An Improved P&O Algorithm for Single-Stage Grid-Connected Photovoltaic System under Rapidly Changing Environment Conditions

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Abstract. In producing its power, Photovoltaic (PV) performance is influenced by environmental factors, such as solar irradiance and temperature. System stability is needed to maintain safe operation of the system. This paper presents a Maximum Power Point Tracking (MPPT) control model of PV array to improve system reliability and the performance of MPPT. The main parameters in Matlab/Simulink simulation that become the highlight influences are the changes in solar irradiance from 500W/m² to 1000W/m² and ambient temperatures from 25°C to 50°C. With the control algorithm that has been made in the Perturb and Observe (P&O) method, it obtains the optimal voltage control point in each PV conditions in a power system. System simulation shows that the voltage stability was maintained above 510 Volt in various conditions of solar irradiance and temperature. The results of the control scheme show the stability of the system and the optimal performance of PV.

1. Introduction
Electrical energy holds a huge role in human civilization. The present of Solar Power Plant as the provider of electricity is expected to increase the reliability of the electric power system. The used of solar energy as the main source of electricity generation depends on the conditions of solar irradiance and the environment and it can affect the output generated by the photovoltaic (PV). Moreover, the solar power plant is connected to the grid, where a stable system is needed, thus it has to be reliable.

Because of inconsistency behavior of environment around the PV system, optimized operation under these conditions are important. To achieve the maximum performance of Maximum Power Point Tracker (MPPT) with better accuracy and speed, many methods are used in order to control the MPPT, such as Perturb and Observe method (P&O method), Fuzzy Logical Control, Incremental Conductance method (INC method), etc. Most of the MPPT control schemes use P&O as their algorithm due to its high reliability, simple implementation, and tracking efficiency [1]. It can adjust the direct change of power and voltage, thus making the ratio of dP/dV close to zero. In term of using this method, P&O has some shortcomings in reaching maximum points in rapidly changing conditions, so the resulting impact is the occurrence of oscillations and loss of tracking. The impact causes inaccuracy in determining the maximum point in obtaining power, so as to reduce the efficiency of PV.

This paper proposes an improvement of P&O algorithm control to produce the high performance of the PV system in rapidly changing conditions of solar irradiance and temperature. By adding the
current as an additional parameter, the MPPT can closely detect the changes in environmental conditions. When working in a situation far from its maximum power point, it will correct the curve point, and if the tracking direction is not good, the doubled step size helps to increase the approach point to maintain the stability of the voltage produced. The PV system is modeled in Matlab/Simulink and the algorithm is verified through simulation.

2. System model

2.1. Photovoltaic model and configuration

Solar power plant is arranged by photovoltaic in series or parallel connection to produce electricity. Photovoltaic is a semiconductor device which converts sunlight into electricity using PN Junction to produce photoelectric effect. In general, the single-diode equivalent circuit of photovoltaic [2] is shown in Figure 1:

![Figure 1. The equivalent circuit of photovoltaic](image)

From Figure 1, the equation of the circuit is show below:

$$I = \left( \frac{R_{sh}+R_s}{R_{sh}} \right) I_{sc} + K_i \Delta T \left( \frac{V}{G_n} \right) \left[ \frac{I_{sc}+K_i \Delta T}{\exp\left(\frac{q(V+R_s I)}{N_S k T_a}\right)-1} \right] - \frac{V+R_s I}{R_{sh}}$$

where:

- $I_{PV}$: PV current
- $V$: Output voltage
- $I_D$: Diode current
- $R_{sh}$: Shunt resistance
- $I_{sh}$: Shunt current
- $R_s$: Series resistance
- $I$: Output current

Ns : Number of cells connected in series

- q : Electron charge (1.6x10^-19 C)
- k : Boltzmann Constant (1.38x10^-23 J/K)
- a : diode constant factor (1≤a≤1.5)
- T : Temperature (Kelvin)
- G : Solar irradiance

For the simulated system as it is shown in Figure 2, it uses 60 panels of Photovoltaic, with the following specification in Table 1.

| Solar Power Plant Configuration |
|--------------------------------|
| **PV Name** | ATERSA Electricidad Solar A-60P, A-66P |
| **60 Panel (series 20, parallel 3)** |
| **PV Maximum Volt DC** | 700Vdc |
| **PV Power Rate** | 260.3W/Panel |
| **PV Total Volt DC Rate** | 614Vdc |
| **PV Short Circuit Current** | 8.99A |
| **PV Array Power DC** | 15.618kW |
| **PV Array Current DC** | 25.44A |
| **Inverter Power DC** | 15.35kW -> AC: 13.8kVA |
| **Frequency** | 50Hz |
| **Inverter Voltage DC** | 600V -> AC: 400V |
| **Transformer Voltage & Power** | 0.4/20kV; 1MVA |
As it is shown in Figure 2, the system configuration is a single-stage converter connected to the grid. The MPPT is combined with the inverter to control the IGBT. The transformer is installed in the system to support the needed voltage of the grid. The output of the inverter is effected by duty cycle value, as it is shown in equation 5:

\[ V_o = \frac{V_i D}{1-D} \]  

where \( V_i \) and \( V_o \) are input and output voltage of Inverter, and \( D \) is duty cycle.

![System topology for modeling](image)

**Figure 2.** System topology for modeling

### 2.2. Maximum Power Point Tracking (MPPT) model

Based on equation (1), the amount of output generated by PV depends on the environment condition, such as solar irradiance and temperature. Inconsistency behavior of the environment makes a non-linear output of PV. A tool is needed to achieve the needed power in various conditions. Maximum Power Point Tracker (MPPT) is an electronic device with a control algorithm that can track the possible maximum power based on the changing of solar irradiance and temperature [3]. Figure 3 show the characteristic of MPPT on the PV system.

In addition, there are various kinds of algorithm that can be implemented in MPPT and each algorithm has different characteristic. In this study, the method that is used is P&O method, because this method is already applied to the PV system and it needs to be improved. Further discussion will be discussed in section 3.

![Characteristic of MPPT](image)

**Figure 3.** (a) Photovoltaic cell P-V curve; (b) Photovoltaic cell I-V curve

### 3. The proposed control scheme

#### 3.1. Basic P&O algorithm

P&O algorithm is one of the methods used in MPPT to track the generation maximum power based on the unpredictable energy source, by perturbing and observing the generation power output. P&O method can increase or decrease the references voltage by changing the converter duty cycle to achieve the maximum power [4]. Basic P&O algorithm flowchart is shown in Figure 4.
Figure 4. MPPT power characteristic of P&O Algorithm

Based on the algorithm, the increasing power because of the voltage perturbation makes the operating point is approaching the maximum power point, and the decreasing power indicates that the operating point has passed the maximum power point [5]. Based on that statement, it can be simplified in Figure 5 [3].

By implementing this basic algorithm into the PV generation system, there is still some oscillation in tracking the maximum power due to rapidly changing in climate conditions. Oscillation happens around the maximum power point when the tracker reaches the PV peak power, and it deviates from its maximum power point. The cause of oscillation is energy losses [10].

![Diagram](image)

Figure 5. (a) Basic Perturb & Observe algorithm flowchart; (b) Proposed Perturb & Observe algorithm flowchart

3.2. Proposed P&O algorithm

To minimize the oscillation problem that is caused by rapidly changing in climate conditions, is to make an improved algorithm of P&O. The new parameter for the algorithm, which is the change in current, is added to increase the reliability of this improved algorithm [6], [9].

| Case | Delta P | Delta V | Delta I | Irradiance | Tracking Direction | Duty Control |
|------|---------|---------|---------|------------|--------------------|--------------|
| 1    | +       | +       | +       | Increase   | Right              | D = D - ΔD   |
| 2    | +       | +       | -       | Constant   | Right              | D = D + ΔD   |
| 3    | +       | -       | +       | Constant   | Right              | D = D + ΔD   |
| 4    | +       | -       | -       | Decrease   | Right              | D = D - ΔD   |
| 5    | -       | +       | +       | Increase   | Wrong              | D = D + 2ΔD |
| 6    | -       | +       | -       | Constant   | Wrong              | D = D + 2ΔD |
| 7    | -       | -       | +       | Constant   | Wrong              | D = D + 2ΔD |
| 8    | -       | -       | -       | Decrease   | Wrong              | D = D + 2ΔD |

Table 2. Duty control of proposed algorithm
Eight cases have been made to represent control in any conditions that might occur due to changes in irradiance and temperature. Based on the basic algorithm, the perturbation direction of step size ($\pm \Delta D$) can be set to increase or decrease the value of the duty cycle. In Table 2, it represents the perturbation conditions that might occur and steps that must be taken by adjusting the duty cycle. Large voltage and current output can be seen from the level of existing irradiance. The tracking direction can also be seen from the amount of power produced. If the received power is negative, the tracking direction is wrong, thus the step size duty cycle level must be doubled to increase the tracking speed. In Figure 6, the new algorithm control flow is proposed that is proposed. With the proposed algorithm, MPPT can control its output from oscillation that occurs due to changing irradiance or perturbation voltage.

4. Simulation and result

Matlab/Simulink application is used to simulate the experiment. Before starting the simulation, the parameters that are used in solar power plants are filled in Figure 2, as it is shown in Table 1. The experiment is created by set variations of irradiance and temperature. As it is shown in Figure 6 (a) and Figure 6 (b), when the temperature is set in a constant value 25°C, variations of irradiance are set from 400W/m$^2$ up to 1000W/m$^2$; when the irradiance is set in a constant value 1000W/m$^2$, variations of temperature is set from 25°C to 45°C. For the perturbation step size, it is set for 0.01 or 1% [7]. It is set in a large step size to see clearly the effect of the basic and proposed algorithm on large oscillation condition [11].

![Figure 6](image1.png)

**Figure 6.** Simulated condition of (a) irradiance and (b) temperature in 10 seconds

Based on the conditions that have been set, it can be seen the simulation results in Figure 7 and Figure 8. In Figure 7, the proposed algorithm has better speed in obtaining the voltage and stability at the observed point. As it follows in Figure 8 with less oscillation compared to the basic algorithm.

![Figure 7](image2.png)

**Figure 7.** Voltage comparison between basic & proposed in PV
Figure 8. (a) Power comparison between basic & proposed in PV; (b) Power comparison between basic & proposed in Bus 1 (B1)

From the results, it can be seen that the basic P&O algorithm is still not fast and high enough in generating voltages, and too many oscillations occur in rapidly changing irradiance. The proposed algorithm shows more stable in producing voltage and power. Moreover, this algorithm is able to reduce oscillation thus it maintains power stability.

5. Conclusion
In this paper, an improvement of P&O Algorithm is presented as a proposed algorithm. The addition of $\Delta I$ is an extra checking condition to improve the control of the MPPT. In the obtained results, it can be concluded that the proposed algorithm can improve PV stability and minimize oscillations on existing systems without the addition of other tools compared to the basic P&O algorithm, and it is very efficient to track changing environmental conditions (irradiance and temperature) to get the Maximum Power Point.

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