Photovoltaic power generation control strategy

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Abstract. This paper establishes the maximum power tracking technology based on the conductance increment method, establishes the PV model in a synchronous rotating coordinate system, and uses the grid voltage-oriented vector control technology to realize the decoupling of the active and reactive power of the PV. In order to meet the low voltage ride-through requirements put forward by the State Grid Corporation of China, this paper proposes a low voltage ride-through strategy for PV.

1. Introduction
As a very important power generation method in IIDG, solar photovoltaic power generation technology has been widely used in recent years. However, as the penetration rate of PV in the distribution network increases, the problems it brings have gradually become prominent. The intensity of sunlight is random and intermittent. How should the photovoltaic power generation system deliver power to the grid efficiently? On the other hand, when a fault occurs and the fault ride-through conditions are met, how should we ensure that as much reactive power as possible is provided when a photovoltaic ride-through fault occurs?

This paper proposes a maximum power tracking technology based on the conductance increment method to ensure the maximum power output of PV to the grid. At the same time, it also proposes a low voltage ride through technology for PV, which determines the reactive power output to the grid according to the amount of voltage drop.

2. PV decoupling control strategy
The equation of the inverter in the dq synchronous rotating coordinate system is [1]:

\[
\begin{align*}
U_{pud} &= U_{gd} + R_g i_d + \omega_L i_q + L_g \frac{di_d}{dt} \\
U_{puq} &= U_{gq} + R_g i_q - \omega_L i_d + L_g \frac{di_q}{dt}
\end{align*}
\]

(1)

Among them, \( U_{pud}, U_{puq} \) are the d-axis and q-axis components of the voltage output by the inverter, \( U_{gd}, U_{gq} \) are the d and q components of the grid voltage, \( i_d, i_q \) are the d and q components of the output current of the power electronic converter, \( \omega_L \) is the grid synchronous rotation angular velocity, and \( R_g, L_g \) is the grid-side filter resistors, \( L_g \) is the filter inductor on the grid side.
Using feedforward compensation and PI control, formula (1) can be rewritten as the current inner loop control equation of PV:

\[
\begin{align*}
U_{pd} &= U_{gd} + \omega L_{g} i_d + \omega L_{g} i_q + \left( K_{p}\frac{U_{gd}}{s} + K_{i}\frac{U_{gd}}{s} \right) (i_{gd}^* - i_{gd}) \\
U_{pq} &= U_{gq} + \omega L_{g} i_d + \omega L_{g} i_q + \left( K_{p}\frac{U_{gq}}{s} + K_{i}\frac{U_{gq}}{s} \right) (i_{gq}^* - i_{gq})
\end{align*}
\]

(2)

Among them, \( K_{p} \) and \( K_{i} \) are the proportional adjustment coefficient and the integral adjustment coefficient of the d-axis component of the current inner loop, \( K_{p} \) and \( K_{i} \) are the proportional adjustment coefficient and the integral adjustment coefficient of the q-axis component of the current inner loop, and \( i_{gd}^*, i_{gq}^* \) are the d and q-axis current reference values of the current inner loop.

In order to realize the decoupling control of PV, the grid voltage oriented vector control technology which oriented the grid voltage vector to the d-axis is adopted. At this time, the active power and reactive power of the inverter are [2]:

\[
\begin{align*}
P &= \frac{3}{2} \text{Re}(U_{g}^* \times I_{g}^*) = \frac{3}{2} (U_{gd} i_{gd} + U_{gq} i_{gq}) = \frac{3}{2} |U_{g}| i_{gd} \\
Q &= \frac{3}{2} \text{Im}(U_{g}^* \times I_{g}^*) = \frac{3}{2} (U_{gd} i_{gd} - U_{gq} i_{gq}) = \frac{3}{2} |U_{g}| i_{gq}
\end{align*}
\]

(3)

From equation (3), the active power and reactive power of the power electronic inverter have been decoupled: the active power of the converter is controlled by the d-axis component of the current, and the reactive power is controlled by the q-axis component of the current.

3. Maximum power tracking technology based on conductance increment method

It can be seen from the foregoing that the d and q axis components of the regulating current can control the active and reactive power delivered to the grid. However, the output power of photovoltaic panels is also related to the DC bus voltage. When the use environment of PV changes (such as light radiation intensity, temperature), the DC capacitor voltage value that reaches the maximum power of the solar panel will also change. The most efficient technology to find the optimal power output state of PV and convert light energy into electrical energy by controlling the DC capacitor voltage is called PV's Maximum Power Point Tracking (MPPT). The characteristic curve of PV cell is shown in Figure 1 [3]:

Figure 1. Characteristic curve of PV cell
It can be seen from Figure 1 that the condition for the maximum output of photovoltaic cells is:

\[
\frac{dP_{pv}}{dU_{pv}} = 0
\]  

(4)

MPPT has two types: open-loop MPPT and closed-loop MPPT. The open-loop MPPT performs open-loop control of the PV voltage according to the influence of ambient temperature, light radiation intensity and load on the PV output characteristics. Although this method is simple and easy to understand, it is not efficient and strongly depends on the output characteristics of PV. Therefore, closed-loop MPPT control is often used in practice. Typical closed-loop MPPT control methods include disturbance observation method and conductance increment method. Using the relationship between the conductance of PV and the rate of change of conductance as a basis, the method to make PV run in the state of maximum power is called Incremental Conductance (INC) [4].

Derivation from the P-U relationship of PV can be obtained:

\[
\frac{dP_{pv}}{dU_{pv}} = U_{pv} \frac{dI_{pv}}{dU_{pv}} + I_{pv}
\]

(5)

The maximum power tracking technology of PV is shown in Figure 2:

![Figure 2. PV maximum power tracking process diagram](image)

When the environmental parameters change, the use of the conductance increment method can make the system track the maximum power point smoothly, and the stability of the system is very high. The tracking process of the MPPT control technology based on the conductance increment method at the maximum power point is not affected by the characteristic curve and parameters of the photovoltaic cell. However, if the initial parameters of the voltage and the value of the voltage increment are not set properly, the system is prone to misjudgment and oscillation problems. In this section, through a large number of simulation tests, the initial voltage parameters and voltage increments are determined.

4. Low voltage ride through characteristics of PV

According to the different voltage levels of PV connected to the distribution network, PV can be divided into small photovoltaic power generation systems and large and medium photovoltaic power generation systems. According to the regulations of the State Grid Corporation of China, when a failure occurs, a small photovoltaic power generation system may not want the grid to provide reactive power support.
When a failure occurs, a large and medium-sized photovoltaic power generation system must be kept from the grid within a specified time and provide the grid reactive power to support the grid voltage. However, the State Grid Corporation has not made clear requirements for the reactive power support capabilities provided by the medium-sized photovoltaic power generation system. Only Germany has made detailed specifications on the reactive power support capability of grid-connected medium-sized PV: when the grid voltage per unit value is greater than or equal to 0.9, low voltage ride-through does not work; when the grid voltage per unit value is less than 0.9, the grid voltage per unit value drops by 1%, PV will provide at least 2% of reactive current to the grid, and the response speed will be within 20ms [5].

In the process of PV low voltage ride-through, while ensuring that PV provides sufficient reactive power support to the grid, PV should also provide active power to the grid as much as possible. At the same time, the total current of PV should be reduced as much as possible. According to the technical specifications of the State Grid Corporation of photovoltaic power plants connected to the grid, the reliable working time of photovoltaics at 1.2 times the rated current should be greater than or equal to 60 seconds.

When it is detected that the per-unit value of the PV terminal voltage is less than 0.9, the reference value of the d and q axis components of the current inner loop is no longer determined according to the reference value of the power outer loop, but is determined by the amount of voltage drop.

According to the German PV grid-connected standards, the PV reactive current reference value is determined according to how much the grid voltage drops:

1. When the grid voltage per unit value is greater than or equal to 0.9, the LVRT system will not start.

2. When the grid voltage per unit value is less than 0.9 and greater than or equal to 0.4, the reference per unit value of the q-axis component of the current inner loop is:

\[ i_q^* = 2 \times (1 - \frac{U}{U_v}) \]  

The reference unit value of the d-axis component of the current inner loop is:

\[ i_d^* = \min \{ \sqrt{1.2^2 - (i_q^*)^2}, i_{dprev} \} \]  

\( i_{dprev} \) is the reference unit value of the d-axis component before the fault.

3. When the grid voltage per unit value is less than 0.4, the reference value of the q-axis component of the current inner loop is 1.2 times the grid rated current, and the reference value of the d-axis component of the current inner loop is 0.

5. Conclusion

The control block diagram of PV is as follows [6]:

![Control block diagram of PV](image-url)
When the PV terminal voltage drops as shown in Figure 4, the relationship between the reference value of the active and reactive current and its actual value is shown in Figure 5 and Figure 6.

**Figure 4.** The terminal voltage drop diagram of PV

**Figure 5.** Reference value and actual value of d-axis component of PV

**Figure 6.** Reference value and actual value of d-axis component of PV

This paper establishes the maximum power tracking technology based on the conductance increment method, establishes the PV model in a synchronous rotating coordinate system, and uses the grid voltage-oriented vector control technology to realize the decoupling of the active and reactive power of the PV. In order to meet the low voltage ride-through requirements put forward by the State Grid Corporation of China, this paper proposes a low voltage ride-through strategy for PV, and the following conclusions are obtained:

1. Using the PV model established in this paper can well achieve low voltage ride-through in the event of a fault, provide sufficient reactive power support for the grid, and provide as much active power to the grid as possible within the tolerance range of the inverter.

2. The fault current characteristics of PV are very different from the traditional synchronous generators used in thermal power generation: regardless of whether the grid is symmetrical or asymmetrical, PV only outputs positive sequence current to the grid without zero sequence Current and negative sequence current.
(3) According to a large number of simulations, it is found that PV can be equivalent to a positive sequence current source when symmetrical faults and asymmetrical faults occur.

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