Research on Control Method of Microgrid Based on Multi Distributed Generation

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Abstract. Reducing the dependence of microgrid upon the communication system and realizing the efficient control of multiple distributed generation of the microgrid are problems that need to be solved urgently. Through the research, based on multiple microgrid operation modes, the peer-to-peer control strategy in microgrid is investigated, and the peer-to-peer control strategy method of microgrid is given for a variety of complex control problems of distributed power. According to the peer-to-peer control strategy method, distributed power supply adopts droop control in adjusting distributed power supply in output voltage and frequency; the droop controller has P-f and Q-U droop characteristics. This paper establishes a peer-to-peer control microgrid simulation model, adopts the droop controller designed in this paper to island mode and grid-connected mode, and investigates how the microgrid switches between the two modes. In accordance with Matlab/Simulink simulation outcomes, the research examines frequency, voltage and power changes in distributed generation in the microgrid, and verifies the validity and feasibility of microgrid peer-to-peer control strategy.

1. Introduction

Microgrid is usually composed of small distributed generation (DG), energy storage equipment, loads and control systems [1, 3]. It has grid-connected mode and island operation mode. Under normal conditions, the microgrid can be connected to the conventional distribution network. When a grid fault or power quality is detected When the requirements cannot be met, the microgrid is disconnected with the grid and switch to island independent operation mode [4, 5].

The coordinated control of microgrid distributed power is among the crucial issues needing prompt solutions during real operations. Effective coordinated control can make the microgrid operate normally in various operation modes to ensure distribution network stability. Literature [8] proposed a "plug and play" control structure, indicating that the microgrid can realize the plug and play in both large power grid and distributed power supply of microgrid. Literature [9] studied the peer-to-peer control strategy of microgrid, showing the equality of all distributed power sources and there is no subordination relationship. Peer-to-peer control is independent of communication, and able to promote system reliability, decrease costs and support plug-and-play function in microgrid, which has attracted widespread attention [10, 12]. Literature [13] proposed for the first time the droop control which supports the plug-and-play function under distributed generation and loads. It simulates the primary
adjustment of the frequency in conventional power system while controlling inverter output power based on droop characteristics between power and voltage. Literature [14] proposed a type of microgrid switch mode control method. All DGs adopt PQ control strategy during grid-connected operation, and regulation in system frequency and voltage proceeds in large grid; during island operation, part of the DG adopts droop control in regulating the microgrid system's voltage and frequency.

For the complicated coordination issue in microgrid distributed generation, the research proposes the microgrid peer-to-peer control strategy method, designs and constructs a droop controller, and establishes a simulation model for the microgrid peer-to-peer control strategy. Under microgrid grid-connected and islanding operation modes, all DGs adopt droop control. Considering the linear droop characteristics of P-f and Q-U, output active power and reactive power must be regulated for adjusting inverter output voltage amplitude and frequency, and sharing the voltage and frequency with grid. Matlab/Simulink simulation outcomes prove the peer-to-peer control strategy’s validity and feasibility.

2. Microgrid basic structure
The basic structure model of the microgrid is illustrated by Figure 1.

![Figure 1. Microgrid structure for Peer-to-Peer control](image)

In Figure 1, DG1 and DG2 are two distributed generation, Load1 and Load2 represent constant power loads linked with DG1 and DG2, which are connected to the main grid via switch K.

It can be seen from Figure 1 that in the microgrid, because the distributed generation are relatively dispersed, it is difficult to control the inverter in a unified manner. For ensuring microgrid power quality and reliability, droop control method is applied in controlling the inverter. The droop coefficient control method does not need additional communication signals, and directly detects the active and reactive power of inverter to regulate output frequency voltage and amplitude, thus ensuring the frequency and voltage of each inverter module are consistent, effectively suppress the circulating current and realize the stability of the system.

3. Peer-to-peer control strategy of microgrid
Master-slave control, hierarchical control and peer-to-peer control constitute three usual control strategies in microgrid distributed power [6].

Master-slave control strategy heavily depends upon the master control unit, raising high demands for its capacity and performance. It is not easy to implement in the microgrid distributed power control strategy. Hierarchical control strategy is heavily dependent upon communication means, and real-time communication is required between multiple DGs to guarantee the stable operation for microgrid, and corresponding operating cost is relatively high. Peer-to-peer control strategy can treat DG in microgrid...
equally, and efficiently support microgrid plug-and-play function by optimizing and adjusting the voltage and power of the DG.

The research applies the peer-to-peer control strategy, and automatically adjusts and controls the voltage and power of the DG through the design and construction of a droop controller, so that the grid runs smoothly under various operating modes, and achieves smooth control of the microgrid mode switching.

3.1. Droop control principle

Droop control principle calculates active and reactive power of DG in microgrid, and adjusts the inverter for regulating the grid system’s active and reactive power based on droop characteristics of P-f and Q-U. Schematic diagram for droop control principle can be seen from Figure 2.

![Figure 2. Droop control structure diagram](image)

According to Figure 2, $P_n$, $U_0$, and $f_n$ represent the real power, voltage, and frequency; $V$ and $i_L$ stand for the output voltage and current in DG; $Z$, $C_f$, $L_f$ are the impedance, filter inductance, and capacitance; $\tilde{m}$ refers to controllable sinusoidal signal; $i_{0f}$, $u_0$, $i_c$ can be respectively expressed as the filtered current, voltage, and current flowing to the filter.

Droop control principle adjusts system voltage and frequency through the relationship curve in Figure 3. Specifically, as DG output active and reactive power increase respectively, DG operating point shifts from point A to point B [3]. The droop characteristic curve for P-f and Q-U has been shown in Figure 3 below.

![Figure 3. Droop Character](image)
Droop control strategy requires no communication among DGs to control the generator, and is generally used for DG interface inverter control by using the peer-to-peer control strategy. The droop control strategy method dynamically controls and adjusts microgrid voltage and frequency, and achieves smooth switching among various operation modes of the micro-grid.

3.2. Droop controller design

3.2.1. LC filter design. Filter can be used for filtering the inverter-induced harmonics. Conventional L-type filter, with easy operations, is suitable for the switching frequency. For satisfying the demand for harmonic filtering in grid-connected microgrid, the LC filter is chosen for filtering the inverter harmonics.

According to the LC filter calculation formula,

\[
G_j(s) = \frac{\frac{1}{L_f} + 1/(j\omega C_f)}{j\omega L_f + R_f + 1/(j\omega C_f)} = \frac{j\omega \cdot 2\xi\omega_0 + \omega_0^2}{(j\omega)^2 + j\omega \cdot 2\xi\omega_0 + \omega_0^2}
\]

\[
f_c = \frac{1}{2\pi \sqrt{L_f C_f}} \quad 10f_n \leq f_c \leq f_s / 10
\]

When the designed LC filter parameter is \(L_f=0.6\text{mH}, C_f=1500\text{uF}, R_f=0.01\Omega\), it indicates superior filtering performance. In the above formula (1), \(\omega_0 = 1/\sqrt{L_f C_f}\), \(\xi = R_f / 2\sqrt{L_f / C_f}\). In formula (2), \(f_n\) represents fundamental frequency, and \(f_s\) suggests carrier frequency.

3.2.2. Power controller design. Power controller measures instantaneous active and reactive power for a comparison with real power, voltage, and frequency. Meantime, under the droop characteristic curve, the dq axis component for voltage is measured, and output to the voltage and current double loop controller for controlling voltage and current.

The power controller structure can be seen from Figure 4.

![Figure 4. Power controller structure diagram](image)

In the droop control link of power controller, the available relationship is:
\begin{align}
\begin{cases}
f = f_n + m(P_n - P) \\
U = U_0 - nQ
\end{cases}
\tag{3}
\end{align}

\begin{align}
\begin{cases}
m = \frac{f_n - f_{\text{min}}}{P_{\text{max}} - P_n} \\
n = \frac{U_0 - U_{\text{min}}}{Q_{\text{max}}}
\end{cases}
\tag{4}
\end{align}

Where \( m, n \) denote the droop characteristic coefficients, \( P \) and \( Q \) indicate the real output active and reactive power in inverter power supply, and \( P_n, f_n, U_0 \) refer to the rated active power, frequency, and initial voltage amplitude.

The Park transformation formula is as follows:

\[
\begin{bmatrix}
X_d \\
X_q
\end{bmatrix} = \sqrt{2} \begin{bmatrix}
\sin(\omega t) & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\
-\cos(\omega t) & -\cos(\omega t - \frac{2\pi}{3}) & -\cos(\omega t + \frac{2\pi}{3})
\end{bmatrix}
\begin{bmatrix}
X_a \\
X_b \\
X_c
\end{bmatrix}
\tag{5}
\]

By formula (5), using the three-phase AC quantity following DG inversion, the voltage dq axis component \( u_{\text{dref}}, u_{\text{qref}} \) can be calculated.

\subsection*{3.2.3. Voltage and current double loop controller design}

The voltage and current dual-loop controller accurately and quickly feeds back the changes in system voltage and power based on the dq axis component input from the front end, and then quickly adjusts the system to achieve dynamic balance. This text adopts PI control, the structure of the dual-loop controller designed is illustrated by Figure 5.

Figure 2 requests the LC filter capacitor voltage and inductor current to meet equations as below:

\[
\begin{bmatrix}
C_f \frac{du_0}{dt} = i_c - i_0 \\
L_f \frac{di_c}{dt} = \frac{1}{2} \bar{m}V_{dc} - u_0
\end{bmatrix}
\tag{6}
\]

![Diagram](image-url)
\( \tilde{m} \) means SPWM signal, with 
\[
\tilde{m} = m^* \sin(\omega t - \phi - \frac{2}{3} \pi).
\]

In Figure 5, \( i_c^* \), \( u_c^* \) are the reference values for capacitor current \( i_c \) and load voltage \( u_c \). \( K \) represents the proportional coefficient for current inner loop control, and \( K_{up} \), \( K_{ui} \) suggests the proportional and integral coefficients for voltage outer loop control.

The larger the proportional coefficient \( K \) in current inner loop control, the faster the dynamic response of system, but it should not be too large, otherwise the system is unstable. According to the transfer function formula (7) and formula (8) for current inner loop and current proportional gain, the calculation shows that when the \( K \) value is 5, the system dynamic response and stability are better.

\[
i(t) = \frac{KV_{dc} C_f s}{L_i C_f s^2 + \frac{KV_{dc}}{2} C_f s + 1} \quad i'_c(t) = \frac{L_f C_i s^2}{L_f C_i s^2 + \frac{KV_{dc}}{2} C_f s + 1} i_0
\]

\[
G_i(s) = \frac{KV_{dc} C_f s}{L_f C_i s^2 + \frac{KV_{dc}}{2} C_f s + 1}
\]

Analyze \( K=5 \), when \( f_n=50 \text{Hz} \), the voltage outer loop transfer function can be expressed as:

\[
u_0 = G_u(s)u_0^* - Z(s)i_0
\]

In the above formula (9), \( G_u(s) \), \( Z(s) \) are

\[
G_u(s) = \frac{KV_{dc} C_f s^2 + \frac{KV_{dc}}{2} K_{up} s + \frac{KV_{dc}}{2} K_{ui}}{L_f C_i s^3 + \frac{KV_{dc}}{2} C_f s^2 + (1 + \frac{KV_{dc}}{2} K_{up}) s + \frac{KV_{dc}}{2} K_{ui}}
\]

\[
Z(s) = \frac{L_f s^2}{L_f C_i s^3 + \frac{KV_{dc}}{2} C_f s^2 + (1 + \frac{KV_{dc}}{2} K_{up}) s + \frac{KV_{dc}}{2} K_{ui}}
\]

Formulas (9), (10), (11) indicate the correlation of equivalent output impedance \( Z(s) \) in inverter power supply with proportional and integral coefficients \( K_{up} \) and \( K_{ui} \) in voltage outer loop control. Droop control strategy is employed by low-voltage microgrid. To maintain the droop characteristic, reasonable values of \( K_{up} \) and \( K_{ui} \) need to be set so that \( Z(s) \) is an inductive impedance.
Figure 6. $Z(s)$ frequency response curve on $K_{up}$ change

Figure 7. $Z(s)$ frequency response curve on $K_{ui}$ change

Figure 6 and Figure 7 show the corresponding $Z(s)$ frequency domain response curves when different values of $K_{up}$ and $K_{ui}$ are set. Figure 6 shows the curve when $K=5$, $f_0=50\text{Hz}$, $K_{ui}=100$, and $K_{up}$ changes from 0.1 to 1000. From the analysis of Figure 6, it can be seen that $K_{up}$ at 1 is the boundary line of $Z(s)$ which is resistive and inductive. In order to make $Z(s)$ perceptual, choose $K_{up}=10$. Figure 7 is a graph when $K=5$, $f_0=50\text{Hz}$, $K_{up}=10$, and $K_{ui}$ varies from 1 to 5000. From an analysis of Fig. 7, it can be seen that the larger the value of $K_{ui}$, the more resistive $Z(s)$ is. For suppressing high-frequency harmonics, select $K_{ui}=100$.

3.3. Droop controller simulation model building

Droop controller simulation model consists of DQ conversion and power calculation module, droop control and reference voltage module, as well as voltage and current double loop control module. The model views inverter power supply voltage and current as input, and after the droop controller calculates it, it obtains the PWM regulation signal and controls the inverter power supply to make the microgrid achieve dynamic balance.
Droop controller simulation model built by the research can be seen from Figure 8.

![Droop controller simulation model](image)

**Figure 8.** Droop controller simulation model

The load voltage, load current, and feedback current are $V_{abc}$, $I_{abc}$, and $I_C$, and the rated frequency, rated power, and voltage amplitude are $f_n$, $P_n$, and $U_0$.

3.3.1. **DQ transform and power calculation module.** It mainly completes the dq conversion and calculates average active and reactive power. The designed DQ conversion and power calculation module can be seen from Figure 9 below.

![DQ transform and power calculation model](image)

**Figure 9.** DQ transform and power calculation model

3.3.2. **Droop control and reference voltage module.** Based on droop characteristics, the module calculates the frequency and amplitude for reference voltage according to input active power, and synthesizes the three-phase voltage vector. After dq transformation, the dq axis component of the voltage is obtained. The droop control and reference voltage module built by the research can be seen from Figure 10.
3.3.3. Voltage and current double loop control module. This module sets the dq axis component of voltage as input, which can be measured using a proportional integral (PI) controller and a proportional (P) controller. After the output result is changed by dq, the PWM control signal is measured for controlling the inverter and achieving the dynamic equilibrium in microgrid. The voltage and current dual-loop control module constructed by the research is illustrated by Figure 11.

Figure 11. Voltage and current double loop controller model

3.4. Building of Peer-to-Peer Control Microgrid Simulation Model
Use Matlab/Simulink software to build the peer-to-peer control microgrid simulation model, as illustrated by Figure 12.
4. Simulation analysis

This paper conducts simulation analysis on the constructed peer-to-peer control microgrid simulation model and then verifies the peer-to-peer control strategy’s validity.

In Figure 12, DG1 and DG2 in the microgrid are under the control of droop controller. They are connected to the bus through switches K1 and K2. Constant power loads load1 and load2 exist in DG1 and DG2 lines. The microgrid can be linked with the main grid via circuit breaker switch K.

Microgrid frequency: $f_g=50\text{Hz}$, Microgrid voltage: $V_g=380\text{V}$; DG1 Line impedance: $Z_1=0.18+j0.51\Omega$; DG2 Line impedance: $Z_2=0.12+j0.34\Omega$; LC filter: $R_f=0.01\Omega$, $L_f=0.6\text{mH}$, $C_f=1500\mu\text{F}$; Load1: $P_1=14.5\text{kW}$, $Q_1=8.7\text{kvar}$; Load2: $P_2=10.5\text{kW}$, $Q_2=6.3\text{kvar}$; droop controller: $m=10^{-5}$, $n=3\times10^{-4}$, $K=5$, $K_{up}=10$, $K_{ui}=100$.

The active power and reactive power of DG1 and DG2 has been shown in Figure 13 and Figure 14.

4.1. Island operation mode

0 ~ 0.1s, the microgrid is island operation. According to the simulation outcomes indicated by Figures 13 and 14, 0.02s later, the active power and reactive power in DG1 reach 14kw and 7.5kvar, and the active power and reactive power of DG2 are 8kw and 4.7kvar. Curves of frequency response and output voltage have been illustrated by Figures 15 and 16.

According to IEEE 1547 standard [15], the allowable frequency deviation is $\pm 0.3\text{Hz}$ and the allowable voltage deviation is $\pm 10\%$ for the distributed generation with capacity of (0-500kva). As shown in Figure 15, frequency deviation in microgrid output is $\Delta f_1=0.004\text{Hz}$, $\Delta f_2=0.012\text{Hz}$, which are not more than 0.3Hz. Figure 16 implies that the voltage deviation of microgrid output is $\Delta V=\text{main grid } V_g - \text{microgrid } V_{MG} = 25\text{V}$, which is not more than 10%. Therefore, the deviation of frequency and voltage under islanding operation mode of microgrid does not exceed the allowable limit specified in IEEE 1547 standard, which means that the standard is met.
4.2. Grid connected operation mode
0.1 ~ 0.2S, the microgrid is grid connected. Fluctuation of output power of distributed generation: the active power and reactive power in DG1 reach 20kW and 11.8kvar, and the active power and reactive power in DG2 reach 18kw and 10.7kvar, as illustrated by Figures 14 and 15. Meanwhile, the microgrid voltage and main grid voltage are both 380V (voltage stability $V_{\text{MG}} = V_g$), and the microgrid frequency and main grid frequency are both 50Hz (frequency stability $f_{\text{MG}} = f_g$), as shown in Figure 15 and Figure 16. Therefore, simulation outcomes demonstrate the voltage and frequency in microgrid remain balanced and stable even though output power in distributed generation fluctuates (or the load changes).

4.3. Island/grid operation mode switching
Through simulation, the voltage change and frequency response of microgrid which switches from grid-connected mode to island mode are as seen in Figure 17 and Figure 18. Subject to grid-connected mode, the RMS of three-phase voltage is 380V and the frequency is 50Hz. Under island mode, the RMS of three-phase voltage is 355v and the frequency is 50Hz, which meets the IEEE 1547 standard. Analytical results indicate the peer-to-peer control strategy is proper for islanded and grid connected microgrid. The operation of distributed generation of microgrid remains stable, and its power quality reaches the standard.

![Figure 13. Active power output in microgrid](image1)

![Figure 14. Reactive power output in microgrid](image2)
Figure 15. Frequency response

Figure 16. Output voltage in microgrid

Figure 17. Output voltage waveform of microgrid during operation mode switching
5. Conclusion
Aiming at the problem that it is difficult to efficiently coordinate and control multiple DGs, this paper gives a microgrid peer-to-peer control strategy method, proposes and constructs a droop controller, and establishes a simulation model for the microgrid peer-to-peer control strategy. In the two operating modes of microgrid grid-connected and islanding, all DGs adopt droop control. Given the linear droop characteristics of Pf and QU, output active power and reactive power should be regulated for adjusting inverter output voltage amplitude and frequency, and sharing voltage and frequency regulation with the grid. With Matlab/Simulink simulation, the research investigates the change law for DG voltage and frequency in microgrid.

Simulation outcomes confirm the validity and feasibility of the peer-to-peer control strategy method. This method automatically adjusts the voltage and frequency of multiple DGs in microgrid in island operation, ensuring microgrid stability. The frequency and voltage amplitude of microgrid can keep stable all the time, and the frequency deviation and voltage deviation can vary in an acceptable scope. The peer-to-peer control strategy for microgrid with multiple distributed generators can make the distributed generators coordinate well and satisfy the demand for system frequency and voltage.

The next research direction is to continue to improve the simulation model parameters of microgrid equivalent control strategy, reduce the frequency and voltage deviation according to the requirements of IEEE 1547 standard, and further improve the power quality, thus achieving better smooth control on voltage and frequency in distributed generation.

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Figure 18. Output voltage waveform of microgrid during operation mode switching
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