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Advanced Perturb and Observe Algorithm for Maximum Power Point Tracking in Photovoltaic Systems with Adaptive Step Size

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Abstract:
Maximum power point tracking (MPPT) algorithms are commonly used in photovoltaic (PV) systems to optimize the power output from the solar panels. Among the various MPPT algorithms, the perturb and observe (P&O) algorithm is a popular choice due to its simplicity and effectiveness. However, the basic P&O algorithm has some limitations, such as oscillations and steady-state error under rapidly changing irradiance conditions. The enhanced algorithm includes a modified perturbation step and a dynamic step size adjustment scheme. This reduces the oscillations and improves the tracking accuracy. In the dynamic step size adjustment scheme, the step size is adjusted based on the rate of change of the PV output power. This improves the tracking performance under rapidly changing irradiance conditions. In order to prove the performance of the designed control algorithm, we will test it under simple climatic conditions of fixed temperature (30°C) and variable irradiation in the form of steps (500W/m^2 and 2000w/m^2) and see the system response. The performance of the enhanced P&O algorithm has been evaluated using MATLAB simulations.

Keywords: *improved tracking accuracy, dynamic step size adjustment, reduced oscillations, maximum power point tracking, perturb & observe algorithm, photovoltaic systems*

1. Introduction

The perturb & observe (P&O) implementation is widely employed for tracking the realization of the MPPT algorithm for photovoltaic systems. There are many research papers and articles published on the P&O algorithm, in both the academic and industrial domains. Some works related to the P&O algorithm are: "Enhanced Adaptive Perturb and Observe Technique for Efficient Maximum Power Point Tracking Under Partial Shading Conditions" by Mahmod Mohammad AN et al. (2020) [1], "Simulation and Analysis of Perturbation and Observation-Based Self-Adaptable Step Size Maximum Power Point Tracking Strategy with Low Power Loss for Photovoltaics" by Zhu et al. (2019) [2], "Classification and Comparison of Maximum Power Point Tracking Techniques for Photovoltaic System" by A. Reisi et al. (2013) [3], "An Enhanced P&O MPPT Algorithm for PV Systems with Fast Dynamic and Steady-State Response under Real Irradiance and Temperature Conditions" by Ambe Harrison et al. (2022) [4], "A Modified Perturb and Observe Method with an Improved Step Size for Maximum Power Point Tracking of Photovoltaic Arrays" by Mohammad Mohammadinodoushan et al. (2021) [5]. These research papers present various modifications and improvements to the P&O algorithm to increase its efficiency and accuracy in tracking the maximum power point of a photovoltaic system.

Similarly, a study by M. Ghaffari et al. (2018) [6] evaluated the performance of the fuzzy logic-based P&O algorithm and found that it was able to track the MPP more accurately and with fewer oscillations compared to the traditional P&O algorithm. Another study by Katche et al. (2023) [7] compared the performance of different MPPT algorithms, including the traditional P&O algorithm and its variants, and concluded that the adaptive step-size P&O algorithm was the most efficient in terms of tracking accuracy and convergence speed. Overall, the enhanced P&O algorithms have shown promising results in improving the tracking accuracy and reducing oscillations around the MPP. However, their implementation may require more complex hardware and software compared to the simulation of P&O program. Therefore, the choice of MPPT program depends on the specific application requirements and constraints. This article focuses on the Perturbations and Observations (P&O) algorithm for tracking the maximum power point influenced by the nonlinear characteristics of the photovoltaic panel depends on the variable environmental conditions, such as solar radiation and ambient temperature [8].

The enhanced Perturb and Observe (P&O) algorithm for Maximum Power Point Tracking (MPPT) offers practical advantages in terms of improved energy harvesting, enhanced system performance, simplicity of implementation, adaptability to varying climatic conditions, and reduced maintenance requirements. The use of MATLAB simulations for evaluation further adds to the algorithm's feasibility and practicality in real-world applications. However, it's important to note that real-world implementation may still require considerations of hardware constraints, noise, and other practical challenges that simulations may not fully capture.

The rest of the paper is organized as follows: after the introduction, the proposed method for PV cell model is presented in Section 2, Section 3 provides an MPPT command approach, simulation results are given in Section 4, and finally Section 5 offers conclusion and perspective.

2. Proposed Method for PV Cell Model

A photovoltaic (PV) cell is an electronic device that converts sunlight into usable electricity. It made up of several layers of semiconductor materials, each with a different electrical property.

The equivalent circuit model of a solar cell is a tool that makes it possible to represent the electrical behavior of the photovoltaic cell. This model is based on the association of electrical components, which represent the electrical characteristics of the cell. The equivalent circuit of a solar cell consists of a current source Iph, an internal series resistance Rs, an external load resistance R load, and a diode in parallel with the current source, called diode photovoltaic.

The equivalent circuit model is used to determine the electrical characteristics of the solar cell, such as the open circuit voltage (Voc), the short circuit current (Isc), the maximum power point (Pmax), and the cell conversion efficiency. These parameters are important for the design and optimization of solar photovoltaic systems Figure 1.

The expression of the PV solar cell for current voltage (I-V) equation:

$$\mathrm{I} = \mathrm{I}_{ph} - \mathrm{I}_0 \left(e^{\left(\frac{qV}{kT}\right)} - 1 \right) \tag{1}$$

Where:

- I is the current generated by the solar cell in amperes (A)
- Iph is the photocurrent, which represents the current produced by the absorption of sunlight, in amperes (A)
- I0 is the reverse saturation current of the solar cell in the absence of light, in amperes (A)
- q is the charge of an electron, in Coulombs (C)
- V is the voltage across the solar cell in volts (V)
- k is Boltzmann's constant, equal to 1.38 × 10(-23) J/K
- T is the temperature in Kelvin (K)

The photocurrent of a photovoltaic (PV) cell is the electrical current generated by the absorption of light by the semiconductor material in the cell

Where:

- Iph,ref is the short-circuit current of the solar cell under reference conditions.
- μsc is the short-circuit temperature coefficient of the solar cell.

$$I_{ph} = \frac{G}{G_{ref}} \left(I_{ph,ref} + \mu_{sc} \times \triangle T \right) \tag{2}$$

On the other hand, the reverse saturation current of the cell is presented by

$$I_0 = I_{0.ref} \left(\left(\frac{T_c}{T_{c,ref}} \right)^3 \right) exp \left[\left(\frac{q_{\varepsilon G}}{A \times K} \right) \left(\frac{1}{T_{c,ref}} - \frac{1}{T_c} \right) \right] \tag{3}$$

Where:

- I_0,ref is the optimal short-circuit current of the solar cell under reference conditions.
- ε_G is the bandgap energy in the solar cell.

3. MPPT Command Approach

3.1. Perturbation & Observation Technique

The Perturb & Observe implementation is one of the most commonly employed algorithms for tracking of the maximum power point (MPPT) command approach. The performance of the P&O algorithm can be analyzed in terms of accuracy, efficiency, and stability. The key factors that affect the performance of the P&O algorithm in a PV system can be summarized in the following points:

- Steady state accuracy: The P&O algorithm works by perturbing the operating point of the PV array and observing the resulting output power to determine the MPP. The accuracy of the P&O program varies in relation to the proximity of disturbances to the MPP. If the disturbances are too small or too large, the

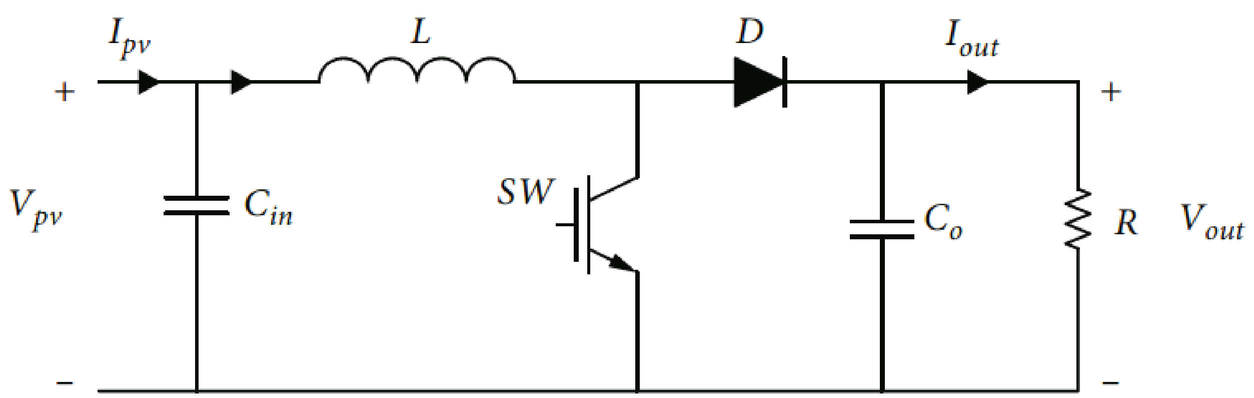

Figure 1. Circuit of boost

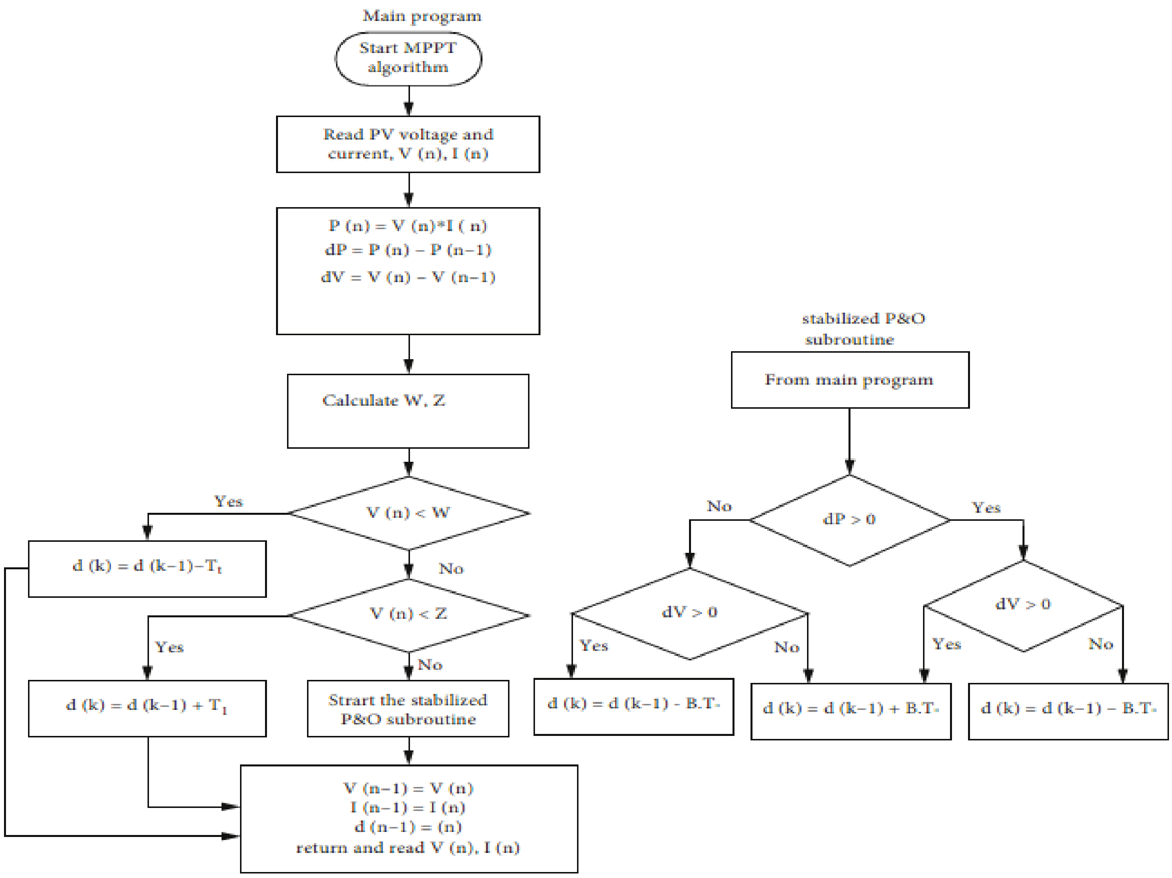

Figure 2. Flowchart of enhanced P&O algorithm

algorithm may converge to an incorrect operating point, resulting in reduced output power. Therefore, the size and frequency of disturbances should be optimized to achieve high steady-state accuracy.

- Dynamic response: The P&O algorithm must respond quickly to changes in irradiance or temperature of the PV panels to track the MPP. If the algorithm responds too slowly, it may cause a reduction in output power. The dynamic response of the algorithm can be improved by adjusting the size and frequency of disturbances or by using a modified P&O algorithm, such as the Incremental Conductance algorithm.
- Oscillations: The P&O algorithm is known to exhibit oscillations around the MPP, which can cause instability and reduced output power. The amplitude and frequency of oscillations can be reduced by optimizing the size and frequency of disturbances or by using a modified P&O algorithm that includes a damping factor.
- Environmental factors: The quality of the P&O implementation is affected by situations, such as solar irradiance, temperature, and shading. In low light conditions, the P&O program can be able to accurately determine the MPP, resulting in reduced output power. Likewise, shading can cause the P&O program to increase to a global maximum rather than the global MPP, thus reducing the output power.

Table 1. PV module electrical specifications

Parameters	Value
Maximum power Pmax (W) 21.02	Maximum power Pmax (W) 21.02
Cells per module (Ncell) 54	Cells per module (Ncell) 54
Maximum point voltage Vpm (V) 19.16	Maximum point voltage Vpm (V) 19.16
Ipm (A) 1.05	Ipm (A) 1.05
Vco (V) 23.81	Vco (V) 23.81
Isc (A) 1.08	Isc (A) 1.08

3.2. PV System Matlab/Simulink

The photovoltaic system studied can be modeled in Matlab as follows:

The characteristics of the photovoltaic module are presented in Table 1. Thereafter the different simulation parameters are presented in MATLAB/Simulink.

4. Simulation Results

The simulation under MATLAB/Simulink is done under the parameters mentioned in Table 1. In order to prove the performance of the designed control algorithm, we will test it under simple climatic conditions of fixed temperature (30°C) and variable irradiation in the form of steps (500W/m^2 and 2000w/m^2) and see the system response. The simulation time is fixed at 3s.

Following the variation of the irradiation from 800W/m^2 to 2000W/m^2 (Fig. 4) while maintaining

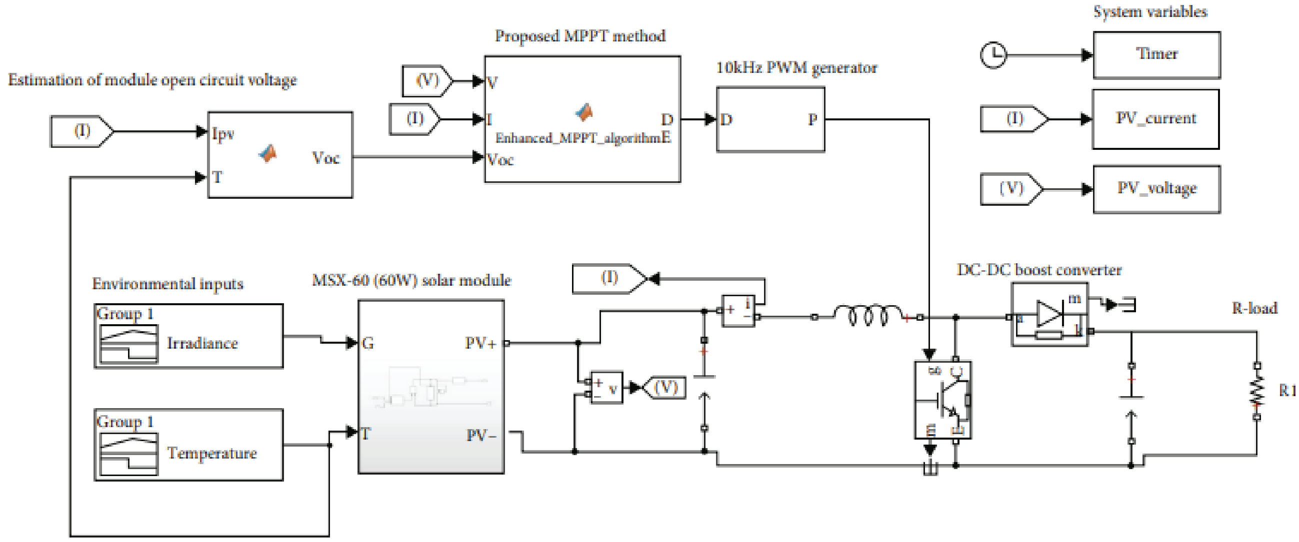

Figure 3. Flowchart of proposed simulation of enhanced of P&O algorithm

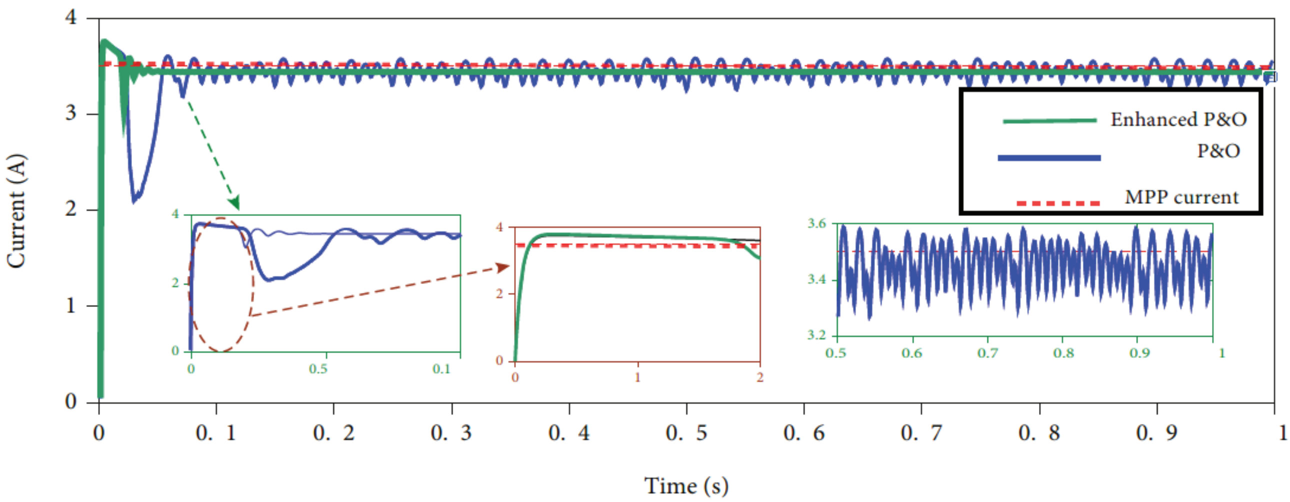

Figure 4. Curve of proposed simulation of enhanced of P&O algorithm

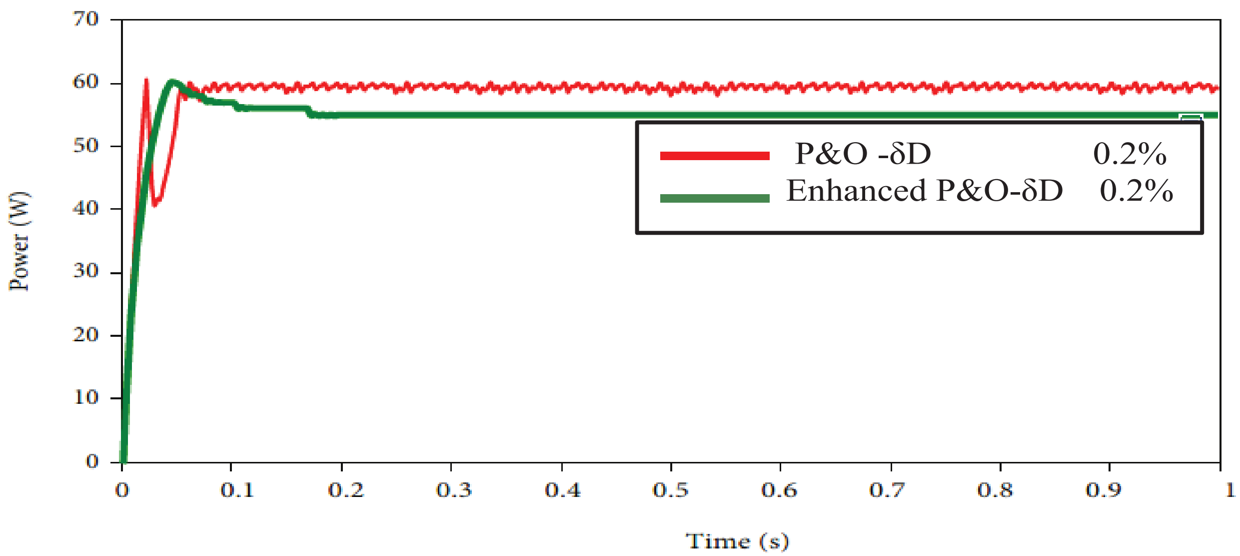

Figure 5. Illustration Enhanced P&O algorithm with δD variation

the fixed temperature (30°C), we see that the algorithm offers a good follow up of the maximum voltage of the panel with respect to its reference given by the manufacturer, which is equal to Vpm = 19.25.

The speed and stability of output power can be seen very clearly in Figure 5. A response time of tr = 50 ms is more than enough for the power to reach its reference value.

The output of electric current perfectly follows the shape of the output power. The maximum output current for $2000 W/m^2$ illumination reaches the manufacturer's value as shown in Figure 5.

The ripples of the electrical quantities, namely the power, the voltage, and the output current, remain largely acceptable given the nature of the photovoltaic generator and the conditions of use.

Finally, and according to these different results, we can see that the effect of the P&O program for a photovoltaic is impressive either in terms of speed or in terms of monitoring instructions in the steady state.

5. Conclusion

In conclusion, Maximum Power Point Tracking (MPPT) algorithms play a crucial role in photovoltaic (PV) systems to optimize the power output from solar panels. Among the various MPPT algorithms, the perturb and observe (P&O) algorithm stands out as a popular choice due to its simplicity and effectiveness. However, the basic P&O algorithm has some limitations, such as oscillations and steady-state errors, particularly under rapidly changing irradiance conditions.

To address these limitations and improve performance, an enhanced P&O algorithm has been developed. This enhanced algorithm incorporates a modified perturbation step and a dynamic step size adjustment scheme. As a result, the algorithm achieves a more stable and accurate tracking of the maximum power point, leading to improved energy harvesting and enhanced system performance.

The dynamic step size adjustment, based on the rate of change of the PV output power, enables the algorithm to adapt to varying irradiation levels efficiently. This adaptability makes it suitable for real-world conditions where solar irradiance can change rapidly.

To validate the performance of the designed control algorithm, tests were conducted under simple climatic conditions with a fixed temperature of 30°C and variable irradiation in the form of steps ($500 W/m^2$ and $2000 W/m^2$). MATLAB simulations were employed for evaluation, providing a cost-effective and efficient means of analyzing the algorithm's behavior under different scenarios.

The practical advantages of the enhanced P&O algorithm include improved energy harvesting, enhanced system performance, simple implementation, adaptability to varying climatic conditions, and reduced maintenance requirements.

Overall, the enhanced P&O algorithm demonstrates its potential to optimize the power output of photovoltaic systems, making it a valuable choice for practical applications in the renewable energy domain. However, further validation through physical testing and considerations of real-world constraints are necessary to ensure its successful implementation in operational solar energy systems.

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