Research on Integrated Control of Microgrid Operation Mode

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Abstract. The mode switching control of microgrid is the focus of its system control. According to the characteristics of different control, an integrated control system is put forward according to the detecting voltage and frequency deviation after switching of microgrid operating mode. This control system employs master-slave and peer-to-peer control. Wind turbine and photovoltaic(PV) adopt P/Q control, so the maximum power output can be achieved. The energy storage will work under the droop control if the system is grid-connected. When the system is off-grid, whether to employ droop control or P/f control is determined by system status. The simulation has been done and the system performance can meet the requirement.

1. Introduction
Microgrid is one of the most promising ways to solve the energy problem. System coordination control is an important part of microgrid research [1]. One of the key problems is the mode switch control. At the same time, it is difficult to realize the coordination control of the system [2-3].

The master-slave control can effectively solve the transient oscillation during the process of grid-connected. But the primary control sources are very dependent [4-6]. P/Q control can ensure the power output of the system when it is the grid-connected. But Q/P control can’t provide voltage and power reference for off-grid. V/f control can provide voltage reference for the system when the system is the off-grid. However the V/f control does not guarantee the power output when the system is the grid-connected. The plug and play is the most characteristic of peer-to-peer control and it’s easy to extend. But it’s an error control. It is difficult to control in practice...... As can be seen, all kinds of control methods have their own characteristics and their scope of use. It is difficult to achieve stable operation of the system with single control mode. In order to effectively reduce the transient oscillation during the operation mode switching process, many control methods have been applied to solve this problem and has obtained abundance production such as multi-layer control [7], three region smooth switch control strategy [8], master-slave control strategy [1], droop controller with droop rate point adjustment ring [9], Compound control employed multi-control [10] etc.. In the paper, considering the characteristics of typical control, an integrated control system is proposed. The system integrated the advantages of multi-control. The voltage deviation and the frequency deviation are
detected when the microgrid’s operating mode changes. Then the control strategy of energy storage is to be determined.

2. Topology of Main Circuit

These assumptions are made below [11]:

1. All devices are ideal and the dead area time of them is ignored.
2. The frequency of the output voltage is much lower. The input and output voltage remain constant during the next few cycles.
3. The filter inductance is linear, without considering the saturation, the filter capacitor is an ideal capacitor, and the parasitic inductance and parasitic resistance are neglected.
4. Only the fundamental frequency of 50Hz of inverter output voltage is considered. According to Kirchhoff’s law, the state equations of filter inductance and filter capacitor can be listed respectively:

\[
\begin{align*}
\frac{du_a}{dt} &= L_f \frac{di_a}{dt} + r_i i_a \\
\frac{du_b}{dt} &= L_f \frac{di_b}{dt} + r_i i_b \\
\frac{du_c}{dt} &= L_f \frac{di_c}{dt} + r_i i_c \\
\frac{di_a}{dt} &= C_f \frac{du_a}{dt} \\
\frac{di_b}{dt} &= C_f \frac{du_b}{dt} \\
\frac{di_c}{dt} &= C_f \frac{du_c}{dt}
\end{align*}
\]

(1)

Where \( u_a, u_b, u_c \) are inverter output voltage, \( V \); \( u_{d0}, u_{b0}, u_{c0} \) are load output voltage. \( V \); \( i_{a0}, i_{b0}, i_{c0} \) are load output current, \( A \); \( L_f \) is filter inductance, \( H \); \( r \) are equivalent resistance of filter inductance; \( C_f \) is filter capacitor, \( \mu F \).

3. Integrated Control Strategy of Microgrid System

Due to intermittent nature and random properties, P/Q control is always used to ensure maximum utilization of wind turbine and PV. Therefore, when the microgrid is island, the main control devices are always batteries and other devices to regulate the output. The stability of voltage and frequency can be achieved. The peer-to-peer control is always used by the system which is composed of these microsources. However, the energy storage device’s control is droop control. The energy storage system can’t change control strategy when microgrid operation mode is switched. That is, the system is grid-connected at first and is off-grid next time. But the output of system is not guaranteed. Once the system load is over a certain value, the deviation of frequency and voltage will exceed the permitted range, then the system can’t operate in a stable state. If the master-slave control is employed, when the system is connected with grid, the energy storage system adopts the P/Q or droop control. The V/f control is employed when operation model is off-grid. At this time, the energy storage device can provide the microgrid stability for island system. But the system switches the mode every time. The energy storage devices need to change the control strategy. The performance of the inverter will be weaken because of the frequent mode switching. The possibility of switching failures will be greatly increased.

An integrated control system including master-slave control and peer-to-peer control is designed for microgrid consisting of microsources such as WT and PV, as Figure 1. The followings are the control steps: (1) P/Q control is always adopted by PV system. (2) The droop control is adopted by energy storage device when the system is grid–connected. (3) The deviation of frequency, represented by\( \Delta f \), the deviation of voltage, represented by\( \Delta U \), are detected when the microgrid is connected with grid to off-grid. (4) If \( \Delta U \) and \( \Delta f \) are within the permitted range, the control strategy of the energy storage remains the same. That is, the droop control is still employed. (5) If \( \Delta U \) or \( \Delta f \) exceeds the permitted range and lasts for a period of time, the energy storage change the control method. The needed voltage and the needed frequency of system are provided by V/f control. On the one hand, the
The integrated control strategy has advantages of master-slave control, that is, the voltage for reference can be got. The frequency for reference can be got too. The dependence on the microsources is reduced. On the other hand, the integrated control strategy reduces the number of switching times of the energy storage. Then, the possibility of switching failures is reduced.

![Figure. 1 Schematic diagram of integrated control strategy](image1)

![Figure. 2 Schematic diagram of the integrated control of the energy storage device](image2)

When the control strategy was switched, the voltage or the frequency will cause violent transient vibration due to the different operating conditions of the voltage link of capacitor or the current control link of inductance etc. The only difference is that the controller needs to calculate active power value for reference and reactive power value for reference. So, the switching control method is adopted according to the adaptive controller states, so as to ensure the states of the system is the same and rapid mode conversion process.

The control strategy of the energy storage with adaptive controller state is shown in Figure. 2.

1. Once the system works from connected with grid to off-grid. The system voltage is detected and the system frequency is also detected. The goal is to determine whether ΔU and Δf are within permitted range. (2) If ΔU and Δf are within permitted range, the droop control is still employed for the energy storage device. (3) If ΔU or Δf exceeds permitted range and lasts for a certain time. The energy storage control will be switched from droop control to V/f control. Using the reference frequency fref. (4) The reference phase θ of the output voltage is calculated. Employing the reference voltage U_dref and U_qref at the same time. Sampling the output voltage U_a of microgrid, then, the voltage U_a and U_q can be obtained. (5) After (2) or (3), comparing U_dref and U_qref with U_d and U_q respectively. The D/Q axis reference current I_dref and I_qref are obtained by PI controller. (6) The D/Q axis reference voltage U_dref and U_qref are obtained after the D/Q axis current I_d and I_q are controlled by PI controller using the D/Q axis reference current I_dref and I_qref. (7) The PWM signal will be generated by the D/Q axis reference voltage U_dref and U_qref.

4. Simulation Analysis

A PV system with energy storage is selected for simulation to validate the integrated control strategy. The PV system parameters are shown below. The parameters of the droop control, the P/Q control and the loads are shown in from table 2 to table 4 respectively. The simulation time is set within 3s. Assuming that the system is grid-connected at the initial time. The system will be off-grid at 0.5s. The load 1 is connected to the system at the initial time. The load 2 is also connected to the system when time is at 1s.
Table 1 Parameters of photovoltaic cells

| Name                      | Value |
|---------------------------|-------|
| Voltage of MPP: V_{mp}/V  | 29.9  |
| Current of MPP: I_{mp}    | 8.03  |
| Voltage of open circuit e: V_{oc}/V | 36    |
| Current of short-circuit: I_{sc}/A | 8.96  |
| Maximum power P/W         | 240   |
| Number of PV modules in series | 40    |

Table 2 Parameters of droop control

| Name     | Value |
|----------|-------|
| U_0/V    | 311   |
| f_r/Hz   | 50    |
| m        | 0.00001 |
| n        | 0.00003 |
| L_r/H    | 0.0006 |
| C_q/μF   | 1500  |

Table 3 P/Q control parameters

| Name | Value |
|------|-------|
| k_p  | 1.3   |
| k_1  | 20    |
| L_r/H| 0.003 |
| C_q/μF| 15   |

Table 4 Load parameters

| Name     | Value |
|----------|-------|
| P_s/kW   | 15    |
| P_s/kW   | 10    |
| Q_s/kVar | 5     |
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* MPP: Maximum Power Point

The deviation of voltage and frequency is less than ±7% and ±0.1Hz respectively.

Figure 3 Output curve of storage system (active power)

Figure 4 Output curve of storage system (reactive power)

Figure 5 Output frequency curve

Figure 6 Output voltage curve

When the time is during 0~0.5s, the microgrid is connected with grid. The active power output and the reactive power output of energy storage is zero (Figure 3, Figure 4). The grid determines the frequency. Similarly, the voltage is also determined by the grid. In the early stage of operation, the system frequency has a slight oscillation. The maximum oscillation is 0.025Hz during about two cycles and then rapidly stabilized at 50Hz (Figure 5). In the initial rise of voltage, there is a peak of about 0.5V and then stabilizes to 219.41V (Figure 6). The possible cause of the spike is the influence of capacitance in the early stage of operation. However the peak effect can be neglected due to the small amplitude. At this time, the PV system supplies active power (reactive power) to load 1. The other part is supplied by the grid. Energy storage can’t work. When t= 0.5s, the PV system with energy storage is off-grid. Under the control of the droop controller, 5.4kW active power and 5kVar reactive power are supplied by the energy storage system (Figure 3, Figure 4). But the frequency drops to 49.95 Hz. (Figure 5), and the voltage drops to 219.3V and remains stable (Figrue 6). Because the deviations of frequency and voltage are within the permitted range, the control strategy of energy

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storage is not switched. The droop control is still employed. Load 2 is incorporated into the grid when the time is at 1s. In order to maintain the system work perfectly, the PV system with storage system provides active power (15.4Kw) and reactive power (10 kVar) respectively. The system frequency drops to 49.84 Hz (Figure.5) and the voltage drops to 219.2V (Figure.6). At the same time, a certain fluctuation exists. Because the system frequency deviation exceeds the permitted range for 0.5s, the energy storage control mode is switched to V/f control. At this time, the energy storage can still compensate the power shortage of microgrid. The frequency of the system is restored from 49.85 Hz to 50 Hz (Figure.5). The voltage of microgrid is restored to 219.41 V (Figure.6).

5. Conclusion
Simulation analysis shows that the PV system with energy storage adopted the integrated control strategy can reduce the change of system frequency and voltage properly to meet the system load demand for small load demand. When the system load increases, the method of changing the energy storage control strategy can solve the problem that the frequency or voltage deviation exceeds the permitted range. The Integrated control can satisfy the frequency stability and voltage stability of the microgrid.

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