Control Strategy of Microgrid Inverter Operation In Grid-connected and Grid-disconnected Modes

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Abstract—*Microgrid is a independent and controllable system which is composed by load and miniature power. It provides for the local power and energy. The complex control of microgrid is implemented by microgrid inverter. This paper introduces two operation modes of Grid-connected and Grid-disconnected for microgrid inverter. On the Grid-connected operation, it uses hysteresis current tracking, by adjusting the output current to the grid to achieve energy transmission. On the Grid-disconnected operation, it uses voltage close loop control, by adjusting the output voltage to ensure stable load voltage. When the gird fails or recovers, microgrid inverter can switch smoothly between two modes of Grid-connected and Grid-disconnected operations. The simulation results show the feasibility and effectiveness of control strategy.*

Keywords-Microgrid Inverter, Grid-connected mode, Grid-disconnected mode, **Hysteresis** *Current*

I. INTRODUCTION

Distributed Generation (DG) is a closely watched the form of electricity generation in recent years. It is the main use of solar, wind, fuel cells and other renewable and clean energy generation, namely the protection of the environment, and also it saves energy and realizes the diversification of energy use.

The current worldwide focus on large-scale use of power generation, long-distance transmission and large power supply grid interconnection, there are some drawbacks: high cost, difficult to run, more and more difficult to adapt to the user's safety and reliability requirements and various of the power demand [1, 2]. Distributed generation system (DGS) can help to improve power quality and power supply flexibility and expandability, maintain grid system stability, optimize the distribution system, which provides the spinning reserve and reduce the transmission and distribution cost which all are of great interest for power utilities. From the viewpoint of emission reduction compared to traditional power plants, DGS is also attractive for societies [3, 4].

The emergence of microgrid has also brought some new problems and challenges, such as the stability of power quality, relay protection setting and so on. Among them, how to effectively control microgrid inverter, which is one of the key issues to ensure that the system is stable and efficient operation, and also which is the main content of this paper.

II. MICROGRID

A. The Microgrid Concept

The CERTS microgrid concept is an advanced approach for enabling integration of, in principle, an unlimited quantity of distributed energy resources into the electricity grid. The microgrid concept is driven by two fundamental principles:

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(1) A systems perspective is necessary for customers, utilities, and society to capture the full benefits of integrating distributed energy resources into an energy system;

(2) The business case for accelerating adoption of these advanced concepts will be driven, primarily, by lowering the first cost and enhancing the value of microgrids [5].

B. The Microgrid Architecture

The basic structure of microgrid is shown in Fig.1, microgrid is included in several small powers and storage systems, which banded together to the load power through the circuit breaker and the static switch connected to the grid.

In Fig.1, microgrid has A, B and C three feeders, which is a radial structure. Feeder A contains important loads, and feeder B micro cogeneration power can be combined cooling heat and power. Feeder C connects normal load, which can be cut off in certain circumstances.
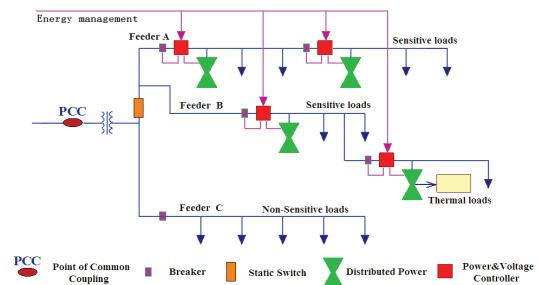

Figure 1.   U.S. CERTS proposed microgrid basic structure

III. GRID-DISCONNECTED OPERATION

Microgrid inverter has two modes of Grid-connected operation and Grid-disconnected operation. Being able to run by breaking away from the grid, which is one of the most important characteristics of microgrid inverter. But traditional Grid-connected inverter doesn't run when the grid fails.

On the Grid-disconnected operation, microgrid inverter breaks away from the grid through the static switch, which can be equivalent to the traditional independent inverter. In this paper, we can take Voltage Source Inverters (VSI) as the microsources, which supplies on the local load. Full-bridge topology for the study, Fig. 2 is the main circuit topology of the voltage full bridge inverter circuit. Udc is distributed power for the equivalent of setting the output of DC power, VT1 - VT4 for power switch device IGBT, L and C composition low-pass filter, RL for local important loads.
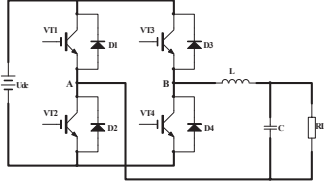
Figure 2. Voltage Source Inverters circuit topology

In the control model for inverter circuits, the basic thought for the high-frequency SPWM modulation mode is to compare the sinusoidal modulation signals with the carrier signals (such as triangular wave) to get the received pulse which controls the power switching devices[8,9]. We can establish frequency domain transfer function G(s), Ls for inductance, 1 / Cs for capacitor, the relationship between output voltage Uo(s) and A, B between two voltage Ui(s) is:

$$G_o(s) = \frac{U_o(s)}{U_i(s)} = \frac{\frac{1}{R} + Cs}{\frac{1}{\frac{1}{R} + Cs} + Ls} = \frac{1}{LCs^2 + \frac{L}{R}s + 1} \quad (1)$$

Using SPWM modulation, output voltage inverter of amplitude value U_{o1} can be expressed as:

$$U_o = \frac{1}{\sqrt{2}} \cdot \frac{U_{rm}}{U_{cm}} \cdot U_{dc} = 0.707 M U_{dc} \quad (2)$$

Where U_{rm} is amplitude sinusoidal reference, U_{cm} for the triangular carrier amplitude, M for the modulation ratio.

We can take the inverter bridge as a proportion, the ratio factor is defined as $k = U_i / U_{rm}$. Input and output transfer function for the inverter is:

$$G(s) = \frac{U_o(s)}{U_{rm}(s)} = \frac{U_o(s)U_i(s)}{U_i(s)U_{rm}(s)} = k \cdot \frac{1}{LCs^2 + \frac{L}{R}s + 1} \quad (3)$$

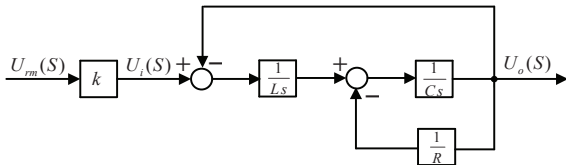According to the transfer function of the expression can be the equivalent block diagram shown in Fig. 3.

Figure 3. Closed-loop control voltage equivalent chart

Simulation

Changing the modulation ratio M for the control strategy, we can use Simulink software in the establishment of a single-phase inverter voltage closed-loop simulation circuit. DC input voltage Udc = 350V, the LC filter L = 1mH, C = 10uF, load R=9 Ω . PI controller parameters: Kp = 10, Ki = 0.2.
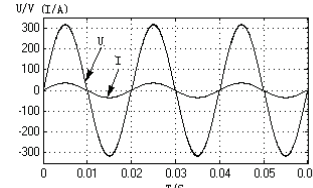

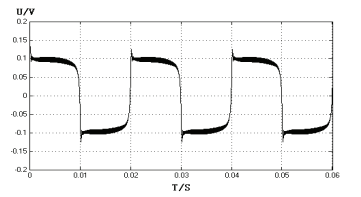Figure 4-1. Load voltage and current waveform
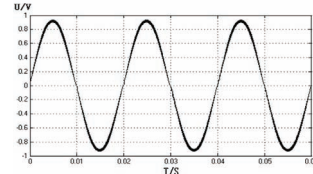Figure 4-2. PI controller output voltage waveform

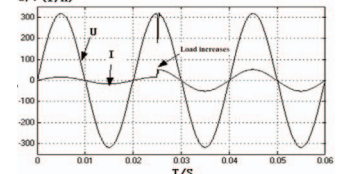Figure 4-3. Sine modulation waveform
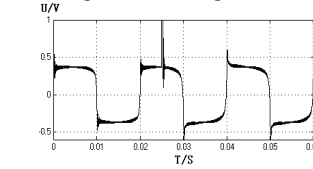Figure 4-4. Voltage and current waveforms when the load changes

Figure 4-5. PI controller waveform when the load changes
Figure 4-6. Sine modulation waveform when the load changes

The simulation results can be seen from the above, changing the modulation ratio M with closed-loop control strategy, microgrid inverter output voltage is stable, and waveform distortion is small. Sudden changes in load, PI regulator responds quickly, after a very short period of time, the output voltage recovery.

IV. GRID-CONNECTED OPERATION

When the inverter connects the grid, the grid can be regarded as an infinite capacity of ac voltage source. If the inverter adopts voltage control mode, it is easier to produce a large circulation, which is a strong impact for the inverter and the grid. The use of current control mode, only the need to control the inverter output current tracking the voltage of the grid, while setting the size of the output current, you can achieve the stability of the parallel operation, the control method is relatively simple and the results are better, so it has been widely used[10,11,12].
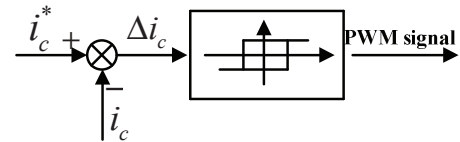

Figure 5. Hysteresis Current Control Chart

Comparison of hysteretic current mode of the instantaneous way shown in Fig.5. Δi_c as the comparator hysteresis loop width, when the command current i_c^* and net current i_c rise the

width than the difference, the hysteresis comparator generates PWM signal for controlling power devices to adjust the grid-connected current. This control scheme features: real-time control, the current of fast response and accurate control method is simple [7].
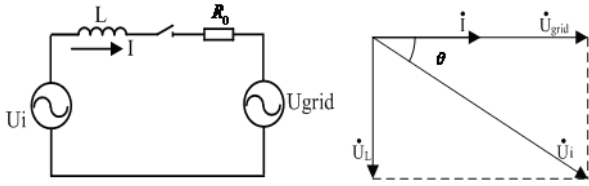

Figure 6. Equivalent circuit diagram
Figure 7. Voltage and current vector diagram on Grid-connected operation

Take the grid current for reference:

$$L\frac{dI}{dt} = Ui - U_{grid} - IR_0 \tag{4}$$

The formula: Ui is the output voltage of inverter, U_{grid} is grid voltage, I is the inductor current (that is the grid current), R0 is the equivalent resistance of the circuit. The plural form of domain is:

$$I(s) = \frac{1}{Ls + R_0}(U_i(s) - U_{grid}(s)) = G_f(S)(U_i(s) - U_{grid}(s)) \tag{5}$$

$G_f(S)$ is the transfer function for the controlled object, when the inverter switching frequency is much higher than the output frequency, $G_f(S)$ can be equivalent to K.
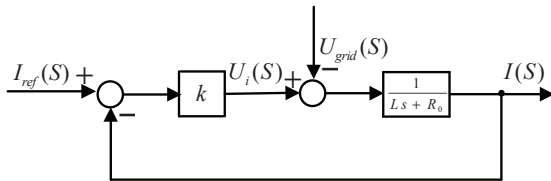
We can draw grid current closed-loop diagram:

Figure 8. Closed-loop grid current chart

Simulation

Using hysteresis current tracking for the control strategy, we can use Simulink software in the establishment of a single-phase inverter voltage closed-loop simulation circuit. DC input voltage Udc = 350V, the LC filter L = 1mH, C = 10uF, load R=9Ω. Hysteresis current controller sets parameters: Io = 14, $\Delta i_c = 0.7$.
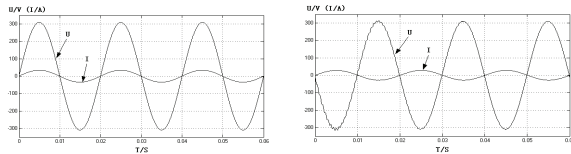

Figure 9-1. Load voltage and current waveform
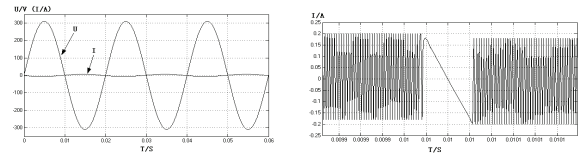Figure 9-2. Output waveform of microgrid inverter

Figure 9-3. Output voltage and current waveform for the grid
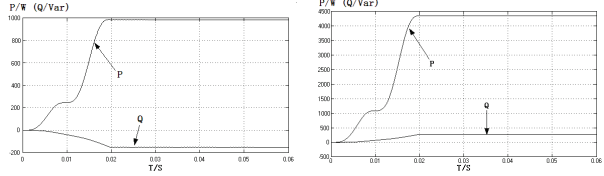Figure 9-4. PWM pulse waveform

Figure 9-5. Output active and reactive power waveform of microgrid inverter
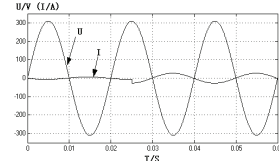Figure 9-6. Output active and reactive power waveform for the grid

Figure 9-7. Voltage and current waveform for the grid when the load changes

The simulation results can be seen from the above, using hysteresis current loop control strategy, microgrid inverter output current is stabile and low distortion. When the load changes, the current flows through the load also changes, and the voltage for the load always maintain a constant voltage.

V. SWITCH BETWEEN GRID-CONNECTED OPERATION AND GRID-DISCONNECTED OPERATION

As the voltage drop, fault, power outage maintenance and other causes interruption of external power connection, microgrid inverter can smoothly transform from Grid-connected operation to Grid-disconnected operation. Microgrid inverter provides power to important loads. After faults remove, the static switch closes; microgrid inverter can steadily switch from Grid-disconnected operation to Grid-connected operation.

A. The simulation from from Grid-disconnected operation to Grid-connected operation

Microgrid inverter is disconnecting to the grid, after 0.06s it connects to the grid, the corresponding results are shown below.
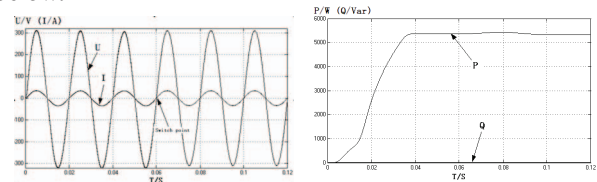

Figure 10-1. Load voltage and current waveform
Figure 10-2. Active and reactive power waveform for microgrid inverter

Figure 10-3. Active and reactive power waveform for the grid

Figure 10-1 shows that in the switching process, the voltage of load is very stable. The amplitude, phase and frequency do not change. Figure 10-2 shows that in the switching process, the output of microgrid inverter has stabilized. And the grid has no effect to the operation of microgrid inverter in the connected-grid mode. Figure 10-3 shows that before the 0.06s, the grid does not provide energy to the load. Connected-grid, the grid begins to provide energy to the load, while it provides reactive power to microgrid in a few cycles.

B. The simulation from from Grid-connected operation to Grid-disconnected operation

Microgrid inverter connects to the grid, at the 0.06s moment it disconnects to the grid, the corresponding results are shown below.

Figure 11-1. Load voltage and current waveform
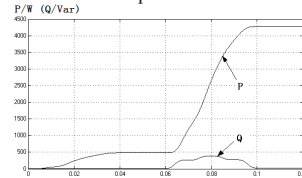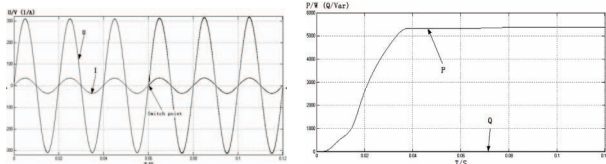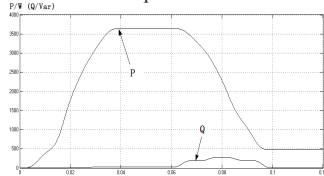Figure 11-2. Active and reactive power waveform for microgrid inverter

Figure 11-3. Active and reactive power waveform for the grid

Figure 11-1 shows that in the switching process, the voltage of load is very stable. Just the switching point, there is a little impact on current. Figure 11-2 shows that in the switching process, the output power of microgrid inverter has stabilized. And the grid has no effect to the operation of microgrid inverter in the disconnected-grid mode. Figure 11-3 shows that before the 0.06s, microgrid inverter connects to the grid, microgrid inverter and the grid provide energy to the loads together. After disconnected-grid, the grid does not provide energy to the load, microgrid inverter provides power to sensitive loads, which ensures uninterrupted power supply sensitive loads.

The simulation results show that the above, microgrid inverter can smoothly switch between two modes. In the process of switching process, frequency and amplitude is stable, which proved the feasibility of this method and reliability. In the conversion process, the inverter output voltage and output current is stable, which has no voltage drop or current overshoot. Microgrid inverter runs with Grid-connected operation, power output of the grid is reduced just mean microgrid inverter power output of the power inverter. After breaking away from the grid, microgrid inverter is on the Grid-disconnected operation, it supplies the sensitive loads, while the grid has no output power. Experimental results demonstrate the feasibility and effectiveness of control methods.

VI. CONCLUSION

This paper summarizes the traditional independent inverter and Grid-connected inverter control strategy, combining the distributed power and microgrid inverter characteristics, a suitable for microgrid inverter control strategy is put forward. Switching between Grid-connected mode and Grid-disconnected mode for microgrid inverter has been studied .On the Grid-disconnected operation microgrid inverter supplies the important loads that ensures load voltage and frequency stability. Microgrid inverter can smoothly switch between Grid-connected operation and Grid-disconnected operation, and switching operation of the system has good performance. The system controller design is simple, practical and efficient, easy to implement. The simulation results show that the proposed control method is feasible and effective.

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