An improved droop control with network adaptive ability in islanded mode of microgrid

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Abstract. When the microgrid operates in island mode, the droop control can be adopted to realize effective power distribution among distributed generations (DGs). Due to the different line impedances of the various DGs, disproportional power distribution and circulating currents occur in conventional droop control, which make it difficult to maximize the efficiency of DGs and even may cause some DGs overloads. Therefore, an improved droop control strategy with an adjustable droop coefficient is proposed. The relationship between line impedance and reactive power is obtained by analysing conventional droop control. Then a new droop control algorithm is proposed. By introducing the output reactive power information of other DGs into the integral feedback link, the droop coefficient is modified to realize the accurate distribution of reactive power. The model is built on the Matlab/Simulink platform, and the effectiveness of the proposed control strategy is verified by comparing its reactive power distribution result with that of the conventional droop control.

1. Introduction

With the emergence of environmental problems such as smog pollution and greenhouse effect, the energy situation will be more severe. Therefore, distributed power generation based on clean energy has been widely used in microgrids. Compared with traditional centralized power generation, distributed energy is widely distributed, is more convenient and flexible without geographical restrictions, and has fewer energy conversion links, which is more economical and better environmental protection. The above advantages of distributed power generation determine that it will become one of the leading forms of power generation in the future, which has important research value and application prospects [1-5].

The microgrid has two modes of operation: grid-connected and islanded. Especially when the microgrid operates in the island mode, DG undertakes the task of adjusting the power quality. The stable operation of the microgrid is closely related to its control technology [6]. Inverter as the interface between DG and microgrid, the research of its control technology has become one of the new
research hotspots in DG field [7-8]. When the microgrid operates in the island mode, droop control is mostly used to adjust the output of active and reactive power according to the set droop curve to maintain the stability of the system frequency and voltage. The key to the parallel operation of each DG is the output power balance, which can effectively exert the efficiency of DG, share the load together, and maintain the stability of the system. The traditional droop control strategy is simple, and the technology is mature, but its inherent limitations make it applied to low-voltage microgrids, especially complex microgrids. The location of DG is scattered, resulting in the differences in output impedances, line impedances and local loads, which in turn lead to different output voltages, affect power sharing, and form a circulating current between inverters, which increases losses, reduces system operating efficiency, and affects system stability [9-10].

Therefore, in order to solve the problem of power distribution deviation in the use of traditional droop control, domestic and foreign scholars have proposed a variety of improvement schemes on this basis [11]. By adding virtual impedances to the droop link, the influence of different line impedances on power distribution is reduced. Reference [12] proposed a virtual resistance optimization algorithm, which aims to minimize the power loss and suppress the circulating current between converters, but this method needs to constantly modify the parameters, and does not consider the influence of local loads, can not maintain the bus voltage at rated value. By obtaining information of other DGs through communication to improve power distribution accuracy. Reference [13] proposed an improved droop control method based on communication. This method can cope with rapid load current changes. It is a hybrid compensation method of secondary control. A compensator is added to the droop link to obtain the DG’s current, voltage, and droop coefficient, and adjust the translation and droop coefficient of the droop curve, which can quickly handle the sudden change of the load and compensate the bus voltage, but this method is more complicated. There are also some new control strategies, such as fuzzy algorithm, which adjusts the droop curve according to the output power of DG, and obtains the bus voltage reference value through fuzzy control. It can also ensure a small bus voltage deviation while achieving power sharing, but the addition of new units makes the system more complicated [14].

To this end, this paper proposes an improved droop control strategy with adaptive power sharing. Firstly, the traditional droop control strategy is introduced. Secondly, considering the effect of line impedances mismatch on power distribution, the deficiency of the traditional droop control strategy is analyzed. In view of the above problems, an improved droop control strategy with adjustable droop coefficient is proposed. Finally, the model is built on the Matlab/Simulink simulation platform, and the effectiveness of the proposed control strategy is verified by comparing the traditional and improved droop reactive power distribution.

2. Parallel Inverter Structure and Traditional Droop Control

2.1. Parallel inverter structure

![Diagram of microgrid with N DGs](image)

Figure 1 is a structure of microgrid with N DGs. The DC source obtains the AC voltage through the inverter, and then through the LC filter circuit, which is connected to the PCC of the AC bus by the line. \( L_i \) and \( C_i \) (i=1,2,...N) are filter inductance and filter capacitor respectively, and \( Z_i = R_i + jX_i \) is the sum of inverter output impedance and line equivalent impedance.
2.2. Traditional droop control

Figure 2. Simplified model of microgrid with two DGs

Figure 2 is a simplified model of microgrid with two DGs, $U_{i} \angle \phi_{i}$ is the output voltage of the inverter, $U_{pcc} \angle 0^\circ$ is the AC bus voltage, and the phase angle difference between the two is $\phi_{i}$. From Figure 2, the inverter output current is:

$$I_i = \frac{u_i \phi_i - u_{pcc} \phi_i}{R_i + jX_i}$$  (1)

The output power of the inverter is:

$$S_i = U_i \angle \phi_i \times I_i^*$$  (2)

In practice, $\phi_i$ is very small, so $\sin \phi_i = 0$, $\cos \phi_i = 1$, and the traditional droop considers the line to be equivalent to inductive, that is, $X_i \gg R_i$, so $P_i$, $Q_i$ can be simplified as:

$$P_i = \frac{U_i u_{pcc} \phi_i}{X_i}$$  (3)
$$Q_i = \frac{U_i (U_i - u_{pcc})}{X_i}$$  (4)

It can be obtained that the active power output by the inverter is related to the voltage phase angle, and the reactive power is related to the voltage amplitude, and then the expression of the traditional droop control is obtained:

$$\omega_i = \omega_i^* - m (P_i^* - P_i)$$  (5)
$$U_i = U_i^* - n (Q_i^* - Q_i)$$  (6)

$U_i^*$, $\omega_i^*$ are the output voltage and frequency of DG; under no load, $U_i$, $\omega_i$ are the output voltage and frequency of DG; under load, $P_i^*$, $Q_i^*$ are the rated reference active and reactive power, m, n is the corresponding sag coefficient.

2.3. The effect of different line impedances on inductive droop control

When the microgrid is running stably, the system frequency tends to be the same, and the active power can be divided evenly at this time; the DG output voltage is affected by the line impedance and the difference in local load, resulting in different output amplitudes, which can be obtained from equation (6):

$$U_i = U_{pcc} + \frac{X_i}{U_i} Q_i$$  (7)

Due to the difference in voltage amplitude, the reactive power corresponding to the voltage amplitude will also have a distribution deviation, resulting in circulating current between inverters, which will affect the stability of the system in severe cases.
Taking two DGs with the same capacity as an example, when the droop curve is the same and the line impedance is different, the output reactive power of the two DGs is shown in Figure 3. Because the line impedance is inconsistent, it can be obtained from equation (9) that the two DGs have different line characteristic curves. The intersection of the line characteristic curve and the droop curve is their actual operating point. As can be seen from Figure 3, the line impedance of DG1 is large, and the allocated reactive power $Q_1$ is small; the line impedance of DG2 is small, and the allocated reactive power $Q_2$ is large, and the two reactive power distribution deviations appear obviously. When the droop coefficient is increased, the deviation of reactive power distribution is reduced, but at this time it will cause a voltage drop, which may cause system instability.

3. An Improved Droop Control Strategy with Adjustable Droop Coefficient

According to the previous analysis, the output reactive power of the inverter will be affected by the line impedance and local load. In order to improve the power distribution accuracy and adapt to the complex microgrid structure, this paper proposes a control method for adaptively adjusting the droop coefficient, and its control block diagram as shown in Figure 4, the control consists of three parts, droop control, voltage and current double closed-loop control. The droop control obtains the reference value of the output voltage, the voltage loop ensures the stability of the output voltage, and the current loop quickly tracks the current reference value to improve the response speed of the system.

The droop control proposed in this paper uses communication to obtain the reactive power information output by other DGs, calculates the reactive power reference value according to its own rated capacity, and adjusts the droop coefficient by superimposing the integral follower term in the droop control to achieve the equalization of reactive power. Equation (10) is its control expression:

$$U_i = U_i^* - n \left[ \frac{Q_i \cdot K_i}{P_i} (Q_{ref_i} - Q_i) \right] (Q_i^* - Q_i)$$

where $K_i$ is the integral control gain, and $Q_{ref_i}$ is the calculated reactive power reference value.

When the capacity of each DG is equal:

$$Q_{ref} = \frac{Q_L}{N}$$

When the capacity of each DG is not equal:

$$Q_{ref_i} = \frac{r_i Q_L}{r_1 + r_2 + \ldots + r_N}$$

Among them, $S_i$ is the rated capacity of DG, $Q_L$ is the total power of reactive load.
Taking two DGs with the same capacity as an example, when the line impedance is the same, there is \( Q_{\text{ref1}} = Q_t \), and there is no need to modify the original droop curve at this time. When the line impedance is different, as shown in Figure 5, the working points of DG1 and DG2 are A and B respectively, and \( Q_2 > Q_1 \). The reactive power output by DG1 and DG2 deviates from the given value \( Q_{\text{ref1}} \). At this time, the integral controller corrects the reactive power deviation. For DG1, the output reactive power \( Q_1 \) is less than the given value \( Q_{\text{ref1}} \), the value after the integration controller is positive, the droop coefficient of DG1 is adjusted from \( n \) to \( n_1 \), and the operating point is adjusted from A to A1, which increases the output of reactive power. For DG2, after the same process, the droop coefficient is adjusted from \( n \) to \( n_2 \), and the operating point is adjusted from B to B1, reducing the output of reactive power.

In summary, the improved droop control strategy proposed in this paper can adjust the droop coefficient adaptively by superimposing the integral follower term, eliminating the influence of local load on the output reactive power, and realizing the accurate distribution of reactive power.

4. Simulation Results and Analysis

In order to verify the effectiveness of the proposed control strategy, this paper builds a simulation model of two DGs in parallel as shown in Figure 1 on the Matlab/Simulink simulation platform. The specific simulation parameters are shown in Table 1.

| Table 1. System parameters in the simulation |
|---------------------------------------------|
| Items                                      | Parameters |
| DC voltage source input                    | 800V       |
| AC voltage reference output                | 380V/50Hz  |
| filter inductance                          | 5mH        |
| filter capacitor                           | 50\( \mu \)F |
| line inductance                            | 0.036mH    |
| line resistance                            | 0.0084\( \Omega \) |

Case 1:

Two DGs with the same capacity and line impedance are operated in parallel. The common load is connected to the AC bus, and the load is 15kW, 5kvar at 0-2s, and the load is increased to 30kW, 10kvar at 2s.

When the traditional droop control is used, the output active power, reactive power, and phase A current of the inverter are shown in Figure 6 (a), (b), and (c) respectively. From the simulation results, it can be seen that the outputs of the two inverters are equal. When the load is increased at 2s, the microgrid enters a new stable operating state.
Figure 6. Simulation results of the traditional control method

When the improved droop control is used, it can be seen from the simulation results that no matter what control method is used, when the line impedance is the same, the electrical quantities output by the two inverters are equal, that is, the active and reactive power output by the two inverters can be equally divided.

Figure 7. Simulation results of the proposed control method

Case 2:

Two DGs with the same capacity and different line impedance are operated in parallel. The line impedance of DG2 is twice that of case 1, and the load switching condition is the same as case 1. When the traditional droop control is used, the output active and reactive power of the inverter are shown in Figure 8 (a) and (b) respectively. From the simulation results, it can be seen that when the line impedance is different, the active power can always be balanced, but the reactive power difference is very large, and there is an obvious distribution deviation. The output phase A current of the inverter is shown in Figure 8(c). From the simulation results, it can be seen that due to the uneven distribution of reactive power, the output current amplitude of the inverter is different, resulting in circulating current.

Figure 8. Simulation results of the traditional control method

When the improved droop control is used, the output active power, reactive power and phase A current of the inverter are shown in Figure. 9 (a), (b) and (c) respectively. From the simulation results, under the effect of integral feedback, the reactive power deviation gradually decreases, and finally the reactive power is evenly divided. At this time, the circulating current problem between inverters has also been significantly improved, and the active power can be evenly distributed throughout the process.
Figure 9. Simulation results of the proposed control method

It can be seen from the above simulation results: when the line impedance is not equal, using the traditional droop control, the active power can achieve balanced distribution, but the reactive power distribution is unbalanced. Using the improved droop control proposed in this paper, that is, the method of adaptively adjusting the droop coefficient, can effectively improve the reactive power distribution between DGs without detecting the line impedance.

5. Conclusion
This paper first analyzes the problem of inaccurate reactive power distribution caused by the line impedance mismatch in the traditional droop control in the microgrid, and proposes an improved droop control strategy with adjustable droop coefficient based on this, that is, using communication to obtain the reactive power information output by other DGs, calculate the reactive power reference value according to its own rated capacity, and adjust the droop coefficient by superimposing the integral follower in the droop control to achieve the effect of accurate power distribution. Since the integral feedback link is added, the adjustment of the droop coefficient can eliminate the impact of the line impedance mismatch, reduce the system circulating current, respond flexibly to sudden load changes, and does not need to detect the microgrid structure and line parameters. It has good network self-reliance and improves the stability of microgrid operation.

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References
[1] Yang, X.F., Su, J., Lv, Z.P. (2014) Overview on micro-grid technology. J. Proceedings of the CSEE. 34(1): 57-70.
[2] Gao, Y., Ai, Q., Wang, J. (2018) Consensus cooperative control of AC/DC hybrid microgrids based on multi-agent system. J. High Voltage Engineering. 44(7): 2372-2377.
[3] Sayed Mohamed, S., Shaaban, M.F. (2019) An Efficient Planning Algorithm for Hybrid Remote Microgrids. J. Automation of Electric Power Systems. 10(1): 257-267.
[4] Yang, Y., Tan, S. C., Hui, S.Y.R. (2018) Mitigating distribution power loss of DC microgrids with DC electric springs. J. IEEE Transactions on Smart Grid. 9(6): 5897-5906.
[5] Fan, B., Guo, S.L., Peng, J.K. (2020) A Consensus-Based Algorithm for Power Sharing and Voltage Regulation in DC Microgrids. J. IEEE Transactions on Industrial Informatics. 26(6): 3987-3996.
[6] Wang, C.S., Xiao Z.X., Wang, S.X. (2009) Multiple feedback loop control scheme for inverters of the micro source in microgrids. J. Transactions of China Electrotechnical Society. 24(2): 100-107.
[7] Brito, M., Alves, M., Canesin, C. (2020) Microgrid System with Emulated PV Sources for Parallel and Intentional Islanding Operations. J. IEEE Latin America Transactions. 18(8): 1462-1469.
[8] Hashemipour, N., Aghaei, J., Lotfi, M. (2019). Multi-Objective Optimization Method for Coordinating Battery Storage Systems, Photovoltaic Inverters and Tap Changers. J. IET Renewable Power Generation, 14(3):475-483.

[9] Zhu, Y.X., Zhuo, F., Wang, F. (2016). Virtual impedance optimization method for microgrid reactive power sharing control. J. Proceedings of the CSEE. 36(17): 4552-4563.

[10] Lv, Z.P., Sheng W.X., Jiang, W.Q. (2013). Frequency dividing droop controllers with the function of voltage stabilization and circulation control. J. Proceedings of the CSEE, 33(36): 1-9.

[11] Zhu, S.S., Wang, F., Guo, H., Wang, Q.F., Gao, Y.X. (2018) Summary of research on DC microgrid droop control technology. J. Proceedings of the Chinese Society of Electrical Engineering. 38(01): 72-84.

[12] Ning, X.J., Yang, H.G., Sha, Y. (2017) Control strategy of paralleling converters to restrain circulating current in DC microgrid. J. Renewable Energy Resources. 35(1): 72-79.

[13] Wang, P.B., Lu X.N., Yang, X. (2016) An improved distributed secondary control method for DC microgrids with enhanced dynamic current sharing performance. J. IEEE Transactions on Power Electronics. 31(9):6658-6673.

[14] Kakigano, H., Miura, Y., Ise, T. (2013) Distribution voltage control for DC microgrids using fuzzy control and gain- scheduling technique. J. IEEE Transactions on Power Electronics. 28(5): 2246-2258.