Research on fuzzy PID droop Control method for DC microgrid in island mode

Qianru Wang¹, Caixia Wang¹*, Ji-peng Gu²

¹ Northwest Minzu University, Electrical Engineering of college, LanZhou, GanSu, Post Code: 730000, China
² Zhejiang University of Technology, College of Information Engineering, HangZhou, ZheJiang, Post Code: 310000, China

*Corresponding author’s e-mail: dqwcx@xbmu.edu.cn

Abstract. In order to solve the problem of difficult power supply in remote mountainous areas and islands, based on the traditional drooping control of DC microgrid, this paper introduces fuzzy PID to realize the self-adjustment of drooping coefficient, which solves the problem of voltage instability of DC bus caused by external environmental conditions and load mutation. MATLAB/SIMULINK simulation results show that the fuzzy PID droop control can effectively reduce the voltage drop, maintain the bus voltage stability, and realize the current sharing of all distributed power sources in the DC microgrid under the load switching condition.

1. Introduction

Droop control does not need digital equipment for communication connection, so it can effectively reduce the operating cost of the system and improve the stability of the system [1]. However, in the case of changes in external environmental conditions and load mutations, the droop coefficient of the dc microgrid under the traditional droop control cannot be automatically adjusted, resulting in poor dynamic output characteristics of the dc microgrid and unable to meet the requirements of high quality electric energy [2,3].

In literature [4], an adaptive fuzzy PID droop controller is designed, which can better suppress the fluctuation of voltage amplitude and frequency when the system has large interference, and has the advantages of strong robustness and good tracking performance. Literature [5] proposes a fuzzy droop control strategy for optical storage DC microgrid. Compared with feedforward droop control, the fuzzy droop control strategy has certain improvements in overshot and adjustment time under the circumstances of external conditions or load changes, and can maintain bus voltage stability. Literature [6] proposes a new adaptive droop control strategy for optical storage DC microgrid, whose droop coefficient can be independently adjusted according to the load power, thus solving the problems such as large voltage offset when the bus voltage of traditional droop control changes with the load power. Literature [7] adds power distribution link and droop coefficient adjustment link to realize accurate power distribution between distributed power sources and improve droop control performance. Literature [8] proposes a self-regulating droop control based on ideal current, which enables the system to have higher degrees of freedom and better regulation performance, and improves the voltage quality of DC bus while improving the power distribution accuracy of micro source.
To sum up, this paper analyzes the operation control scheme of microgrid, and improves it on the basis of traditional droop control based on double loop. The self-adjustment of droop coefficient is realized by fuzzy logic judgment and reasoning. To improve the anti-disturbance ability of the controller to nonlinear interference factors such as load random fluctuation, so as to guarantee the stability of the bus voltage of the microgrid and improve the power quality.

2. Traditional droop control

Without communication and coordination between units, the droop control achieves the goal of micro-source plug and play and peer-to-peer control, and ensures the balance and unity of power in the micro-grid in island mode. It has the characteristics of simplicity and reliability. The simplified equivalent circuit of two micro source DC microgrid is shown in Figure 1.

![Figure 1 Simplified equivalent circuit of two micro source DC microgrid](image1)

![Figure 2 Droop control block diagram](image2)

The load voltage $U_{load}$ and the output current $I_{dc1}$ and $I_{dc2}$ of the two converters can be expressed by formula (1):

$$
\begin{align*}
U_{load} &= U_1 - (R_{d1} + R_{line1})I_{dc1} \\
U_{load} &= U_2 - (R_{d2} + R_{line2})I_{dc2}
\end{align*}
$$

(1)

Assuming $U_1 = U_2$, formula (2) can be obtained from formula (1):

$$
\frac{I_{dc1}}{I_{dc2}} = \frac{R_{d2} + R_{line2}}{R_{d1} + R_{line1}}
$$

(2)

Because the line impedance $R_{line}(i = 1, 2)$ of the two converters to the load is not equal, it is possible that the current distribution between the two converters is uneven or not proportionally distributed. The solution is to make the output impedance of the converter far greater than the line impedance, that is, $R_d \gg R_{line}$, in order to reduce the effect of the line impedance on the current distribution, that is, the droop control is in series virtual impedance at the output end of the converter. The droop control frame is shown in Figure 2. Where, the first PI controller represents the voltage control outer ring; The second PI controller represents the current control inner loop.

When the load changes, the output current of the converter changes, due to the current feedback link, the output voltage of the converter also changes. Therefore, adding the droop control to the converter is equivalent to increasing the output impedance of the converter, making the output impedance much larger than the line impedance, namely, $R_{di} \gg R_{line}$. Then formula (2) can be simplified to formula (3):

$$
\frac{I_{dc1}}{I_{dc2}} = \frac{R_{d2}}{R_{d1}}
$$

(3)

Formula (3) shows that the droop control can achieve the goal of evenly dividing the output current of the two converters, so as to realize reasonable power distribution. Then, the expression of the above droop control can be written as formula (4):

$$
U_{refi} = U_{nom} - I_{dc}R_{di} \quad (i = 1, 2)
$$

(4)

In the actual application of droop control, line impediments exist objectively and are different. Different droop coefficients have different effects on the performance of bus voltage deviation and shunt accuracy. The droop coefficient curve is shown in Figure 3.

Assume that the initial voltage of the two converters is the same, that is, $U_1 = U_2 = U_0$, and the same droop curve coefficient $R_{d1} = R_{d2} = R_d$. The external characteristic impedance $R_{0i}$ of the two
converters is defined as the sum of their droop curve coefficient and line impedance, as shown in Formula (5).

\[
\begin{align*}
R_{O1} &= R_d + R_{line1} \\
R_{O2} &= R_d + R_{line2}
\end{align*}
\]  
(5)

Combined with Equation (5) and Figure 3, it can be seen that when the droop curve coefficient is the same, the external characteristic impedances of the two converters are also different due to the difference in line impedances, resulting in the two converters actually operating on the external characteristic curves with different slopes. When the load is the same and a smaller droop curve coefficient is selected, the shunt deviation of the two converters is \( \Delta I \) and the deviation from the initial voltage is \( \Delta U \); When a larger droop curve coefficient is selected, the shunt deviation of the two converters is \( \Delta I' \) and the deviation from the initial voltage is \( \Delta U' \). \( \Delta U \) is less than \( \Delta U' \) and \( \Delta I \) is greater than \( \Delta I' \).

In other words, when the droop curve coefficient is smaller, the bus voltage deviation can be reduced, but the shunt accuracy will be reduced. When a larger droop curve coefficient is selected, the shunt accuracy can be improved, but the bus voltage deviation will be increased. Therefore, it is the limitation of traditional droop control that it cannot pursue smaller bus voltage deviation and improve shunt accuracy simultaneously.

In formulas (1) to (5), the meanings of each symbol are shown in Table 1, the schematic table of traditional droop control variables.

**Table 1 Schematic table of traditional droop control variables**

| Symbol | Meaning |
|--------|---------|
| \( U_1 \) | Initial given voltages for the two converters |
| \( U_2 \) | |
| \( R_{di} \) | Output impedance of each converter |
| \( I_{dci} \) | Actual output current of each converter |
| \( U_{dci} \) | Actual voltage output by each converter |
| \( R_{line1} \) | Line impedance of two converters to load |
| \( R_{line2} \) | |
| \( U_{refi} \) | A given value of the voltage loop for each converter |
| \( U_{nom} \) | Expected value of dc power output from the converter |

### 3. Fuzzy droop control

Due to the strong nonlinearity of the microgrid and some uncertain factors in the system, it is necessary to adopt reasonable parameter tuning method to realize the high-precision robust control of the voltage amplitude and frequency of the system in the isolated operation of the microgrid. Fuzzy control has the advantages of good robustness, simple algorithm, and good adaptability to nonlinear systems. Therefore, this paper uses the fuzzy PID controller to realize the parameters of the droop coefficient. The block diagram of the fuzzy droop control system is shown in Figure 4.

1) **Fuzzy definition of input and output variables**

The voltage deviation value \( e(t) \) and the voltage change rate \( ec(t) = de(t)/dt \) are used as the inputs of the fuzzy control system, and the values of \( K_P \), \( K_I \), \( K_D \) are used as the outputs. Where, the
domain of voltage deviation value $e(t)$ is [-22 22]; The domain of voltage change rate $ec(t)$ is [-230 230]; The domain of $K_P$ is [-1 1]; The domain of $K_I$ is [-1 1]; The domain of $K_D$ is [-1, 1]. Four fuzzy subsets [L, M, N, Z] are defined for them respectively.

2) Fuzzy rule control table

The Mamdani fuzzy reasoning method was used for reasoning, and the average area method was used for solving the fuzzy method. The fuzzy rules for regulating $K_P$, $K_I$, $K_D$ are shown in Table 2, and the control surface diagram of $K_P$, $K_I$, $K_D$ are shown in Figure 5.

| $k_P$ | $k_I$ | $k_D$ | $e$ | $ec$ |
|-------|-------|-------|-----|-----|
| L     | L/Z/S | M/S/M | S/M/Z | Z/L/Z |
| M     | M/Z/M | S/M/M | M/L/S | M/L/Z |
| S     | L/Z/L | M/Z/L | L/L/S | L/L/S |
| Z     | L/Z/L | M/Z/L | L/L/S | Z/L/Z |

4. Simulation result

The DC microgrid studied in this paper consists of a photovoltaic, two batteries, inverter circuit and resistive load, as shown in Figure 6. The photovoltaic module is connected to the DC bus through the Boost circuit, and the two batteries are connected to the DC bus through the two-way Boost circuit. The resistive load is directly suspended on the DC bus. The electrical energy required by resistive load is jointly provided by photovoltaic and battery. Because the output of photovoltaic cell is intermittent, it cannot be used to maintain the stability of bus voltage. The battery needs to be connected as the relaxation end to stabilize bus voltage. When the load power increases, the battery increases the power output. When the load power decreases, the battery power output decreases.

The system design is as follows: at $t = 1s$, the resistible load changes from 100Ω to 50Ω. The feasibility of the fuzzy droop control method is verified under the condition of load fluctuation. The bus voltage comparison between traditional and fuzzy droop control is shown in Figure 7.
Since the power supply voltage is not stable at $t = 0$, that is, at the beginning, the bus voltage will fluctuate at the beginning and then rise. In Figure 7, in the change waveform of bus voltage ($U_{bus1}$) under the traditional droop control, the rise time is about 0.16s, the adjustment time is about 0.23s, and the peak value is about 260V. In the bus voltage change waveform ($U_{bus2}$) under fuzzy droop control, the rise time is about 0.16s, the adjustment time is about 0.19s, and the peak value is about 258V. In addition, compared with the traditional sagging control, the fuzzy sagging control has a smaller voltage drop and a shorter bus voltage stabilization time when the load changes at $t = 1s$, and a smaller voltage deviation when the voltage is stabilized.

The current of battery 1, battery 2 and photovoltaic cell in the droop control is shown in Figure 8(a), and the current in the fuzzy droop control is shown in Figure 8(b). Among them, $I_{dc1}$, $I_{dc2}$ and $I_{dc3}$ represent the current of battery 1, battery 2 and photovoltaic cell respectively.

Under traditional droop control, the output current of each converter is not equal because the sum of the line impedance of each output unit and the droop curve coefficient is not equal. Under the fuzzy sagging control, the output current of each converter is evenly divided because of the strong anti-interference of the fuzzy controller.

The output power of battery 1, battery 2 and photovoltaic cells in the droop control is shown in Figure 9(a), and the output power in the fuzzy droop control is shown in Figure 9(b). Where, $P_1$, $P_2$ and $P_3$ represent the power of battery 1, battery 2 and photovoltaic cell respectively.
According to Figure 9(a), output power of each output unit is allocated in a certain proportion under the traditional droop control, which is related to the droop coefficient and line impedance. According to Figure 9(b), under the fuzzy droop control, the output power of each converter is basically evenly divided.

5. Conclusion
In this paper, for the DC microgrid system in island mode, a microgrid model including photovoltaic power generation and battery charging and discharging is built in MATLAB/SIMULINK. In order to maintain the voltage stability and the current sharing of each microsource, a fuzzy PID controller is designed to correct the droop coefficient in real time. The simulation results show that fuzzy PID droop control strategy has the following advantages over the traditional droop control strategy: 1. Anti-interference, high accuracy. 2. Achieve the balance of current and power on each micro source.

Acknowledgments
This work is financially supported by Fundamental Research Funds for the Central Universities of Northwest Minzu University (Grant No.31920190067) and Gansu Provincial First-class Discipline Program of Northwest Minzu University (Grant No.11080305) and Central University Graduate Research Innovation Project of Northwest University for Nationalities (Grant Yxm2021090).

References
[1] Zhixiong Zhong. Tracking Synchronization for DC Microgrid With Multiple-Photovoltaic Arrays: An Even-Based Fuzzy Control Scheme [J]. SPECIAL SECTION ON NEW DEVELOPMENTS ON RELIABLE CONTROL AND FILTERING OF COMPLEX NONLINEAR SYSTEMS, 2018.
[2] Xu Hongjian, Zhao Tao, Zhu Aihua, Ji Ningyi. An improved droop Control Strategy for DC Microgrid [M]. Nanjing Institute of Technology, 2019.
[3] Mahdieh S. Sadabadi, Qobad Shafiee, Alireza Karimi. Plug-and-Play Robust Voltage Control of DC Microgrids [J]. IEEE TRANSACTIONS ON SMART GRID, 2016, 6886-6895.
[4] Yang Zhichun, Liu Kaipei, Le Jian, Wan Zilin, Wang Dongxu, Su Yi. Design of fuzzy PID droop controller in guda operation microgrid [J]. Automation of electric power systems, 2013, 37(12): 19-23+68.
[5] Chen Shuquan, Zhang Zhaoyun, Li Tianli. Research on voltage stability control of dc microgrid based on fuzzy droop control [J]. Electric technology, 2020, 21(08): 40-45.
[6] Zhang Kaitao, Zhang Hui, Zhi Na, Yao Jianshuang. Power electronics technology, 2018, 52(09): 87-88+124.
[7] lei lei yong. Research on improved droop control strategy for dc microgrid [J]. Electric drive, 2019, 49(12): 82-87.
[8] Cao Wei, Qiu Chunfeng, Zhang Tian, Gao Boyu. Self-regulating drooping control of dc microgrid based on ideal current [J]. Journal of hydropower energy science, 2020, 38(03): 204-208.