A Study on Maximum Power Point Tracking Technology for Solar Power Systems Using Power Variation to Adjust Step Response

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Abstract

The Perturb and Observe (P&O) method is a widely used Maximum Power Point Tracking (MPPT) algorithm in photovoltaic power generation systems. However, it faces a trade-off between minimizing steady-state oscillation losses and accelerating the transient response. This study introduces an enhanced P&O method with an adjustable step size to address this issue. The method starts with a larger step size during the initial tracking phase, and when the operating point surpasses the Maximum Power Point (MPP), the step size is dynamically adjusted by multiplying it by a factor F, reducing the perturbation magnitude. The step size gradually decreases until it reaches the minimum value that the hardware or system can set up and execute. The proposed method retains the transient advantage of a larger perturbation step size while reducing power loss by minimizing steady-state oscillations. Compared to fixed perturbation step sizes and a fixed multiplier, the proposed method achieves faster perturbation convergence, maintaining a 9 step rapid tracking with a 4% duty cycle in transients and up to 99.98% in steady-state tracking.

Keywords: Maximum power point tracking, P&O method, variable step-size P&O method.

1. Introduction

In the next five years, the installed capacity of renewable energy will continue to increase, with solar photovoltaic systems and wind energy accounting for a record 96%. With continued policy support, it is expected that by 2028, the installed capacity of solar photovoltaic and wind energy will more than double compared to 2022. Throughout the forecast period, records will be continuously broken, with solar installed capacity reaching nearly 539.6 GW (main case). Therefore, how to effectively utilize solar energy has become an important issue. This study primarily explores the advantages and disadvantages of solar MPPT algorithms. Using the simulation software MATLAB, it simulates the P&O methods, including fixed step size[1], [2], [3] the variable step size [4], [5], [6], [7] and the algorithm proposed in this paper. The steady-state and transient responses are analyzed in detail. The P&O for adjusting the step response of power changes proposed in this paper alters the duty cycle disturbance of the controller based on the path of the operating point movement and the power change. The algorithm proposed in this paper is easy to implement and has high steady-state tracking accuracy and fast-tracking performance, achieving the goal of MPPT.

2. PV MODULE

In this study, The PV cell is a single-diode equivalent circuit model, which is described in Fig. 1, including the diode(D), parallel resistance (RP), and series resistance (Rs). The output current and voltage of a solar cell is expressed as equation (1).

$$I = I_{pv} - I_s\left\{\exp\left[\frac{q(R_s I + V)}{nKT_k}\right] - 1\right\} - \frac{R_s I + V}{R_p} \qquad (1)$$

When K is the Boltzmann’s constant; q is the charge of an electron (1.602×10-19 coulomb); n is the ideality factor; TK is the temperature in Kelvin; Ig, Is and I is photogenerated current, saturation current and panel current.

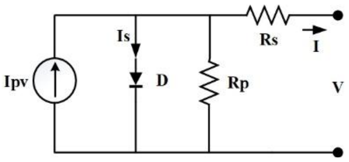


Fig 1. PV module equivalent circuit.

The simulation characteristic curves used in this study are based on the parameters listed in Table 1.

Table. 1 PV module parameters

Parameters	Symbol	Value
Maximum output power	P_{max}	234.24W
Open circuit voltage	V_{OC}	51.7 V
Maximum power voltage	V_{mp}	44.27 V
Short circuit current	I_{SC}	5.6 A
Maximum power current	I_{mp}	5.29 A

3. System Configuration

A DC-DC converter is a crucial element in PV systems. It provides an interface between the PV array and load. The PWM signal's duty cycle is adjusted based on the value determined by the MPPT algorithm for maximum power tracking. The relationship between the output voltage (V_o) and input voltage (V_{in}) of a boost converter is expressed as equation (2).

$$\frac{V_o}{V_{in}} = \frac{1}{1-\delta} \tag{2}$$

The duty cycle is denoted as δ. Consequently, the relationship between the output current and input current can be expressed as equation (3)

$$I_{in} = \frac{1}{(1-\delta)} I_o \tag{3}$$

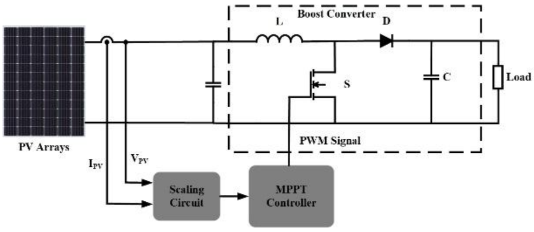


Fig. 2 System architecture diagram

To track the MPP of a solar cell, the output voltage and current signals of the solar cell are first captured. These feedback signals are then input into the controller for computation, which generates a new duty cycle to control the boost converter, thereby achieving MPPT. The system architecture is illustrated in Fig 2.

4. Variable Step Size and Proposed Algorithm

The algorithm introduced in this section is based on the principle of the P&O method. To address the limitations of the fixed-step P&O method, a variable-step P&O method is required for improvement. Many variable-step algorithms proposed in the literature involve numerous parameters, making them relatively complex. Based on the concept of variable steps and the P&O method, equation (4) represents the M-factor P&O method, and the proposed relationship is expressed as follows.

$$\Delta D(n) = M \times \Delta D(n\text{-}1) \tag{4}$$

Where $\Delta D(n)$ is the modified duty cycle.

$\Delta D(n\text{-}1)$ is the previous duty cycle.

M is a fixed proportional factor.

As seen from equation (4), the current duty cycle perturbation magnitude D is related to the previous duty cycle perturbation magnitude $D1$ and the M-factor. The relationship is straightforward.

To maintain the advantage of rapid response, the following conditions must be met before executing this relation (4) and (7), as shown in equations (5) and (6).

$$P(n-2) < P(n-1) \tag{5}$$

$$P(n-1) > P(n) \tag{6}$$

The parameters defined in the above two equations are as follows:

$P(n)$: Latest power value

$P(n-1)$: Previous power value.

$P(n-2)$: The power value from the two previous times.

The power variation adjustment step rule proposed in this paper is expressed in equation (7). $\Delta D(n)$ is the modified duty cycle. $\Delta D(n\text{-}1)$ is the previous duty cycle.

It utilizes a fixed duty cycle under steady-state variations to obtain the perturbation power change on the left side (ΔP_L) and the right side (ΔP_R). The maximum value of the power changes from both sides is taken as the denominator (ΔP_F) in equation (8). Here, ΔP represents the power difference between the latest power value and the previous power value.

$$\Delta D(n) = \frac{\Delta P(n)}{\Delta P_F} \times \Delta D(n\text{-}1) \tag{7}$$

$$\Delta P_F = \max(\Delta P_L, \Delta P_R) \tag{8}$$

equations (5) and (6) are the primary conditions for determining the use of the relationships in equations (4) and (7). In Fig 3, power tracking path 1 crosses the MPP, transitioning from the left half-plane of the P-V curve to the right half-plane, while path 2 follows the opposite direction. Both conditions involve crossing the MPP. If this phenomenon occurs, it indicates that the operating point is oscillating near the MPP. If the method used is the fixed step P&O rule to adjust the fixed duty cycle near the MPP, it is called the oscillation phenomenon, causing a loss in the steady state. Therefore, the duty cycle is multiplied by the M-factor from equation (4) to reduce its variation, thereby minimizing disturbances and improving steady-state tracking accuracy. This design can be applied to either the open-circuit voltage side or the short-circuit current side for tracking, achieving the same effect.

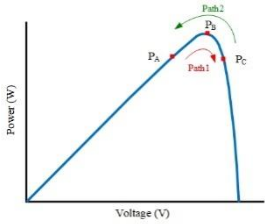


Fig. 3 Two paths passing through the MPP.

The flowchart is shown in Fig 4. First, the voltage and current values of the solar cell are measured, and the power value is calculated while continuously performing the P&O method. When the conditions in equations (5) and (6) are met, the fixed-proportion method uses equation (4) to update the duty cycle. Meanwhile, the proposed power variation adjustment step method utilizes equations (7) and (8) to calculate the latest duty cycle, continuing until the minimum preset perturbation magnitude is reached. From the above, it is known that the goal of achieving fast transient tracking to MPP and reducing oscillation at the MPP during steady state can be met. Therefore, this study conducts simulation experiments using a fixed duty cycle, the M fixed proportional factor, and the proposed power variation adjustment step response method.

5. Experimental Results

Using MATLAB to simulate the proposed method, variable step size with a fixed ratio M value of 0.9, and fixed duty cycles of 4% and 1% for P&O. Fig. 5(a) shows the waveform of these three methods for 1000 W/m^2 and 700 W/m^2 solar irradiances. Fig. 5(b) is the Duty cycle variation and stopping perturbation process. The performances of the tested methods are summarized in Table 2. The transient step is the number of steps required for the system to reach a steady state, and this value can be used to calculate its loss.

The proposed method requires 9 steps for transient rise at 1000 W/m^2, which is the same as the maximum fixed-step 4% P&O method in terms of time. Tracking accuracy is when the system reaches steady-state and the total recorded data contains 200 points for calculating the power average loss. Both the fixed-ratio perturbation and the proposed method ultimately stabilize at 0.1%, achieving the same accuracy of 99.98%. The average power losses are 8.55W, 12.87W, 3.32W, and 2.99W. Under solar irradiation of 700 W/m^2, the transient rise of the proposed method requires 7 steps, with a transient loss of 173.91 W. The tracking accuracy is 99.99%, and the average loss is 0.96 W. It can be seen that the proposed method controller can improve the transient and steady-state performance of the PV system simultaneously.

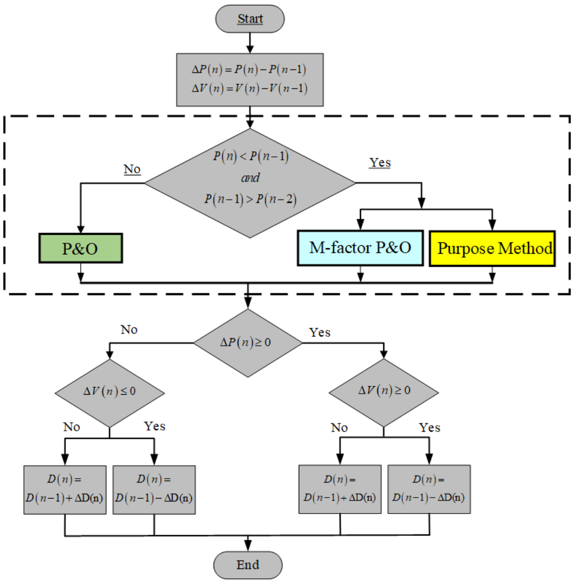


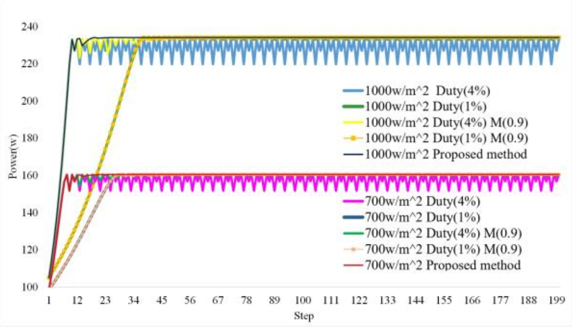
Fig 4 Flow chart of the three P&O methods

Table 2. Summarized performance of methods.

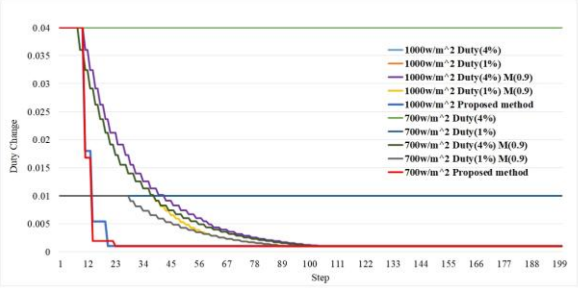
Methods	W/m2	P&O(4%)	P&O(1%)	M-factor (0.9)	Proposed
Transient Step	1000	9	36	9	9
	700	7	27	7	7
Transient Loss	1000	578.58W	2506W	578.58W	578.58W
	700	173.91W	785.48W	173.91W	173.91W
Tracking accuracy	1000	97.54%	99.82%	99.98%	99.98%
	700	98.07%	99.83%	99.99%	99.99%
Average loss	1000	8.55W	12.87W	3.32W	2.99W
	700	3.98W	4.16W	1.09W	0.96W

6. Conclusions

This study utilizes MATLAB software to simulate three methods of MPPT for solar systems. From the experimental results, it can be seen that the proposed method of adjusting the power change step P&O has high efficiency in steady-state response and fast transient response, effectively achieving MPPT for solar energy. The transient response maintains the rise time of the traditional 4% P&O, which takes 9 steps, while the steady-state tracking accuracy reaches as high as 99.98%. The average tracking power loss of 2.99W is the lowest in the test, thus the overall efficiency is high, which verifies its advantages and makes it easy to implement.



(a). PV source output performance.



(b). Duty cycle variation.

Fig. 5 Simulation results of three methods.

Acknowledgements

This work was supported by the National Science and Technology Council (NSTC), Taiwan [Project code NSTC 113-2222-E-224 -003 -].

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