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A smooth transition control strategy for microgrid operation modes

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Abstract

According to the characteristics of microgrid in both grid-connected and islanding operation modes, control strategies are proposed to achieve smooth transition between these two modes. Under grid-connected mode, the fluctuation of power in microgrid is balanced by utility power grid. while DGs are adopting the PQ control to ensure the balance of power and realize energy management when the energy storage is in the state of charge standby; When microgrid transits to islanding mode, the droop V/f control strategy is employed to energy storage to support the voltage and frequency of the microgrid system and the power shortage of the whole system will be compensated. When microgrid reconnect to utility power grid, especially a three phase software phase-locked loop (SPLL) based pre-synchronizing unit is designed to track the utility grid voltage, which makes the process of reconnecting to grid stable and safe. In the whole process, the optimal distribution and reliable protection of the energy storage is well considered to meet control targets of smaller capacity and high efficiency, which can reduce the pollution and emissions levels. Simulations are carried out by MATLAB/SIMULINK. Simulation results confirm that the smooth switch of the control system is effective and stable.

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Keywords: Microgrid;energy storage;smooth transition;control strategy;pre-synchronizing;

1. Introduction

Researches of Microgrid have been developed promptly in recently years because of energy crisis and environmental concern. The microgrid should operate normally in grid-connected and transfer to islanding operation mode when a utility fault occurs. However, to stabilize the voltage and frequency on the AC bus during mode transfer is difficult for microgrid control. There are more and more researches about mode transfer. Reference [1] uses an improved droop control strategy, before and after mode switching control strategy unchanged, in line with plug and play features. While solving the applicability of the microgrid control strategy, but not considering suppressing the impact of the current for re-connection process in the droop control. And in the state of grid-connection, due to fluctuations grid voltage and frequency output power will deviate from the nominal operating point control. Reference [2] proposed a dual-mode inverter, grid-connected operation uses PQ control while island uses droop control. However conventional drop control assumed power lines was pure inductive or resistive and this

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low-pressure microgrid line inductance cannot be ignored, it lacks of applicability and there is the risk of switch failure.

This paper describes the form of distributed power and energy storage devices combining microgrid and their control strategies for different operation modes. Energy storage unit composed of the storage unit and the inverter bridge, in the grid-connected operation mode, it can absorb the excess energy to store; islanding operation, energy storage can increased the dynamic response speed of microgrid, and regulate active and reactive power balance to ensure stable operation of the microgrid [3]~[5]. DGs use PQ control, but for the energy storage device is charging in the standby state in the gird-connected mode when in the island mode the energy storage device uses an improved V/f droop control to maintain the internal microgrid voltage and frequency stability. While adding the pre-synchronization processing unit, by detecting the change of local voltage and frequency, timely compensate, effectively reducing transient oscillations during re-connection. Throughout the process, we have fully considered the optimal allocation of storage capacity and reliable protection, with a smaller capacity to meet the control objectives, to improve the efficiency of DGs, to reduce fuel and emissions levels.

2. The Structure Of A Microgrid System

Microgrid is made up of generation, load, energy storage devices and control devices to form a single, controllable and independent power supply system. It also can smooth access utility power grid and independent and autonomous operation. It is an effective way to play a distributed power performance. American Consortium for Electric Reliability Technology Solution (CERTS) proposed a micro grid structure as shown in figure 1. Microgrid is a kind of system by load and DGs; it can provide electricity and heat at the same time. Power electronic devices is responsible for energy conversion and provides the necessary control for the internal power of Microgrid; Microgrid relative external power grid characterized by single control unit, at the same time satisfy the user to the power quality and power supply reliability and safety requirements [6]~[9]. It is based on the distributed power generation technology, energy storage, control and protection devices, and able to work in the grid-connected and island two modes.

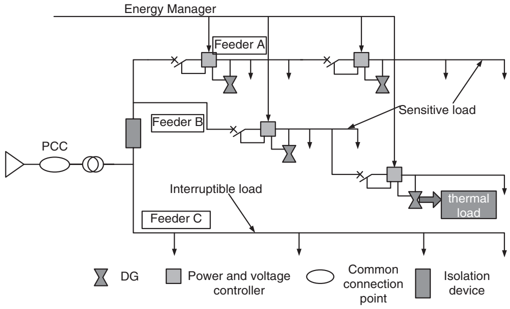

Fig.1 Structure of a Microgrid

The structure of three feeders is radiate, interruptible loads connected to one feeder; important or sensitive loads connected to another feeder and install DG, energy storage device and their corresponding control, regulation and protection equipment. PCC is appoint of common connection, where to separate microgrid

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from power grid when the external power grid failure or request from the microgrid to operate in island mode. Through the isolation devices to remove some of the interruptible load to ensure that important or sensitive loads normal running; after the failure disappeared, microgrid operate again in the gird-connected mode.

3. Microgrid Inverter Control Strategy

3.1 PQ Control

PQ control output of the active and reactive power respectively as its reference value P_{ref} and Q_{ref}, usually used for grid-connection mode of microgrid. In this state, microgrid voltage and frequency stability can't guarantee, load fluctuations within the microgrid, frequency and voltage disturbances borne by the large grid, each DG don't need to consider the frequency regulation and voltage regulation, directly use of large grid frequency and voltage as regulation basis, controlling the inverter according to the given reference value of active power and reactive power output, controller adopts double loop control, outer loop control needed to produce the reference signal current loop based on power target, current inner loop played the role of fine-tuning [10][11].

$$\begin{cases} i_{dref}=\left(k_{p1}+\frac{k_{i1}}{s}\right)\left(P_{ref}-P_m\right) \\ i_{qref}=\left(k_{p2}+\frac{k_{i2}}{s}\right)\left(Q_{ref}-Q_m\right) \end{cases} \tag{1}$$

k_{p1}, k_{i1}, k_{p2}, k_{i2} are the control parameters of the PQ controller.

$$\begin{cases} V_{sd}=\left(k_{iP}+\frac{k_{iI}}{s}\right)\left(i_{dref}-i_d\right)+V_d-wLi_q \\ V_{sq}=\left(k_{iP}+\frac{k_{iI}}{s}\right)\left(i_{qref}-i_q\right)+V_q+wLi_d \end{cases} \tag{2}$$

In dq0 coordinate system, generally make q axis component V_q is 0.

Designed by the above formula (1) (2) PQ controller schematic is shown in Figure 2.

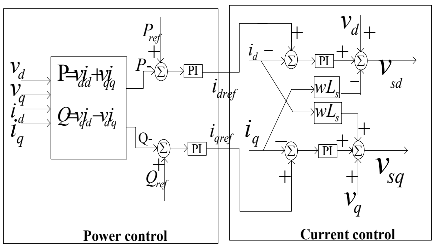

Fig2 Structure of grid-connected PQ controller

The output voltage of current controller is modulated by the Park and SVPWM, can get a sinusoidal modulation signal, and thus completes the PQ decoupled constant power control.

3.2 Improvement of V/f control strategy

In island operation mode, in this paper the energy storage is controlled by improving V/f droop controller, energy storage provides output voltage and frequency for other DGs and guarantees constant voltage and frequency of microgrid, compensate for power deficiency at the same time. Improvement V/f droop control is tracking faster than the traditional V/f droop control, the principle diagram of the controller is shown in figure 3.

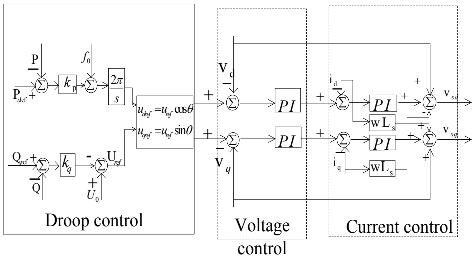

Fig3 Structure of island droop V/f controller

Droop control is based on the traditional generator "power frequency static characteristics" of control theory to control [12]. When the active power needed in the system is increased, providing less will result in a frequency decrease; when the system needs to increase the reactive power, reactive power supplied insufficient, resulting in voltage amplitude reduction, and vice versa. Therefore, a reasonable allocation of the power gets through the droop characteristics of the part of droop control and obtains the reference signal to control the inverter, but the droop control is a single-loop control, the inverter output voltage is susceptible to changes in load, thus adding voltage control to avoid voltage fluctuations, ensuring stable output signal. Current control achieves the current static error tracking. Droop characteristic equation:

$$\begin{cases} f^* = f_0 - k_p(P_{ref} - P) \\ \mathrm{U}^* = U_0 - k_q(Q_{ref} - Q) \end{cases} \tag{3}$$

k_p, k_q are droop coefficients.

3.3 Pre-synchronizing control unit

When microgrid is in islanding operation mode, due to played the supportive role in microgrid, voltage source inverter (VSI) works in accordance with the drooping characteristic, microgrid voltage and grid voltage will generate a deviation, and re-synchronization process between the two modes is that the key to achieving a seamless switch microgrid operation modes. Synchronous tracking technology based SPLL (Phase Locked Loop) measures the phase angle and frequency to achieve synchronization with the large microgrid voltage and utility grid voltage, thus avoiding the impact of current, and ultimately the microgrid system seamless switch to grid-connected mode from the island mode [13].

As shown in figure 4, the terminal voltage phase Angle for the SPLL is θ_g; it is the amount of tracking actual voltage phase angle. In the measurement, q-axis voltage is first obtained by the coordinate transformation can be expressed as:

$$\mathrm{v}_{gq} = V\sin(\theta - \theta_g) = V\sin\Delta\theta \tag{4}$$

Synchronization tracking process is that though dynamically adjusting the frequency synchronization compensation angle of the inverter output voltage to realize the voltage phase synchronization between microgrid and utility grid, when the two are completely synchronized, Δθ should be zero, the bus voltage microgrid projected on the q-axis component is zero, and so the synchronization can be achieved by controlling $V_{gq}=0$.

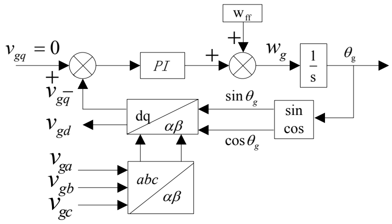

Fig4. Three-phase grid voltage SPLL

4. Simulation Results And Analysis

4.1 Simulation Parameters

In order to verify the correctness and validity of the proposed method, the paper uses Matlab /Simulink simulation platform of a microgrid structure shown in Figure 1, in this paper, two sets of DGs are in parallel for example, the initial parameters of DG1 for the simulation: P_{ref1}=10KW, Q_{ref1}=1000Var, DG2: P_{ref2}=20KW, Q_{ref2}=0Var, utility voltage is 380V, frequency is 50HZ. In the V/f control strategy parameter: v_{dref}=380V, v_{qref}=0V.DG1 and DG2 comprehensive line impedance resistor: R=0.64Ω/km, inductance: L=0.1H/km. Storage is the battery, the terminal voltage is 280V; rated amp-hour capacity is 70Ah. Load with constant power load: P_1=10kW,Q_1=1000var;P_2=20kW,Q_2=5000Var, P_3=10kW,Q_3=0Var.

4.2 Simulation Analysis

Conditions as follows:

1) At 0-0.3s moment, microgrid is in grid-connected mode, DG1, DG2 are in PQ control, battery is in charging state;
2) t =0.3s, the utility grid occurs three phase short circuit fault, then the microgrid detects islanding, PCC disconnected, at the same time the microgrid switch to the island operation, then energy storage switch to the discharge state and was controlled by improve it the V/f control droop.
3) t =0.6s, pre-synchronization control starts for preparing for reconnection of Microgrid.
4) t =0.65s, PCC closed and microgrid is in grid-connection mode, energy storage into the charging status.

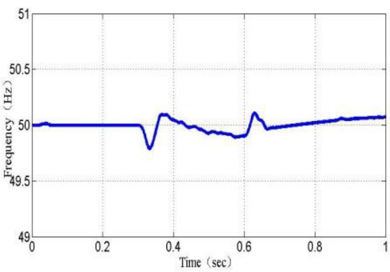

Fig.5 Bus frequency change curve in switching process

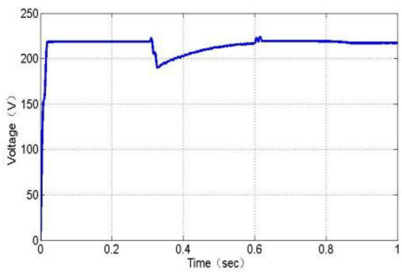

Fig.6 Bus voltage in switching process

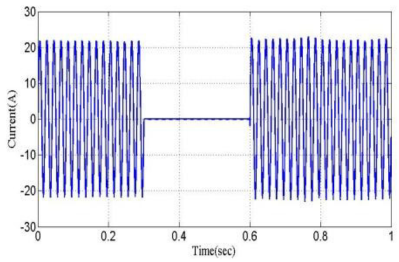

Fig.7 Response of current in PCC

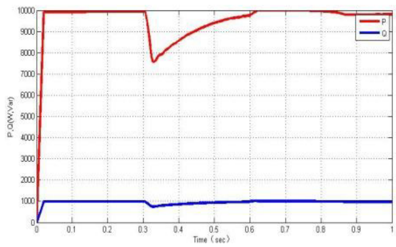

Fig.8 Output active and reactive power of DG1 in switching process

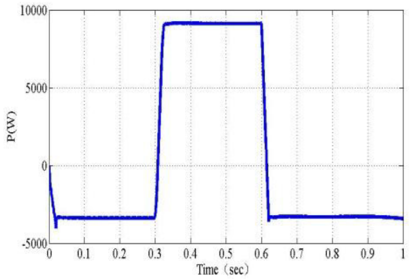

Fig.9 Output active power of storage

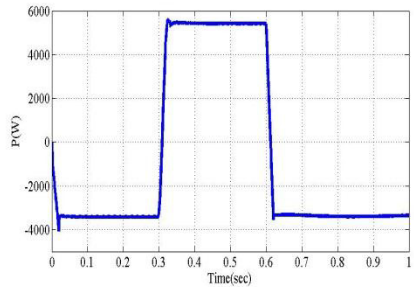

Fig.10 Output reactive power of storage

As we can be seen from Figure 5,6, in the switching process, the fluctuations of the microgrid voltage and frequency are within the allowable range, the system can meet the requirements for stable operation. In the grid-connection to switch island mode, voltage and frequency have undergone small drop, but then they quickly rebounded, mainly because the storage quickly fill power vacancies in the mode switching. In the island to grid-connection, voltage transition is very smooth; the most important reason is that adding pre-synchronization processing unit, which also makes fewer inrushes current we can see from Fig.7.

As shown in Figure 8, DG1 always adopt PQ control, so no matter under which mode, output power always follows the change of the reference values.

From Figure 9, 10, storage has been in a state of charge in grid-connection mode, and when the microgrid is in island mode, energy storage carried improving V/f droop control, providing the voltage and frequency of the microgrid to ensure the system stable operation, and promptly fill the power shortfall.

5. Conclusion

Microgrid has the ability to smoothly run and transfer. Flexible and effective control strategy in microgrid is the fundamental guarantee of reliable operation. In this paper, different control strategies for modeling and simulation analysis in different mode verify its validity and feasibility. Simulations show that the storage control ensures the stability of voltage, frequency and the output power of DGs in island mode, thus ensuring the reliability of the power load. For reconnection processing, the pre-synchronization processing unit effectively suppresses shock of inverter and improves the safety and stability of the system. Microgrid can achieve smooth transfer between island and grid-connection operating modes. That's have a great role in promoting the future development of the smart grid.

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