Adaptive multi-variable step size P&O MPPT for high tracking-speed and accuracy

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Abstract. Improvement of the output power under different weather conditions is one of the major concerns for photovoltaic (PV) system design. The perturbation and observation (P&O) maximum power point tracking (MPPT) algorithm is the most commonly used technique in practice due to its simplicity and ease of implementation in low-cost hardware. However, the conventional fixed-step P&O tracking method uses a fixed iteration step size based on the requirements of the steady-state accuracy and the speed of the algorithm. In addition, it is very hard to specify the variable step-size scaling factor (M) under fast ripped change of insolation. This paper presents an adaptive multi-variable step-size to solve the trade-off between the speed of the algorithm and efficiency at steady-state. Computer simulation is carried out on MATLAB/Simulink to validate the performance of the proposed algorithm. By using multi-variable step-size algorithm, MPPT response speed and accuracy can be significantly enhanced under rapid change of irradiance compared to one scaling variable step-size P&O method.

1. Introduction
Nowadays the worldwide installed photovoltaic (PV) power capacity shows a nearly exponential increase and are expected to continue this trend in the future [1]-[3]. The actual power yield from PV systems is highly dependent on the environmental conditions such as solar irradiance and temperature. Therefore, it is difficult to achieve the maximum power under different environmental condition for a practical photovoltaic (PV) system without utilizing maximum power point tracking (MPPT) techniques [4]-[5]. So far, many MPPT methods have been created and developed to increase the energy efficiency of the PV system.

MPPT techniques such as fractional short circuit current [6], fractional open circuit voltage [7], perturb and observe (P&O) [8]-[10], incremental conductance (IC) [11], temperature and irradiance based method (T&I) [12], fuzzy logic [13], ripple correlation control (RCC) [14], sliding mode [15] control techniques have been advanced to harvest the maximum power from the PV array.

Among all various types of MPPT techniques, perturbation and observation (P&O) method is widely used due to its simplicity, ease of use and low cost [9]. Unfortunately, the fixed step P&O tracking algorithm suffers from a tradeoff between tracking speed and accuracy. Thereby, several techniques and developed algorithms have been created to mitigate that problem. In reference [8], the authors presented IP&O method based on an adaptive algorithm which adjusted the perturbation step and the width of the hysteresis band to improve the performance of classic P&O method. Although the
method improved the performance of tracker under various solar irradiation conditions, its tracking speed was lower than the fixed-step algorithm.

A combined two-technique MPPT control scheme was suggested in [9]. The aim of the scheme was to improve the MPP tracking efficiency of the classical P&O method by using a combination of P&O and constant voltage (CV) methods. The time delay in switching between one method to the other was the main challenge of the proposed scheme, whereas it causes an additional power loss. Two step sizes in [10] were used in MPPT algorithm, one of them was used to quickly converge of MPP and the other used for eliminating the oscillations around MPP. However, additional high-resolution sensors were required to reduce power losses under very low solar irradiance which increase the cost of implementation.

This paper aims at creating a new adaptive multi-variable step P&O MPPT technique to increase the steady-state energy efficiency as well as enhance the performance of tracking speed and accuracy.

2. Conventional fixed-step P&O algorithm
The basic operation of P&O MPPT algorithm can be described as follows [8], [9]:

1) The algorithm scans the P-V curve of the PV module to look for the MPP by changing the operating point which is known as perturbation step.
2) The observation step [i.e. the change in power (ΔP)] is measured.
3) The direction of perturbation depends on the value of \( \frac{\Delta P}{\Delta V} \):
   a. If it is greater than zero, the perturbation of the voltage should be increased.
   b. If it is lower than zero, the perturbation of voltage should be decreased (i.e. reverse the direction of search).
4) The algorithm continues the search for the MPP so as to find an operating point such that \( \frac{\Delta P}{\Delta V} \) is very close to zero in any direction.
5) The P&O keeps perturbing the system to detect any change in the MPP (caused by a change in the climate), which triggers a new scan. This can be represented by the following equations:

\[
\begin{align*}
\frac{\Delta P}{\Delta V} &= 0 \text{ at MPP} \\
\frac{\Delta P}{\Delta V} &> 0 \text{ at left of MPP} \\
\frac{\Delta P}{\Delta V} &< 0 \text{ at Right of MPP}
\end{align*}
\]

\( V(K) = V(K-1) \pm M \) \hspace{1cm} (1)

Where, k and k-1 are the present and previous instants and M is constant search step.

3. Concept of multi-variable step P&O algorithm
In the fixed-step algorithm, the operating point at steady-state oscillates around the MPP resulting in the waste of some amount of the available energy. By reducing the step size, these oscillations can be minimized, but it takes a relatively long time to reach the MPP which also leads to energy loss. Modification has been proposed to reduce this problem by introducing variable search steps [9]. The modified variable step can be described as in (3).

\[
V(k+1) = V(k) \pm M (P(k) - P(k-1))
\]

\( V(K) = V(K-1) \pm M \) \hspace{1cm} (3)

Here parameter \( M \), is a constant scaling factor used to tune the perturbation step sizes in the design, which is proportional to (ΔP) term. However, choosing the value of scaling factor is difficult
and remains unsolved. Figure 1 illustrates the PV module characteristics under different irradiation levels with various loci of the MPPs.

![Figure 1. The PV characteristics under different irradiation levels.](image)

When radiation changes from $G_1$ to $G_2$ (W/m$^2$), the instantaneous power decreased by $\Delta P$ and the system operate far from the MPP. Therefore, the instantaneous voltage should be shifted by $\Delta V$ to obtain the new maximum power point. To adopt an accurate value of scaling factor, several values of $\Delta P$ and the corresponding values of $\Delta V$ are recorded and then plotted in Figure 2. As can been seen, the relationship between the voltage difference and power difference is nonlinear. Therefore, it is hard to choose one scaling factor that appropriates for all changes in radiation levels. Consequently, multiple scaling factors should be used to increase the speed response of the MPPT under sudden change of insolation.

![Figure 2. Relationship between difference voltage and power.](image)

In this work, three scaling factors (i.e. $M_1$, $M_2$, and $M_3$) are specified to guarantee high speed and accuracy of the algorithm. The scaling factors can be determined by the slope of three tangents as in (4).

$$M_i = \frac{\Delta V_i}{\Delta P_i} \quad &i = 1, 2, 3. \quad (4)$$

The three scaling factors produce two threshold power, known as $P_{thr1}$ and $P_{thr2}$. For a small change in radiation (i.e. $\Delta G$ is small), a small change in power ($\Delta P$) occurs, which requires a small step ($\Delta V$). Thus, the scaling factor ($M_3$) is suitable in this case until the threshold power $P_{thr2}$. Higher change in radiation produces a higher change in power. When the change of power greater than $P_{thr2}$ and smaller
than $P_{\text{thr1}}$, the factor $M_2$ is appropriate for this condition. If the change of power is very large greater than $P_{\text{thr1}}$, then the scaling factor $M_1$ is utilized in this situation, where a large step $\Delta V$ is required for a high-speed response. The flow-chart of multi-variable P&O (MV-PO) MPPT algorithm is as shown in Figure 3.

**Figure 3.** Flow-chart of multi-variable P&O MPPT algorithm.

### 4. Simulation results

Computer simulation is carried out on Matlab/Simulink software in order to verify the feasibility and effectiveness of the proposed algorithm. For the propose of simulation, a commercial PV module (i.e. SunPower SPR-305) is chosen to meet the electrical demand of the load. The PV module is represented by one diode model as described in [16]. A DC-DC boost converter is utilized as a power conditioning unit between the PV module and the load. The schematic diagram of the PV system with MPP tracker is depicted in Figure 4. For all simulations, the temperature is assumed constant at 25 °C.

**Figure 4.** Schematic diagram of PV system with MPP tracker.
A dynamic simulation with solar irradiance profile varies in steps between levels 1000 W/m², 800 W/m², 200 W/m² and 1000 W/m² as displayed in Figure 5 is done. It should be noted that the three steps in the profile represent a small, moderate, and large changes in solar radiation, respectively. The corresponding output power results for the proposed algorithm is as shown in Figure 6. As can be seen, the MV-PO algorithm succeeds to capture the maximum output power under different irradiance levels. On the other hand, the tracker fails to track the maximum output power, when only one scaling factor is considered as shown in Figures 7, 8 and 9. As expected from Figure 3, when the algorithm uses one scaling factor M1, M2, or M3, the tracker has a successful operation only for large, moderate, or small changes in solar radiation, respectively.

5. Conclusions
In this paper, a multi-variable step-based P&O method is proposed to specify an accurate value of the scaling factor (M). Determination of the scaling factor is discussed in details, and a quite simple realization rule is presented. The MV-PO method can improve not only the steady-state performance of the PV system but also the dynamic response. Furthermore, the proposed algorithm has a wider operating range than the previous variable step-size MPPT algorithms. Subsequently, MV-PO algorithm is more suitable for practical operating conditions.
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