Research on the Operation Mode Switching Strategy of Wind Power-Photovoltaic Micro Grid

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Abstract. Wind energy and solar energy can make full use of the clean energy for wind and solar energy and have high reliability. It is very important to smooth transition between grid-connected mode and the island mode. The micro grid of hybrid power generation system based on wind power is established in DigSILENT/Power Factory. The improved control strategy, P-Q control and the control strategy based on droop characteristics, have been proposed to be applied in the transition state simulation study mode based on the micro grid. The results show that this advanced control strategy can ensure the power balance and reasonable power distribution, and can maintain the voltage and frequency stability of the connection bus during the operation mode switching.

1. Introduction
The micro grid is a system with loads and power. In the micro grid, power electronics are used to change energy and provide the necessary controls. Compared with the external grid, the micro grid is a single controllable unit, it can meet the demand of the customer on the quality, reliability and safety of electric power [1].

When the power grid fails, the micro grid can be operated in the isolated mode, and the reliability and safety of the power supply will be improved. The island operation relies on the smooth transition between the grid-connected and the island mode. Therefore, it is necessary to study the control strategy in the process of micro-grid switching.

2. Micro grid parallel operation and island operation
2.1. The method of Micro grid parallel operation and island operation
The micro grid can be switched between parallel operation and the island operation. Grid mode means that there is a connection between the micro grid and the big power grid, and the load flows between them. The island model means that when the grid fails, the micro grid is isolated from the big grid, and distributed generation systems provide power to the load. The island operation improved the reliability of the power supply [2].

The existence of isolated islands is very dangerous: firstly, the voltage and frequency may be unstable and may be dangerous to the safe operation of power equipment because the isolated island operation area is not controlled by the power grid. Secondly, when the island is in operation, the staff cannot judge whether the equipment is charged or not, thus it is dangerous to the life safety of the staff. Finally, when the micro grid is connected to the main grid, the main grid will be affected.
2.2. The provisions of the large power grid on the island operation

Due to the great harm of the isolated island operation, UL1741 and IEEE 929-2000 require that once distributed generation is in an island operation, distributed generation needs to disconnect with the large power grid. The island effect can guarantee the normal operation of the power grid, but with the increase of distributed generation capacity, there are some problems with the island effect. For example, distributed power generation can't be fully used, reducing the reliability of distributed power networks, and so on. It is well known that faults are unavoidable in power systems. When a fault occurs, the distributed generation is disconnected from the power grid, it is difficult to guarantee the reliability of power supply and the advantages of distributed generation.

Based on the above analysis, when failure occurs, switching off the power supply will no longer be a practical or reliable solution. Ieee1547-2008 proposed a new standard for the operation of the planned islands and the unplanned island operation [3]. The planned island operation means that a small grid or part of the grid, composed of a load and a distributed generation system, is separated from the power system and according to the previous plan. The planned island operation can maintain the stable operation of micro grid and improve the reliability of power supply. The unexpected island operation state refers to the distributed generation system independent of the load power supply. The operating state is contingent and unstable. This method allows the island to operate as planned, prevent accidental island operation.

3. Control strategy for the micro grid operation and the parallel grid operation

3.1. Traditional control strategies

Currently, master-slave control strategy and peer control strategy are applied in the micro grid. Master-slave control strategy refers to the micro grid all distributed power supply in parallel mode adopted in the P-Q control strategy, but in the isolated operation mode, in order to maintain the stability of voltage and frequency, one or more distributed power uses V/f control strategy based on droop characteristics. The peer control strategy refers to the use of droop control in the distributed power supply in the micro grid, thus ensuring a reasonable power distribution.

The P-Q control refers to the maximum power output of a distributed power source or to specify a specific power generation according to the actual situation. The principle of P-Q control is shown in figure 1, when the frequency of the micro grid is 50Hz and the bus voltage is rated, the distributed generation system runs at point B and the output power is \( P_{\text{ref}} \) and \( Q_{\text{REF}} \) [4]. If the frequency of connecting bus voltage and micro grid increases or decreases, the working point moves from B to A or C to maintain power output at point \( P_{\text{ref}} \) and \( Q_{\text{REF}} \). The purpose of P-Q control design is the maximum use of renewable energy, which is suitable for intermittent energy. P-Q control is relatively easy, but it can't keep the voltage and frequency stably [5].

P-Q control follows the reference current by adjusting the active current (ID) and the unreactive current (IQ).

\[
\begin{bmatrix}
U_a \\
U_b \\
U_c
\end{bmatrix} = \begin{bmatrix}
U_m \cos(\omega t) \\
U_m \cos(\omega t - \frac{2\pi}{3}) \\
U_m \cos(\omega t + \frac{2\pi}{3})
\end{bmatrix}
\]

\[ (1) \]

\( U \) is network voltage, \( U_m \) is the amplitude of phase voltage. Do a change in \( U \):

\[
\begin{bmatrix}
U_d \\
U_q
\end{bmatrix} = T_{abc-dq} \begin{bmatrix}
U_a \\
U_b \\
U_c
\end{bmatrix} = \begin{bmatrix}
U_a \\
0
\end{bmatrix}
\]

\[ (2) \]
In the dq coordinate system, decoupling the d axis and the q axis, \( U_d \) is constant, \( U_q \) is 0. Then the active power is set to the \( P_{\text{ref}} \) and reactive power set to \( Q_{\text{ref}} \). The reference current of the inverter is expressed as follows:

\[
\begin{align*}
    i_{d\text{ref}} &= \frac{P_{\text{ref}}}{U_d} \\
    i_{q\text{ref}} &= \frac{Q_{\text{ref}}}{U_d}
\end{align*}
\]  

(3)

In summary, the research on control strategy has shifted from the output power to the current research.

Figure 2 shows the principle of droop control: When distributed generation is connected in parallel to the micro grid, the relationship between the real-time output power and the frequency of the micro grid is linear, and the relationship between the reactive power output and the connection bus voltage is the same.

When the output power of distributed generation increases, the operating point moves from A to B. When the bus voltage and micro grid frequency change slightly, the power output should be adjusted reasonably.

\[
\Delta P = K_p (f_0 - f_1)
\]  

(4)

\[
\Delta Q = K_q (V_0 - V_1)
\]  

(5)

Droop control is a kind of control mode that does not require the communication between power supplies. It is suitable for the control of distributed power inverter.

3.2. Improved control strategy

The single control strategy cannot meet the operation demand of micro grid. In the model based on wind power and photovoltaic hybrid system, the photovoltaic power generation system is intermittent and the control goal is to maximize the use of renewable energy, so P-Q control is applicable to the photovoltaic system [6]. The output characteristic of the wind power system containing accumulator is relatively stable, so the droop control is suitable for wind power system. When operating on the micro-grid island, it is used to ensure reasonable power distribution and to maintain the frequency of the voltage and micro-grid connected to the bus line to remain stable.

Figure 1. Principle of P-Q control
4. Model and simulation

Figure 3 shows the model of wind and PV hybrid power system. In this model, the voltage of the micro grid is 0.4kV, which is connected with the power grid of 10kV. The micro grid consists of a 0.045MW wind powered generator and 10 pieces of 0.01MW photovoltaic array. The wind turbine is composed of the synchronous generator, the converter, the battery and the control system. Photovoltaic generation system consists of the dc voltage source, the inverter and the control system. Design capacity of the photovoltaic system is 100kW active, 0kVar reactive power. Wind power output is 10kW active power, 10kVar reactive power. The power of load 1, 2 and 3 is respectively 5kVar, 10kW; 0kW, 5kVar; 10kW, 10kVar. Build a hybrid power system in DlgSILENT/PowerFactory.
4.1. Output power

Figure 4 shows the output power of wind power system and photovoltaic power generation system respectively. The wind power generation system adopts the droop control strategy, and the power output of the wind power unit is 10kW, which was originally 10kvar. At 0.2s, the grid connection mode is transformed into an isolated island, while the power of the micro grid is unbalanced. The output power of the wind turbine is changed to ensure the stability of the micro grid, and its power output changes to 5kW, -5kvar. At 0.5s, the micro grid is reconnected to the main grid, and the output power of the wind power system will become stable after a slight change. Photovoltaic power generation adopts PQ control strategy, the output of active power and reactive power output of photovoltaic power generation system is 100kw, 0kVar. At 0.2s, the micro grid is transformed from the grid-connected mode to the isolated island mode, and the output power of the photovoltaic system is slightly fluctuated. After adjustment, the power output will be stable. After 0.5s, the micro grid is reconnected to the main grid, and the output power of the photovoltaic system is still 100kW, 0kvar.

![Figure 4. (a) Output of wind power; (b) Output of photovoltaic.](image)

4.2. Frequency

As shown in figure 5 (a), in parallel operation, its frequency is kept at 50 Hz. At 0.2s, the micro grid has the grid-connected mode to the isolated island mode, and the micro grid quickly adjusts the frequency to maintain the power balance. At 0.5s, the micro grid is reconnected to the main grid, and the frequency of the micro grid becomes 50Hz.

4.3. Voltage of connecting bus

Figure 5 (b) shows the bus voltage of the micro grid connection. Before 0.2s, the micro grid was connected to the main network, and the voltage of the connecting bus is 0.4kV. At 0.2s, the micro grid is transformed from the grid-connected mode to the island mode. Due to the droop control, the change of the connecting bus voltage is 0.4003kV, and the change range is less than 10%. At 0.5s, the micro grid is reconnected to the main power grid, and the connected bus voltage is changed to 0.4kV.
5. Conclusion
The simulation study of wind power and photovoltaic hybrid system shows that the improved control strategy model conforms to P-F and Q-V control characteristics. The simulation results show that the control strategy combined with P-Q control and droop control can guarantee the power balance and reasonable power distribution. The strategy can be further applied to practical application.

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