Research on Technology of Grid-Connected/Islanded Smooth Switchover of Microgrid

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Abstract

In order to solve the problem of transient oscillation of microgrid during process switching between grid-connected operation and islanded operation, the basic principle of traditional control strategy is analyzed, a novel control structure of smooth switchover for microgrid based on the double negative feedback controller is proposed. Also, to avoid the risk of voltage oscillation caused by the mutual interference of the two controllers in the traditional quasi-synchronization method, an improved quasi-synchronization controller is proposed, which is simpler and easier to implement. Finally, the simulation results verify the validity of the proposed structure. Research results show that the busbar voltage and current oscillation can be solved better with the novel structure, and lay the foundation for smooth switchover.

Keywords: microgrid; quasi-synchronization; grid-connected operation; islanded operation; smooth switchover

1. Introductions

As the problem of environment pollution and energy crisis becoming prominent increasingly in today's society, the clean and renewable distributed generation (DG) has become the focus of the world. But due to the intermittent nature of distributed power supply, which leads to DG difficult to get grid-connected in large-scale[1-4]. Microgrid technology is one of the effective ways to solve the problem. Microgrid can operate both in grid-connected operation and off-grid operation[5-7].

Because the transient oscillation of switching process will affect the power supply of local load, and even cause switchover failure, how to realize smooth switchover of microgrid is one of the key issues of researchers[8-10].

In this paper, key technology of grid-connected/islanded smooth switchover will be discussed based on master-slave microgrid. Aiming at the problems existed in the smooth switching process of master-slave microgrid, literature [11] analyzes the factors of transient oscillation caused by switchover and put forward the corresponding smooth switchover control strategies, but ignores the suppression method of the corresponding transient fluctuation; literature [12] presents a smooth switchover control strategy, but the results of the experiments show that in the switching process, bus voltage of microgrid still had transient impact, and reached islanding protection conditions of the system, which may lead to system crash; literature [13] adopts the voltage and current weighted control algorithm, to achieve a seamless handover, but ignores when the capacity of the

main control unit is not sufficient to preserve microgrid power demand, using the control strategy only can not realize the smooth switching of operation state.

Therefore, in this paper, based on the analysis of basic structure and control methods of the master-slave microgrid, an improved controller is put forward, which can ensure the inner current loop reference value tamed between the switching processes, and prevent bus voltage and current appear large range of oscillation in the process. Then, Secondly, a quasi-synchronization method which is suitable for microgrid is proposed to ensure the accuracy of voltage amplitude, frequency, and phase in synchronization process.

2. Microgrid Structure and Control Strategy

2.1 Structure of Microgrid

In this paper, the structure of the microgrid system is shown in Fig.1, where all the distributed generations are connected to the AC bus through the three-phase inverter. The microgrid system is connected to the public power grid by the static switch (STS). When the microgrid works in grid-connected mode, the distributed generations and the public power grid work together for the local load. When distributed power supply is more than the load required, the microgrid can transport excess power to the grid. When fault happens in public grid or planned island occurs, the STS will be disconnected and the microgrid will work in the off-grid mode. Then, the distributed generations and energy storage system will supply the power for the local load.

Figure. 1. The Structure of the Microgrid System

For the master-slave microgrid, the main control unit is usually a controllable power supply, such as a micro gas turbine, power conversion system (PCS), diesel generator, etc. When operates in grid-connected mode, both master unit and the slave units adopt the constant power control (PQ); when operates in off-grid mode, master unit switches to the control of constant voltage and constant frequency (V/f), providing voltage and frequency for the slave units, the slave unit still using PQ control. As the control of power conversion system is flexible and active/reactive power regulation is convenient, it is generally chosen as the master unit, and its main circuit structure is shown in Fig.2. In which the main controller realizes the island detection and carries on the control algorithm to switch and the static switch control.

Figure 2. Main Circuit Structure of PCS

2.2 Control Strategy of Master Unit

The switchover of the control strategy of master unit is the key problem of the research on smooth switchover of microgrid. Therefore, this paper mainly studies the control strategy of the master unit.

2.2.1 PQ Control Strategy: When operates in grid-connected mode, the master unit is running in *PQ* mode. In this mode, the voltage and frequency reference is provided by the grid, *d* axis orientation in the direction of grid voltage vector in *dq* rotating coordinate system. Then, the fundamental component of the grid, the converter output current and converter output voltage has the following relationship (ignoring the filter capacitor *C_d*):

$$\begin{cases} e_d = u_d - \omega L i_q + L \frac{di_d}{dt} \\ e_q = \omega L i_d + L \frac{di_q}{dt} \end{cases} \quad (1)$$

The e_d and e_q are the *d* axis and *q* axis components of the converter output voltage, u_d is *d* axis component of the grid voltage, ω is the reference angular frequency, L is the filter inductance ($L = L_{fa} + L_{fb}$), as shown in Fig. 2, the *PQ* control structure diagram shown in Fig. 3.

Figure 3.PQ Control Structure Diagram

2.2.2 V/f Control Strategy: When the microgrid is running in the off-grid mode, the master unit adopts V/f control to provide voltage amplitude and frequency reference for the slaver unit. V/f control is a voltage and current double closed-loop controlling method. The output of the voltage loop is given as a reference to the current loop. The control structure is shown in Fig.4, and the current loop of the current loop is completely consistent with the PQ control strategy as shown in Fig.3.

Figure. 4. V/f Control Structure

In practice, the reference values of the voltage outer loop d and q axis are respectively:

$$\begin{cases} u_{dref} = U_0 \\ u_{qref} = 0 \end{cases} \quad (2)$$

3. Modified Controller based on Double Negative Feedback

When the microgrid operation mode is switched, the control strategy of the master unit needs to be switched between PQ control and V/f control. When the master unit switches from the PQ control to the V/f control, the current loop reference value is supplied by the power loop switch to the voltage loop supply. The inconsistency

between the current reference values in different modes will result in the system transient. Because of in V/f mode the output of voltage loop PI controller need to be regulated from zero to the steady state value, which means after operation mode switching current reference value will mutate to zero, and which led to the bus bar voltage of microgrid dips. Similarly, when the public grid returns to normal and microgrid reconnects to the grid, same problem will happen. This will not only make the power conversion system get a big impact, but will affect the stability of the microgrid bus voltage, threaten security and stable operation of the system. In order to realize the smooth switching of the system, this paper presents a modified controller structure based on double negative feedback, as shown in Fig.5. Due to the current inner loop of PQ control strategy and V/f control method are completely consistent, and in order to ensure the output of the current loop can realize smooth transition in the process of switchover, the control structures have a current loop.

Figure 5. Modified Controller based on Double Negative Feedback

Among them, the logic control switch K_1 - K_6 need to be controlled reasonably, when PQ control is adopted, K_1 , K_4 , K_6 closed, K_2 , K_3 , K_5 open; when V/f control is adopted, K_2 , K_3 , and K_5 closed, K_1 , K_4 , K_6 keep open. And logic switch need to be switched along with the control strategy of master unit.

a. When operates in grid-connected mode, master unit adopt PQ control, K_1 , K_4 and K_6 are closed.

In grid-connected mode, d axis reference value of current inner loop i_{dref} is equal to i_{dref_P} . The control structure takes power outer loop output of PQ controller and voltage outer loop output of V/f controller as a negative feedback and the result is the input of V/f controller voltage loop. After adjusting by the PI controller, the output of the V/f control voltage outer loop is:

$$i_{dref_v} = (k_{pv} + \frac{k_{iv}}{s})(i_{dref_P} - i_{dref_v}) \quad (3)$$

Easy to know that the output of V/f control voltage loop i_{dref_v} can follow the output of the PQ controller i_{dref_P} .

b. Grid-connected mode switch to off-grid mode, master unit switch to V/f control strategy, K_2 , K_3 and K_5 are closed.

At this point, the controller switches, d axis reference value of current inner loop i_{dref} is equal to i_{dref_v} , the output of the V/f control voltage outer loop is:

$$i_{dref_v} = (k_{pv} + \frac{k_{iv}}{s})(v_{dref} - v_d) + i_{dref_p} \quad (4)$$

The control structure takes voltage outer loop output of V/f controller and power outer loop status as a negative feedback and the result is the input of PQ controller power loop. After adjusting by the PI controller, the output of the PQ control voltage outer loop is:

$$i_{dref_p} = (k_{pp} + \frac{k_{ip}}{s})(i_{dref_v} - i_{dref_p}) \quad (5)$$

c. Off-grid mode switch to grid-connected mode, master unit switch to PQ control strategy, K_1 , K_4 and K_6 are closed.

At this point, the controller switches, d axis reference value of current inner loop i_{dref} is equal to i_{dref_p} ,

$$i_{dref_p} = (k_{pp} + \frac{k_{ip}}{s})(P_{ref} - P) + i_{dref_v} \quad (6)$$

By the above formula: at the moment of operation mode conversion, steady-state output of outer loop is equal, namely the modified controller can ensure reference value of current inner loop keep same before and after the mode switch. And the reference value of current inner loop will take the reference value in the moment before switchover as the initial state of the PI controller, to achieve the smooth transition of the control strategy, prevent mutation of switching transient current loop given signal, and ensure the microgrid operation mode switch smoothly.

4. Modified Quasi-Synchronization Controller for Microgrid

Considering the control process of traditional quasi-synchronization controller is complicated, in this section, a modified quasi-synchronization controller for microgrid is proposed.

Quasi-synchronization control including three aspects: voltage amplitude, frequency and phase. It's easy to find that the three control elements all can be reflected in voltage in dq rotating coordinate system. Aiming at each control unit may interfere with each other, we adjust the voltage in dq rotating coordinate system directly to avoid the coordinated scheduling of multiple control units.

From literature [14], we can know that if we get cosine and sine of synchronous rotary angle $\omega t + \theta$ by adaptive notch filter (ANF) and transform original voltage to dq rotating coordinate system, the voltage contains information such as amplitude, frequency and phase. Both controlled quantity of the modified quasi-synchronization controller and V/f controller are voltage in dq rotating coordinate system. So quasi-synchronization control and V/f control can be implemented simultaneously. System oscillation caused by quasi-synchronization controller and V/f controller interference can be avoided as well as the number of control units can be reduced. Modified quasi-synchronization controller structure is shown in Fig. 6.

In modified quasi-synchronization controller, all of the controlled quantity is DC signals in dq rotating coordinate system. Therefore, the three-phase voltage U_A , U_B , U_C of microgrid system and three-phase voltage U_U , U_V , U_W of power distribution network must be transformed to dq coordinate system. As shown in Fig. 6, take microgrid system as an example, according to literature [14], sine and cosine value of the synchronous rotation angle of bus voltage can be obtained. Then by the means of Park transformation, the voltage in dq rotating coordinate system U_{M_d} , U_{M_q} contains the voltage amplitude, frequency and phase information of microgrid

system can be obtained. Similarly we can get voltage U_{G_d} , U_{G_q} of distribution network system in dq rotating coordinate.

Figure 6. Modified quasi-Synchronization control Block Diagram

In the dq synchronous rotating coordinate system, the voltage reference value of the voltage and current double closed-loop controller are changed to:

$$\begin{cases} U_{d_ref} = U_{G_d} - U_{M_d} + U_d^* \\ U_{q_ref} = U_{G_q} - U_{M_q} + U_q^* \end{cases} \quad (7)$$

Where U_d^* and U_q^* are respectively the d and q axis voltage reference value of voltage loop in off-grid mode. Voltage deviation adjusting signal of the microgrid is included in the U_{ed}^* and U_{eq}^* . The deviation will be adjusted by the voltage and current double closed-loop controller. When the bus voltage of the microgrid meet the condition of quasi-synchronization, dictation is sent out by switching signal control unit and static switch $PCC-K$ is closed. Then the microgrid switches to grid-connected mode. When the synchronization is successful, the power conversion system is switched to PQ control, and the quasi-synchronization controller is out of operation.

5. The Simulation Results and Analysis

In order to prove the feasibility of the proposed control structure and quasi synchronization control method in this paper, the simulation is carried out in MATLAB/simulink software. In the simulation, a power converter serves as a master unit and a photovoltaic inverter serves as a slaver unit. The main electrical parameters of the microgrid are shown in Tab. 1. The power distribution of the microgrid is shown in Tab. 2. The power output of each unit is expressed with a negative sign.

Table 1.The Main Electrical Parameters of the Microgrid

Microgrid	Parameter	Value
Master Unit	Rated Power S/kVA	50
	Switching Frequency /kHz	10
	Filter Inductance (L_{fa}/L_{fb}) L/mH	0.3/0.1
	Filter Capacitor C/uF	47
	DC Side Voltage /V	800
Slaver Unit	Rated Power S/kVA	50
	Switching Frequency /kHz	10
	Filter Inductance (L_{fa}/L_{fb}) L/mH	0.3/0.1
	Filter Capacitor C/uF	47
	DC Side Voltage /V	800
Public Grid (V/f/L)		380V/50Hz

Table 2.The Power Distribution of Themicrogrid

Microgrid	Grid-Connected Mode/kW	Off-Grid Mode/kW
Master Unit	-30kW	-50kW
Slaver Unit	-40kW, -16kVar	-40kW, -16kVar
Public Grid	90kW, 26/kVar	90kW, 26/kVar
Load	-20kW, -10kVar	0kW, 0kVar

Microgrid operates in grid-connected mode in initial state, public power grid breaks down at 0.1s, and microgrid switches to off-grid mode. Public power grid failure recovers at 0.3s;microgrid switches to grid-connected mode again.The simulation results of traditional control structure are shown in Fig.7 and the simulation results of modified control structure is shown in Fig.8.Bus voltage of microgrid, output current of power converter and current of power feeder are shown in the figure top-down.It can be seen from the simulation results,fluctuation of power converter's output current and public grid's output current is small in switchover process with the modified control structure, while the results have more intense jitter and large overshoot with traditional control structure. It is easy to conclude that the modified control structure of this paper has the advantage over the traditional method, and it can realize smooth switchover between operating mode.

Current reference values of d axis with two control structures are shown in Fig.9.It is easy to see that the transient mutation of current reference value is intense with traditional control structure while the current reference value realizes smooth transition with modified structure. The simulation results show the feasibility of the modified control structure.

Figure 7.The Simulation Results of Traditional Control Structure

Figure 8.The Simulation Results of Modified Control Structure

Figure 9.Current Reference Values of d Axis with Two Control Structures

According to the modified quasi-synchronization controller for microgrid proposed in section3, we build the simulation model in the Matlab/Simulink software and to prove the feasibility of it. Microgrid operates in off-grid mode in initial state, power converter receive the dictation of grid connection at 0.05s. At this time, the quasi-synchronization controller is put into work and track the voltage public grid. When the bus voltage of microgrid meets the condition of quasi-synchronization, microgrid switches to grid-connected operation mode. And power converter switches to PQ control strategy at the same time. The simulation result is shown in Figure. 10.

Figure 10.Simulation Waveform of Quasi-Synchronization Control in Microgrid

The results of the simulation show the voltage, phase and frequency of the microgrid are getting closer to the public grid when the quasi-synchronization controller is put into work. The bus voltage of microgrid meets the condition of quasi-synchronization at 0.2s, so the STS closes and microgrid switches to grid-connected operation mode. We can find that voltage amplitude, phase and frequency were fluctuant and phase fluctuation is large at 0.2s which is due to the switchover of control strategy of power converter. The validity of the proposed controller is verified by simulation.

6. Conclusions

Smooth switchover of the microgrid is one of the key issues to ensure the reliable operation. Aiming at the shortcomings of the traditional control structure, this paper puts forward the modified control structure and the modified quasi-synchronization method. And verify the validity of the proposed solutions with the MATLAB/Simulink software. The simulation results show the feasibility and superiority of the proposed structure and quasi-synchronization method.

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