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Research on Droop Control of Single Phase Parallel Inverter

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Abstract

Parallel operation of Multi-inverter can greatly improve the system's flexibility , power system's Capacity, redundancy and reliability, current through the power switch is divided, so the current stress for power switch can also be greatly reduced, the performance is improved with costs effective and power density. The conventional droop-control strategy which is adopted generally for parallel inverter regulates the phase and the amplitude of the output voltage according to output active power and reactive power , respectively.And active power and reactive power are related to both output amplitude and output phase for double closed-loop feedback voltage—source inverter. The control method of the droop control with virtual impedance is applied in this paper. The PQ droop control strategy for parallel single phase inverter is illustrated. PQ droop control scheme can effectively stabilize the droop control system to automatically exit, and also can achieve the expected load-sharing flow effect. Droop control without mutual connection, the inverter can be conveniently connected and removed. Finally, simulation results by obtained MATLAB / Simulink software is given to verify the effectiveness of theoretical analysis .

Keywords: *inverter, parallel system, PQ droop control, virtual impedance*

1. Introduction

At present, the parallel control of inverter is mainly divided into centralized control[1], master-slave control[2], decentralized logic control[3], and non interconnected linear control[4]. Centralized control will cause the whole system to collapse when the control module is in the problem; Master slave control, although it is better than the centralized control to improve the reliability, but if the process of switching loss of synchronization signal will also make the system collapse ; Although the redundancy and reliability of the distributed logic control is improved, the interconnection lines in this way are very large, but the amount of information is very large, so it is difficult to realize; PQ droop control method in each module is independent each other, there is no interconnection between each module, the system is simple, but also easy to install, maintenance and expansion.. PQ droop control method in each module is independent each module, the system is simple, but also easy to install, maintain and expand.PQ droop control method, inverter parallel system in each inverter can be completely independent operation, and without the need of interconnection lines, so the external characteristics of the control mode of the inverter parallel system redundancy has been greatly improved. PQ droop control mode is simple, so it is easy to install and maintain each inverter, and the inverter parallel system is also very simple. If there is a failure of the inverter, the inverter can be free to exit without affecting the normal operation of the system, so the reliability of inverter parallel system can be greatly improved. The premise condition of this control method is that the detection and control of the system is very high and the calculation speed is very fast,

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otherwise the effect will be very poor. PQ the schematic diagram of the droop control is shown in the following diagram:

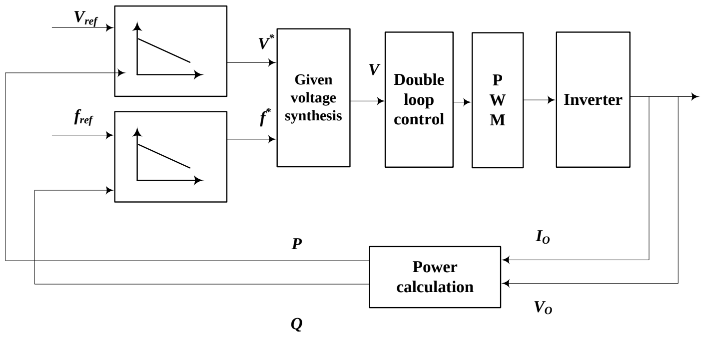


Figure 1. Droop Control Princip

2. Double Loop Control for Single-phase Inverter

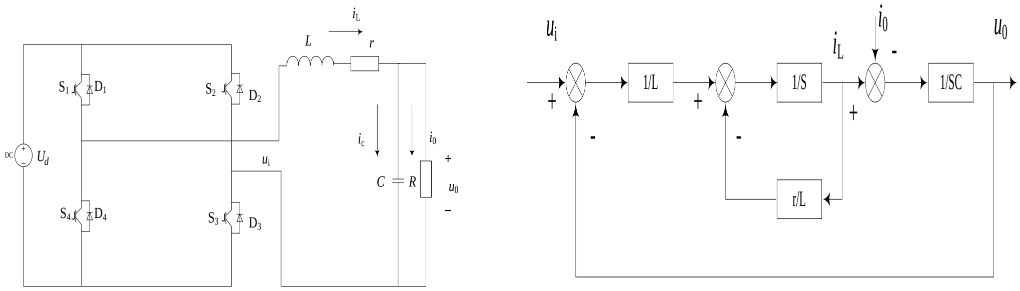
2.1. Double Loop Control

No matter what kind of inverter circuit, in order to get better quality but also more in line with the sinusoidal output waveform we need, the closed-loop control of the inverter technology can not be separated. With the development of power electronic technology, the research on the control of inverter circuit is more and more deeply. The application situation of the inverter circuit is very high, but it also requires the system to have a faster response speed, the single closed-loop control method is very difficult to meet this requirement. This design uses the voltage loop and current loop control to improve the system response speed and control precision, the former through the current loop to achieve, and the latter is achieved through the voltage loop. Voltage type single phase full bridge inverter circuit topology is shown in Figure 2.1, U_d is the single phase full bridge inverter circuit DC voltage, U_i is the output voltage of single-phase inverter bridge arm, r is a comprehensive consideration of various factors after the equivalent damping part, r including IGBT on the state resistance, dead time effect, filter inductance and line impedance. Adding a filter to the load, the purpose of adding the appropriate filter is to prevent the distortion of the output voltage of the inverter. Figure 2.1 shows the transfer function of single phase-inverter system.

Then the output current is used as a perturbation, and the output current can be obtained according to the Mason's gain formula：

$$U_o(s) = \frac{1}{LCs^2 + rCs + 1} U_o(s) - \frac{Ls + r}{LCs^2 + rCs + 1} I_O(S) \qquad (1)$$

$$U_o(s) = \frac{G_u(s)G_i(s)}{LCS^2 + CSG_i(s) + G_u(s)G_i(s) + CSr + 1} U^*(s) - \frac{LS + r + G_i(s)}{LCS^2 + CSG_i(s) + G_u(s)G_i(s) + CSr + 1} I_o(s) \qquad (2)$$



a Closed-loop control topology of single phase inverter b Transfer function block diagram of single phase inverter system

Figure 2. Single Phase Inverter System

2.2. Filter

Using filter we can achieve the purpose of eliminating the higher harmonics in the output voltage. Improve the value of the capacitor in the filter,then the inverter circuit output voltage ripple will become smaller,But the increase of the value of the capacitor will increase the reactive power.so when the simulation parameters, as long as the power to ensure that the system is controlled in a certain range, Capacitor value as small as possible.The Selection of capacitance reference formula.Inductanceof LC filter is themain reason for reducing the harmonic content of output voltage waveform.In theory, the higher the value of inductance, the better the performance of the higher harmonics. But at the same time, theinductance value of the general assembly to flow through the inductance of the current change is very slow,the simulation time response time becomes very long, the actual use of the inductance of the volume is relatively large. So in the simulation to ensure the stability of theinverter output waveform, after a comprehensive consideration, do not have to choose a large filter inductance.

3. Parallel Connection of Single-phase Inverter

3.1. Parallel Power Analysis of Single Phase Inverter

Based on two single phase full bridge inverter, the inverter parallel system is analyzed with PQ droop control, and the equivalent model of the inverter parallel system is obtained, as shown in Figure 3:

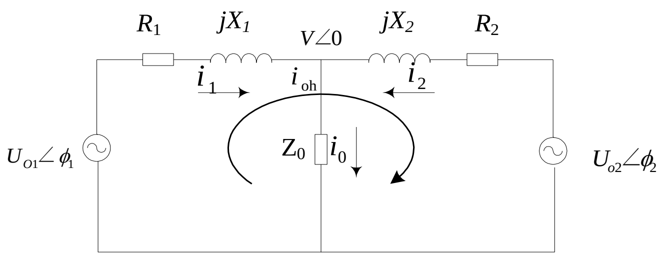


Figure 3. Equivalent Model of Two Inverters in Parallel

$\dot{I}$ is the output current of two inverters in single-phase inverter parallel system. $\dot{I}_{oh}$ is the circulation of the single-phase inverter system. Z_0 is the load of single-phase inverter parallel system. The load voltage is considered to be a reference vectorAccording to the parallel model shown in figure, the output current andthe output current of the two inverters can be obtained

$$\begin{cases} i_1 = \dfrac{U_{O1}(\cos\phi_1 + j\sin\phi_1) - V}{R_1 + jX_1} \\ i_2 = \dfrac{U_{O2}(\cos\phi_2 + j\sin\phi_2) - V}{R_2 + jX_2} \\ i_0 = i_1 + i_2 \end{cases} \tag{3}$$

$$\begin{cases} S_1 = V \cdot \dot{I}_1^{*} = P_1 + jQ_1 \\ S_2 = V \cdot \dot{I}_2^{*} = P_2 + jQ_2 \end{cases}$$

(4)

By (3) and (4) can be obtained:

$$\begin{cases} P_1 = \dfrac{R_1 U_{O1}\cos\phi_1 - R_1 V^2}{X_1^{\ 2} + R_1^{\ 2}} + \dfrac{X_1 U_{O1} V}{X_1^{\ 2} + R_1^{\ 2}}\sin\phi_1 \\ Q_1 = \dfrac{X_1 U_{O1}\cos\phi_1 - X_1 V^2}{X_1^{\ 2} + R_1^{\ 2}} - \dfrac{R_1 U_{O1} V}{X_1^{\ 2} + R_1^{\ 2}}\sin\phi_1 \\ P_2 = \dfrac{R_2 U_{O2}\cos\phi_2 - R_2 V^2}{X_2^{\ 2} + R_2^{\ 2}} + \dfrac{X_2 U_{O2} V}{X_2^{\ 2} + R_2^{\ 2}}\sin\phi_2 \\ Q_2 = \dfrac{X_2 U_{O2}\cos\phi_2 - X_2 V^2}{X_2^{\ 2} + R_2^{\ 2}} - \dfrac{R_2 U_{O2} V}{X_2^{\ 2} + R_2^{\ 2}}\sin\phi_2 \end{cases} \tag{5}$$

Because the output impedance and line impedance in the parallel system are small, and the voltage of the system is different from that of a single stage inverter.

$$\begin{cases} R_1 = R_2 \approx 0 \\ \sin\phi_n = \phi_n \\ \cos\phi_n = 1 \end{cases} \tag{6}$$

In this design, the n value is 1 or 2, respectively, which indicates that the parameters of each inverter are not different, so the parameters of each inverter are not significant:

$$X_1 = X_2 = X \tag{7}$$

By the above all kinds of not rare to:

$$\begin{cases} P_1 \approx \dfrac{U_{O1} V}{X}\phi_1 \\ Q_1 \approx \dfrac{U_{O1} V - V^2}{X} \\ P_2 \approx \dfrac{U_{O2} V}{X}\phi_2 \\ Q_2 \approx \dfrac{U_{O2} V - V^2}{X} \end{cases} \tag{8}$$

Differential:

$$\Delta P_1 \approx (V / X)(U_{O1}\Delta\phi_1 + \Delta U_{O1}\phi_1 + \Delta U_{O1}\Delta\phi_1) \tag{9}$$

Single on the numerical value, the phase difference is far less than the magnitude difference, so:

$$\Delta P \approx (V / X) U_{O1} \Delta \phi_1 \tag{10}$$

In the same way:

$$\begin{cases} \Delta Q_1 \approx (V / X) \Delta U_{o1} \\ \Delta P_2 \approx (V / X) U_{o2} \Delta \phi_2 \\ \Delta Q_2 \approx (V / X) \Delta U_{o2} \end{cases} \tag{11}$$

From equation (10) and (11) can get the conclusion is: inverter output active power increases with the larger phase angle of the output voltage of the inverter, and inverter output without reactive power with variable inverter output voltage amplitude becomes larger with increasing.

It can be seen from the above conclusion, single-phase inverter parallel system in single inverter output circuit is purely inductive, the inverter output active power mainly by the output voltage phase angle decided, with the change of frequency is closely related to the phase angle changes, so that the single inverter parallel system output active power can be controlled by frequenc, and the amplitude of the output voltage can be used to control the reactive power, the relation between these two control is independent of each other.

Under the premise of the output impedance is pure perceptual, the relationship of PQ droop control is shown below:

$$\begin{cases} f_n = f^* - k_p p_n \\ Q_n = U^* - k_q p_n \end{cases} \tag{12}$$

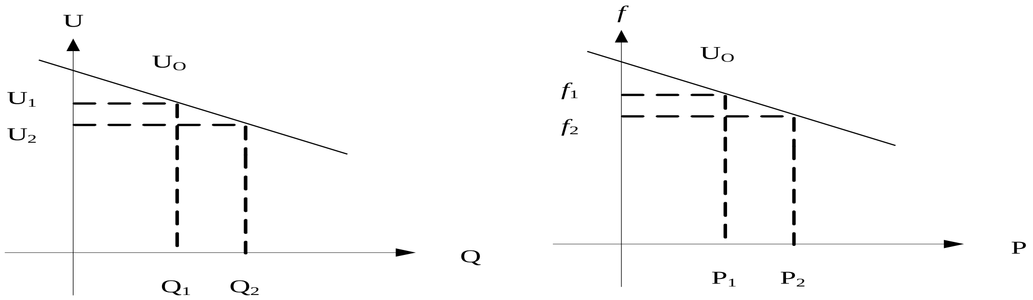


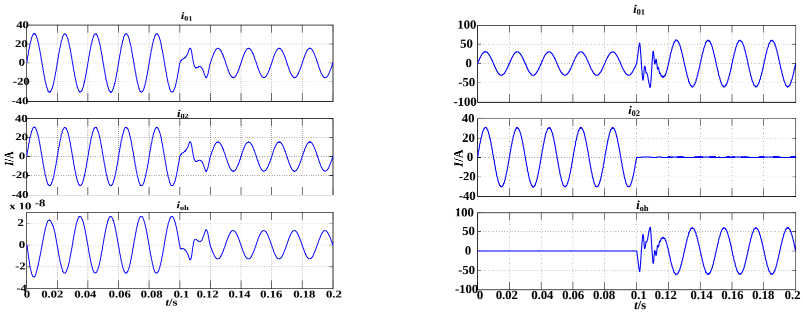
Figure 4. Droop Control Diagram

Assuming that the two inverters in a single phase parallel system adopt the same droop coefficient as the active power of a single inverter in the system, The droop control module (12) makes the output frequency of the inverter become larger than the other one, so the phase difference of the two inverters is gradually reduced until the phase difference is zero, and the active power is achieved at the same time.

3.2. Parallel Simulation of Single-Phase Inverter

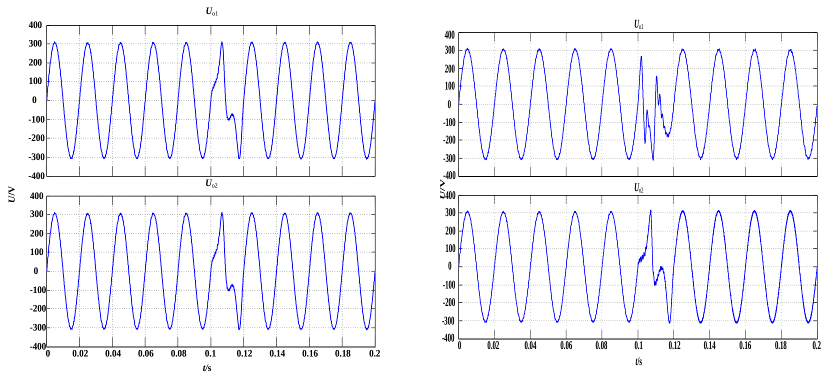
The simulation module of the parallel system based on PQ control system is divided into 8 main modules, which are single phase full bridge inverter module, PWM modulation wave generation module, filter circuit, output impedance load, PQ power calculation module, droop control module, voltage reference value calculation module, voltage reference value calculation module, voltage reference value.The specific principle of the equivalent model of the two inverters are: the single-phase full bridge inverter module generates AC output voltage and AC current through the 380V modulation module. The output voltage and sinusoidal output voltage and reactive power are calculated. The active and reactive power are calculated. The voltage amplitude and frequency are calculated. The voltage amplitude and frequency are calculated. The voltage amplitude and frequency are calculated. The reference voltage, the PWM wave modulation module is generated by the current inner loop and the wave is generated by a PWM wave.

$$U^* = U\sin(2\pi ft + \varphi) \qquad (13)$$



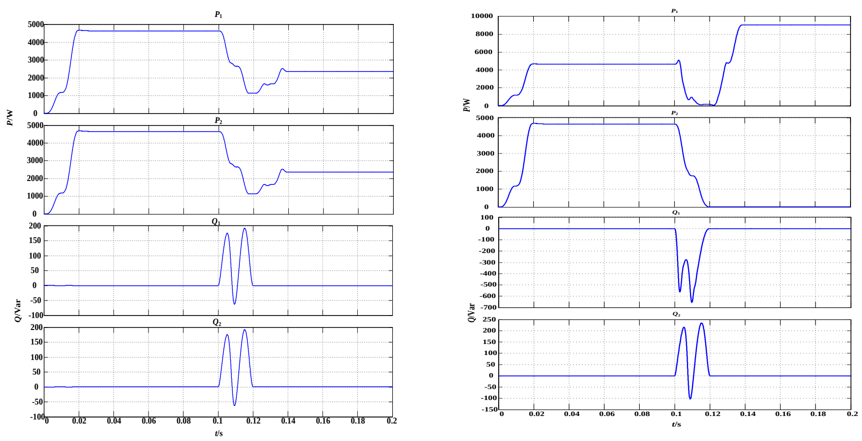
a Sudden increase in load   b inverter is suddenly cut down

Figure 5. Current and Circulation of Conventional Droop Control



a Sudden increase in load   b inverter is suddenly cut down

Figure 6. The Output Voltage of Conventional Droop Control



a Sudden increase in load   b inverter is suddenly cut down

Figure 7. Power Situation of Conventional Droop Control

In this simulation system, Output voltage is 310V, load resistance is 10Ω.The result of simulation proves that PQ droop control scheme can effectively sharing the load, At the same time, reached the purpose of restraining circulating current. The simulation verifies the feasibility of PQ droop control.But, When the inverter is changed, the current and voltage fluctuate greatly. Therefore, we improve the traditional droop control method. Premise of formula (12) an be set up the premise is that the output impedance is resistive,, but in practical engineering application, output impedance is much more complex than this, because the impact of the actual inductance values of different voltage levels of the circuit is different. And in droop control, the voltage amplitude and phase with the output power of the reactive component and the active component is increased in accordance with a fixed slope downward. That this method can only apply within a certain power range, when there are large changes in the output power range, We need to change the slope of the sag to meet the requirements of parallel operation, so the traditional PQ control can not adapt to the actual situation. According to the analysis above, and some scholars have proposed an improved droop control. The basis for this control strategy in the formula (4-10) is added to the concept of the virtual impedance inductive, based on the traditional PQ droop control strategy improvements.

After adding a virtual impedance control diagram is shown below:

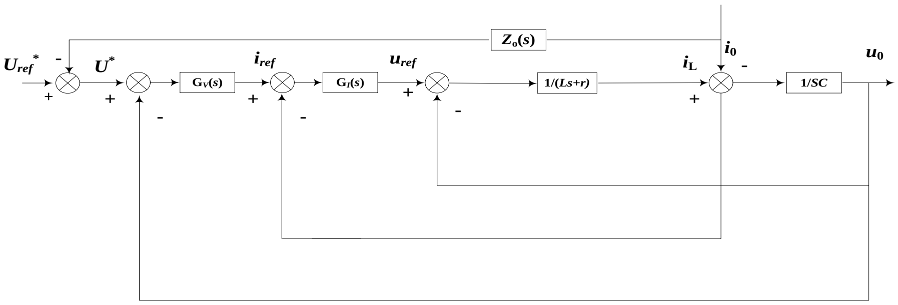


Figure 8. Improved Control Block

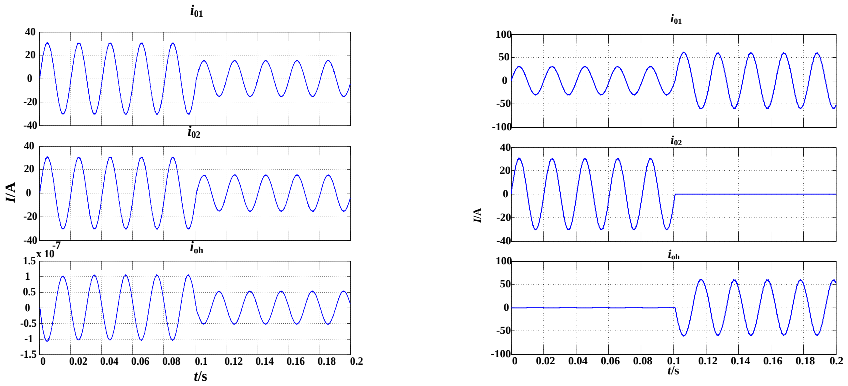
According to reference found that the introduction of the virtual impedance can be equivalent to:

$$Z_o(s) = k_z Ls \quad (14)$$

*R*n represents n-th resistor inverter circuit, *X*n denotes the n inverters total output inductance and line inductance. At this time, regardless of size *R*n can not be ignored. At this point of power relations:

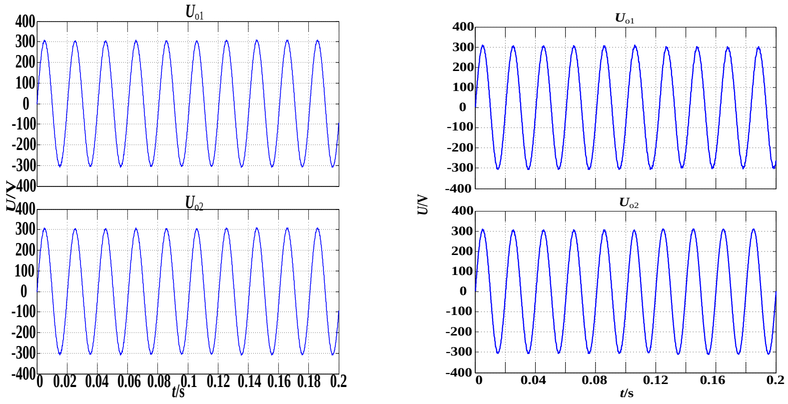
$$\begin{cases} f_n = f_n^{\ *} - k_{pf} P_n + \dfrac{k_{qU}}{U_n} \dfrac{R_n}{|Z_n|} Q_n \\ U_n = U_n^{\ *} - k_{pf} U_n \dfrac{R_n}{|Z_n|} - k_{qU} Q_n \end{cases} \quad (15)$$

Simulation waveforms under the same conditions:



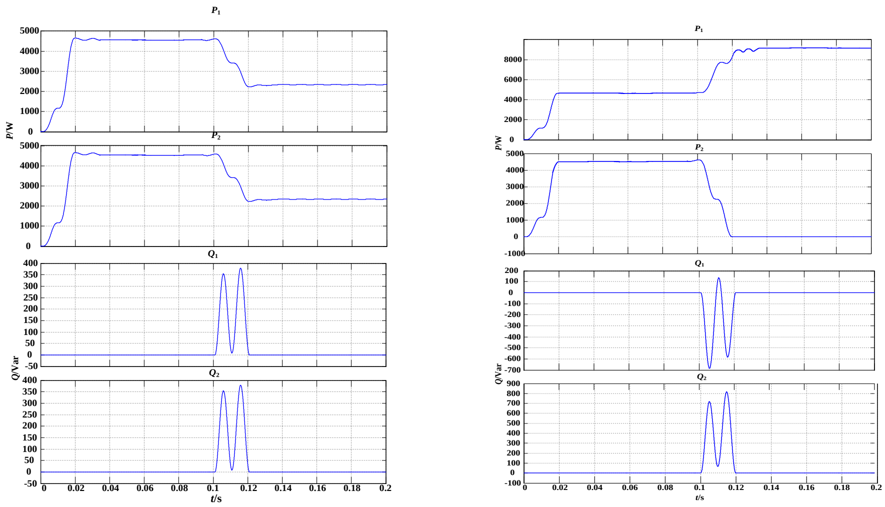
a Sudden increase in load b inverter is suddenly cut down

Figure 9. Current and Circulation of Virtual Impedance Control



a Sudden increase in load   b inverter is suddenly cut down

Figure 10. Voltage of Virtual Impedance Control



a Sudden increase in load   b inverter is suddenly cut down

Fig11.Power Situation of Virtual Impedance Control

The simulation results show that: The traditional PQ droop control scheme can effectively divide the load,, and maintain normal operation when the system suddenly increases or reduces the inverter, power has been effectively divided; but compared two groups of simulation waveforms under the same conditions is not difficult to see that the traditional. droop load control system will produce mutations and relatively severe waveform distortion when one inverter suddenly quit, this will affect the system the power quality, and improved control strategy is to avoid this problem, although the system also has a smaller shock, but in the output waveform within a very short period of time the system was restored to normal. The feasibility of the improved PQ droop control and it is relatively traditional control methods better place, it greatly improves the stability and redundancy of the system, it is not difficult to see from here, droop control can indeed achieve power supply hot-swappable, which also provides a great convenience for conduct our maintenance and inspection work.

4. Conclusion

Double loop control of single inverter can get a good control effect; therefore, we can get the ideal output waveform. The traditional droop control is not required to be connected with each other, which can achieve the parallel effect that we need, but there is still a large fluctuation when the inverter mutates. On the basis of the droop control, the virtual impedance is added, and the output fluctuation of the inverter can be seen clearly by the simulation waveform.The shortage of this paper is that there is no detailed analysis of the various impedances of the system, In the future work will be supplemented and improved.

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