Application of Photovoltaic Power Optimizer in Distributed Photovoltaic Power Generation System

Qian ZHANG*, Peng-Fei LI, Yue-Lin SONG and Yan-Chi ZHANG

Shanghai Dianji University, 236 Xiali RD. Pudong New District, Shanghai, China

*Corresponding author

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Abstract. Compared with centralized photovoltaic power generation systems, the distributed generation system's power generation conditions are more complex and changeable, and are extremely susceptible to environmental impacts. To study the mismatch problem of distributed generation systems, a parallel-connected single-switch photovoltaic optimizer circuit was proposed. The current control method was used to realize the energy balance of the mismatched components inside the module, and the working points of each photovoltaic substring were adjusted to improve the photovoltaic efficiency. The output power of the component when the component is internally mismatched.

Introduction

In the past ten years, the development of photovoltaic power generation in China is very good. In 2017, China's newly installed photovoltaic power generation capacity reached 53.06 GW, of which, the installed capacity of photovoltaic power stations reached 33.62 GW, an increase of 11% over the same period of last year; distributed photovoltaic installed capacity reached 19.44 GW, a year-on-year increase of 3.7 times. As of the end of December 2017, the cumulative installed capacity of photovoltaic power generation nationwide has reached 130.25 GW, of which installed capacity of photovoltaic power plants has reached 100.59 GW, and distributed photovoltaic installed capacity has reached 29.66 GW.

At present, photovoltaic power generation systems generally suffer from problems such as shadowing, performance differences among components, hot spot effects, and aging of the battery panels [1]. Furthermore, photovoltaic power generation systems are sensitive to changes in external environments and the consistency of components. When shading is blocked or the mismatch caused by the individual differences of PV modules, the output power of the system will drop significantly. Over time, these conditions will lead to greater and greater loss of power generated by photovoltaic power generation systems, which will restrict the further promotion and application of photovoltaic power generation [2]. Therefore photovoltaic power optimizer came into being.

Photovoltaic Power Generation Mismatch Problem

To study the solution to the mismatch problem of photovoltaic power generation, we first need to classify the categories of mismatch problems [3]. In a centralized photovoltaic power generation system, since the erection sites are generally selected as open plains or deserts, the lighting conditions of the various photovoltaic modules are highly consistent, and the components such as the string mismatch and component mismatch are likely to appear only outside the large clouds. While in distributed photovoltaic power generation systems such as building integrated photovoltaic systems, the power generation conditions are more complex and changeable. The number of photovoltaic modules is small, and it is vulnerable to the impact of local shadows. The main problem encountered is the mismatch within the module [4]. The various types of photovoltaic mismatch caused by partial shadow shading are shown in Fig.1.
There are two main reasons for the output power attenuation of photovoltaic power generation systems under mismatch conditions. First, because the output characteristic curve exhibits multiple peaks, the traditional Maximum Power Point Tracking (MPPT) algorithm is subject to multiple extreme values. Point interference, cannot find the true maximum power point; Second, due to the characteristics of mismatch, the maximum power point of the various parts of the system operating current is different, even if the maximum power point in the system characteristic curve, there is a waste of power generation potential.

Mismatch Problem Solutions

For the mismatch problem of photovoltaic power generation, many scholars have done in-depth research and formed the concept of PV optimizer. Photovoltaic optimizers are also referred to as a MIC (Module Integrated Converter), a PV conditioner, or a Generation Control Circuit (GCC) in some literatures. According to its use, it can be divided into an optimizer for solving the string mismatch and component mismatch outside the module, and an optimizer for solving the internal mismatch problem inside the module. According to the connection structure of the photovoltaic optimizer and the photovoltaic module, it can be divided into a series-type photovoltaic optimizer and a parallel-type photovoltaic optimizer. The specific classification is shown in Table 1.

Table 1. Photovoltaic optimizer classification.

<table>
<thead>
<tr>
<th>Panel-integrated PV optimizer</th>
<th>Tandem type</th>
<th>Parallel type</th>
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<tbody>
<tr>
<td>Full power conversion</td>
<td>partial power conversion</td>
<td>Optimizer input to other components</td>
</tr>
<tr>
<td>Buck</td>
<td>Full bridge</td>
<td>Buck</td>
</tr>
<tr>
<td>Boost</td>
<td>Push-pull</td>
<td>Buck-Boost</td>
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<td>Buck-Boost</td>
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The problem of string mismatch and component mismatch is mainly solved by a series-connected photovoltaic optimizer. Related research has become more mature. This kind of method needs to change the connection structure of the photovoltaic power generation system, adjust the output of each photovoltaic module through a DC-DC converter, and then form a series string in series, and finally connect the grid through the inverter. This structure allows independent distributed MPPT for each PV module, so that in the case of string mismatch and component mismatch, each PV module still operates at its respective maximum power point.

Photovoltaic cells as a special “battery”, the power drop problem in the partial shadow after series connection, although the nature of the problem with the traditional battery charge balance is different, there are certain similarities in the solution. In the literature [5], there is a method for equalizing the voltages of each battery in a series battery pack through an equalizing circuit. The principle block diagram is shown in Fig.2.
Applying the self-equalization energy of this series structure to photovoltaic modules, the parallel photovoltaic optimization method can be deduced to achieve energy balance of photovoltaic modules under unbalanced power generation conditions. Its block diagram is shown in Fig3. The so-called parallel photovoltaic optimization refers to optimizing the (equalization) unit and a certain number of photovoltaic cells in parallel connection, the external output power, and then adjust the corresponding working method of photovoltaic cells. Similar to the battery charge equalization method, the inputs $U_{IN1}$ and $U_{IN2}$ of the photovoltaic sub-string equalization unit may be from an external power supply, or from the total output of the photovoltaic module. The difference is that the optimization (equalization) units in parallel in PV applications do not control the voltages of individual photovoltaic sub-strings to be identical. Instead, the operating current of each photovoltaic sub-string escapes the limitation of the branch current. The actual operating point can be adjusted independently. Through a certain control algorithm, each photovoltaic substring can work at the maximum power point under the current lighting conditions.

Assuming that there are two photovoltaic sub-strings in a PV module, in which the sub-string 2 is shaded, the radiation power is reduced from the normal 1000 W/m$^2$ to 700 W/m$^2$. The characteristics of photovoltaic modules and individual photovoltaic sub-strings are shown in Fig.4. Due to the different illumination radiation received by the two photovoltaic sub-strings, the characteristic curves and voltages $U_{1\text{max}}$ and $U_{2\text{max}}$ and currents $I_{1\text{max}}$ and $I_{2\text{max}}$ corresponding to the maximum power points $P_{1\text{max}}$ and $P_{2\text{max}}$ are all different, and the characteristic curve synthesized in series exhibits a multi-peak phenomenon. At this point, the traditional MPPT algorithm will be affected by the multi-peak phenomenon, and the output power will drop. Even by improving the algorithm, the maximum output power $P_{\text{pmax}}$ in the synthesis characteristic can be achieved. Due to the equal limitation of the series branch current, it is impossible for the two photovoltaic sub-strings to work at the maximum power point at the same time, and the power value is still less than the sum of $P_{1\text{max}}$ and $P_{2\text{max}}$. That is, there is a waste of power generation potential.

According to the photovoltaic cell mathematical model, the photovoltaic cell output current is

$$I_{out} = I_{ph} - I_0 \left[ e^{\frac{q}{nkT}(U_{oc}+I_{oc}R_s)} - 1 \right]$$

(1)
In the formula, \( I_{\text{ph}} \) is the photocurrent, which is proportional to the light intensity \( I_n \); \( I_o \) is a dark saturation current; \( n, q, K, T \) represent the ideal factor of P-N junction, charge constant, Boltzmann constant, and temperature, respectively, and can also be considered as constants; \( R_S \) is the series parasitic resistance of the battery. In this analysis ignore, formula (1) can be simplified as

\[
I_{\text{out}} = k_1 I_{n1} - I_0 (e^{k_1 U_{\text{out}1}} - 1)
\]

(2)

In the formula, \( k_1 \) and \( k_2 \) are constants. In the case of partial shadow shading as described above, the I-U curve of the shaded photovoltaic sub-string falls below the normal curve, as shown in Fig. 5.

When the photovoltaic module is operated in zone1, since the photovoltaic sub-string 2 operates in the second quadrant, its corresponding bypass diode is turned on, and only the photovoltaic sub-string1 generates electricity, and the distributed MPPT can be performed through the conventional cascade optimizer. The PV module operates at the maximum power point.

When the PV module operates in zone 2, no bypass diode conducts, then there is

\[
I_1 = k_1 I_{n1} - I_0 (e^{k_1 U_{\text{out}1}} - 1)
\]

(3)

\[
I_2 = k_1 I_{n2} - I_0 (e^{k_1 U_{\text{out}2}} - 1)
\]

(4)

According to Kirchhoff’s law, the series branch current is equal. That is \( I_1 = I_2 \), the voltage relationship can be introduced as

\[
k_1 (I_{n1} - I_{n2}) - I_0 (e^{k_1 U_{\text{out}1}} - e^{k_1 U_{\text{out}2}}) = 0
\]

(5)

The output power is

\[
P_{\text{out}} = I (U_{\text{out}1} + U_{\text{out}2}), 0 < I < I_{\text{ph2}}
\]

(6)

When adding a parallel PV optimizer, the current relationship is

\[
I_1 = I_2 + \Delta I
\]

(7)

The voltage relationship is

\[
k_1 (I_{n1} - I_{n2}) - I_0 (e^{k_1 U_{\text{out}1}} - e^{k_1 U_{\text{out}2}}) = \Delta I
\]

(8)

The output power is

\[
P'_{\text{out}} = I_1 U_{\text{out}1} + I_2 U_{\text{out}2} = I_2 (U_{\text{out}1} + U_{\text{out}2}) + \Delta IU_{\text{out}1}, 0 < I_2 < I_{\text{ph2}}
\]

(9)

After the shunt optimizer proposed in this paper is added, by compensating the current \( \Delta I \) (which is the difference between the maximum power currents of the two substrings) of the photovoltaic sub-strings receiving lower power of irradiation radiation, the two photovoltaic sub-strings can be individually adjusted. The operating current is the operating point, so that the two substrings work at the maximum power point under the current conditions, thereby increasing the output power. Regardless of the power loss of the equalization unit, the total output power of the PV module is boosted. At the same time, the parallel equalization unit compensates only the unbalanced part of the energy and belongs to the partial power converter. Compared to full power converters, the energy handled is low and losses are low.

**Summary**

This paper analyzes some of the mismatch problems that occur in volt-power generation systems, briefly explains the advantages of the solar power optimizer that distinguishes it from the traditional optimizer, and the reasons why the power optimizer improves the photovoltaic power generation
system, and proposes the parallel power under the partial shadow of the photovoltaic components. The optimization method, which can achieve power boosting under the condition that the photovoltaic components are subjected to different shading. The advantage of this method is obvious. The proposed parallel optimizer starts from the wasteful power generation potential of photovoltaic modules under the condition of partial shadow release, and eliminates the multi-peak phenomenon of the PU characteristic curve of photovoltaic modules without changing the internal structure of photovoltaic modules. The maximum output power of the PV module in this case. However, it should be noted that the shunt optimizer needs to be used with a PV module power optimizer or micro-inverter with MPPT capability to maintain maximum power output over a wider range of output voltages. Parallel power optimization methods still require further in-depth research.

References


