DC bus voltage control strategy based on hybrid energy storage

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Abstract. In view of the fluctuation of DC bus voltage caused by the load change of power system, a method based on hybrid energy storage system control is proposed to stabilize the bus voltage of microgrid. Based on the complementary characteristics of battery and supercapacitor, the voltage division strategy is adopted to improve the DC bus voltage. The simulation results show that the method can stabilize the voltage of DC bus.

1. Introduction
At present, the application of optical storage DC micro grid is more and more extensive. The DC micro grid with photovoltaic power generation system and hybrid energy storage system as the main body can fully absorb renewable energy and improve efficiency. Due to the volatility and randomness of solar energy resources, photovoltaic micro grid often encounter power quality problems. In order to solve this problem, energy storage system is added to make up for the intermittent photovoltaic output, but a single energy storage unit can not meet the characteristics of high power density and high energy density at the same time. Therefore, hybrid energy storage becomes the research focus. The hybrid energy storage unit composed of battery and super capacitor improves the response speed, regulates the impact of the volatility of renewable energy, improves the energy storage efficiency, reduces the number of cycles of energy storage unit and improves the service life.

According to the characteristics of DC microgrid, there is no problem of phase and frequency in DC microgrid. As long as the bus voltage of DC microgrid is controlled, the power quality of DC microgrid can be improved. Because most of the renewable energy is output in the form of DC, the system is simplified. This paper makes use of the characteristics of super capacitor, such as fast response and high power density, to form a hybrid energy storage system with battery. The battery provides low-frequency power and super capacitor provides high-frequency power. The purpose of maintaining the stability of the system and improving the power quality of DC microgrid is realized.

2. Structure of DC microgrid
The DC microgrid designed in this paper consists of photovoltaic power generation, battery, super capacitor and DC / DC converter.

2.1. Model of photovoltaic power generation system
The optical storage DC micro grid mainly consists of four parts: distributed photovoltaic power generation system, hybrid energy storage system, grid connected inverter and load. It mainly integrates
the power supply, power converter and load through DC bus. Its typical optical storage DC microgrid structure is shown in Figure 1.

![Optical storage DC microgrid structure](image)

**Figure 1.** Optical storage DC microgrid structure

2.2. Topological structure of hybrid energy storage system

The battery and super capacitor are connected to DC bus through bidirectional DC / DC converter respectively. Compared with passive and semi-active connection, this active connection has the advantages of strong controllability, convenient input and output and high system utilization. Both of them jointly maintain the power balance of the system and the stability of the bus voltage. The disturbance observation method is used to control the photovoltaic system to work at the maximum power point, so as to improve the stability and efficiency of photovoltaic power generation.

2.3. Control strategy of hybrid energy storage system

The double closed-loop control is adopted in the design of battery and super capacitor. The basic design idea is: first, the current regulator in current loop is designed, then the current loop is simplified into a link in voltage loop, and together with other links, the control object of external loop voltage regulator is formed. The output of voltage loop is given as current loop, and the current is controlled by voltage.

The traditional frequency division control is to filter the total load power of hybrid energy storage system, decompose it into low-frequency component and high-frequency component, and track the power by battery and super capacitor respectively. Because of the function of the outer voltage loop, the voltage of the DC bus does not change greatly, and the power is the product of the current and the voltage. The sudden increase and decrease of the power will cause the sharp change of the current. Therefore, the reference current output from the voltage loop will be divided into two parts. The high-frequency and low-frequency current components will be used as the reference values of the super capacitor and the battery current inner loop respectively. To realize the compensation and response of super capacitor and battery to high-frequency power and low-frequency power, and to achieve the purpose of reasonable power distribution.

Compared with traditional power frequency division, it does not need to sample the power change of DC bus, but directly filter the reference current. The method is simple and easy to realize. The specific control module block diagram is shown in Fig. 4. \( V_{\text{ref}} \), \( I_{\text{ref}} \) and \( I_{\text{sc\_ref}} \) are DC bus voltage reference value, battery current reference value and super capacitor current reference value respectively; \( V_{\text{bus}} \), \( I_{\text{bat}} \) and \( I_{\text{sc}} \) are DC bus voltage, battery current and super capacitor current respectively.
In the control scheme, the super capacitor and the battery share the same voltage outer ring, and the bus voltage stability is maintained by the joint action of the battery and the super capacitor. As the sampling signal of voltage outer loop, the deviation between DC bus voltage and voltage reference value is adjusted by \( \pi \), and the reference current value \( I_{\text{ref}} \) is obtained. After being filtered by Butterworth low-pass filter, the low-frequency current component is obtained. The difference between DC bus voltage and \( I_{\text{ref}} \), i.e. high-frequency component, is taken as the reference value of super capacitor, forming the current inner loop of super capacitor. \( I_{\text{ref}} \) is directly used as the reference value of battery current inner ring. The deviation between \( I_{\text{ref}} \) and \( I_{\text{SC} - \text{ref}} \) and the actual current value \( I_{\text{BAT}} \) and \( I_{\text{SC}} \) of the battery and super capacitor is adjusted by PI as the input of PWM signal, and then the on-off of IGBT in the converter of each voltage rise and fall circuit is controlled, and finally the reasonable distribution of power among the energy storage elements is realized. Due to the slow response speed of the battery, the high frequency component in the \( I_{\text{ref}} \) has been quickly compensated by the super capacitor, and the remaining low frequency component is responded by the battery. In order to prevent the damage of the battery caused by the excessive discharge current of the battery and the influence of the excessive discharge current of the super capacitor on the stability of the DC bus voltage, the reference current is limited.

![Figure 2. Control block diagram of hybrid energy storage system](image)

### 3. Simulation results and analysis

Through the simulation experiment, the effectiveness of the control strategy of hybrid energy storage system is verified, and the output size and load size of photovoltaic power generation system are adjusted to simulate the power quality problems that DC bus may encounter.

(1) Photovoltaic system:
- In 0-2s, the light radiation intensity is kept at 800W/m\(^2\).
- In 2.5-4s, by cutting off the photovoltaic power generation system, the output of the micro source is 0, and the voltage interruption is simulated.
- In 4-6s, the light intensity rises to 600W/m\(^2\).
(2) Load:
- In 1.4-1.8s, the voltage fluctuation of DC bus is simulated by switching two loads.
- In 5-6s, the voltage sag of DC bus is simulated by cutting in large load.
Among them, VDC Hess and VDC bat are DC bus voltage in hybrid energy storage system and battery energy storage system respectively.

Pload, phase bat and phase SC are load power, battery power in hybrid energy storage and super capacitor power in hybrid energy storage respectively.

In the case of single battery, the fluctuation range of bus voltage is 5-15v in 1.4-1.8s, and 8V in 2S. The peak value of fluctuation is 3V in 4S and 18V in 5S.

In the case of mixed energy storage, the fluctuation amplitude of bus voltage is between 5-10v in 1.4-1.8s, and the peak value is 5V in 2S.

It can be seen that the impact of load change on DC bus is stronger than that of microsource fluctuation.

The energy storage system adopts hybrid energy storage system and single battery energy storage system. The following experimental waveforms are obtained by Matlab / Simulink simulation.

The hybrid energy storage system stabilizes the bus voltage, limits the bus voltage fluctuation within ±10V, and effectively stabilizes the DC bus voltage.

It can be seen from the results that due to the fast response of supercapacitor to the current change, the time for bus voltage and battery current to restore stability is reduced, and the stability of the system is improved. Compared with single battery energy storage system, the current change of battery is more gentle, which delays the deep discharge of battery and prolongs the life of battery.
The initial system is externally connected with 5kW load. Within 1.4-1.8s, the load switching changes and the power changes within 1.5kw-3kw.

At 5S, the load suddenly changes to 7.5kW.

Compared with the single battery energy storage system, the super capacitor responds to the change of high frequency power, and the battery responds slowly to the change of power, which mainly maintains the stable power supply to the load.

When the load power is greater than the photovoltaic output, the battery and photovoltaic system supply power for the load together; when the load power is less than the photovoltaic output, the battery charges to absorb the extra energy; when the photovoltaic output fluctuates or the load changes suddenly, the battery and the supercapacitor discharge at the same time to ensure the smooth power output of the system to the load. However, it can be seen from Figure 5 that the super capacitor will respond to the high-frequency power change faster than the battery.

4. Conclusion

In this paper, the hybrid energy storage system in DC photovoltaic micro grid is studied. A hybrid energy storage control strategy based on the reference current is designed. Through the filtering of reference current, the high and low frequency power can be reasonably and effectively distributed, so that the battery can give full play to the advantages of high energy density, super capacitor can give full play to the advantages of high power density, effectively coordinate the DC bus fluctuation caused by micro source and load fluctuation, and improve the power quality. Compared with the traditional control strategy, the control method is simple and fast, which can ensure the continuous and effective power supply to the load.

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