Application in photovoltaic MPPT based on improved hysteresis loop comparison method

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Abstract. In order to overcome the misjudgement and oscillation of the traditional perturbation observation method when tracking the maximum power point of the PV system, this paper proposes a fixed-zone variable-step hysteresis comparison algorithm. The bi-directional perturbation of the hysteresis loop can effectively avoid the occurrence of misjudgement; after setting the partition voltage threshold, different step lengths can be used to track specific regions, which can ensure the tracking speed and maintain the system stability. Finally, the proposed algorithm is validated in Matlab/simulink and the results show that the method is effective in tracking the maximum power point of the PV system in all aspects compared to conventional algorithms.

1. Introduction
With the gradual maturity of science and technology, people's demand for energy is gradually transforming from traditional fossil fuels to new sources of clean, safe, efficient and renewable energy. With the background of the times and government support, solar energy has become mainstream in the power generation industry. However, solar power plants require high upfront investment and the efficiency of solar power generation is easily affected by the external environment. In order to keep the photovoltaic system working efficiently at all times, researchers have proposed the maximum power tracking technique (MPPT) for photovoltaic systems[1]. MPPT algorithms with different tracking accuracies and development costs are used in different applications, the most commonly used being Perturbation and Observation (P&O) and Incremental Conductivity (INC). Both of these algorithms track the maximum power point by adding a small amount of perturbation to the system and are simple to implement. However, the need to continuously apply perturbations results in a system that is constantly in a state of dynamic change, and the oscillations caused by this dynamic change are very detrimental to the stability of the system. Therefore, the choice of the size of the added perturbation becomes particularly important[2]. In addition, when the operating environment of a PV system changes, the tracking of traditional algorithms can lead to misjudgements, causing the tracking point to deviate infinitely from the actual maximum power point, thus reducing the energy conversion efficiency[3]. In this paper, we analyse the shortcomings of the traditional P&O algorithm and propose a fixed-zone variable-step hysteresis comparison algorithm. The unidirectional perturbation of the traditional P&O algorithm is replaced by a bidirectional one to avoid the problem of misjudgement due to environmental changes; then different perturbation steps are selected according to the partitioning of the voltage power curve, so that the system can maintain maximum system stability while ensuring rapidity.
2. Photovoltaic cell model and output characterisation

Photovoltaic cells are able to generate electricity due to the photovoltaic effect[4]. When light is shone on the surface of a photovoltaic panel, a potential difference is created by the directional movement of electron and hole pairs within the semiconductor material, which can generate an electric current if an external circuit is connected. The individual photovoltaic cell model is usually represented in Figure 1.

![Photovoltaic cell equivalent model circuit diagram.](image)

Figure 1. Photovoltaic cell equivalent model circuit diagram.

Applying Kirchhoff's law in Figure 1 yields the PV cell output current-voltage relationship:

\[
I = I_{ph} - I_d \left[ \exp \left( \frac{q(U + IR_s)}{KA} \right) \right] - \frac{U + IR_s}{R_s} \quad (1)
\]

Where \(I_{ph}\) is the current flowing from the photogenerated current source and its value magnitude is related to the intensity of the light; \(I_d\) is the current flowing on the diode; \(A\) is the diode quality factor; \(T\) is the absolute temperature; and \(K\) is the Boltzmann constant.

To obtain the output characteristic curve of the PV cell, the PV cell is modelled in the simulation conditions of Matlab/simulink. The main parameters of the PV panel are: \(I_{SC}=6.83A\), \(U_{OC}=43.92V\), \(I_{m}=5.69A\), \(U_{m}=35.13V\). Figure 1(a) and Figure 1(b) show the output characteristics of the PV cell with constant temperature and variable light at 25°C. Figure 1(c) and Figure 1(d) show the output characteristics of the PV cell when the light intensity is kept constant at 1000W/m² and the temperature is changed.

![Photovoltaic cell output characteristic curve.](image)

Figure 2. Photovoltaic cell output characteristic curve.

Analysis of the output of the PV cell during the four environmental changes in Figure 2 shows that: when the ambient temperature is a fixed value, the maximum power point of the PV system will increase with the increase in light intensity; when the light is fixed, the position of the maximum
power will gradually decrease with the increase in temperature. The output characteristics of a PV cell will change to varying degrees following changes in the external environment, resulting in a maximum power point that cannot be fixed at a standard value. However, as can be seen in the P-U output characteristic curve, the maximum value is uniquely present on a separate curve. Therefore, the use of maximum power tracking technology can maintain the output power of the PV system near the maximum value at all times in a dynamically changing environment, avoiding the consequences of low efficient output with high economic input.

3. Traditional P&O algorithm and their problems
The P&O algorithm is one of the most frequently used algorithms in MPPT for photovoltaic power generation[5]. It has few objects to control and a simple tracking process. It does not require too many calculations, but simply adds a certain step of perturbation to the detected PV cell output voltage periodically. The power difference is then calculated before and after the cycle to determine the direction of the next perturbation until the power output of the system reaches its maximum. The voltage change pattern during the perturbation process is shown in (2).

\[ V_{k+1} = V_k + \text{sgn}(dP/dV) \Delta V \]  

Where \(dP\) is the amount of change in power, \(dV\) is the amount of change in voltage and \(\Delta V\) is the perturbation voltage step added. It can be seen that a forward perturbation needs to be added when the amount of change in power and voltage are of the same sign, and when the sign of change in both is different, the perturbation is made to proceed in the opposite direction.

When using a fixed step size for power tracking of PV systems, the P&O algorithm is unable to meet both high accuracy and fast speed due to the choice of step size. If the step size is chosen to be large, the system can quickly reach near the maximum power point, but the system will operate with more serious power oscillations; if a small voltage is used for the step size, the oscillation problem is suppressed, but the tracking speed will be much slower. At the same time, the photovoltaic system is always in a changing environment, and according to the output characteristics curve of the photovoltaic cell, the maximum power point will change as the output curve moves. If the tracking rule of the traditional disturbance observation method is still used to judge the direction of the disturbance addition when the curve is shifted, the system is likely to gradually move away from the real maximum power point due to misjudgement[6], thus causing a large amount of energy loss.

4. The fixed-zone variable-step hysteresis comparison algorithm
In order to solve the problem of possible misjudgement of the traditional P&O algorithm when the environment changes, a hysteresis loop comparison is introduced on the basis of the basic disturbance. The hysteresis loop comparison method[7] adds a two-way power difference comparison to the control principle so for the system to make a judgement on whether the external environment is changing, the basic control logic is:

Let the starting point of the perturbation be point A. Take a point B and a point C in equal steps before and after this point, and record the power values \(P_A, P_B\) and \(P_C\) at the three points. compare the power values at points B and C with those at point A. When \(P_A > P_C\), the symbol is "+", when \(P_B > P_A\), the symbol is "−", in the rest of the cases the symbol is recorded as "−". A common situation is shown in Figure 3.

\[ (a) \quad (b) \quad (c) \]

Figure 3. Three-point power comparison diagram.
After two perturbations the power comparison results are obtained: if the situation in Figure 3 (a) is positive for both perturbations, the voltage is on the left side of the maximum power point and needs to be perturbed further; if the situation in Figure (c) is positive, the voltage is already on the right side of the maximum power point and the perturbation direction needs to be changed; if the situation in Figure (b) is positive, the voltage is already running at the maximum power point. If the situation shown in (b) means that the voltage is already running near the maximum power point or that the external environment is changing, it is sufficient to keep the voltage perturbation situation unchanged.

The hysteresis loop comparison method can be used to determine whether to continue adding perturbations to the system by means of symbols, for the purpose of avoiding misjudgements. However, the hysteresis loop comparison method has the same problem of step size selection as the P&O algorithm. In order to accelerate convergence while providing system operation accuracy, the concept of fixed partitioning with variable step size is proposed. Figure 4 shows the partitioning of the power-voltage output curve of the PV cell.

![Figure 4. Partition diagram of photovoltaic cell output curve.](image)

In Figure 4 the power-voltage curve is divided into three zones. Zones 1 and 3 are farther away from the MPP and the step size should be chosen to match the need for accelerated convergence, and the slope of the curve in zone 3 is greater, as illustrated in [8], and the slope of the curve in zone 3 is 4 times that of zone 1, so zone 3 should be higher than zone 1 in the choice of step size. In zone 2, the power has gradually converged around the MPP and the step size should be reduced to reduce the power oscillation back and forth during operation and improve accuracy. In order to minimise the oscillations around the MPP, set Minimum power difference. When the power difference obtained from the first two perturbations meets the specified value, the system will judge that the power is already at its maximum value, thus outputting the current voltage, the basic flow chart of the algorithm is shown in Figure 5.

![Figure 5. Algorithm flow chart.](image)
5. Analysis of simulation results
In order to verify the effectiveness of the fixed-zone variable-step hysteresis comparison algorithm for tracking in PV MPPT, the conventional P&O algorithm was compared with it by simulation. The simulation model was built in Matlab/simulink based on the system diagram shown in Figure 6, where the model parameters in the PV panel are shown in Table 1. The Boost converter is used to adjust the load resistance to match the internal resistance of the PV panel, so as to output the maximum power. The parameters of the Boost circuit are: $C_1=0.1\text{mF}$, $C_2=0.1\text{mF}$, $L=0.01\text{mH}$ and $R=10\Omega$.

![Figure 6. Photovoltaic power generation system diagram.](image)

The simulation time was set to 0.2s, the initial environment was $25^\circ\text{C}$, and the light intensity was $700\text{W/m}^2$. The step size of the perturbation observation method was chosen to be $0.5\text{V}$ after combining rapidity and stability, and the light intensity suddenly changed to $1000\text{W/m}^2$ at 0.1s. The simulation output waveforms of the PV cell for the perturbation observation method and the hysteresis comparison method with constant partitioning and variable step size are shown in Fig. 7(a) and Fig. 7(b) respectively.

![Figure 7. Photovoltaic cell simulation output waveform.](image)

(a) the disturbance observation method
(b) the fixed-zone variable-step hysteresis comparison algorithm

![Figure 8. Simulation local details.](image)

(a) Startup process
(b) Steady state oscillation process
(c) Light intensity change process
From Figure 7(a) simulation results can be seen, the traditional P&O algorithm because of the fixed value of the step, it is difficult to meet the growth rate of the voltage in different stages, in the tracking system maximum power point when the output power of the volt battery produced a significant oscillation. The simulation waveforms of the fixed-zone variable-step hysteresis comparison algorithm in Figure 7(b) can all see that the voltage grows at a rate up to the maximum power point in the pre-start period, and the power output is smoother, and the voltage and current waveforms of the PV cell output have been improved. Compared to the P&O algorithm, the improved algorithm not only has improved dynamic response capability, but also has very good stability performance. Figure 8 shows the comparative local details of the two algorithms. In Figure 8(a) it can be seen that the fixed-zone variable-step hysteresis comparison algorithm uses a larger step size in the first stage of tracking, so the tracking speed is improved by a factor of 1 compared to the P&O algorithm. Figure 8(b) shows a graph of the oscillation waveform of the algorithm at the maximum power point attachment. The improved algorithm has reduced the oscillation rate to a very low level and the oscillation step is present to continue tracking the maximum power point that may change under sudden environmental changes. As can be seen in Figure 8(c), the power tracked by the P&O method is shifted more when the light amplitude is changed and the energy loss is more severe. The improved algorithm stabilises the voltage within the correct perturbation range because of the hysteresis loop, ensuring that the system can track quickly and accurately to the new maximum tracking point. Experiments have demonstrated that the method is effective in overcoming misjudgements when tracking the maximum power point of the PV system, with fast and accurate tracking and also stability, resulting in a steady increase in the energy utilisation of PV power.

6. Conclusions
In this paper, after analysing the problems of the traditional perturbation observation method, we propose a fixed-zone variable-step hysteresis comparison algorithm. The power-voltage curve of the PV cell is partitioned so that a large step size can be used to speed up the tracking speed at a distance from the maximum power point, while a small step size can be used nearer to the maximum power point to make the system output more stable. Simulation results demonstrate the effectiveness of the method in PV maximum power point tracking.

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