Simulation of distributed photovoltaic power generation system

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Abstract: Combined with the operation characteristics of photovoltaic power generation system, the mathematical model and simulation model are established, and the control strategy of bipolar inverter with wide output characteristics and the maximum power point tracking (MPPT) control method of conductance increment method are designed. The maximum power output and stable operation of distributed photovoltaic power generation system are realized. The simulation results show that the photovoltaic power generation system model established in this paper can effectively reflect the characteristics of distributed photovoltaic power generation and MPPT control. With the change of lighting conditions, the distributed photovoltaic power generation system can accurately adjust the system output, which is of great significance for the research and operation of distributed photovoltaic power generation system.

Key words: Distributed photovoltaic; maximum power point tracking (MPPT)； inverter control； modeling and simulation.

1. Introduction

With the continuous progress of distributed photovoltaic technology and the gradual decline of equipment cost, distributed photovoltaic has more prominent technical advantages in power generation performance, operation control and environmental protection. At the same time, the proportion of installed power generation capacity in our country is increasing year by year. According to the statistics of the National Energy Administration, in 2021, the newly added photovoltaic grid-connected capacity reached 54.88 million kW, a cumulative total of 3.06 trillion kW, an increase of 13.9% year on year, among which the newly added distributed photovoltaic grid-connected capacity was 29 million kW in 2021, accounting for 55%. In terms of newly installed capacity connected to the grid, distributed PV power generation has surpassed centralized PV power generation.

With the rapid growth of photovoltaic power generation, especially distributed photovoltaic power generation, in order to master the characteristics and operation characteristics of distributed photovoltaic power generation, strengthen the management and control of distributed photovoltaic power generation, and improve the operation capability and control level of distributed photovoltaic power generation, it is necessary to carry out research on the operation characteristics of distributed photovoltaic through modeling and simulation of distributed photovoltaic system [1-3].

In this paper, based on the operation characteristics of distributed photovoltaic, the mathematical model and simulation model of distributed photovoltaic are established, and the control strategy of bipolar inverter and the maximum power point tracking (MPPT) control method of incremental conductance method are designed. In addition, The simulation system of distributed photovoltaic power generation system is also built, and the change of lighting conditions, MPPT control and operation control of the simulation system are designed. Finally, the simulation results of distributed photovoltaic power generation system are analyzed[4-6].

2. PV array modeling

When the sunshine intensity and temperature are constant, the V-I curve of the output voltage and current of the photovoltaic array is called the volt-ampere characteristic of the photovoltaic array. Typical PV array V-I characteristic curve is shown in Figure 1.

As shown in Figure 1, V_{oc} and I_{sc} represent the open circuit voltage and short circuit current of the photovoltaic array. As can be seen from the V-I characteristic curve in Figure 1, the output current I of the photovoltaic array varies with the output voltage V. The output power of photovoltaic array is the product of output voltage and output current, that is, output power P=V*I, which is the area S of the shaded part in Figure 1.

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The key of photovoltaic power generation system MPPT is to find an output voltage V_m and output current I_m, so that the shadow area P_m is the maximum, and at this time, is the voltage V_m, current I_m and maximum power value s corresponding to the maximum power point.

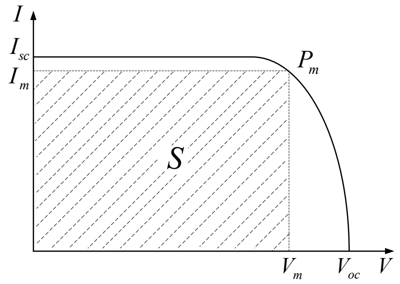


Fig.1 V-I characteristic curve

For reference to sunshine intensity and ambient temperature, the short-circuit current and open-circuit voltage of the photovoltaic array are respectively I_{scref} and V_{ocref}, and the working current and working voltage of the maximum power point are respectively I_{mref} and V_{mref}. Under any sunshine intensity and ambient temperature, the output voltage V and output current I of the photovoltaic array can be calculated by formula (1) ~ (7) :

$$I = I_{scref}[1 - C_1(\exp(\frac{V - \Delta V}{C_2 * V_{oc}})\text{-}1] + \Delta I \tag{1}$$

$$T_c = T + t_c * R \tag{2}$$

$$\Delta T = T_c - T_{cref} \tag{3}$$

$$\Delta I = a * \frac{T}{R_{ref}} * \Delta T + \left(\frac{R}{R_{ref} - 1}\right) * I_{scref} \tag{4}$$

$$\Delta V = -b * \Delta T - R_S * \Delta I \tag{5}$$

$$C_2 = \frac{\left(\frac{V_{mref}}{V_{ocref}} - 1\right)}{\left(\ln(1 - \frac{I_{mref}}{I_{scref}})\right)} \tag{6}$$

$$C_1 = (1 - \frac{I_{mref}}{I_{scref}}) * \exp(-\frac{V_{mref}}{V_{ocref} * C_2}) \tag{7}$$

In Formula (1) ~ (7), R is the total sunshine intensity of photovoltaic array surface; T_c is the surface temperature of the photovoltaic array; T is the ambient temperature; t_c is the temperature coefficient of photovoltaic array; R_{ref} is the reference sunshine intensity of photovoltaic array; T_{ref} is the reference temperature of photovoltaic array; a is the current-temperature coefficient of photovoltaic array under the reference sunshine; b is the voltage-temperature coefficient of photovoltaic array under the reference sunshine; R_S is the series resistance of photovoltaic array; C_1 and C_2 are correction coefficients of photovoltaic array; ΔT is the temperature compensation value; ΔI is the current compensation value.

3. MPPT control

Under any sunshine intensity, temperature and other environmental conditions, the output power of the photovoltaic array changes with the change of working voltage, and the output power is maximum only at the maximum power operating point. Therefore, it is necessary to track the power control of photovoltaic power generation system, and the incremental conductance method is a stable and effective MPPT control method.

When the photovoltaic array works at the maximum power point, the derivative of its output power to the working voltage is zero, that is, $dP/dV = 0$. According to the current formula, Formula (8) :

$$\frac{dP}{dV} = \frac{dVI}{dV} = V\frac{dI}{dV} + I = 0 \tag{8}$$

Therefore, by judging the $V * \frac{dI}{dV} + I$ value at different working voltages V, we can judge whether the voltage is at the maximum power point voltage, so as to realize the MPPT of photovoltaic array.

The principle of the incremental conductance method MPPT is shown in FIG. 2, $P_n(V_n, I_n)$ is the output power of the PV module in the NTH iteration, $P_m(V_m, I_m)$ is the output power of the PV module in the m iteration, ΔV is the voltage step, $P(PU)$ and $V(PU)$ are respectively the output power of the PV module and the unit value of the voltage. When the environmental conditions change quickly, the incremental conductance method has the advantages of realizing MPPT voltage tracking quickly, and its voltage fluctuation is small.

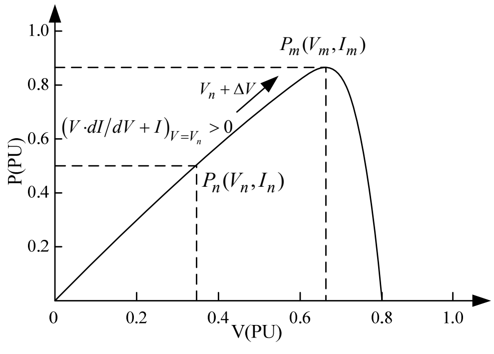


Fig.2 Incremental conductance method MPPT principle

4. Control strategy of photovoltaic power generation system

The two-stage distributed photovoltaic power generation system is composed of photovoltaic array, DC/DC conversion circuit, DC/AC inverter circuit, filter circuit and large power grid, as shown in Figure 3.

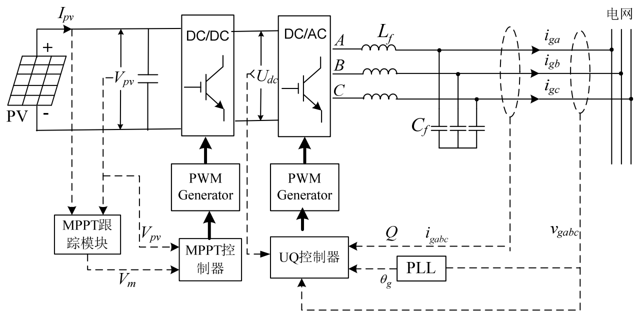


Fig.3 Control structure of distributed photovoltaic power generation system

The Boost circuit with more stable output and continuous output current is used for DC conversion in MPPT control circuit of distributed photovoltaic power generation system.

In application, considering that the DC/AC part can maintain the constant DC side voltage U_{dc} of the inverter, that is, the output side voltage in the DC/DC circuit is constant, the duty ratio D should be adjusted at this time to ensure that the DC voltage U_{pv} of the photovoltaic array can always track the output voltage value U_m at the maximum power point, so as to realize the MPPT of the photovoltaic array.

Inverter control adopts voltage-reactive power control, control inverter DC side voltage constant, that is, inverter output reactive power constant, adopt double closed-loop control, the outer ring is the voltage ring, the inner ring is the current ring, and the inner ring adopts decoupling control. The specific control strategy is shown in Figure 4.

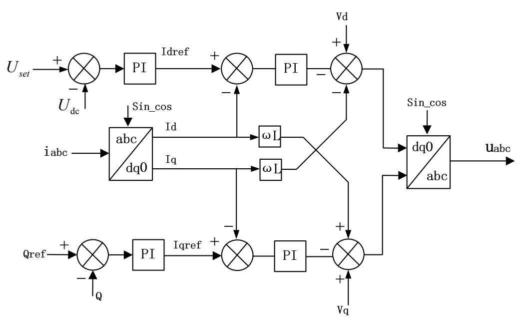
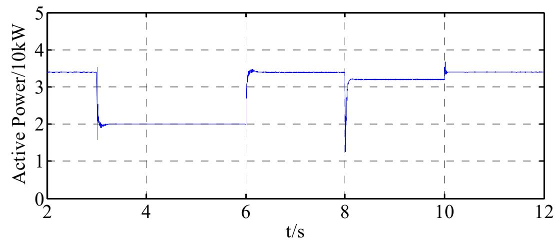


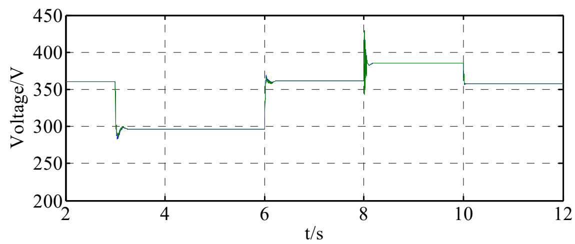
Fig.4 DC/AC control policy

5. Example simulation

The simulation model of photovoltaic power generation system is built. The distributed photovoltaic power generation system is simulated and analyzed. Set the initial moment, light intensity 1000W/m2, temperature 25°C; At t=3s, the illumination intensity decreases from 1000 W/m2 to 700W/m2. When t=6s, the light intensity increases from 700 W/m2 to 1000W/m2. At t=8s, due to scheduling requirements, the distributed photovoltaic power generation system carries out limited power output, which is required to limit the output power to 32kW. The system switches from MPPT control to limited power control operation. When t=10s, the power limiting output requirement of the distributed photovoltaic power generation system is lifted and the power limiting control is switched to MPPT control. The simulation results are shown in Figure 5.



(a) Output power



(b) Photovoltaic array output voltage

Fig.5 Simulation results of distributed photovoltaic power generation system

As shown in Figure 5, at t=3s, the light intensity drops sharply, the output power of the distributed photovoltaic power generation system rapidly drops to 20kW, and the terminal voltage of the photovoltaic array drops to 300V. When t=6s, the illumination intensity returns to the initial state, and the output power of the distributed photovoltaic power generation system and the output voltage of the photovoltaic array also return to the initial output state. At the moment t=8s, the output power of the distributed photovoltaic power generation system quickly stabilizes at 32kW due to the requirement of power limiting. At the same time, the output voltage of the photovoltaic array also runs to the non-maximum power operating point voltage, indicating the effectiveness of the power limiting control strategy of the distributed photovoltaic power generation system. When t=10s, the power limit requirement is lifted, the system restores MPPT control, and the system running state is restored to the initial state, indicating that the distributed photovoltaic power generation system runs smoothly and the status switch is smooth.

6. Conclusion

The simulation model of distributed photovoltaic power generation system established in this paper accurately reflects the characteristics of distributed photovoltaic power generation and MPPT control. The output characteristics of photovoltaic array under different temperature and illumination conditions are simulated. The control strategy of bipolar inverter and the maximum power control method of conductivity increment method are used to establish a complete distributed photovoltaic power generation system. Distributed photovoltaic power generation system under the change of lighting intensity, power control and other environmental conditions, the simulation results show that the dynamic adjustment of the simulation model is fast and effective, and can prepare to reflect the operating characteristics of distributed photovoltaic power generation system under the change of external environment, to ensure the maximum power output and stability control of the photovoltaic power generation system. It is of great guiding significance to the research and operation of distributed photovoltaic power generation system.

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