Research on MPPT technology based on three-stage variable step size disturbance observation method

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Abstract. For the traditional disturbance observation method, it is impossible to take into account both tracking speed and steady-state accuracy with a fixed step size, so we change the step size and propose disturbance observation method based on three-stage variable step size. The specific method is to set the basic step size and the slope threshold of the P-V curve, and then scale factors according to the interval segment of the slope value of the working point, so as to realize the dynamic adjustment of the step size. Simulation experiments show that after the algorithm is improved, the tracking speed is faster when the environment changes suddenly; when the environment is stable, the power oscillation is reduced. The above has certain positive significance for improving efficiency of the photovoltaic system.

1. Introduction
When a solar cell undergoes photoelectric conversion, the output power is nonlinearly affected by irradiation intensity and temperature. Under stable operating conditions, there is a single maximum power point for solar cells. In order to improve the energy efficiency of the photovoltaic system, we use MPPT technology to make its power about the maximum power. There have been many researches on MPPT algorithm, such as disturbance observation method [1], conductance increment method [2], fuzzy control method [3] and particle swarm optimization method [4]. Among them, the disturbance observation method has simple structure, is easy to be implemented, has low cost and has good tracking effect, but it cannot guarantee the tracking speed and the steady-state accuracy at the same time. Therefore, in this paper, the traditional disturbance observation method is changed to the disturbance observation method based on three-stage variable step size, and the Simulink algorithm is used to verify the before and after improvement of tracking speed. The result show that compared with the traditional disturbance observation method, the improved algorithm has faster tracking speed and smaller power oscillation at steady state.

2. Principle of Traditional Disturbance Observation Method
The output power of solar cells is affected by the environment. Figures 1 and 2 are standard characteristic curves of the output power of solar cells when light source maintains radiation intensity of 1000 W/m2 or the temperature remains unchanged at 25 °C, and another condition is changed. In the figures, no matter under what circumstances solar cells work, there is a maximum power point in its output power, and the maximum power point will also change as external conditions change. Therefore, it is necessary to use MPPT technology to track it.
Fig. 1 The characteristic curve of the standard output power of the solar cell when the temperature changes

Fig. 2 The characteristic curve of the standard output power of the solar cell when radiation intensity changes

The basic workflow of the disturbance observation method shown in Figure 3:
The disturbance observation method is to use the output voltage of the solar cell array as a reference voltage $V_{\text{ref}}$ in a certain state, and to increase or decrease the reference voltage $V_{\text{ref}}$ gradually by adding the disturbance voltage $\Delta V$ in a fixed period, thereby changing the output power of the array, and compare the power value before and after the change to determine how to change the disturbance voltage in the next step. If the output power of the solar cell array becomes larger due to a certain disturbance, the direction of the disturbance remains unchanged. On the contrary, if the output power becomes smaller due to the disturbance, it indicates that the direction of the disturbance voltage change needs to be changed in the next cycle. Through this repeated operation, the system output can be maintained near the maximum power point [1].

The disturbance observation method has simple structure, and we can achieve tracking by measuring few parameters. However, in this method, the tracked power will oscillate around the maximum power point, part of electrical energy will be lost. The disturbance of the regulation voltage can change the oscillation.

3. Improvement of the step size of the algorithm

For traditional algorithms, this paper proposes a method to change the fixed step size. We use the tangent slope ($dP/dV$) of the P-V characteristic curve as a basis to determine whether the step size should be increased or decreased by a large amount.

In the standard P-V characteristic curve of the output power of the solar cell, When the operating point is to the left of the maximum power point, the value of the tangent slope of the operating point is
greater than 0, when the working point is far from the maximum power point, the slope value of the tangent of the working point is relatively large, and conversely, the smaller when the working point is close to the maximum power point and gradually approaching 0. When the operating point is to the right of the maximum power point, the value of the tangent slope of the operating point is less than 0. When the operating point is away from the maximum power point, the value of the tangent slope of the operating point is relatively small. When the operating point is closer to the maximum power point, the value of the tangent slope is greater, it gradually approaches 0. The absolute value of the slope of the tangent of the P-V characteristic curve can be expressed by Equation 1:

\[
Slop = \frac{P_n - P_{n-1}}{V_n - V_{n-1}}
\]  

(1)

As can be seen from the P-V characteristic curves in Fig. 1 and Fig. 2, when the operating point is on the left side of the maximum power point, the same voltage changes, and the power change is slower than the right side. In the research of Al-Diab and Fangrui [5] [6], the adjustment of the step size is gradually changed according to \(dP/dV\) or \(ΔP/ΔI\). This method has certain shortcomings, that is, the step size changes gradually in any case, even if it is far from the maximum power point. This will have a certain effect on the tracking speed. To avoid this effect, when the operating point is on the left side of the maximum power point, we make multi-stage adjustments to the step size.

First, we set a smaller base voltage to adjust the step size \(ΔV_b\). The setting of this step size is based on the steady-state oscillation range of the maximum power point that can be tracked. Then we set a larger step size scaling factor \(N\), which is related to the tracking speed of the algorithm. Finally, we select the corresponding slope critical value according to the number of segments, and set the number of segments to \(n\) which will affect the tracking speed of the maximum power. When the number of segments is large, the step size will gradually change, and the tracking process will be smooth, but the tracking speed of the algorithm cannot be guaranteed. When the number of segments is too low, the tracking speed will increase, but it may cause more power loss due to excessive steady-state oscillation. The mathematical relationship of the multi-stage variable step size is shown in Equation 2:

\[
\begin{align*}
\Delta V &= ΔV_b × N \quad Slop > S_i \\
\Delta V &= ΔV_b × N\left(\frac{n-2}{n-1}\right) \quad S_i < Slop < S_{i-1} \\
\Delta V &= ΔV_b × N\left(\frac{1}{n-1}\right) \quad S_{i-1} < Slop < S_{n-2} \\
\Delta V &= ΔV_b \quad Slop < S_{n-1}
\end{align*}
\]  

(2)

In the formula: \(S1, S2, ... S_{n-1}\)-the critical value of the segment slope.

In this paper, \(n = 3\), that is, the algorithm of a three-stage variable step size. According to the above equation, the relationship is:

\[
\begin{align*}
\Delta V &= ΔV_b × N \quad Slop > S_i \\
\Delta V &= ΔV_b × \frac{N}{2} \quad S_i < Slop < S_{i-1} \\
\Delta V &= ΔV_b \quad Slop < S_{i-2}
\end{align*}
\]  

(3)

Fig.4 is the workflow of the disturbance observation method of the three-stage variable step size.
4. Simulation analysis

During the test, the temperature or irradiation intensity changes respectively or simultaneously. The basic step size before and after the improved algorithm is set to 0.001, the scale factor after the improved algorithm is set to 10, and the segmentation thresholds are set to S1 = 4 and S2 = 2. The radiation intensity and temperature change curves taken by the test are shown in Figures 5 and 6.
First, the tracking effect before and after the disturbance observation method is tested. For example, Fig. 7 shows the case where the fixed temperature is 25°C. According to the situation in Fig. 5, we compare test results by the disturbance observation method with varying irradiation intensity. In the figure, when the temperature is unchanged and the irradiation intensity is changed separately, the output current before and after the algorithm will change greatly with the large change in the irradiation intensity, the output voltage is basically stable, and the output power change trend closely follows the current change trend. However, when the radiation intensity changes suddenly, the overshoot of voltage and current is small, and the output power of the improved algorithm is more stable than that of the traditional algorithm.
(b) Improvement on the tracking effect of disturbance observation method

**Fig.7** The tracking effect before and after the improvement of the disturbance observation method when the temperature is unchanged and the irradiation intensity changes

Fig.8 shows that when the irradiation intensity is unchanged at 1000 W/m², according to the disturbance observation method of changing temperature in Fig.6, we improve and then compare test results.
Fig. 8 The tracking effect before and after the improvement of the disturbance observation method when the irradiation intensity is constant and the temperature changes.
We compare the figures. When the irradiation is fixed and the temperature changes independently, the output current of the algorithm before and after the improvement is basically stable, but the output voltage will change greatly with the temperature change, and the change trend of the output power closely follows the temperature. But in the improved algorithm, when the temperature changes suddenly, the tracking speed is significantly faster than the one in the traditional algorithm, but the overshoot is slightly higher; when the temperature changes suddenly, the tracking speed is significantly faster than the one in the traditional algorithm, and the overshoot significantly lower. The overall tracking effect of the improved algorithm is better.

Fig. 9 is a comparison of effects of the disturbance observation method before and after improvement when the temperature and the irradiation intensity change simultaneously according to situations of Fig. 5 and Fig. 6. In the figure, when the irradiation intensity and temperature change at the same time, the output current and output voltage of the algorithm before and after the improvement are unstable, which results in a large change in output power, but when the environment changes suddenly, the tracking speed of the improved algorithm is obviously faster than that of the traditional algorithm, and the overshoot during the mutation adjustment is smaller.
Fig. 9 When the temperature and irradiation intensity change at the same time, the tracking effect of the disturbance observation method before and after improvement.

5. Summary
In this paper, the traditional disturbance observation method is improved, and disturbance observation method based on three-stage variable step size is proposed. Through simulation analysis, we find that the improved algorithm's maximum power tracking is greatly improved than the traditional algorithm's tracking. When the temperature and irradiation intensity change separately or at the same time, the tracking performance of disturbance observation method based on three-stage variable step size both are superior to the traditional disturbance observation method, and have good dynamic performance and steady-state performance.

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