Research of virtual impedance layering and distributing control strategy of hybrid renewable energy microgrid

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Abstract. Micro-grid technology will combine hybrid renewable energy and power generation technology, clean and environmental protection, improve the utilization of renewable energy; the use of distributed generation units installed in the local characteristics of the governor from the transmission loss and cost. This paper introduced the virtual impedance into the traditional droop control, make the output impedance and line impedance of the inverter are mainly inductive, so the droop control algorithm is implemented. This paper presented a new method based on the virtual impedance to adjust the frequency and voltage of the micro-grid bus two times, to realize the two adjustment of the frequency and voltage of the micro grid. In addition, for the micro-grid power network interaction, based on PQ closed loop control method is proposed to response to the dispatching command. The simulation results show high performance of the designed control strategy.

1. Introduction

Micro-grid technology will combine hybrid renewable energy and power generation technology, clean and environmental protection, improve the utilization of renewable energy; the use of distributed generation units installed in the local characteristics of the governor from the transmission loss and cost [1-5]. In this paper, the control of parallel inverter in micro-grid is studied in detail. When the line impedance is perceptual, traditional droop control can always accurate to adjust each inverter output active and reactive power, but the low voltage micro grid line impedance mainly presents the resistance, the traditional droop control will not be based on the droop coefficient effectively adjust the inverter output power, even may cause the micro grid collapses, embodied in the following two points: low voltage micro power grid due to impedance line impedance function, makes the active and reactive power, there are serious coupling between the droop control performance degradation; In the independent operation of the low-voltage microgrid, the voltage of the microgrid is not global and the distribution accuracy of reactive power cannot be guaranteed due to the mismatch between the line impedance and the inverter output line impedance. The equivalent output impedance can be effectively increased by connecting the inductance at the outlet of the inverter so that the traditional droop control can be used. Inductance also increases the system loss, line voltage drop, volume weight [6-10].

In this paper, the layered control strategy of micro grid is analysed in detail, in which the first control is droop control, the second control is secondary voltage regulation and frequency modulation control, and
the third control is grid-connected power scheduling control. This paper presented a new method based on the virtual impedance to adjust the frequency and voltage of the micro-grid bus two times, to realize the two adjustment of the frequency and voltage of the micro grid. In addition, for the micro-grid power network interaction, based on PQ closed loop control method is proposed to response to the dispatching command.

2. Virtual impedance control of Hybrid renewable energy microgrid

Drooping control is used on the premise that the output impedance of the inverter is perceptual. When the line impedance of the low-voltage microgrid mainly presents resistance, the traditional drooping control cannot effectively adjust the output power of each inverter according to the drooping coefficient. Figure 1 shows the drooping control block diagram after adding virtual impedance. With the addition of control loop \( L_v(s) \), the line output impedance characteristic of the micro-grid inverter is purely perceptual. Since the feedback control is not the actual impedance in series, it is called virtual impedance method. In order to make the output impedance of the inverter perceptual, the virtual resistance in the proposed virtual impedance is set as 0, including only virtual inductance. In the subsequent derivation, the concepts of virtual impedance and virtual inductance are not strictly differentiated.

![Droop control block diagram with virtual impedance](image)

Figure 1. Droop control block diagram with virtual impedance

Where, \( E_{a,n}^* \) subtracting the component of output current on virtual impedance \( L_v(s) \) is used as the given value of output voltage of the inverter, the difference value obtained \( E_{a} \) is used as the given value of the inverter, and \( L_v \) is the virtual inductance value.

Mismatching of line parameters will lead to slight difference in inverter output voltage, which will lead to circulation between two inverters. When the circulation is very large, it may cause overcurrent damage to the inverter and further deteriorate the output state of the inverter. The virtual impedance method for changing the equivalent output impedance can reduce the circulation between the inverters.

The virtual impedance loop of the three-phase inverter system in the abc coordinate system can be expressed as:

\[
\begin{bmatrix}
E_{a,n}^* \\
E_{b,n}^* \\
E_{c,n}^*
\end{bmatrix} =
\begin{bmatrix}
E_a \\
E_b \\
E_c
\end{bmatrix} - L_v \begin{bmatrix}
\frac{di_a}{dt} \\
\frac{di_b}{dt} \\
\frac{di_c}{dt}
\end{bmatrix} \tag{1}
\]

\( E_{a,n}^* \)、\( E_{b,n}^* \)和\( E_{c,n}^* \)是三相参考电压值由虚阻抗控制获得的，而\( E_a \)、\( E_b \)和\( E_c \)是电压调节器的设置值，由虚阻抗控制获得。虚阻抗控制是电流的差分计算。方程（1）被abc-dq改变为:

\[
\begin{align*}
E_{a,n}^* &= L_v \frac{di_a}{dt} + E_d - \omega L_n i_q \\
E_{b,n}^* &= L_v \frac{di_b}{dt} + E_q + \omega L_n i_d
\end{align*} \tag{2}
\]

The transformation of \( E_a \)、\( E_b \) and \( E_c \) from virtual impedance loop to two-phase rotating coordinate system for voltage closed-loop control is generally realized in the following two ways: abc-dq coordinate system transformation is firstly carried out, and then calculated according to Equation (2); Differential
operation is carried out on the current of Equation (1), and then coordinate transformation is carried out on the operation results. Block diagrams of the implementation of the two methods are shown in Figure 2 and Figure 3.

![Figure 2. Methods 1 to realize virtual impedance](image1)

![Figure 3. Methods 1 to realize virtual impedance](image2)

After the differential part, digital filter is added to eliminate the high frequency component caused by digital differential. Since method 1 differentiates the direct flow, low-pass filter is adopted in the filtering part. Method 2 differentiates the AC quantity. In order to avoid the attenuation of the obtained AC quantity, the bandpass filter is adopted in the filtering link. The expressions of first-order low-pass filter and band-pass filter are as follows:

\[
F_1(s) = \frac{\omega_c}{s + \omega_c} 
\]

\[
F_2(s) = \frac{\omega_c s}{Q s^2 + \frac{\omega_c}{Q} s + \omega_c^2} 
\]

Among them, \(Q\) and \(\omega_c\) are the quality factor and the turning frequency. In method 1, a lower transition frequency can be set and better filtering performance can be obtained. In method 2, the transition frequency must be set to 50Hz. In this paper, method 1 is adopted to realize the function of virtual impedance.

3. Layering and distributing control strategy of microgrid

3.1 Structure of Layering and distributing microgrid

As shown in Figure 4, the layered control strategy of microgrid is analysed in detail, in which the first control is droop control, the second control is secondary voltage regulation and frequency modulation control, and the third control is grid-connected power scheduling control.

3.1.1 Secondary frequency control of microgrid. In order to keep the frequency offset caused by load change within the allowable range, the frequency should be adjusted twice on the basis of one adjustment. The output active power of synchronous generators is the main reason affecting the frequency of large power grids. Therefore, secondary controllers of large power grids are mainly used for frequency recovery. They are composed of a PI controller with dead zone, which is called automatic generation
controller in the United States and load frequency controller in Europe. When the frequency deviation is higher than the allowable range of frequency offset, the principle of the microgrid controller to control the frequency recovery compensator is as follows:

$$\Delta f = K_{pf}(f^* - f_G) + K_{pf} \int (f^* - f_G) dt \tag{5}$$

Where, $K_{pf}$ and $K_{pf}$ are the relevant parameters of the frequency recovery compensator in the centralized secondary controller. After the micro grid frequency $f_G$ is acquired by the remote sensor, the deviation $\delta f$ after comparing with the reference value $f^*_G$ is sent to the secondary controller, and finally the output signal is sent to the primary control of each DG unit.

![Figure 4. Control diagram of layering and distributing microgrid](image)

3.1.2 Secondary voltage control of microgrid. Similar to the secondary frequency control, the secondary voltage control also takes a similar treatment. When the micro grid voltage RMS migration exceeds the scope permitted, PI controller compensation micro power grid voltage amplitude, voltage value and the actual value compared with the reference voltage value after the deviation of voltage through two-way communication network into each DG unit level control, the centralized in the micro grid controller secondary control voltage compensator principle is as follows:

$$\Delta U = K_{pu}(U^*_G - U_G) + K_{pu} \int (U^*_G - U_G) dt \tag{6}$$

$K_{pu}$ and $K_{pu}$ are the relevant parameters of the voltage recovery compensator in the centralized secondary controller, similar to the frequency compensation. The deviation $\delta U$ of the microgrid voltage $U_G$ obtained by the remote sensor and compared with the reference value $U^*_G$ is sent to the secondary controller, and the output signal is finally sent to the primary control of each DG unit.

Remote sensors after busbar voltage RMS and frequency, micro power grid through a communication network to transmit the data to the micro grid controller, after the actual value compared with the reference, will handle the deviation value into the secondary controller through a communication network is sent to all the DG unit level controller, complete the second adjustment of voltage and frequency. For the parallel connection of $n$ inverters, the voltage and frequency regulation generated by the micro-grid controller is distributed according to Equation (7).
\[
\Delta f_i = \frac{c_i}{c_1 + c_2 + \ldots + c_n} \Delta f \quad (i = 1, 2, \ldots, n)
\]  

(7)

In Equation (7), \(c_i\) is the capacity of the number \(i\) inverter, the frequency regulation generated by the central manager of the micro grid, and the frequency regulation received by the number \(i\) inverter. Similarly, the voltage regulation generated by the microgrid controller is distributed according to formula (8).

\[
\Delta U_i = \frac{c_i}{c_1 + c_2 + \ldots + c_n} \Delta U \quad (i = 1, 2, \ldots, n)
\]

(8)

In Equation (8), \(c_i\) is the capacity of the number \(i\) inverter, the voltage regulation generated by the central manager of the micro grid, and the voltage regulation received by the number \(i\) inverter.

3.2 Simulation results of microgrid

Traditional microgrids generally work in VF mode when off-grid, and generally work in PQ mode in grid-connected mode. However, when VF is off-grid operation, it is a voltage-type control, and on-grid PQ mode is a current-type control. When switching between off-grid and on-grid mode, it is inevitable to involve the switching between the two sets of control strategies, resulting in the relative switching strategy complex. If the microgrid can work in the droop mode both in off-grid and on-grid mode, the off-grid switching strategy will be relatively simple, and compared with the traditional VF and PQ switching, the risk of switching failure is reduced. In this section, a single droop control inverter is connected to the grid as an example, and the proposed control strategy is analysed and explained in detail.

![Diagram](image_url)

**Figure 5.** Schematic diagram of grid mode power interaction

Figure 5 shows the grid-connected power interactive control strategy of the droop control inverter in the grid-connected mode. It can be seen from the figure that an external power loop is added on the basis of the droop control strategy to realize the closed-loop control of active and reactive power. The regulator generated by the power outer loop acts directly on the reference values of active and reactive power controlled by droop. It can be seen that when the inverter is running off the grid, the power outer loop is cut off, and the inverter works in droop mode, which is voltage type control. When the inverter is connected to the grid, active and reactive power closed-loop control is put in on the basis of droop control, and the droop control structure is not changed, which is conducive to the seamless switch between the grid-connected mode and the off-grid mode.

Simulation model based on MATLAB/Simulink. Simulation conditions: the simulation starts at 0s, pre-synchronization starts, closes at 0.2s, turns off pre-synchronization, and enables PQ control. 50kW active power is generated at 0.5s, 30kVAR reactive power is generated at 1s, and the simulation ends at 2s.

Figure 6 shows the active power waveform of grid-connected system. It can be seen that when the power is switched on at 0.2s and the active power closed-loop control is put in, the active power waveform has a slight fluctuation, and then it is stabilized at 0kW, and at 0.5s, it is 50kW active power.
step. It can be seen that the dynamic response is good, and the active power instruction is responded after about 0.1s. At 1s, the active power fluctuates because of the reactive step. This control strategy is different from the traditional PQ control strategy, which is coupled by the voltage amplitude and the power angle. It can be seen that the active power waveform is good in the whole simulation process.

![Figure 6. Grid active power waveform](image)

**Figure 6.** Grid active power waveform

![Figure 7. Grid reactive power waveform](image)

**Figure 7.** Grid reactive power waveform

Figure 7 as the grid reactive power waveform, it can be seen that 0.2 s closing and closed loop control in reactive power, reactive power waveform has small fluctuations, then stability in 0 kw, 50 kw active step 0.5 s, you can see the reactive power produced larger fluctuation, this is because this kind of control based on voltage type inverter grid PQ runs, active power and reactive power are coupled together by angle and voltage amplitude, active, reactive power is change accordingly, after entering the steady-state active power, reactive power and stable in the given value, and vice versa. Compared with the traditional PQ current control, the main advantage of voltage control is that its AC output voltage is controllable, so it is more suitable for both isolated island operation and grid-connected operation. However, its disadvantages are also obvious, which are mainly characterized by the uncoupling of active and reactive power, resulting in dynamic coupling of active and reactive power. At 1s, given the reactive power step of 30kVAR, it can be seen that after the dynamic process of 0.2s, the reactive power is stable at 30kvar.

![Figure 8. AC bus voltage and current waveform](image)

**Figure 8.** AC bus voltage and current waveform
Figure 8 for AC busbar voltage and grid current, visible in 0.2 s grid after closing, grid current basic is zero, that do not produce a larger impact closing 0.5 s active step, the current waveform is good, no obvious flow phenomenon, reactive power step, the current waveform is good, also did not appear obvious flow phenomenon, this article demonstrates that the proposed based on network of the central manager network of layer 3 control strategy is feasible.

4. Conclusion
This paper introduced the virtual impedance into the traditional droop control, make the output impedance and line impedance of the inverter are mainly inductive, so the droop control algorithm is implemented. This paper presented a new method based on the virtual impedance to adjust the frequency and voltage of the micro-grid bus two times, to realize the two adjustment of the frequency and voltage of the micro grid, and the switching between the micro-grid and the grid. In addition, for the micro-grid power network interaction, based on PQ closed loop control method is proposed to response to the dispatching command of the superior dispatching center. The simulation results show high performance of the designed control strategy.

5. References
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