong public support for renewable energy sources, particularly solar power, which holds immense promise due to its abundance and versatility.

Among the various renewable energy technologies, photovoltaic (PV) systems stand out as a reliable and scalable solution for harnessing solar energy. PV systems find applications in diverse domains, such as water pumping, battery charging, and grid-connected frameworks. The effectiveness of these systems is highly dependent on their capability to function at the maximum power point (MPP) in changing environmental circumstances [1], [2], [3]. The power-voltage (P-V) curve of a solar panel exhibits a distinct MPP, which differs with variations in solar irradiance and cell temperature [4], [5]. Identifying and maintaining this MPP is critical to ensuring the efficient transfer of energy from the PV system to the load. To achieve this, maximum power point tracking (MPPT) methods have been developed, enabling PV systems to dynamically adjust to environmental fluctuations. Among the conventional MPPT methods, the Perturb and Observe (P&O) procedure is commonly utilized due to its uncomplicatedness and ease of execution. Though, the traditional P&O approach suffers from certain limitations, such as a slow response in tracking the MPP, especially under rapidly changing environmental conditions[6], [7], [8]. This drawback can lead to suboptimal energy harvesting and reduced system performance.

To address these challenges, researchers have proposed various enhancements to MPPT techniques, aiming to improve their efficiency and responsiveness. This paper introduces a novel MPPT strategy that incorporates a modified Perturb and Observe algorithm. The proposed method enhances the convergence speed to the MPP, reducing the time required to stabilize at the optimal operating point. By overcoming the limitations of the conventional P&O method, the new technique ensures improved energy extraction from PV systems, even under dynamic conditions.

The paper is structured as follows: Section 2 offers a comprehensive outline of the traditional MPPT methods and their associated challenges. Section 3 details the proposed modified P&O algorithm, highlighting its advantages over existing approaches. Section 4 presents the simulation results and performance analysis, demonstrating the effectiveness of the new technique. Finally, Section 5 concludes with a discussion of the results and possible future study directions.

In summary, the utilization of advanced MPPT strategies is essential for maximizing the efficiency of PV systems. By leveraging the proposed modified P&O algorithm, this study aims to contribute to the current efforts to enhance the performance and reliability of solar energy systems, finally supporting the global change toward sustainable energy solutions.

Solar Cell Equivalent Circuit

The solar cell serves as the elementary building block of a photovoltaic (PV) system. A single solar cell generates direct current and normally produces power ranging from 1 to 2 watts, which is insufficient for most applications. A photovoltaic (PV) cell, commonly known as a solar cell, is a device crafted from semiconductor materials such as silicon or gallium arsenide. It functions by converting sunlight straight into electric current. The voltage output of a solar cell is influenced by both solar irradiance and the cell's temperature[9], [10]. By connecting solar cells in series, PV modules can be configured to operate at various voltage levels. When sunlight is absorbed by solar cells, it generates free electrons and holes at their positive and negative junctions. Connecting these junctions to DC electrical devices allows current to flow, supplying power to the equipment.

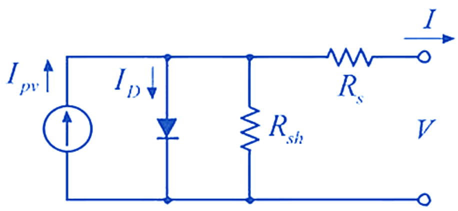

Figure 1: ***equivalent circuit of pv cell***

$$I = I\text{PV} - I\text{D} \quad (1)$$

$$I\text{D} = Io\,[\exp\,(\text{qVd/akT}) - 1] \quad (2)$$

where Ipv,cell is the flow produced by the episode light (it is straightforwardly corresponding to the Sun illumination), ID is the Shockley diode condition, I0,cell is the turn around immersion or spillage flow of the diode , q is the electron charge [1.60217646 • 10−19C], k is the Boltzmann steady [1.3806503•10−23J/K], T [K] is the temperature of the p-n intersection, and an is the diode ideality consistent.

Problem Overview

Fig. 2 shows the trademark power bend for a PV cluster. MPPT strategies aim to identify the (VMPP) voltage or (IMPP) current for which a photovoltaic (PV) system should function to achieve maximum power output (PMPP) under specific temperature and irradiance conditions. In cases of partial shading, there may occasionally be multiple local maxima, but typically, only one true MPP exists. While most methods adapt to variations in both temperature and irradiance, some are particularly advantageous when temperature remains relatively constant. Most methods would consequently react to changes in the exhibit because of maturing, however some are open-circle and would require occasional adjusting. In our con-message, the exhibit will ordinarily be associated with a power converter that can differ the present originating from the PV cluster.

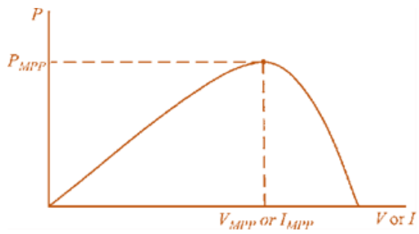

Figure 2: characteristic power curve for a PV array

4. Perturb & Observe Method

The P&O calculation is record broadly utilized for MPPT of sun powered PV cell, otherwise called slope climbing technique. This calculation has extremely straightforward game plan and little estimated constraints. In this method, the unit voltage is regularly adjusted and related to its preceding value[11], [12]. A minor adjustment is presented as part of the process, causing the module's voltage to vary. If the power output rises, the adjustment continues in the same course, Next to attaining peak point of the power at MPP is zero and then declines thus irritation changes its direction. The Perturb and Observe technique is one of the most frequently used MPPT techniques for solar photovoltaic systems. Its simplicity, ease of implementation, and relatively low requirement for computation make it suitable for many applications. The main purpose of the P&O method is to increase the power output of the PV array by adjusting the operating voltage or current to keep the system at its MPP [13], [14], [15].

Working Principle

The P&O algorithm is based on the fact that the PV module's power output varies with its operating voltage[16], [17], [18], [19]. The flowchart of P&O algorithm is shown in figure 3. Periodic perturbation of (that is, change in) the operating voltage and measuring the corresponding change in power determines whether the perturbation moves the operating point closer to or farther from MPP. The basic steps are as follows:

1. Measure Initial Parameters: Measure the current voltage and power ((P_k) of the PV module.
2. Perturb the Voltage: Increment or decrement the operating voltage by a small step.
3. Measure New Power: Calculate the new power (P_{k+1}) after perturbation.
4. Compare Power Values:

The sequence of steps performed is as follows:

- Whenever $P_{k+1} > P_k$ that means the disturbance has shifted the operating point near the MPP, and keep the direction as it is going to the next step.

When $P_{k+1} < P_k$ a disturbance has drifted the operating point away from MPP, or reverse the perturbation direction to the next steps.

5. Iterate: Repeat for the number of times until that system operates very close to its own MPP repeatedly.

Advantages

- Easiness in Implementation: This algorithm is pretty simple to apply and requires lesser computational resources.
- Non-Expensive: It also does not have the need to use expensive sensors or complicated mathematical models.
- Robustness: Suitable for slowly varied environmental conditions

Limitation

- Oscillation Around MPP: The oscillations are typically small around MPP because continuous perturbation in the system makes it happen.
- Performance Under Rapid Changes: If irradiance or temperature changes quickly, the algorithm will not follow the MPP, and therefore power will be lost.
- Fixed Step Size: An increased step size accelerates the convergence but oscillates more and, on the other hand, a smaller step size improves the stability but the convergence is very slow.

The main drawback of P&O remains its balance of simplicity and effectiveness, making it a very popular choice for MPPT in solar PV systems, despite these limitations. Techniques involving variable step size were developed to minimize the shortcomings and enhance the system's performance during dynamic conditions.

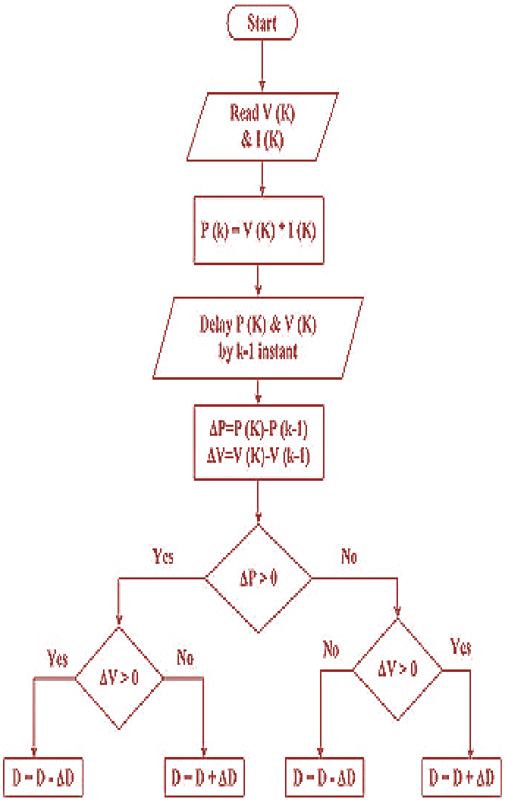

Figure 3: ***Flowchart of p&o algorithm***

Prented Perturb & Observe Method

In the presented P&O calculation, another MPPT calculation For the PV module, a new algo which relies upon traditional P&O calculation. As seemed in figure below, the P&O approach at mid-term detects an Additional computation of PV showcase control at mid-control period [11] The Power contrast $dP_{0.5}$ in mid control P(k-0.5) and the onset force P(n-1) of MPPT control comprises both the power shift due to the MPPT control and irradiance change.

A power difference dP can be calculated as: -

$dP_{0.5} = P(n - 0.5) – P(n - 1)$ (3)

$dP_1 = P(n) – P(n - 0.5)$ (4)

$dP = dP_{0.5} – dP_1$ (5)

By analyzing the above equations, the MPPT controller can identify the optimal direction to achieve the maximum power output from the PV array. The flowchart of inmproved P&O algorithm is shown in figure 4.

Following points are also related to the presented scheme:

1. Incorporation of Dynamic Step Adjustment:

- The classic P&O method generally adopts a fixed step-size. It usually leads to some oscillations at the MPP or slows down its tracking ability with respect to an abrupt change in irradiance. An enhanced method can dynamically control the step-size with the aid of the power rate of change (dP/dV) in such a way as to achieve good trade-offs between speed and stability.

2. Applying Derivative Analysis to Capture Irradiance Changes:

- The algorithm may be made to differentiate between the change in power caused by MPPT adjustments and irradiance variations. This can be achieved by including derivative-based calculations. This would make the MPPT more robust under rapidly changing environmental conditions. 3. Incorporation of a Low-Pass Filter:

- The power calculations may have noise due to sudden changes in irradiance. Applying a low-pass filter can help smooth the power curve, making the decision-making in the algorithm more accurate. 4. Real-Time Data Logging for Predictive Adjustments:

- Log historical power and irradiance data so that, through predictive models, this algorithm can predict what MPP variations may arise over some future period, maximally increasing efficiency during transient conditions.

5. Verification of Stability by Dual Points

- The enhanced P&O algorithm with a verification step, in which the computed MPP is verified by power similarity at the two adjacent voltage points. This is used for a stable and non-misleading decision during the tracking process.

6. Temperature Compensation:

- Temperature variations greatly affect the characteristics of the PV module. The algorithm can be enhanced by

integration of temperature sensors for compensating these effects to ensure accurate tracking of MPP.
7. Hybrid Control Mechanism:
- Hybrid approach combining P&O with other algorithms like INC can improve performance in situations where P&O alone may struggle, such as under rapidly fluctuating irradiance or partial shading conditions.
8. Implementation of Hysteresis Logic:
- The algorithm could be designed to incorporate hysteresis logic that defines a power tolerance range. The tracking would stop adjusting once the power stabilizes within this range. This minimizes oscillations around the MPP.
9. Adaptation for Partial Shading Conditions:
- Improved algorithms may have a second stage that detects multiple power peaks due to partial shading, so the global MPP is reached instead of a local MPP.
10. Flowchart Improvements:
- The improved P&O algorithm flowchart must explicitly incorporate the above improvement, including dynamic step adjustment, input of temperature and irradiance, and stability checks. This is to ensure that clarity and implementation are improved.

The points extended the discussion of the improved P&O algorithm with respect to practical enhancements that will improve the shortcomings in the traditional method.

Simulation And Experimental Results

The Simulink model of improved p&o mppt system is shown in figure 5. The Tracking of MPP for different duty steps size using the proposed model is shown in figure 6. The Tracking of MPP for different duty steps size using the traditional P&O method with different step sizes model is shown in figure 7. The tracking time taken to track different peak power by the proposed method for different step sizes is given in table 1 to 4. The Power, Voltage and current curves for two different values of irradiation are shown in figure 8, 9 and 10 respectively. It can be observed from these figures and tables, that the performance of the presented method is improved and reliable. The results demonstrate that the improved P&O MPPT system ensures faster and more accurate tracking of the maximum power point compared to the traditional method. The proposed approach exhibits better adaptability under varying irradiation conditions, as shown in Figures 8-10. Additionally, Tables 1-4 highlight the reduced oscillations and enhanced stability of the system. This enhanced performance makes the proposed method more effective and efficient for practical photovoltaic applications.

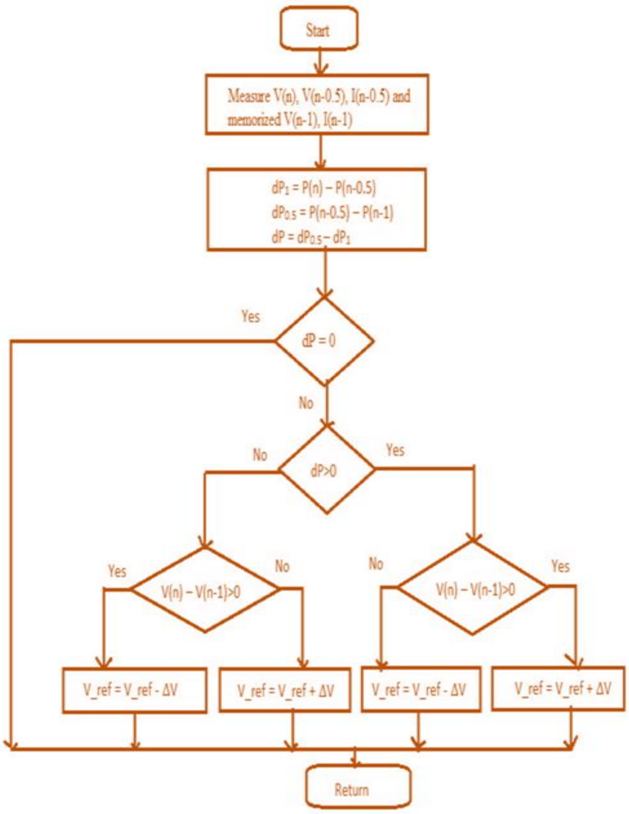

Figure 4: ***Flowchart of improved p&o algorithm***

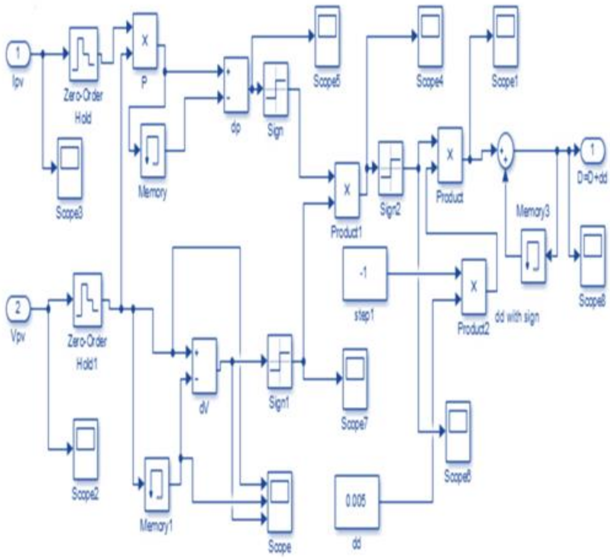

Figure 5: S*imulink model of improved p&o mppt system*

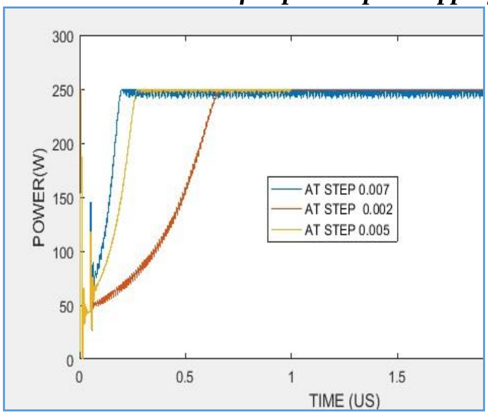

Figure 6: ***Tracking of mpp using the proposed methodl at different duty steps***

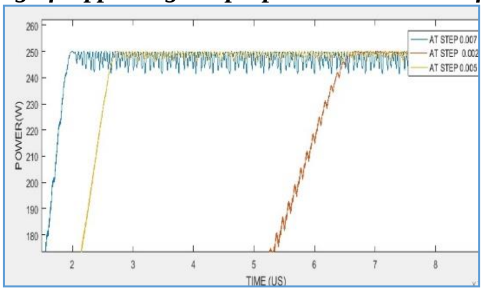

Figure 7: ***Tracking time of mpp using the traditional P&O method at different duty steps***

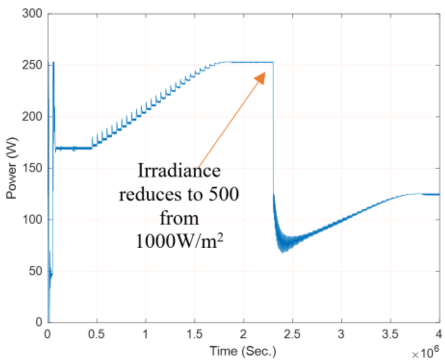

Figure 8: Power curve for two different values of irradiation

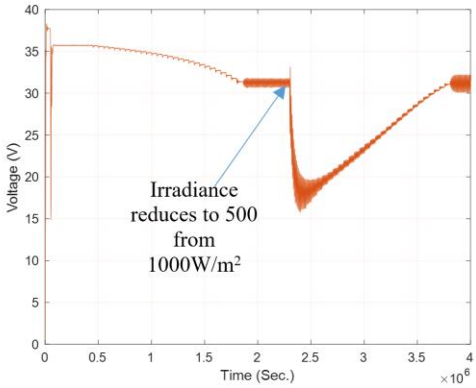

Figure 9: Voltage curve for two different values of irradiation

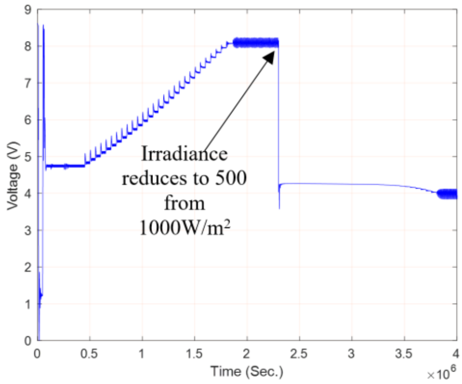

Figure 10: Current curve for two different values of irradiation

Table 1: Time of tracking of Mpp at duty step 0.007

Maximum power point(w)	Time of tracking(us)	Step size(duty ratio)
247	1.934	0.007
247.1	1.937	0.007
247.2	1.936	0.007

Table 2: Time of tracking of Mpp at duty step 0.005

Maximum power point(w)	Time of tracking(us)	Step size(duty ratio)
247.3	2.67e+05	0.005
248.6	2.686e+05	0.005
249.7	2.722e+05	0.005

Table 3: Time of tracking of Mpp at duty step 0.002

Maximum power point(w)	Time of tracking(us)	Step size(duty ratio)
248.3	6.611	0.002
249.8	6.935	0.002
249.9	6.933	0.002

Table 4: Comparision of time of tracking of Mpp at different duty step		
Maximum power (w)	**Time of tracking(us)**	**(duty ratio)**
249.9	**6.933**	**0.002**
249.7	**2.722**	**0.005**
247.1	**1.937**	**0.007**

Conclusion

An improved P&O MPPT strategy have been exhibited. The most extreme power point is gotten effectively by this calculation. It can be seen that the exhibition of the changed P&O calculation at various irradiance and at consistent temperature. Every one of the reproductions were done using MATLAB/Simulink. Through results it is inferred that the adjusted P&O calculation has effectively defeated the downsides of ordinary P&O calculation by giving the quick assembly speed and little motions.

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