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Research on Bus Voltage of DC Microgrid Containing Hybrid Energy Storage System

Feiyue Feng[1,*], Changchun Chi[1]

[1]Electrical Engineering, Shanghai DianJi University, Shanghai, China

Abstract. In order to suppress the busbar voltage fluctuations in the DC microgrid, this paper establishes an optical storage DC microgrid system with a hybrid energy storage system to achieve the purpose of stabilizing the DC bus voltage. This system focuses on the component hybrid energy storage unit, and uses the structure of three batteries and supercapacitors (SC) in parallel to improve the stability of the system, while ensuring the frequency division distribution between devices.

1 Introduction

With the over-development of traditional energy sources, the problem of energy shortages has continued to expand on a global scale. Conventional energy sources, such as oil and coal, have limited global reserves. At the same time, the use of these energy sources will bring about a series of environmental pollution problems. The development of new energy or low-carbon energy has become an important solution to alleviate the shortage of resources. For example, water power, wind power, and solar energy, etc. The development and utilization of these new energy sources have little impact on the environment, and they have inexhaustible advantages, and gradually become the direction of energy development and utilization in various countries in the future. The utilization of new energy is mainly converted to electric energy. The distributed generation (DG) [1-2] under current research can make full use of renewable energy such as solar energy and wind energy in different geographical locations. However, DG has problems of intermittent, randomness and volatility. The direct large-scale application of traditional power grids will affect the short-circuit current and voltage of the power grid, bring serious safety hazards, reduce the reliability of the power grid, and restrict the development of DG energy. Therefore, many scholars have put forward the technology of microgrids (Microgrids) on this basis.

Microgrid system refers to a small power distribution system that can realize self-management and control, and can improve the power grid's ability to absorb and reliably utilize distributed energy [3-5]. Photovoltaic (PV) power generation is an important part of DG, and its output characteristics are characterized as DC. Some DC power supply components such as batteries are also widely used in microgrid systems. If the distributed energy module, energy storage module, and load are connected together through a device with DC characteristics, the formed DC microgrid [6] system eliminates the need for inverter links and improves energy transmission efficiency; the control is more convenient and improved It improves the stability of the microgrid system; eliminates certain eddy current loss and reactive power loss, and improves power supply efficiency [7-8]. Due to the advantages of the DC grid, this paper builds a photovoltaic DC microgrid model, which needs to include photovoltaic power generation modules, hybrid energy storage modules, grid-connected modules, etc. The hybrid energy storage module is a parallel structure of SC and three batteries. This system can achieve the requirements of maintaining the stability of the DC bus voltage, ensuring the reasonable distribution of power among hybrid energy storage devices, and improving the power quality of the grid-connected side.

2 Materials and Methods

2.1. System structure and working principle

The structure of the DC microgrid is shown in Figure 1. Among them, DG unit, energy storage unit, DC load and other modules jointly maintain the balance of supply and demand of power at both ends of the power supply and the load. The energy storage unit can absorb or supplement the excess or too little energy on the DC bus. The working principle of the DC microgrid in Figure 1: DG is connected to the bus through an AC/DC converter and a unidirectional DC/DC converter. At the same time, energy flows from the DG end to the DC load and energy storage unit. The energy storage unit is a hybrid type, including battery cells and SC units, and the energy storage unit and system can make energy flow through Boost and bidirectional DC/DC converters.

* Corresponding author: fengfeiyueflyy@163.com

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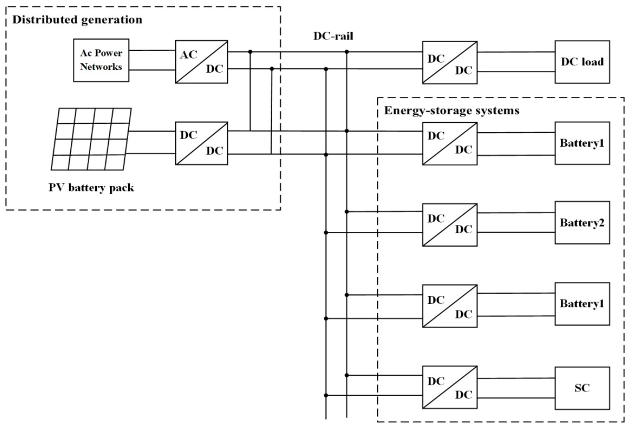

Fig. 1. Basic structure of DC microgrid.

2.2. PV power generation unit

The PV unit converts light energy into electrical energy, and its equivalent circuit diagram is shown in Figure 2.

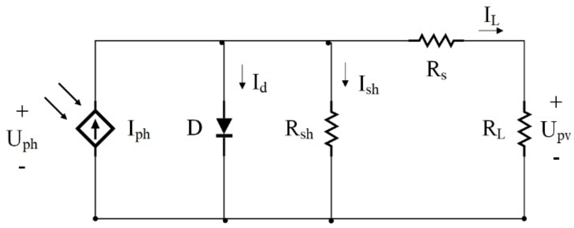

Fig. 2. PV cell equivalent circuit model.

It can be seen from the figure that the PV power generation unit is mainly composed of a light-controlled current source, a diode D, a parallel resistance R_{sh}, a series resistance Rs, and a load resistance RL. Generally, Rs is between 7.7 and 15.3 megohms, and R_{sh} is 150-280 megohms. between.

I_{ph}——The current generated by PV power generation, which can be regarded as a constant current source;

I_d——When PV power generation lacks solar radiation, the dark current that flows through the diode under the action of external voltage;

I_{sh}——current flowing through the parallel resistor;

I_L——PV power generation unit output current;

U_{pv}——The output voltage of the PV generating unit.

When the PV power generation unit works without failure, according to Kirchhoff's law and the above circuit diagram, we get:

$$I_L = I_{ph} - I_d - I_{sh} \tag{1}$$

Among them:

$$I_d = I_{d1}\left\{\exp\left[\frac{q\left(U_{pv}+I_L R_s\right)}{frT}\right]-1\right\} \tag{2}$$

$$I_{sh} = \frac{U_{ph}+I_L R_s}{R_{sh}} \tag{3}$$

Incorporating equations (2) and (3) into equation (1), we get:

$$I_L = I_{ph} - I_{d1}\left\{\exp\left[\frac{q\left(U_{pv}+I_L R_s\right)}{frT}\right]-1\right\} - \frac{U_{pv}+I_L R_s}{R_{sh}} \tag{4}$$

In formula (4):

I_{d1}——Reverse saturation current flowing through diode D;

q——The amount of charge of the PV battery;

f——Diode curve constant;

r——Boltzmann constant (its value is generally 1.38×10^{-23}J/K);

T——Absolute temperature inside the PV cell;

I_{sc}——Short-circuit current under standard conditions.

It can be seen from formula (4) that the size of U_{pv} decreases as R_{sh} decreases. When RL approaches zero, the PV cell is regarded as a short circuit. At this time, IL is basically equal to I_{sc}, and U_{pv} is zero. When the diode is forward-conducting, Rs is much smaller than the equivalent resistance of the diode, and I_{ph} is similar to I_{sc} at this time. In addition, in actual situations, the value of Rs is smaller and the value of R_{sh} is larger, so you can get:

$$\begin{cases} I_{ph} \approx I_{sc} \\ I_L R_s \approx 0 \\ U_{pv}+I_L R_s \approx 0 \\ I_{sh} = \dfrac{U_{pv}+I_L R_s}{R_{sh}} \approx I_{sc} \end{cases} \tag{5}$$

Simplify (4) from formula (5) to:

$$I_L = I_{sc} - I_{d1}\left[\exp\left(\frac{qU_{pv}}{frT}\right)-1\right] \tag{6}$$

Because the value process of some values in formula (6) is more complicated, formula (6) is further simplified as:

$$I_m = I_{sc}\left\{1-C_1\left[\exp\left(\frac{U_m}{C_2 U_{OC}}\right)-1\right]\right\} \tag{7}$$

$$C_1 = \left(1-\frac{I_m}{I_{sc}}\right)\exp\frac{-U_m}{C_2 U_{oc}} \tag{8}$$

$$C_2 = \left(\frac{U_m}{U_{oc}}-1\right)\left[\ln\left(1-\frac{I_m}{I_{sc}}\right)\right]^{-1} \tag{9}$$

Among them:

Under normal circumstances, $\exp\frac{U_m}{C_2 U_{oc}}$? 1.

I_m——Under standard conditions, the voltage corresponding to the maximum power;

U_m——The current corresponding to the maximum power under standard conditions;

U_{oc}——open circuit voltage under standard conditions.

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2.3. Hybrid energy storage unit

2.3.1. Battery unit

At present, there are many battery models. This article selects Thevenin equivalent circuit model for research, as shown in Figure 3.

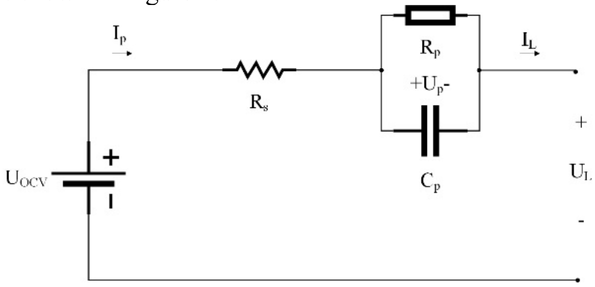


Fig. 3. Thevenin equivalent circuit model.

At present, there are many battery models. This article selects Thevenin equivalent circuit model for research, as shown in Figure 3.

Assuming that the battery voltage is a constant value, according to Kirchhoff's law and the above circuit diagram, we get:

$$U_L = U_{ocv} - U_p - I_L R_s \tag{10}$$

Suppose the battery power is P_L, then:

$$I_p = \frac{U_{ocv} - U_p - \sqrt{\left(U_{ocv} - U_p\right)^2 - 4P_L R_s}}{2R_s} \tag{11}$$

In formula (10)-(11):

U_{OCV}——battery open circuit voltage;
Ip——battery open circuit current;
R_S——ohmic resistance;
U_P, R_P, C_P——parallel RC network;
U_L——battery terminal voltage;
I_L——battery terminal current.

2.3.2. SC unit

Figure 4 shows the SC series RC model.

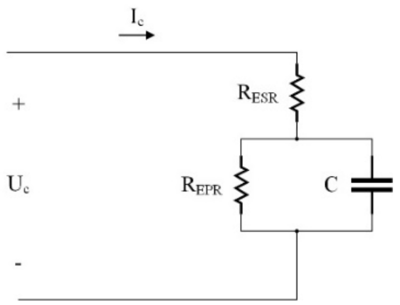


Fig. 4. Thevenin equivalent circuit model.

Through the analysis, the mathematical relationship of the SC series RC model can be obtained as:

$$U_c = I_c R_{ESR} + \frac{1}{c}\int I_c dt \tag{12}$$

In formula (12):

U_c——SC open circuit voltage;
I_c——SC open circuit current;
R_{ESR}——Ohmic resistance.

3 Results & Discussion

In order to verify the established DC microgrid system with hybrid energy storage system, a DC microgrid simulation test model was built in Matlab/Simulink. The structure diagram of the hybrid energy storage system is shown in Figure 5.

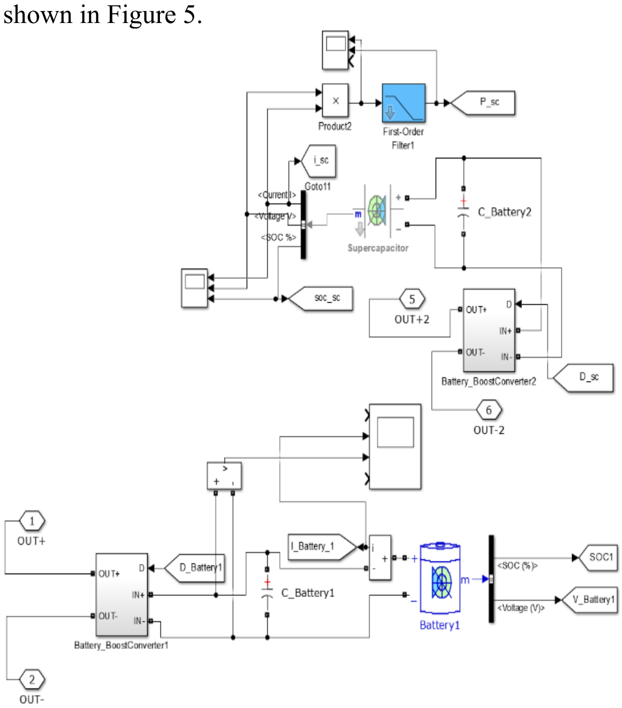
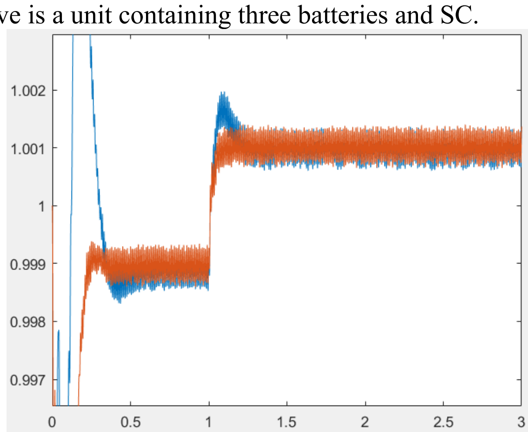
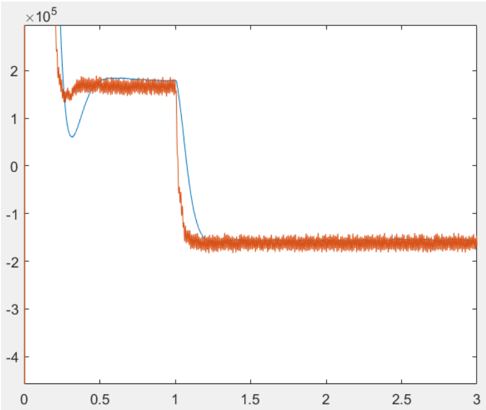


Fig. 5. Structure diagram of hybrid energy storage unit.

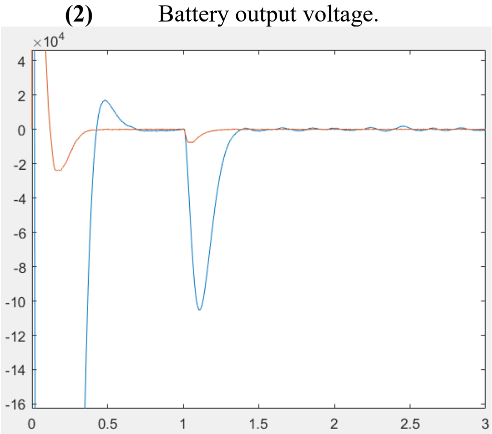
In the simulation, the reference value of the DC bus voltage is set to 10kV; the rated terminal voltage of the battery is 4kV, the battery capacity is set to 52Ah, and kp is 9, and ki is 300 in the battery current loop PI control parameters. Figure 6 shows the simulation results of a DC microgrid with a hybrid energy storage system. Among them, the blue curve is a hybrid energy storage unit containing a single battery and SC, and the red curve is a unit containing three batteries and SC.



(1) DC bus voltage.



(2) Battery output voltage.



(3) SC output voltage

Fig. 6. Simulation results of DC microgrid with hybrid energy storage system.

As can be obtained from Figure 6, the system begins to adjust the DC bus voltage when the simulation starts. When t=0~0.25s, PV power generation is insufficient and unstable, and the energy storage system outputs current to fill a certain energy deficiency; when t=0.25~1, PV power generation gradually stabilizes, and the DC bus voltage reaches the normal working voltage. When t=1~3s, the PV power generation rises, and the DC bus voltage rises accordingly. It can be seen from Figure 6(2) that the output voltage of the energy storage unit at this time is negative, which means that the energy storage unit is in a charging state and absorbs excess energy. On the whole, the blue curve fluctuates greatly, and the red curve is much more stable than the blue curve. Therefore, the establishment of a hybrid energy storage system can indeed improve the stability of the DC bus voltage while ensuring a reasonable distribution of the power of the regulation system.

4 Conclusions

In this paper, by establishing a DC microgrid system containing hybrid energy storage units, this system has the advantages of both battery and SC, and has made a good improvement to the instability problem in the DC microgrid:

- Improve the stability of the DC bus voltage;
- Improved the stability of battery terminal voltage and SC terminal voltage;
- Better play to the advantages of SC.

This paper verifies the effectiveness of the hybrid energy storage system and provides a new method for suppressing the fluctuations in the DC microgrid and stabilizing the DC bus voltage.

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