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Research on Micro-grid Control Mode

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ABSTRACT. *Micro-grid is an organic whole composed of various functional modules, It is only reasonable and reliable control mode which can maintain the system under excellent operation.In this paper, photovoltaic cells are used as micro power supply, and a hybrid energy storage system is constituted by batteries and supercapacitors. There is a design of master-slave control mode based on power current double closed loop and voltage current double closed loop. The hybrid energy storage system is regarded as the main power source because of its stable output. Meanwhile, its inverter adopts V/F control mode, it is random in photovoltaic cell output power, and it adopts PQ control mode. Finally, there is a simulation model established in MATLAB/simulink. The simulation results verify that the control method can ensure the micro-grid system stably operating in the process of grid connection, off-grid and switching.*

KEYWORDS: *Micro-grid; Master-slave control; PQ control mode; V/F control mode*

1. Introduction

Micro-grid is an independently controllable small power supply system consisting of distributed power, energy storage device, energy conversion device, related load and control protection[1]. It can be connected to the large power grid through static switch, and also can be operated separately[2]. It is different from the traditional rotating power supply equipment, and there exists huge distinction in the performance of various micro power sources and energy storage components. Moreover, the power output of the distributed power source is not power frequency alternating current, and must be converted by conversion device before utilization. At the same time, what micro power source outputs is often random, so, to obtain the maximum power output, reasonable control is demanded to improve the utilization rate of renewable energy. Only through in-depth research and continuous optimization of the micro-grid operation control mode can various micro-grid functional modules operate in order, giving full play to the advantages of micro-grid.

The control mode of micro-grid can be analyzed from two aspects, the overall control strategy of micro-grid and the specific control method of inverter. The overall

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control strategy of micro-grid includes master control strategy, peer control strategy and hierarchical control strategy [3]. On the other hand, there are three common inverter control methods: droop control, constant voltage and constant frequency control (V/F control) and constant power control (PQ control) [4], respectively. Generally, master-slave control means that the inverter of the main power supply uses V/F control mode to realize system voltage and frequency stability. Moreover, the inverter of the secondary power supply takes advantage of PQ control mode for the maximum power supply of distributed clean energy and the guarantee of load demand. Peer control points that all micro source inverters adopt the droop control method and adjust and distribute power in accordance with the set droop control coefficient. However, this control is not high in precision. The hierarchical control strategy is applicable to those micro-grid systems with complex structures and communications among layers. In this paper, there appears a design of a master-slave control method on basis of power current double closed loop and voltage current double closed loop.When micro-grid is incorporated into a relatively strong large power grid system, it can only deliver power to the grid as a power source. The frequency and voltage of the system do not need it to support. Nevertheless, once micro-grid is connected to a relatively weak power grid system, it is necessary to assume certain frequency and voltage regulation capacity. If micro-grid is running on the isolated network, the frequency and voltage of the whole system needs to be supported by the distributed power supply itself. At this time, the distributed power supply with stable output in micro-grid is regarded as the main power source, and the other is used as the slave power source to jointly supply the required power. [5]

2. PQ Control Design

Figure 1 shows the structure of PQ control mode. The grid-connected inverter changes DC power into AC power. In order to smoothly realize inverter's function and obtain high-quality AC power, it is necessary to control the inverter PQ control mode consists of a power outer loop and a current inner loop. The power outer loop is used to calculate and obtain the inner loop current reference. The current inner loop is made use of to obtain the switching signal required by the inverter, to realize the reasonable switching on/off of the grid-connected inverter, and power fluctuation can be quickly suppressed. In addition, since voltage and current signals obtained at the AC bus belong to alternating current which varies with time, and active power and reactive power are directly coupled, it is difficult to calculate. Therefore, it is necessary to decouple and simplify calculation by coordinate transformation. After complete calculation, the control quantity of inverter is reverted to AC quantity by inverse coordinate transformation [6].

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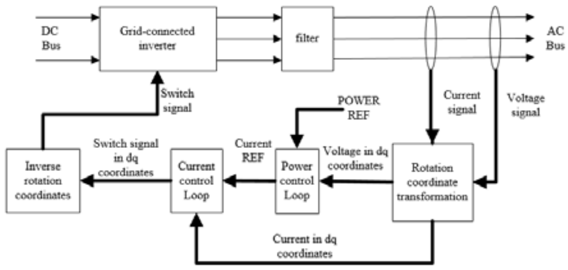

Fig.1. PQ control structure diagram

When converted to the two-phase rotation dq coordinate system by Park transformation, [7] power calculation is shown as the following equation (1-1):

$$\begin{cases} P = u_d i_d + u_q i_q \\ Q = u_q i_d - u_d i_q \end{cases} \quad (1\text{-}1)$$

The d-axis is selected to coincide with the inverter outlet voltage vector, so that $u_d = U \,\&\, u_q = 0$ are introduced into equation (1-1), and power calculation can be simplified into equation (1-2). Obviously, the decoupling control of active power and reactive power is realized by coordinate transformation. In dq coordinate system, active power is only determined by d-axis current, and reactive power is only up to q-axis current. [8]

$$\begin{cases} i_d = \dfrac{P}{U} \\ i_q = -\dfrac{Q}{U} \end{cases} \quad (1\text{-}2)$$

In consideration of the active power and reactive power reference values, if equation (1-2) is taken as the theoretical basis of the power outer loop, the dq axis reference value of the current inner loop can be calculated. At this point, power control can be further converted into current control. As shown in Figure 2, there is the power outer loop control block diagram:

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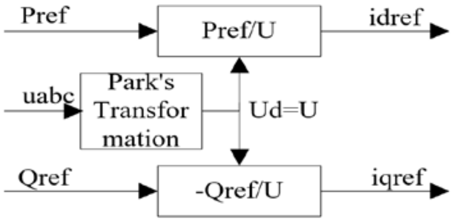

Fig.2. Power outer loop control diagram

The function of the current inner loop is to make the output current follow the reference current without static difference. First, the current reference value is compared with the current output value, then the current error signal is obtained, and last the PI controller performs the operation. By adjusting the PI parameter, the error is finally reduced to 0 to ensure that output current quickly and stably tracks reference value, thereby finishing stable control of active power and reactive power[9].since the d-axis voltage and the q-axis voltage are coupled in the calculation, it is necessary to increase the decoupling control. Besides, it is necessary to add a voltage feed-forward compensation link in the current control adjustment, which can effectively reduce the influence caused by various disturbances, making the control more stable and reliable. The current-adjusted output corresponds to the d-axis and q-axis components of the sinusoidal control voltage, and is converted into a sinusoidal time-varying signal, and compared with the simultaneously engraved carrier signal to obtain a trigger sequence. The mathematical model of the current loop is as shown in equation (1-3).

$$\begin{cases} u_{dref} = (K_{p1} + \frac{K_{i1}}{s})(i_{dref} - i_d) - wLi_q + u_d \\ u_{qref} = (K_{p2} + \frac{K_{i2}}{s})(i_{qref} - i_q) + wLi_d + u_q \end{cases} \quad (1\text{-}3)$$

In terms of equation (1-3), it proposes the control block diagram of the inner ring of current.

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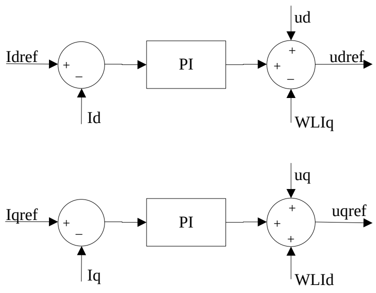

Fig.3. Current inner loop control diagram

3. V / F Control Design

The essence of V/F control is to stabilize system voltage and system frequency in light of reference value through feedback adjustment. It consists of the voltage outer loop and the current inner loop. [11] Among them, the voltage outer loop uses system state variable feedback information to keep the micro power supply output voltage and frequency stable. The current inner loop is utilized to reduce the influence of disturbances on the system and increase the response bandwidth of the distributed power supply. [12] The V/F control structure is shown in Figure 4.

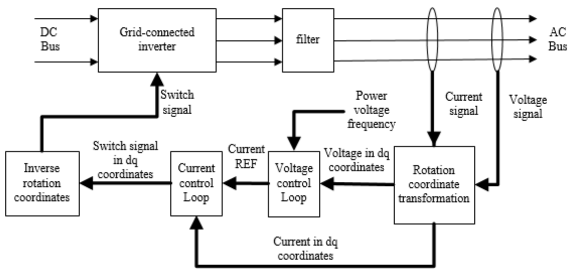

Fig.4. V / F control structure diagram

As what can be seen from Fig. 4, the sampled AC voltage signal is converted into a d-axis voltage component and a q-axis voltage component by coordinate transformation, the voltage component is then fed into the voltage control loop. At the same time, the AC frequency obtained by the phase-locked loop is also input into the

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voltage control loop. After calculation, the reference current value of the output current inner loop is input into the current control loop, together with the sampled voltage coordinate transformation value, and switch signal is finally obtained, so as to control the orderly on-off of the switch tube on the inverter bridge arm and obtain high-quality power frequency AC power.

The effect of the voltage outer loop is to make the sampled voltage and frequency track reference voltage and reference frequency, thus realizing the constant voltage and frequency. [13] In order to facilitate control, Park transformation is carried out under the AC voltage on the sampled load to obtain the d-axis voltage component and the q-axis voltage component. The reference value of the current inner ring can be obtained with the help of the PI controller.The mathematical expression of voltage control is as follows:

$$\begin{cases} i_{dref} = (K_{p1} + \frac{K_{i1}}{s})(u_{dref} - u_d) - wCu_q \\ i_{qref} = (K_{p2} + \frac{K_{i2}}{s})(u_{qref} - u_q) + wCu_d \end{cases} \tag{1-4}$$

The PI controller is used to realize fast and stable voltage tracking. Because output voltage d-axis and q-axis components are coupled to each other, decoupling control is required, and the output current of voltage control is regarded as the current inner loop reference value. In Figure 5, there is the voltage outer loop control block diagram.

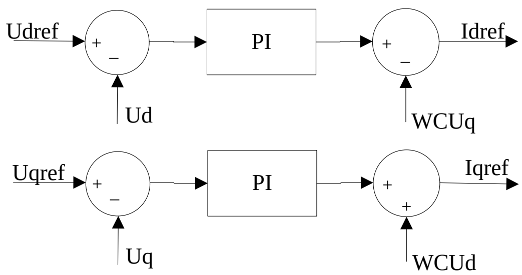

Fig.5. Voltage outer loop control diagram

The current inner loop is the same as the current inner loop under the PQ control mode, and the PI control mode is also adopted, which enables current to rapidly track reference value. Thus, it ensures that voltage is maintained at the set value. PI parameters of both voltage loop and current loop are designed through transfer function method. The inner current loop is designed first and then treated as a transfer function in the outer voltage loop. After calculation, PI parameter values are K_{ip}=0.12, K_{ii}=0, K_{up}=0.541 and K_{ui}=1562.5, respectively.

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4. simulation Analysis

In this simulation, the hybrid energy storage module, in parallel with battery and super capacitor, is used as the main power source DG1 [14] where the rated parameter of the supercapacitor group is 405V/20F and the rated parameter of the battery reaches 400V/195Ah. After boosting, these two are connected in parallel to provide 800V DC voltage, and the inverter adopts V/F control, which is responsible for the voltage and frequency control when the system is under off-grid operation. The reference voltage u_d is set at 326V and the reference voltage u_q is set at 0V. The photovoltaic power supply is used as the auxiliary power source DG2, which is formed by connecting 10 sets of photovoltaic arrays in parallel. Each group of photovoltaic arrays is made up of 14 photovoltaic cells which are connected in series. Because of booster circuit, 800V DC voltage can be obtained, and the inverter adopts the PQ control mode. To maximize the extent of renewable energy utilization, the active power is set at 25kW, the reactive power is set at 0Var, and the large grid is set at 400V voltage level, providing voltage and frequency reference values for grid-connected operation. There are three loads in demonstration project, namely Load1, Load2 and Load3. Load1 and Load3 are secondary loads whose required active power is 10 kW, and the reactive power is 0Var and 5kVar, respectively; Load2 is the main load with the required active power at15 kW, and the reactive power is 0Var. The master-slave control model of micro-grid is shown in Figure 6.

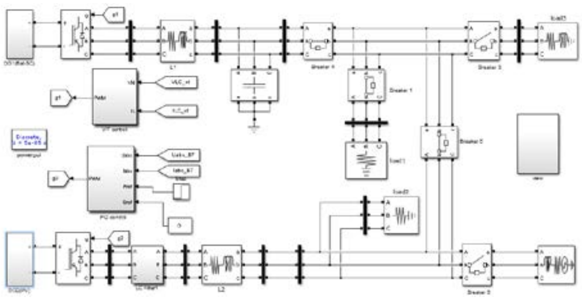

Fig.6. Master-slave control model

4.1 Load increase and Decrease Simulation Analysis

At the initial moment, micro-grid runs through the network and micro power sources are put into utilization. Load1 and Load2 connect micro-grid, the required active power is 25kW and the reactive power is 0Var. Load3 is not connected. At the moment of t=0.5s, breaker 3 is closed and Load3 is connected to micro-grid. At this time, active power increases from 25kW to 35kW, and reactive power increases from 0Var to 5kVar. When t=1s, circuit breaker 1 is turned on and Load1 is removed from micro-grid. Meanwhile, active power demand is reduced to 25kW and reactive power remains at 5kVar. The simulation results are shown in Figure 7 and Figure 8.

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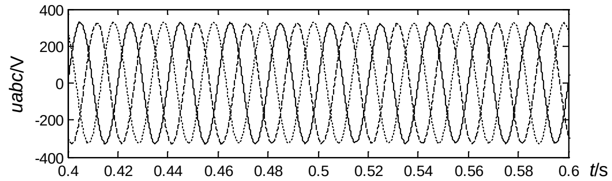
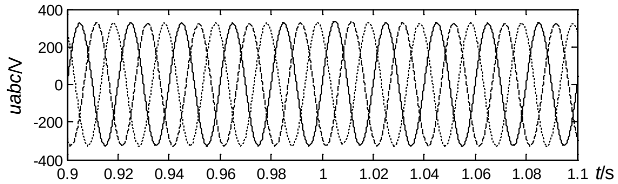
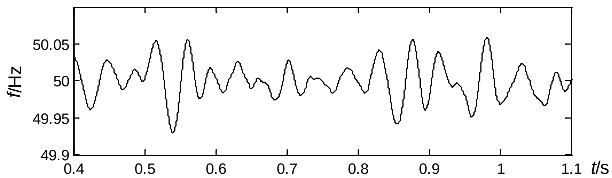


a) Bus voltage curve with load increasing

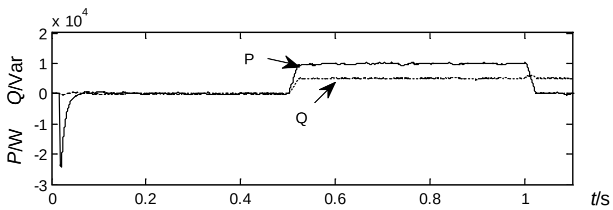


b) Bus voltage curve with load decreasing

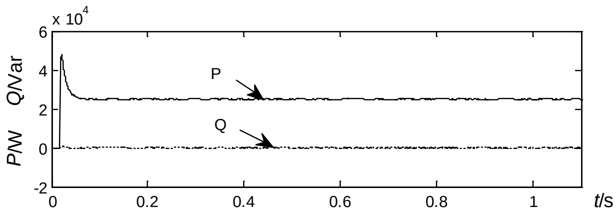


c) Frequency curve

Fig.7 Bus voltage and frequency with load changing



a) DG1 output power curve



b) DG2 output power curve

Fig.8. DG1 and DG2 power output with load changing

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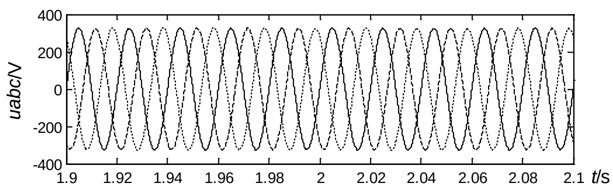
It can be seen from Fig. 7a)- b) that, in the process of load increase and decrease, voltage waveform is relatively stable. Under comparison, the frequency waveform in figure c) fluctuates slightly, but its fluctuation amplitude does not exceed 0.1hz, which can meet the voltage and frequency requirements of power system. Thus, V/F control can achieve stable control of voltage and frequency.

In Figure 8, a) represents the power output of DG1, and b) points the power output of DG2 which adopts the PQ control mode. Its active power output value always follows the reference value of 25kW, and its reactive power value always follows the reference value of 0Var. When the required power of load is not equal to the output power of DG2, DG1 shall bear the residual power output. At 0~0.5s, the power required by the load is just equal to the active power output of DG2, and the active power output of DG1 is 0. At 0.5~1s, the active power required by the load is 35kW, while DG2 can only provide 25kW of active power, and DG1 provides 10kW, satisfying the supply and demand relationship. From 1 to 1.1s, active power is reduced to 25kW due to the removal of load 1 which is equivalent to the active power provided by DG2, so DG1 does not output active power. After 0.5s, the reactive power required by the load is 5kVar. Since DG2 does not provide reactive power, it is all output by DG1.

4.2 Simulation Analysis of Grid-connected and Off-grid

In the above analysis, micro-grid has been in the off-grid operating state. The V/F control mode provides support of voltage and frequency, and the PQ control mode offers constant output of active power and reactive power. When T=2s, the circuit breaker 4 is opened, the circuit breaker 6 is closed, and DG1 is cut off. Meanwhile, DG2 is merged into the large power grid, and micro-grid enters into the grid-connected operation state. Simultaneously, the large power grid provides the voltage and frequency support for DG2; When t=3s, the DG2 active power reference value is reduced to 15kW; and if t=4s, the circuit breaker 6 is opened, the circuit breaker 4 is closed, and micro-grid returns to the off-grid operation state under the master-slave control mode. In Figure 9 to Figure 10, there are some results related to the off-network simulation.



a) Grid voltage curve

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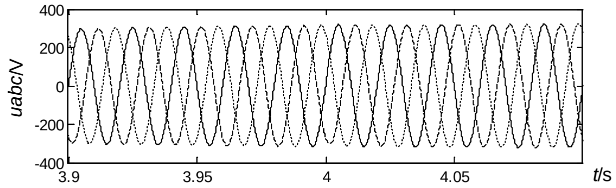
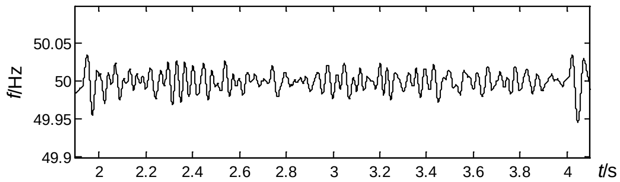


b) Off-grid voltage curve

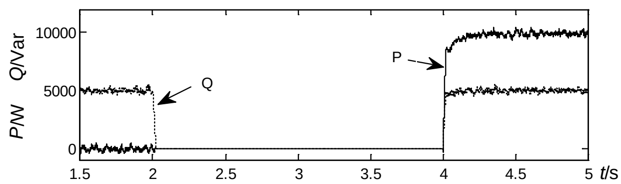


c) Frequency curve

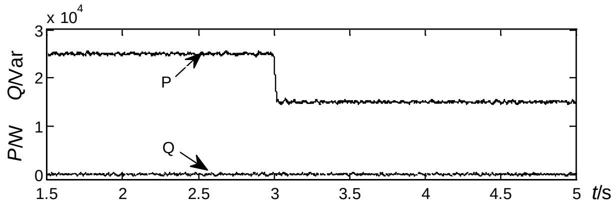
Fig.9. Voltage and frequency simulation results of grid and off-grid

As shown in Figure 9 a) , when micro-grid is connected to the grid at t=2s, voltage waveform changes in terms of the three-phase sinusoidal law, and there is no fluctuation. In Figure 9 b), at t=4s, voltage transition is smooth when micro-grid leaves the large grid. There is no abnormality in the waveform. At the same time, it can be seen from the c) diagram that, although system frequency has been fluctuating, fluctuation amplitude can meet the requirements of power system, so the control method can be well realized and controlled under off-grid situation. [15]

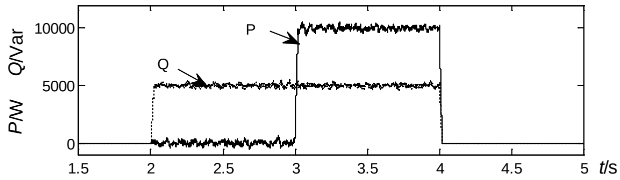
In Figure 10 b), during the grid-connected and off-grid switching process, DG2, quickly and stably, follows reference value to output active power and reactive power, and the remaining load power shifts between DG1 and the large grid. As demonstrated by Figure a) and Figure c), when micro-grid is off-grid, DG1 takes up the remaining power. When it is connected to the grid, DG1 leaves the system and no longer responds to power demand. Instead, the large power grid provides the remaining power. When t=4s, system transition is from the grid-connected state to the off-grid state. Except for 15kW of active power provided by DG2, the remaining 10kW active power is transferred from the large grid to DG1.



a) DG1 output power curve



b) DG2 output power curve



c) Grid output power curve

Fig.10. The power simulation results under grid and off-grid

5. Conclusion

In this paper, it takes advantage of the master-slave control method on basis of the V/F control mode and the PQ control mode to realize the control of micro-grid. According to simulation results, whether load is increased or decreased under the operation of the isolated network or the switching between grid-connected and off-grid operating states, the voltage and frequency on the bus can be maintained within a reasonable fluctuation range, which can satisfy the user. At the same time, active power and reactive power required by load can be quickly transferred among individual micro-power sources or large power grids. The control method can realize reasonable and effective control of small micro-grid and provide a reference for further research on the control mode of micro-grid.

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