E3S Web of Conferences **185**, 01064 (2020)
ICEEB 2020
http://doi.org/10.1051/e3sconf/202018501064

Research on Bus Voltage Control Strategy of Off-grid DC Microgrid

Yilong Kang[1*], Ningkang Zheng[1], Xiangyang Yan[1], Huanruo Qi [1], Kai Li[1]

[1]State Grid Henan Economic Research Institute, Zhengzhou, Henan, China, 450000

Abstract: It is important to achieve stability of bus voltage in control of DC microgrids. In the DC microgrid, the traditional droop control method is usually adopted to stabilize the bus voltage for its high reliability and cost-effectiveness. However, line resistance will reduce the voltage quality of the DC bus in actual situations. In order to improve the voltage quality of the DC bus, a novel bus voltage control strategy based on modified droop characteristic is proposed. Finally, the simulation model of the off-grid DC microgrid with improved droop control strategy is built on PSCAD/EMTDC platform, and the results verify the effectiveness and feasibility of the proposed control strategy.

1 Introduction

With the gradual depletion of fossil fuel and the further requirements of human for environmental protection, photovoltaic power and wind power generation, as the representative of the new energy, has been highly valued by the countries all over the world for its sustainability, environmental protection and pollution-free. Due to the intermittency, randomness and unpredictability of renewable energy, the structure and control strategy of traditional power supply and distribution system is difficult to satisfy the large-scale grid connection of distributed power resources (DGRS). Microgrid, as an integrated form of distributed generation (DG), distributed load and energy storage system (ESS), has gradually become the hotspot in the power electronics field and industry at home and abroad [1-3]. It utilizes power electronic converters to realize energy control and conversion, which can operate in grid-connected and off-grid modes. Besides, microgrid can be divided into AC microgrid and DC microgrid according to the voltage type of common bus. Compared with AC microgrid, DC microgrid also has the advantages of simple structure, low cost and high reliability, and there is no need to consider the phase and reactive power in DC microgrid, which obtains better power quality.

If the line resistance is not taken into account, the traditional droop control can guarantee the stability of the DC bus voltage. But in the actual DC microgrid, there is line resistance between the DG outlets and DC bus, which will lead to the decline of voltage quality of the DC bus [4], especially for the low-voltage DC microgrid. In view of the above problems, a variety of modified schemes have been put forward on the basis of traditional droop control. In reference [5], a virtual resistance optimization algorithm with minimum power loss is proposed to suppress the circulating current between parallel converters. The simulation results show that the DC bus voltage has been improved, but cannot be stabilized at the rated value. The reference [6] proposes an improved current control strategy, in which a zero-resetting controller for voltage change rate is introduced to compensate the proposed droop control and make sure the stability of output voltage.

2 Topological Structure of Off-grid DC Microgrid

The DC microgrid integrates the DRGS, energy storage unit and DC load with the DC bus, and apply unified management and control. Moreover, the active power fluctuation of the DC microgrid directly affects the stability of the bus voltage, so the bus voltage is only standard to reflect the power balance of the system. The typical topological structure of off-grid DC microgrid is shown in Figure 1. The control mode of off-grid DC microgrid is divided into centralized control with central controller and distributed control without central controller. Centralized control is the optimal control of DC microgrids in the cities, based on the collection, prediction and analysis of information, which is suitable for the DC microgrid with large-capacity due to the correlation between the converters and high requirement for communication and controller. While the distributed control, which is represented by droop control, can realize the stability of bus voltage without communication line or weak communication. The control mode is simple and each converter is equal and operates independently, which is more suitable for the DC microgrid with small capacity.

*Corresponding author's e-mail: kang658vip@163.com

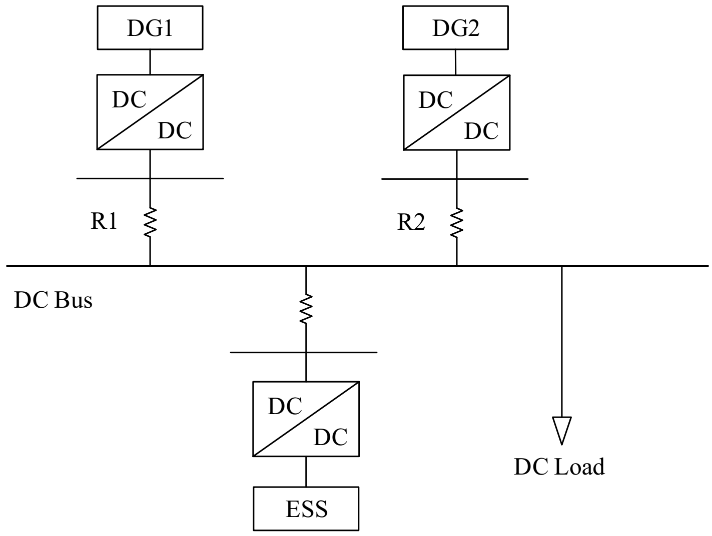

Fig. 1 Topological structure of off-grid DC microgrid

3 Traditional droop control strategy

DC microgrid usually adopts "voltage-power" droop control method, and the mathematical model is as follows

$$U_{\mathrm{d}}=U_{\mathrm{d}}^{*}-lP_{\mathrm{d}} \tag{2-1}$$

Where, U_{d} denotes the DC voltage of the output of the converter, P_{d} denotes the active power of the output of the converter, U_{d}^{*} denotes the reference value of the output voltage with no-load, l denotes the droop coefficient. The droop control curve of U_{d} and P_{d} is shown in Figure 2. In the Figure, $P_{\mathrm{d}}^{\mathrm{ref}}$ is the rated value of the output active power of DG and $U_{\mathrm{d}}^{\mathrm{ref}}$ is the rated value of the output voltage of DG at rated output power.

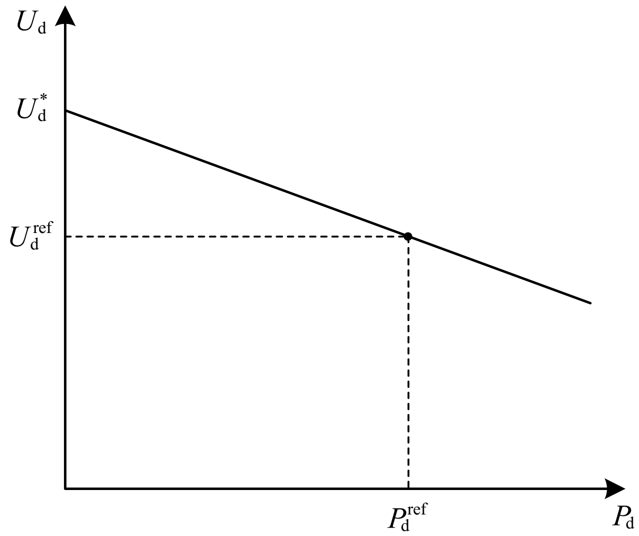

Fig. 2 Traditional droop control curve

If the line resistance is ignored, the output DC voltage output of the DG converter U_{d} is the voltage of DC bus, and the load power of each DG is distributed according to the droop coefficient and the precise control of the DC bus voltage is satisfied. However, in the actual DC microgrid, the existence of line resistance leads to the deviation of DC bus voltage from the target value. Consequently, the traditional droop control strategy is modified to realize the constant stability of DC bus voltage at the rated value in the paper.

4 Modified droop control strategy

Since there is a voltage drop due to the line resistance, the expression of droop control method can be modified to formula

$$U_{\mathrm{d}}=U_{\mathrm{d}}^{*}-lP_{\mathrm{d}}+\left(U_{\mathrm{d}}-U_{\mathrm{dc}}\right) \tag{3-1}$$

Where, U_{dc} denotes the actual value of the DC bus voltage. U_{d}, the control reference value of the voltage loop of the DG converter, is obtained from the formula

(3-1), which can be transformed into the control signal of the converter with the voltage-current double-loop PI control to realize the accurate tracking of the DC voltage of the DG.

Further, the formula (3-1) can be transformed into formula

$$U_{dc}=U_d^*-lP_d \quad (3\text{-}2)$$

In the traditional droop control strategy, U_d^* denotes the reference value of DC output voltage of DG at no load, U_{dc}^* denotes the reference value of DC bus voltage at no load. Then, U_d^* is equal to U_{dc}^*, so the formula can be calculated as follows

$$U_{dc}=U_{dc}^*-lP_d \quad (3\text{-}3)$$

The droop control curve of the formula (3-2) is shown in Figure 3 by the dotted lines. The vertical axis represents the DC bus voltage and the horizontal axis is the output power of the DG, in which the reference value of the DC bus voltage is U_{dc}^* and the voltage of the DC bus is $U_{dc}^{'}$ at the rated output power of DG. In order to solve the problem that the load change causes the DC bus voltage to deviate from the rated value, the compensation value ΔU_{dc} should be added to the reference value U_{dc}^* of the DC bus voltage, which adjusts DC bus voltage $U_{dc}^{'}$ to the rated value U_{dc}^{ref} as below:

$$U_{dc}=U_{dc}^*+\Delta U_{dc}-lP_d \quad (3\text{-}4)$$

where ΔU_{dc} is calculated by the rated value of DC bus voltage U_{dc}^* and the actual value of DC bus voltage U_{dc}. And the modified droop control curve of the formula (3-4) is shown in Figure 3.

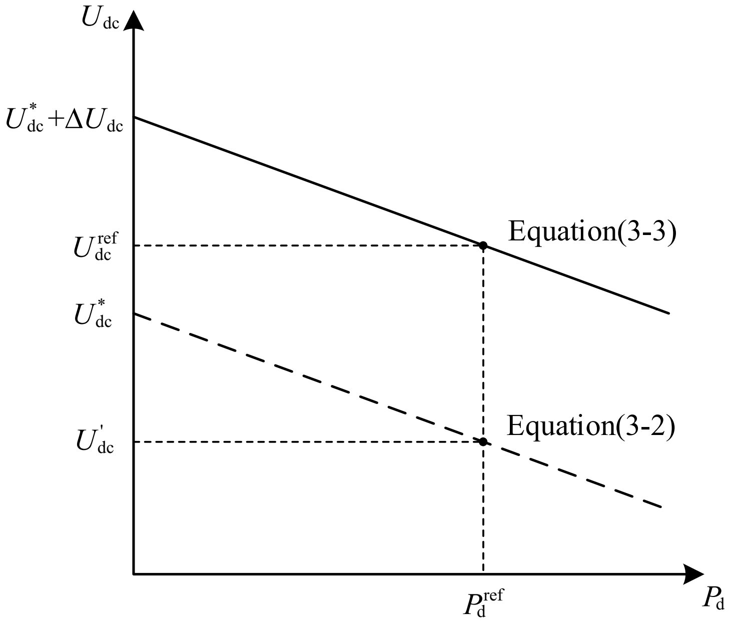

Fig.3 Modified droop control curve

When the power in the DC microgrid changes, ΔU_{dc} will also change to keep the DC bus voltage stable at the rated value. The modified droop control diagram of off-grid DC microgrid is shown in Figure 4, which is local control to ensure the safety and reliability of DC microgrid operation.

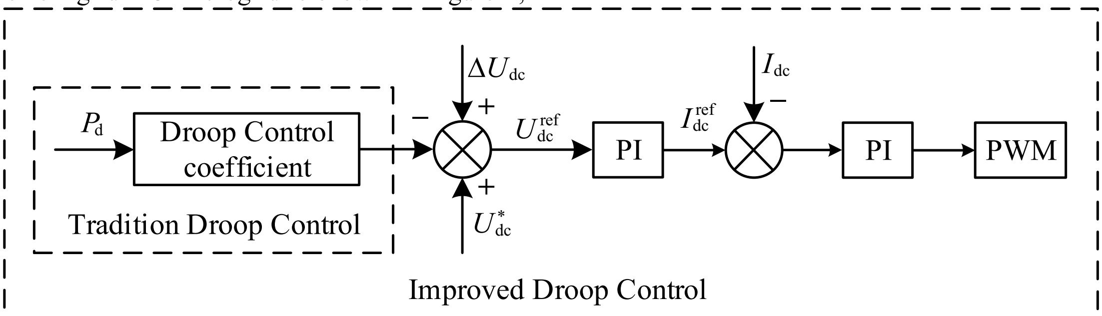

Fig.4 The modified droop control diagram for off-grid DC microgrid

5 Simulation and analysis

In order to verify the feasibility and effectiveness of the modified droop control strategy proposed in this paper, the simulation model of off-grid DC microgrid as shown in Figure 1 is constructed in PSCAD/EMTDC. Besides, the traditional droop control model is built as comparison to reflect the superiority of the modified droop control strategy proposed in the paper. And, the simulation parameters of systems are shown in Table 1.

Table 1 The simulation parameters of systems

Simulation Parameters	Value
DC bus rated voltage	0.4kV
Rated output power DG1	60kW
Rated output power DG2	40kW
R1	0.8Ω
R2	0.8Ω

In this example, the DC load is set to 60kW at the first 3s and 80kW after 3s. The simulation waveform diagrams are shown in Figure 5~7. Figure 5 is the steady-state wave diagram of the DC bus voltage., It can be seen from the figure that the DC bus voltage is stable at 400V under the modified droop control strategy while that is 382V under the traditional droop control strategy. Accordingly, it can be concluded that the modified droop control strategy could keep the DC bus voltage stable at the rated value.

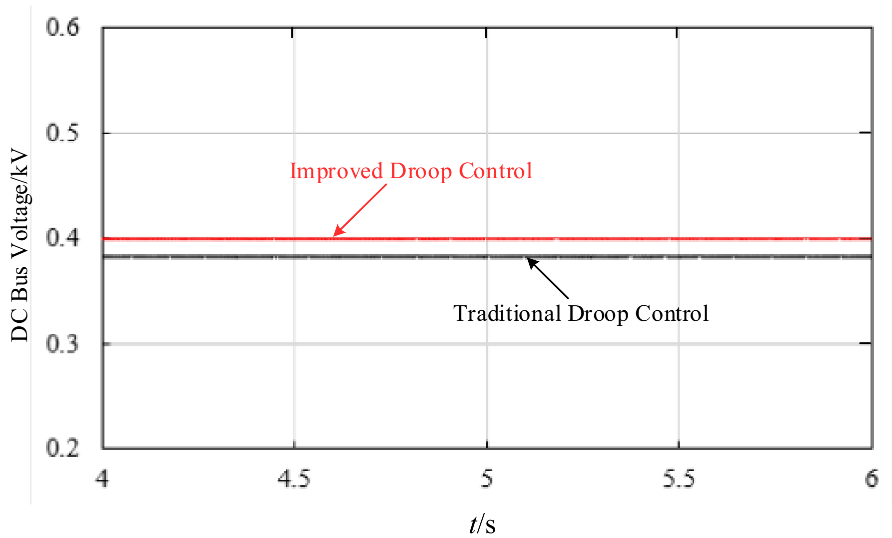

Fig. 5 Steady-state waveform of the DC bus voltage

Figure 6 is the steady-state waveform of the DG1 output voltage, from which it can be seen that the output voltage of DG1 is stable at 426V under the modified droop control strategy while the output voltage of DG1 is 409V under the traditional droop control strategy. Consequently, it can be concluded that the DG1 output voltage of the modified droop control strategy has been improved, which is consistent with the above theoretical analysis.

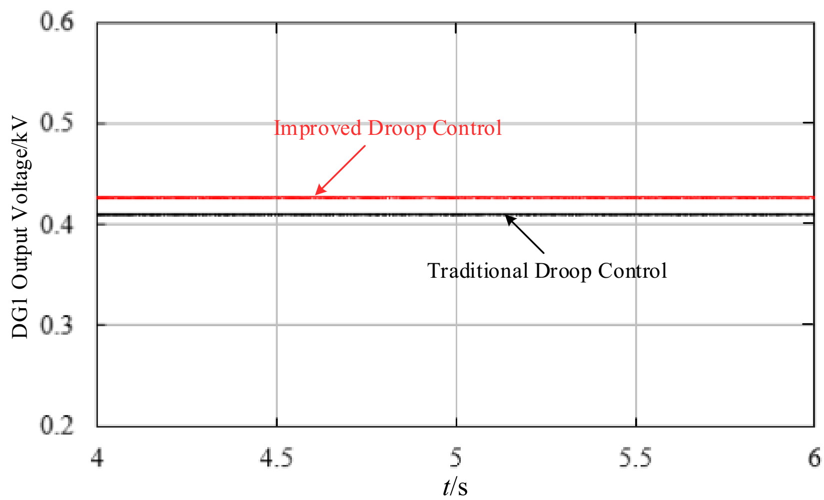

Fig. 6 Steady-state waveform of the DG1output voltage

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Figure 7 is the steady-state waveform diagram of the DG2 output voltage. It can be seen from the graph that the output voltage of DG2 is stable at 413V under the modified droop control strategy while the output voltage of DG2 is 392V under the traditional droop control strategy. Therefore，the conclusion can be drawn that the output voltage of DG2 under the modified droop control strategy is higher than that of the traditional droop control strategy, which is also consistent with the above theoretical analysis.

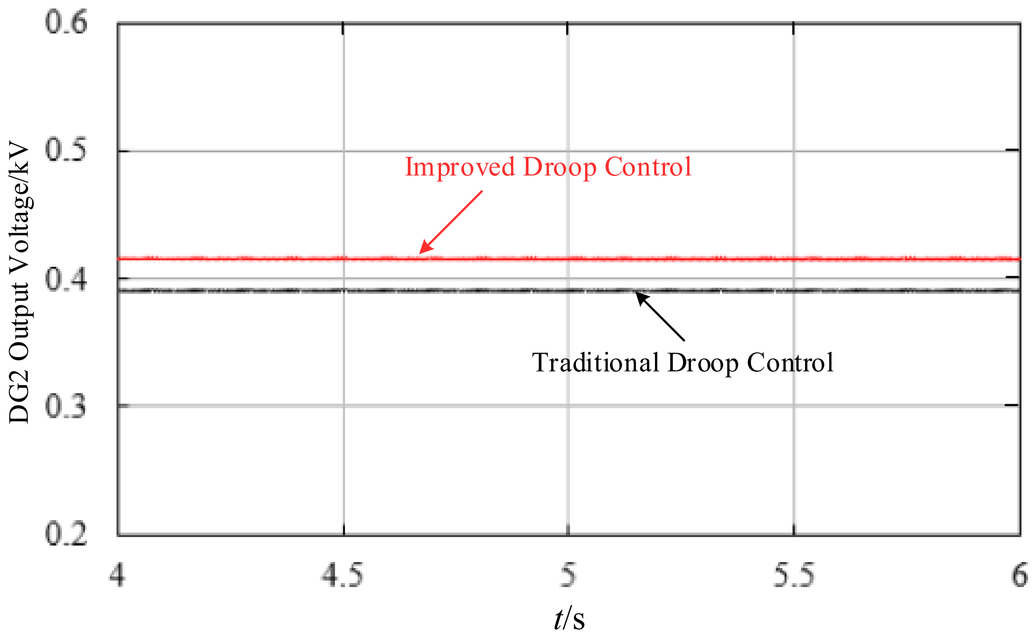

Fig. 7 Steady-state waveform of the DG2 output voltage

6 Conclusion

Aiming at the problem that the line resistance could cause the bus voltage to deviate from the rated value in the DC microgrid, based on the traditional droop control strategy, a set of bus voltage control strategy of off-grid DC microgrid is proposed, which ensures the stability of the bus voltage at the rated value and the reliability of the DC microgrid. Finally, the simulation model with the proposed control strategy is constructed in PSCAD/EMTDC, and the simulation results have verified the feasibility and effectiveness of the proposed control strategy.

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