Improved Droop Control Strategy of Energy Storage in Islanded Microgrid

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Abstract. In islanded AC microgrid, droop control strategy is usually adopted for independent distributed generators (DG) which can realize coordinated operation of each unit under the conditions of less data communication. For different capacity of energy storages (ES) system, due to the difference of SOC value, capacity and other state parameters, some units may reach the threshold quickly, thus affecting the system stability. Therefore, on the basis of traditional droop control, combined with the SOC value of energy storage unit, the droop curve which is automatically adjusted with the change of SOC value is constructed. At the same time, the bus voltage is corrected to run at a predetermined point through the voltage feedback link to eliminate the voltage fluctuation. Finally, a microgrid model with dual energy storage system is built in Matlab/Simulink simulation environment. The results show that the improved droop control method can make the SOC values of the two energy storages consistent.

1. Introduction

At present, there are natural short boards in the application flexibility and schedulability of large power grid. Under the situation of energy shortage and increasing environmental pollution, the distributed generation technology represented by solar energy and wind energy is getting more and more widely used, which is also a beneficial supplement to the centralized power supply in China [1-4].

There are two operation modes of microgrid: grid-connected operation and isolated island operation[5][13-14]. Under island operation, the distributed energy storage inverters are connected to the bus in parallel. Different distributed power sources play different roles in microgrid, and the control strategies adopted by inverters are also different. It is mainly reflected in the external loop control of the inverter. Droop control is one of the most widely used control methods. In recent years, some scholars have done a lot of research on it. In the reference document of [9], the droop coefficients M and N are replaced by simple functions related to active and reactive power. The droop coefficients will be adjusted dynamically with the change of power. In reference [10], a power sharing control strategy based on virtual capacitor is proposed. The parallel capacitance of the inverter is dynamically adjusted to improve the reactive power sharing ability. In reference [11], according to the difference of line impedance, the reference voltage of each inverter is adjusted by matching the power
compensation coefficient with the difference of impedance, so as to realize the reasonable distribution of power and the suppression of reactive circulation.

Therefore, this paper starts with the parallel model of energy storage inverter, and improves power transmission characteristics and adjusts the output power of energy storage based on SOC value. The ES with higher SOC value thereby has higher output power. At the same time, the reference voltage is adjusted by PI control feedback to realize the bus voltage stability.

2. Traditional droop control

Droop control of inverter is based on that the line inductance is much greater than the resistance. The adjustment of secondary frequency modulation is based on the relationship between the frequency of the generator and the active power.

Figure 1 shows a simplified model of two inverters in parallel. It is equivalent to a voltage source with internal resistance and connected to microgrid in parallel.

![Parallel inverters on equivalent electric circuit diagrams](image)

Figure 1. Parallel inverters on equivalent electric circuit diagrams.

The power flow of the inverter is from point A to point B. The voltage of DG1 is $U_1 \angle \theta_1$. Point B is AC bus parallel network. The voltage in this point is $U_0 \angle 0$. The line impedance is expressed as $Z = R + jX$. The expression of apparent power output is as follow:

$$S_i = P_i + jQ_i = U_i \times I' = \left( U_1 \cos \theta_1 + jU_1 \sin \theta_1 \right) \times \left[ R + (U_1 \cos \theta_1 - U_0) + XU_1 \sin \theta_1 \right] \frac{R^2 + X^2}{R^2 + X^2}$$

Therefore, the output active power and reactive power of the parallel network are as follows:

$$P = \frac{R(U_1^2 - U_1 U_0 \cos \theta_1) + XU_1 U_0 \sin \theta_1}{R^2 + X^2}$$

$$Q = \frac{X(U_1^2 - U_1 U_0 \cos \theta_1) - RU_1 U_0 \sin \theta_1}{R^2 + X^2}$$

In the high voltage grid, the inductive reactance is much greater than the impedance. Therefore, the effect of resistance R in the circuit can be ignored. The formulas above can be simplified as follows:

$$P = \frac{U_1 U_0 \sin \theta_1}{X}$$

$$Q = \frac{U_1 (U_1 \cos \theta_1 - U_0)}{X}$$

In the formula, the $\theta$ is very small. For the convenience of calculation, $\sin \theta$ can be replaced by $\theta$. It can be seen from the relationship between frequency and phase angle:

$$f = \frac{\omega}{2\pi}$$

Therefore, it can indirectly control the frequency through the active power control of inverter output, and the voltage through the reactive power control of inverter output. P-f and Q-U control methods are based on droop control principle:

$$P = P_0 + (f_0 - f) K_f$$

$$Q = Q_0 + (U_0 - U) K_u$$

The droop characteristic curve is shown in Figure 2.
The application of droop control can realize the power sharing of inverter and the stability of microgrid under the condition of reasonable voltage and frequency fluctuation. At present, the research on the improvement of droop control generally aims at solving the frequency deviation and voltage deviation caused by droop control curve. The existing improvements generally aim at transforming P-f or Q-f control strategies into p-δ or q-δ in order to keep the frequency constant. At the same time, by modifying the droop coefficient, the droop rate of voltage bus can be reduced in a certain range of power fluctuation. The current SOC value is seldom considered in the discharge control strategy for energy storage. It will cause the SOC of energy storage to be lower than the threshold value in some scenarios and the network will be cut off, which will cause the fluctuation of the power grid and is not conducive to the stability of the power grid.

In view of the above situation, the droop control strategy of the parallel converter is improved, and the droop curve is adjusted dynamically by adding SOC electric quantity in the power feedback link, so as to realize the purpose of dynamic adjustment of output power under different SOC states with different energy storage. At the same time, the voltage U deviation caused by the droop principle forces the bus to follow the target voltage by adding a voltage feedback link to improve the quality of network power supply.

3.1 Improvement of droop control combined with SOC value
According to the principle of droop control curve, the DG with larger SOC is set to control its active power output. The DG with lower SOC is set to reduce the active power provided. The schematic diagram is as follows:

Figure 4. Characteristic curve of improved droop control.
The output power of the inverter can be reduced and the power output of the energy storage system can be suppressed by adding a $\Delta P$ power increment related to the SOC state quantity in the power feedback. Although no parameters of the droop curve have been improved, the introduced $\Delta P$ parameter enables the actual output of energy storage to be executed according to the equivalent droop curve. And in different SOC States, the corresponding $\Delta P$ is also different. Therefore, the equivalent droop curve is constantly moving, and the larger the SOC is, the larger the actual power output is. The principle is shown in the following formula:

$$P_0 = P_{ref} - k(e - e^{r\cdot SOC})$$

(9)

$P_0$ is the corrected active power output value, which is the reference value of the active power before the correction. $r$ is the proportional coefficient, and $K$ is the influence speed factor. The principle diagram of improved loop control is shown below:

Figure 5. Principle diagram of improved loop control.

When multiple inverters operate in parallel with traditional droop control, they can achieve a more accurate power sharing. However, for energy storage units with large SOC differences, it is beneficial to optimize the power allocation by giving priority to the energy of high SOC units.

In the droop control module, the droop curve can be adjusted adaptively, and finally the SOC of the two energy storage systems can be changed in step.

3.2 Grid connected control strategy with voltage compensation

The bus voltage will have obvious voltage drop with load variation. According to the droop control curve, when the reactive power is not 0, the voltage offset will occur.

In order to eliminate the influence of this offset, this paper adds a voltage compensation module in the inverter control unit to realize the precise control of the voltage. The proportional amount of voltage deviation is fed back to the reference voltage. In the steady-state condition, the voltage drop $\Delta U$ is 0. Therefore, it can force the bus voltage to be equal to the set value and eliminate the influence of bus voltage drop.

Figure 6. Principle diagram of improved loop control with voltage compensating factor.
In droop control, the change of reactive power Q leads to voltage drop of bus, and then the actual power consumption of load will decrease. There are generally two solutions to this situation: (1) Setting a small sag coefficient by predicting the fluctuation range of load; (2) Setting voltage compensation for bus voltage. The former sets a smaller droop coefficient, which will reduce the dynamic response speed of the system and affect its stable operation state. In this paper, by adding the bus voltage deviation into the droop control and introducing the double loop control module through PI control, the set voltage target value can be tracked well.

4. Improved droop control
Through MATLAB/Simulink simulation tool, the microgrid model of double energy storages droop control is built. The selection of sag coefficient is as follows: \( K_f = 1e^{-5} \) / \( K_q = 5e^{-4} \). The specific parameters of the inverter circuit are shown in Table 1.

| Parameter                  | Value       |
|----------------------------|-------------|
| Filter inductance (Lf/ mH) | 0.6         |
| Filter capacitor (Cf/ μF)  | 1500        |
| Filter resistor (Rf/ Ω)    | 0.01        |
| Line inductance (Ll/ mH)   | 0.528       |
| Output voltage (U0/ V)     | 311         |
| Droop coefficient Kp       | 0.00001     |
| Droop coefficient Kq       | 0.0005      |
| Initial SOC state of ES1   | 80%         |
| Initial SOC state of ES2   | 79%         |

In the initial state, the load active power of the bus is 30kW, and the reactive power is 10kVar. Then connect 10kW active load and 15kVar reactive load to power grid at 0.4s. At 0.7s, cut off the two loads from microgrid. The filter circuit and line impedance of two parallel branches are the same. The power system is set with rated frequency of 50Hz and rated voltage of 311V.
In figure 7 and 8, under the condition of reactive output fluctuation, the bus voltage is also changing. At the beginning, due to the inductive reactance of the line, the voltage will be slightly deviated. At 0.4s, when the reactive output is 15kvar, the voltage drop is nearly 10V, reaching 301V. In figure 9, the power of the total load cannot reach the nominal value due to voltage drop and there is a deviation of \( \Delta P \) in the system. Figure 10 and 11 show the active and reactive power output of ES1 and ES2 when the power is equally divided. Figure 12 shows the SOC changes over a 30 second period, and in this period, the SOC state of dual energy storage decreased in step.

As can be seen in figure 14-19, through the improvement of droop control and bus PI feedback control, each energy storage unit can realize automatic power regulation according to SOC state. In Figure 14, the bus voltage amplitude is basically stable at 311V. With the load fluctuation, the voltage amplitude has no obvious change. Figure 17-19 show the active and reactive power output of each DG.
after improvement, and the energy storage with higher SOC undertakes more power output tasks of the grid. Finally, two SOC values of energy storage can be reduced at the same rate.

5. Conclusion
This paper briefly describes the basic principle and control realization of droop control, and adjusts droop curve in real time with SOC state value of energy storage units. By improving the droop curve, DG undertakes different power output tasks according to its SOC state. At the same time, according to droop principle, voltage compensation link is added to stabilize the voltage value in the bus near the target value. According to the simulation results, the feasibility of the improved method is verified.

The inductive reactance of the transmission line set in this experiment is far greater than the resistance, and the resistive circuit has not been fully studied and there are some extra limitations in the experiment.

In this paper, just two inverters are simulated in parallel. In the following experiment, more than one inverter can be added in the experiment in further study.

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