Parallel Control Method of Microgrid Inverter Based on Adaptive Droop Control

Linlin Hu¹*, Jian Guan¹, Long Fu²

¹College of Electrical and Electronic Engineering, Guangdong Polytechnic College, Zhaoqing, China
²Department of industrial automation, Guangdong Polytechnic College, Zhaoqing, China

*E-mail: 443174712@qq.com,

Abstract. Energy is the driving force of social and economic development. With the gradual depletion of conventional energy and the increasingly prominent ecological and environmental problems, the power industry needs to find a sustainable development path. Parallel control of microgrid inverters based on adaptive droop control is an important part of future intelligent and sustainable power systems. However, with the continuous increase of power generation equipment capacity and the continuous increase of load power consumption, the form of power supply by a single inverter can no longer meet the requirements. Therefore, parallel connection of multiple inverters has been widely used in the microgrid. In this paper, a set of parallel control methods for microgrid inverters based on adaptive droop control is established. This paper is based on the inductance of the inverter's terminal impedance, and the amplitude of the inverter terminal voltage is positively correlated with the output reactive power and has a strong correlation. It is concluded that the microgrid based on adaptive droop control has the ability to automatically adjust the voltage and frequency of the microgrid. Properly reducing the droop coefficient can improve the primary frequency modulation capability of the microgrid. In this paper, an improved resistive control equation is used in a parallel system, a multi-loop control structure with a quasi-resonant controller is used for the inverter in the parallel system, and a virtual complex impedance is added to perform small signal analysis on the improved resistive control equation. The overall performance of the parallel system is analyzed, and the effect of different control coefficients on the system performance is clarified. The experimental research results show that when analyzing the effect of the inductance coefficient value on the equivalent output impedance in the virtual complex impedance, the value of KL is 1. At this time, the equivalent output impedance becomes resistive again, and the property is stronger than when KL is 0.05.
Keywords: Microgrid Inverter, Parallel Inverter Control, Adaptive Based on Adaptive Droop Control, Small Signal Analysis

1. Introduction

With the continuous development of science and technology, a series of clean and efficient energy sources such as solar energy, wind energy, nuclear energy, water conservancy and natural gas are developed and utilized by people [1]. Distributed generation (DG) is an emerging power generation technology since the 1990s. It is a form of utilization of clean energy. The so-called distributed generation refers to the use of various scattered energy forms (such as fossil) Fuel, etc.) Generate electricity locally in scattered areas, and connect the electricity to a large power grid [2-3].

From the definition and composition of the microgrid, the microgrid has the following characteristics: the microgrid is connected to the large power grid at a single point. From the large power grid side, the microgrid is a controllable unit, which can reduce the intermittent direct impact on the power quality of surrounding users [4-5]. The microgrid can be operated in grid-connected mode and island mode to improve the reliability of power supply to sensitive loads [6-7]. The micro-grids are distributed and have a large geographical distance from each other; the voltage level of the micro-grids is relatively low, which is generally connected to the low-voltage distribution network, and the transmission line impedance is generally resistive [8]. A large number of power electronic devices are used as interface circuits with the microgrid bus and provide the necessary control. The microgrid has a small inertia, and energy storage devices need to be installed to improve the transient stability of the microgrid [9-10].

This paper analyzes the power based on adaptive droop control. Mainly analyzes the working principle of PQ based on adaptive droop control and the effect of line impedance and inverter output impedance on the power sharing effect of the inverter in parallel in the microgrid environment; by analyzing the conditions of power sharing in parallel, the In this paper, the improved resistive control equation is used, and a small signal analysis is performed on the equation. In this way, the comprehensive performance of the parallel system is analyzed, and the influence of the control coefficient on the system is obtained. The equivalent output impedance of the inverter is analyzed. Mainly introduces the multi-loop control structure of the single inverter in the parallel system, the type and addition method of the virtual impedance; the value of the virtual impedance and the parameter value of the quasi-resonant controller are analyzed by the Bode diagram of the equivalent output impedance of the inverter Impact on the entire inverter system. The experimental results show that when the value of KL is 1, the equivalent output impedance becomes resistive again, and the property is stronger than that when KL is 0.05.

2. Proposed Method

2.1. Improvement Based on Adaptive Droop Control

In this paper, based on the theoretical basis of inverter improvement based on adaptive droop control, an improved method based on adaptive droop control is proposed, which fully considers the effect of active power on voltage and reactive power on frequency. Then the stability of the improved algorithm
is analyzed, and the effects of impedance angle, power angle and droop coefficient on the stability are analyzed. Finally, on the platform, the traditional adaptive droop control and the improved adaptive droop control were compared and analyzed.

(1) Active power characteristics

The partial difference of the expression in the formula is obtained by the phase angle difference and amplitude of the inverter terminal voltage, respectively, and the change relationship of the two variable pairs is obtained.

\[
\frac{dP}{d\phi} = \frac{EV}{Z} \sin \theta
\]

\[
\frac{dP}{dV} = \frac{E}{Z} \left( \cos \theta + \sin \theta \cdot \phi \right)
\]

It can be seen from formulas (1) and (2) that the values of \( \frac{dP}{d\phi} \) and \( \frac{dP}{dV} \) are both greater than zero, that is, the active power output by the DG inverter is positively related to the phase angle difference \( \phi \) and amplitude \( V \) of the voltage. Use formula (3) to compare their correlations. Since the inverter is usually connected to the grid through a filter device such as a filter inductance, the terminal impedance of the inverter is inductive, \( \theta = 90 \), so the formula (4) can be obtained, indicating that the correlation between \( P \) and \( \Phi \) is greater than the correlation, ie The influence of \( P \) on \( \Phi \) is much greater than the influence on \( \Phi \).

\[
\frac{dP}{d\phi} \frac{dP}{dV} \gg \frac{V \sin \theta}{\cos \theta + \sin \theta \cdot \phi}
\]

\[
\frac{dP}{d\phi} \frac{dP}{dV} \gg 1
\]

(2) Improve small signal stability analysis based on adaptive droop control

The small signal model of DG inverter proposed in this paper analyzes the small signal stability of DG inverter. When the impedance angle varies from 61 degrees to 90 degrees, the characteristic root locus of the DG inverter state matrix, where the direction of the arrow indicates the direction of movement of the root locus as the impedance angle increases. The selection of each droop coefficient of \( p-\omega, Q-V \) based on adaptive droop control is based on the assumption that the terminal impedance of the DG inverter is approximately purely inductive, that is, the assumption of decoupling control of \( P, Q \) and \( \Phi, V \). In actual operation, the terminal impedance of the DG inverter is not purely inductive, and its impedance angle will affect the stability of the operating parameters of the DG inverter: the smaller the impedance angle, the smaller the degree of inductance of \( Z \), the influence of \( Q \) on \( \Phi \) and \( P \) on The greater the influence of \( V \), the less the assumption of decoupling control is established, and the worse the stability of the DG inverter.

2.2. Inverter Modulation Technology

The driving voltage is required to turn on the IGBT. The provision of driving voltage is called modulation technology. At present, the commonly used driving voltage provides mainly two modulation technologies: SPWM and SVPWM. SPWM is sinusoidal pulse width modulation, which is divided into two types: unipolar and bipolar. The difference between the two is mainly reflected in the way of generating pulses. Unipolar only generates positive or negative pulses in a half cycle. The
pulses generated by bipolar appear alternately. SVPWM modulation technology is space vector modulation technology. This technology is currently widely used in the three-phase inverter modulation and motor speed control neighborhood. The advantage of this modulation method is mainly the higher utilization rate of DC power, which is about 1.1732 Times, but if you want to apply this modulation technique to a single-phase inverter, a conversion process is required, so for single-phase inverters, the application of SPWM technology is more common.

3. Experiments

The microgrid is inseparable from the existence of inverters in its three operating states, and the current power consumption is getting larger and larger. These inverters usually achieve energy conversion through parallel connection. The focus of this chapter is on the inherent characteristics of the medium and low pressure environment. It will introduce the working principle of the control equation under resistive conditions in detail, reveal the shortcomings of the traditional control methods, and lead to the improved resistive control equations adopted in this article.

A complete inverter will have a filter inductance and a filter capacitor at the output end. The influence of the capacitance of the filter capacitor on the overall inverter can be ignored in the control system. Many documents believe that the presence of the filter inductance makes the inverter equivalent. The output impedance becomes nearly pure inductive, so people usually ignore the resistive component, which can be the following two types:

\[ P = \frac{V_i E}{X_1} \theta_1 \]  
\[ Q = \frac{(V_i - E)}{X_1} E \]  

It can be seen from the above two formulas that the active power P is mainly affected by \( \theta \), and the reactive power Q is mainly affected by V-E. Derivation of equation (5) and equation (6) with voltage phase angle and voltage amplitude as variables can obtain equation (7):

\[ \begin{aligned} 
\frac{dp}{d\theta} &= \frac{X_1 EV_1}{R_1^2 + X_1^2} \\
\frac{dq}{d\theta} &= \frac{E(R_1 + X_1 \theta)}{R_1^2 + X_1^2} \\
\frac{dV_1}{dv} &= \frac{X_1 E}{R_1^2 + X_1^2} 
\end{aligned} \]  

The derivation values of observation formula (7) are all positive values, from which the adaptive droop control equations under traditional perceptual conditions can be obtained.

\[ \begin{aligned} 
w &= w^* - mP \\
V &= V^* - nQ
\end{aligned} \]  

In formula (8), \( w^* \) is the rated frequency of the inverter, in practice it is usually the power frequency; \( V^* \) is the rated voltage of the inverter when it is no-load; m and n are the droop coefficients of reactive power and active power respectively.

4. Discussion

4.1 Analysis of the Effect of Virtual Complex Impedance Parameters on Equivalent Output Impedance
This paper analyzes the effect of virtual complex impedance parameters and QPR controller parameters on the entire system through Bode diagram. Here, the parameter values of the inverter control system are shown in Table 1. First, analyze the values of R and KL in the virtual complex impedance; second, analyze the values of Kp and Ki in the QPR controller. The experimental results are shown in Table 1 below.

**Table 1.** Electrical parameters of inverter with multiple loops control

| parameter                  | Value     |
|----------------------------|-----------|
| Quasi-Resonant Controller  | Kp=0.04   |
|                            | Ki=48     |
| Proportional controller    | Kp2=0.04  |
| Virtual complex impedance  | R=1       |
|                            | Kl=0.04   |
|                            | Ls=0.004  |
| Inverter filter inductance | 5mH       |
| Inverter filter capacitor  | 9μF       |

As shown in Table 1 above, according to Table 1, the values of the inverter parameters are set. Other values are unchanged, and only the resistance component in the virtual complex impedance is changed. From this table, it can be known that when the virtual complex impedance is R, the values are 0.5 and 0.75, respectively. Equivalent output impedance changes at 1, 2 and 2.

4.2 Analysis of the Effect of Quasi-resonant Controller Parameters on Equivalent Output Impedance

With the gradual increase of the value of R, the amplitude frequency and phase frequency curve changes basically linearly in the vicinity of the low frequency band and the power frequency. The value of R increases, and the slope of the amplitude frequency curve of the low frequency band approaches from -20dB to close to 0dB, the equivalent output impedance of the system gradually changes from inductive to near resistive to obtain the change shown in Figure 1.
Figure 1. Bode diagram of equivalent output impedance with different resistive element coefficients

As shown in Figure 1 above, the value of the resistive component is not as large as possible. There are two reasons for this: First, R will assume part of the voltage in the inverter multi-loop control structure, and the voltage value is proportional to the value of R. If the value is too large, the voltage drop will be exacerbated in the parallel system, which will further affect the power quality; secondly, in the inverter parallel system, the excessive value of R will affect the resistance of the system to disturbances, which is not conducive to achieving parallel redundancy. I control, so this article takes it as 1. Then analyze the effect of the value of the inductance in the virtual complex impedance on the equivalent output impedance when R is 1.

In the figure, KL takes the change curve of the equivalent output impedance when 0.05, 0.25, 0.5, and 1. By observing the amplitude frequency and phase frequency curves, it can be seen that there is a nonlinear change near the power frequency. From the amplitude frequency curve, it can be seen that with The value of KL ranges from 0.05 to 0.5. At the line frequency, the slope of the graph gradually changes from 0dB to -40dB, which gradually changes from resistive to inductive. When KL is 1, the equivalent output impedance changes It is resistive and stronger than when KL is 0.05. However, the value of KL cannot be too large, because the larger the value of KL, the greater the degree of cancellation of the inductive component in the equivalent output impedance of the inverter. The equivalent output impedance includes the filter inductance of the inverter. Too much offset the value of the filter inductance of the inverter itself, which will cause the voltage at the output of the inverter to contain a lot of harmonics. Therefore, for comprehensive consideration, the value of this article is 0.05.

5. Conclusions

In this paper, the use of improved control equations must be based on the multi-loop control structure, so a detailed explanation of the inverter multi-loop control structure is given. In addition to the traditional voltage and current double closed loop, there are virtual impedance loop and power Based on the adaptive droop control loop, in order to eliminate the impact of voltage fluctuations on the multi-loop, a voltage feed-forward loop is added; at the same time, several key parts of the inverter multi-loop control structure are also introduced. Secondly, the corresponding transfer function is obtained from the inverter multi-loop control structure, and the effects of the virtual complex impedance and the parameters in the QPR controller on the equivalent output impedance are analyzed. Through theoretical analysis, the effect of the virtual complex impedance parameter on the value of the equivalent output impedance when it takes different values is analyzed, and the corresponding response of the QPR controller parameter when it takes different values is also analyzed. influences. Finally, it is verified that these two methods can effectively eliminate the inductive component in the equivalent output impedance and increase the resistive component when they act together on the inverter control structure.

Acknowledgments

Key specialty of "electrical engineering and automation" of quality engineering project 2019 of Guangdong Polytechnic College.
References

[1] Wang Y, Luo A, Jin G, et al. Microgrid inverter parallel operation strategy in large feeder impedance environment[J]. Zhongguo Dianji Gongcheng Xuebao/proceedings of the Chinese Society of Electrical Engineering, 2015, 35(4):858-865.

[2] Khajesalehi J, Hamzeh M, Sheshyekani K, et al. Modeling and control of quasi Z-source inverters for parallel operation of battery energy storage systems: Application to microgrids[J]. Electric power systems research, 2015, 125(aug.):164-173.

[3] Chen X, Hou Y, Hui S Y R. Distributed Control of Multiple Electric Springs for Voltage Control in Microgrid[J]. Smart Grid IEEE Transactions on, 2017, 8(3):1350-1359.

[4] Hai N T, Kim K H. An Adaptive Virtual Impedance Based Droop Control Scheme for Parallel Inverter Operation in Low Voltage Microgrid[J]. International Journal of Power Electronics and Drive Systems, 2016, 7(4):1309.

[5] Ramezani M, Li S, Sun Y. Combining droop and direct current vector control for control of parallel inverter in microgrid[J]. Renewable Power Generation, IET, 2017, 11(1):107-114.

[6] Serban I, Ion C P. Microgrid control based on a grid-forming inverter operating as virtual synchronous generator with enhanced dynamic response capability[J]. International journal of electrical power and energy systems, 2017, 89(JUL.):94-105.

[7] Wang X, Ma H, Zhang Y. Networked control for microgrid three-phase parallel inverter and network delay analysis[J]. Taiyangneng Xuebao/acta Energiae Solaris Sinica, 2015, 36(7):1602-1609.

[8] Xiao H, Luo A, Shuai Z, et al. An Improved Control Method for Multiple Bidirectional Power Converters in Hybrid AC/DC Microgrid[J]. Smart Grid, IEEE Transactions on, 2016, 7(1):340-347.

[9] Jayachandran M, Ravi G. Predictive power management strategy for PV/battery hybrid unit based islanded AC microgrid[J]. International Journal of Electrical Power & Energy Systems, 2019, 110(SEP.):487-496.

[10] Xu Y, Chen H, Gu J. Power loss analysis for switched reluctance motor converter by using electrothermal model[J]. Power Electronics, IET, 2015, 8(1):130-141.