Research on control strategy of maximum power tracking variable step size perturbation & observation method for photovoltaic power generation system

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Abstract. There are three defects of traditional perturbation and observation method in the maximum power tracking control process of photovoltaic power generation systems, which are oscillation, misjudgment and poor tracking accuracy. Thus, a variable step perturbation and observation method based on power prediction is proposed for three-level DC/DC converters in this paper, which effectively solved oscillation, misjudgment, tracking accuracy problems, improving the tracking speed and precision of the algorithm, and the verification results of the maximum power tracking algorithm based on the three-level DC/DC converter structure has also been indicated.

1. Introduction
With the increasing demand for electricity, photovoltaic microgrid system, as a power supply mode for rational utilization of renewable energy, has received extensive concern and attention [1]. Maximum Power Point Tracking (MPPT) technology is a key technology in photovoltaic power generation systems, algorithms based on which have been proposed so far. Common methods including Constant Voltage Method (CVT), Perturbation & Observation Method (P & O), Incremental Conductance Method (INC), and Fuzzy Control Method (FLC). Recent years, both domestic and foreign scholars have been researched the maximum power tracking algorithm. Based on the output characteristics of photovoltaic arrays, many effective and improved maximum power tracking algorithms have been raised. However, most implemented MPPT technologies are based on two-level DC/DC converters, few researches have been done on three-level DC/DC converters.

The traditional two-level DC/DC converter has the defects of weak withstand voltage and large switching loss, which seriously restricts its use in high-voltage, high-power photovoltaic microgrid power generation systems. The three-level DC/DC converter can apply switching devices with lower withstand voltage to high-voltage and high-power applications [2-3]. However, the three-level DC/DC converter has multiple levels of output, which will cause the midpoint voltage fluctuation of the output DC voltage, which will affect the quality and stability of the output voltage. At the same time, it is also necessary to solve the technical problem of MPPT of the three-level DC/DC converter in order to ensure the efficient and stable operation of the photovoltaic microgrid power generation system.
The variable step size perturbation & observation method based on power prediction researched in this paper improves misjudgment, oscillation and tracking accuracy problems compared to the traditional perturbation observation method. The simulation model is built under MATLAB, the results show that the algorithm can be well applied to photovoltaic power generation systems of three-level DC/DC converters. It not only completes the task of maximum power tracking and obtains higher output power, but also solves the oscillation problem of the traditional algorithm, reduces the power loss and assures higher output accuracy.

2. Traditional disturbance observation method

Perturbation & observation method is one of the most widely used MPPT algorithms nowadays, its working principle is shown in Figure 1.

![Figure 1. Control schematic of perturbation & observation method.](image)

The basic principle of this method is as follows: generating perturbation voltage with a fixed step size, collecting and comparing the output power of the solar panel after the perturbation voltage is applied. If the output power increases, indicating that the direction of the perturbation is positive, the voltage will increase at the same step size; If the value of the output power decreases, indicating that the direction of the disturbance is negative, decreasing the voltage in the opposite direction with the same step. In this way, the solar cell is finally operated near the extreme point. There are three main defects of traditional perturbation & observation method: oscillation, misjudgment and fixed step. Detailed analysis of the three defects are as follows [4-6].

2.1. Oscillation phenomenon

Due to the dynamic tracking process of perturbation & observation algorithm, there is always a disturbance voltage, even if there is no change in the external environment, oscillation will still occur near the maximum output voltage. As shown in Figure 2, when the photovoltaic module is working at point A at a certain moment, $\Delta U$ interference has occurred to the voltage at the operating point, the operating status is updated to point B. At this time, $\Delta P > 0$, $\Delta U > 0$, according to the traditional perturbation & observation method, forward interference voltage $\Delta U$ will continue to be generated, then the next working state is point C, and the state change at this time to $\Delta P < 0$, $\Delta U > 0$, and it will return to point B again. When it works, the reverse interference voltage will be generated in the next cycle. It can be seen that the maximum power output point will jump back and forth at three points A, B, and C, leading to oscillation.

![Figure 2. Oscillation phenomenon.](image)
2.2. Misjudgment phenomenon

When the external environment changes abruptly, the algorithm is prone to misjudgment. As shown in Figure 3, the light intensity suddenly changes. The photovoltaic cell operates near the MPP A under stable illumination conditions, output power PA. If the light conditions do not change, move to the right when the voltage of the disturbance M at a point in time to be output Pm Power, at which point $\Delta P > 0$, $\Delta U > 0$, the disturbance direction is correct.

If the light intensity suddenly decreases and the output power decreases from $P_m$ to $P_B$, $\Delta U$ is still greater than zero at this time, while $\Delta P * < 0$, the control strategy will determine that the current positioned on the right of the maximum power point, and the disturbance direction is wrong. Reduce the output voltage of photovoltaic cell modules. If the light continues to fall, there may be continuous misjudgment of the system, which will cause the operating point to be farther away from the maximum power point, which will have an erroneous impact on the direction and trend of the disturbance, and the maximum power point cannot be tracked.

![Figure 3. Misjudgment](image)

2.3. Fixed step size analysis

The step size not only affects the control accuracy, but also affects the response speed during the dynamic change of the system. The fixed tracking step size cannot simultaneously improve the tracking accuracy and the system tracking speed. When the step size is large, the speed of searching for the maximum power point is significantly improved, but at the same time, the output power oscillates back and forth near the MPP with a large amplitude, which makes it impossible to accurately track the MPP; When the step size is small, although the accuracy of finding the maximum power point is increased, the dynamic response speed is slowed down, the time when the power point approaches the maximum power point is increased, resulting in the battery working in a low efficiency output area for a long time.

3. Variable step size perturbation & observation principle based on power prediction

In order to solve the problem that tracking accuracy and response speed cannot be taken into account, a variable step size control method is adopted instead of a fixed step size control method. Working principle: As the working point is far away from the MPP, select a larger step size to improve the response speed of the algorithm, and track to the vicinity of the MPP as soon as possible; when the working point is close to the MPP, reduce the step size, improve the accuracy of the algorithm and find the MPP.

The formula for determining the step size is as follows:

$$\Delta U = \omega \frac{dP}{dU} = \omega \frac{P(n+1) - P(n)}{U(n+1) - U(n)}$$  \hspace{1cm} (1)

$dP$: The power value of the (n+1)th after the voltage disturbance minus the value of the nth.
$dU$: The voltage value of the (n+1)th after the voltage disturbance minus the value of the nth.
$\omega$: Constant determined by system characteristics, usually is 0.1 - 0.2.

Light intensity and temperature are slowly changing, the stability of the system can be assured when the step size is changing, but the problem of misjudgment cannot be solved very well. Therefore, a method based on power prediction is proposed. Working principle: When the sampling frequency is constant, the light intensity per unit time remains unchanged, and the output power of the PV is basically unchanged, which can be regarded as a linear change, as shown below in Figure 4.
When \( t = nT \), the output voltage is \( U_{(n)} \), and power is \( P_n \). At this moment, no disturbance signal is applied to the voltage, and the output power is \( P_{(n+1/2)} \) after half a period. The sampling frequency is extremely fast, similar to linear changes. The D-value \( \Delta P^2 \) of the prediction value after one period \( P^*_{(n+1)} \) and the nominal power of a half period \( P_{(n+1/2)} \) is equal to \( \Delta P_1 \) which is the D-value of \( P_{(n+1)} \) to the original output value \( P_n \).

![Figure 4. Power prediction principle diagram.](image)

The predicted power after a period \( t = (n+1)T \) is:

\[
P^*_2 = 2P_{(n+1/2)} - P_n
\]  

(2)

After obtaining predicted power at \( t = (n+1)T \) is applied to the interference voltage, when \( t = nT \) the actual voltage is \( U_{(n+1)} \) and the power value is \( P_{(n+1)} \). To some extent, \( P^*_2 \) and \( P_{(n+1)} \) are two points under the same condition, the difference is whether the voltage has been disturbed. According to these two data, the interference of external conditions can be avoided and the right direction can be found.

Based on the above two improvement strategies, the improved disturbance observation method flowchart can indicated as below in Figure 5.

![Figure 5. Flow chart of improved P & O.](image)
4. Variable step size perturbation & observation principle based on power prediction

Based on the three-level DC/DC converter, the MPPT control algorithm is simulated and verified. Verified whether the disturbance prediction method based on power prediction can work effectively under the condition of three-level DC/DC converter, whether the dynamic tracking speed and the static tracking accuracy are improved compared with the traditional disturbance observation method.

In view of this project is photovoltaic power generation system based on three-level DC/DC converter and has the characteristics of high voltage and high power, the selected objects are simulated by a JA Solar produced JAM6(K)-60-270/4BB polycrystalline silicon photovoltaic panels. A $15 \times 3$ photovoltaic array is established as an input, that is, total 45 photovoltaic panels are used, every 15 panels are connected in series as a column, and the 3 columns connected in series are connected in parallel. Its equivalent circuit is shown in Figure 6.

![Figure 6. $m \times n$ photovoltaic cell equivalent circuit.](image)

In a standard environment $R_{ref} = 1000\text{kW/m}^2$, $T_{ref} = 25^\circ\text{C}$, the parameters of a single photovoltaic panel are: $P_{max} = 0.27\text{kW}$, MPP voltage $U_m = 30.68\text{V}$, MPP current $I_m = 8.80\text{A}$, short-circuit current $I_{sc} = 9.29\text{A}$, and open-circuit voltage $U_{oc} = 38.39\text{V}$. According to the equivalent circuit of the photovoltaic array shown in Figure 6, in the standard environment, $15 \times 3$ photovoltaic array parameters are: $P_{max}^* = 12\text{kw}$, $U_m^* = 460.2\text{V}$, $I_m^* = 26.4\text{A}$, $I_{sc}^* = 27.87\text{A}$, $U_{oc}^* = 575.85\text{V}$. The simulation systems of the traditional P & O and the variable step size P & O based on power prediction are shown in the following two pictures (Figure 7 and Figure 8).

![Figure 7. MPPT simulation system of traditional P & O.](image)

![Figure 8. MPPT simulation system based on power prediction P & O.](image)
The sampling time is uniformly set to 0.0001s, and in the power-prediction variable step size disturbance observation method, the proportionality constant $\omega$ is set to 0.1.

Input PV array parameters for simulation. The output power of the photovoltaic array is different in different situations:

- $S = 1000\text{W/m}^2$ light intensity and $\text{Tem} = 25^\circ\text{C}$ temperature, the maximum output power of photovoltaic array $P_m = 12.2\text{kW}$;
- $S = 800\text{W/m}^2$ light intensity and $\text{Tem} = 25^\circ\text{C}$ temperature, the maximum output power of photovoltaic array $P_m = 9.41\text{kW}$;
- $S = 1000\text{W/m}^2$ light intensity and $\text{Tem} = 15^\circ\text{C}$ temperature, the maximum output power of photovoltaic array $P_m = 12.25\text{kW}$;

**4.1. Constant temperature ($\text{Tem}=25^\circ\text{C}$)**

Figure 9 shows the MPPT control output power under the traditional P & O algorithm. At the beginning, the light intensity was 1000W/m$^2$, and the output power gradually increased from time 0. The tracking of the MPP was completed at about 0.039s, and the output power was tracked to $P_{\text{mmp}} = 11.18\text{kW}$. At 0.1s, the light intensity drops to 800W/m$^2$, the output power starts to oscillate within a short duration, the amplitude is $\Delta y = 0.302\text{W}$, and the MPP is traced after a short oscillation, oscillating continued for about 0.03s, nominal power is 9.109W.

![Figure 9.](image)

**Figure 9.** Tem=25 $^\circ\text{C}$, the output power of traditional P & O when light intensity changes.

Figure 10 shows the output power under the tracking of the improved P & O. At the beginning, the light intensity is 1000W/m$^2$, and the voltage gradually rises from time 0. The tracking of the MPP was completed at about 0.026s, and the output power was tracked to $P_{\text{mmp}} = 11.97\text{kW}$. At 0.1s, the light intensity drops to 800W/m$^2$, strong oscillation in a short time with an amplitude $\Delta y = 0.129\text{W}$ and oscillation duration is nearly 0.02s. The final measured nominal power is 9.217kW.

![Figure 10.](image)

**Figure 10.** Tem=15 $^\circ\text{C}$, the output power tracked by improved P & O when light intensity changes.
4.2. Constant light intensity

Since the temperature change has hardly influence on the nominal power, we focus on the analysis of the mutation of temperature. The light intensity is constant $S=1000\text{W/m}^2$. Output power tracked by traditional P & O is shown in Figure 11, in 0.2s, the temperature of $25^\circ \text{C}$ mutated to $15^\circ \text{C}$, the output power fluctuated sharply for a short time at the moment of mutation, but it soon tracked to a new MPP. The final nominal power obtained by traditional P & O was 11.89kW, with a maximum oscillation amplitude of about 0.12kW.

![Figure 11.](image)

In the case of temperature changes, the output power waveform of the improved P & O is shown in Figure 12. Under the improved P & O control strategy, the tracking output power is 12.01kW, which is improved than the old method, and the maximum amplitude is just 0.06W, which is much smaller than the traditional method.

![Figure 12.](image)

The simulation data is summarized in Table 1 and 2, the relevant conclusions can be drawn as follows:

1) For photovoltaic power generation systems with high power and high voltage, the P & O with variable step size based on power prediction can be well applied to photovoltaic power generation systems with three-level DC/DC converters under conditions of changing light intensity and temperature. It not only completes the task of maximum power tracking, but also improves the tracking accuracy from 97.2% to 98.1% and obtains higher output power.

2) From the simulation results, the output waveform tracked by improved P & O is much more stable, and the oscillation amplitude is much smaller, which effectively solves the oscillation problem and reduces power loss.

3) To solve the contradiction of tracking accuracy and response speed, under the conditions of obvious changes in environment, not only increase the MPP reaching speed by 40%, but also improve the output accuracy to the MPP.

Therefore, that the variable step size P & O based on power prediction can be effectively applied to photovoltaic microgrid power generation systems based on three-level DC/DC converters, which has good applicability and superiority. It not only solves the problem of the MPP tracking algorithm of the
three-level DC/DC converter in the photovoltaic microgrid system, but also get rid of the shortcomings of traditional methods and greatly improve the stability of the system.

Table 1. Constant temperature (Tem=25 ℃), comparison the results of two algorithms.

| Algorithm         | $S = 1000 \, W/m^2$ | $S = 800 \, W/m^2$ | Oscillation amplitude $\Delta y$ | Oscillation time $\Delta t$ |
|-------------------|---------------------|---------------------|----------------------------------|-----------------------------|
| Traditional P & O | 11.87 kW            | 9.109 kW            | 0.302 kW                         | 0.03 s                      |
| Improve P & O     | 11.97 kW            | 9.217 kW            | 0.129 kW                         | 0.018 s                     |

Table 2. Constant light intensity ($S = 1000W/m^2$), comparison the results of two algorithms.

| Algorithm         | $Tem = 25 \, ^\circ C$ | Oscillation amplitude $\Delta y$ | Oscillation time $\Delta t$ |
|-------------------|------------------------|----------------------------------|-----------------------------|
| Traditional P & O | 11.87 kW               | 11.89 kW                         | 0.012 kW                    | 0.006 s                     |
| Improve P & O     | 11.95 kW               | 12.01 kW                         | 0.002 kW                    | 0.0012 s                    |

5. Variable step size perturbation & observation principle based on power prediction

This paper studies the MPPT technology applicable to the three-level topology, and proposes a variable step size P & O based on power prediction. Through simulation modeling and comparison, it is verified that the improved P & O not only improves the tracking speed and the accuracy of the system, but also reduces the oscillation amplitude of the output waveform, ensures the balance of the output voltage, improves the output performance of the system, and achieves the expected effect in this paper.

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