A REVIEW ON STABILITY IMPROOVEMENT WITH CONTROL STRATEGY OF DC MICROGRID WITH HYBRID ENERGY

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ABSTRACT

As the fossil energy crisis and environmental pollution become more and more serious, clean renewable energy becomes the inevitable choice of energy structure adjustment. The power system planning and operation has been greatly influenced by the instability of the power output of distributed renewable energy systems such as solar energy and wind energy. The hybrid energy storage system composed of accumulator and supercapacitor can solve the above problems. Based on the analysis of the energy storage requirements for the stable operation of the DC microgrid, battery–supercapacitor cascade approach is adopted to form hybrid energy storage system, in a single hybrid energy storage subsystem for battery and supercapacitor and in the microgrid system of different hybrid energy storage subsystem, respectively, and puts forward the corresponding power allocation method to realize the smooth control of the battery current, to reduce the battery charge and discharge times, to prolong the service life of battery and to improve the running stability of the microgrid.

1 INTRODUCTION

Compared with AC microgrid, DC microgrid has the following advantages: (i) It provides a more efficiently supply of DC loads and reduce losses due to the reduction of multiple converters used for DC loads. (ii) It can easily integrate DC distributed energy resources. (iii) It eliminates the need for synchronising generators. (iv) Also there is no need to consider the problem of frequency and phase in DC microgrid [1, 2]. Therefore, DC microgrid has become a research focus. However, due to the unpredictability and intermittency of wind power generation and photovoltaic power generation, the stability of the DC microgrid is reduced, so how to eliminate the fluctuation of output power of the distributed generation system become the key of DC microgrid [3]. Batteries have high energy density, which are energy-type energy store (ES) device. The continuous charging and discharging time level of battery is minutes to hours, so it is not suitable for frequently charging and discharging. Batteries are appropriate to serve as the power support of the system and provide main and stable power of the system. On the contrary, ultracapacitors have large power density, but their capacities are relatively small, which are power-type ES device. The continuous charging and discharging time level of ultracapacitors is seconds to minutes, which can charge and discharge relatively frequently, and are suitable for responding to the high-frequency power fluctuation [4– 6]. Therefore, battery-ultracapacitor hybrid energy storage system (HESS) will effectively suppress the fluctuations of the distributed power system and improve the power quality [5]. Compared with the one type of ES system (e.g. only having batteries), HESS can increase the life span of the batteries [6]. Many topologies of battery-ultracapacitor HESS have been proposed in [7–8]. In addition, control strategies of ES system in DC microgrid mainly include the following. In [9], a control method is proposed that different state and characteristics of batteries are taken into account, but a central controller may be required that will reduce the stability of the system. A method that keeps the SoC balance for the ES units based on droop control is proposed in [10]. However, it did not realise the ES system responses to power fluctuations based on frequency. Multi-agent control strategies to coordinate power sharing between heterogeneous ES devices distributed throughout a DC microgrid is proposed in [11]. In this paper, a novel distributed control method of HESS is proposed and designed. In this control method, low-frequency power fluctuations are assigned to battery, while high-frequency power fluctuations are allocated to ultracapacitors. Moreover, to protect the ultracapacitors, the SoC among ultracapacitors can be balanced and stabilised.

2 THE BASIC STRUCTURE AND WORKING PRINCIPLE OF MICROGRID

2.1 The improved hybrid energy storage system topology

This paper uses active cascade connection of battery–supercapacitor hybrid energy storage system to form the hybrid energy storage system topology, as shown in Figure 1, battery after DC– DC2 converter connected to the supercapacitor, a hybrid energy storage system, and then through DC–DC1 converter connected to the DC bus, because the supercapacitor is a power-type energy storage device, so it can provide relatively high power in a short period of time, this article will supercapacitor by DC–DC1 converter connected to the DC bus, through supercapacitors charge– discharge balance the high-frequency part of the DC bus power fluctuations, stable busbar voltage. Through the corresponding control strategy, the power input and output of the battery and the supercapacitor can be accurately controlled. As an energytype energy storage element, the battery mainly undertakes the low-frequency part of the fluctuating power in the microgrid, which can improve the steady-state performance of the microgrid. The two bi-directional DC/DC converters of this structure are

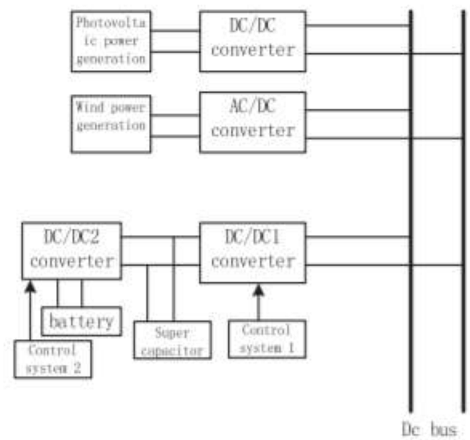

Figure 1. The improved hybrid energy storage system topology.

controlled separately, which have a strong flexibility and make the charge and discharge control of the battery and the supercapacitor more efficient, and can reduce the number of charge and discharge of the battery and improve the service life of the battery.

2.2 DC microgrid system working principle and the system structure of the improved hybrid energy storage system topology

As shown in Figure 2 for typical scenery complementary DC microgrid simplification structure. Main parts are DC bus, wind power generation unit, photovoltaic cell, hybrid energy storage system and the load. In this system, all units are directly connected to the DC bus through converter. Photovoltaic array and wind turbines are connected to the DC bus through the converter, in order to use wind and solar power better and to generally control its operation in the maximum power point. Hybrid energy storage system composed of multiple subsystems in parallel.

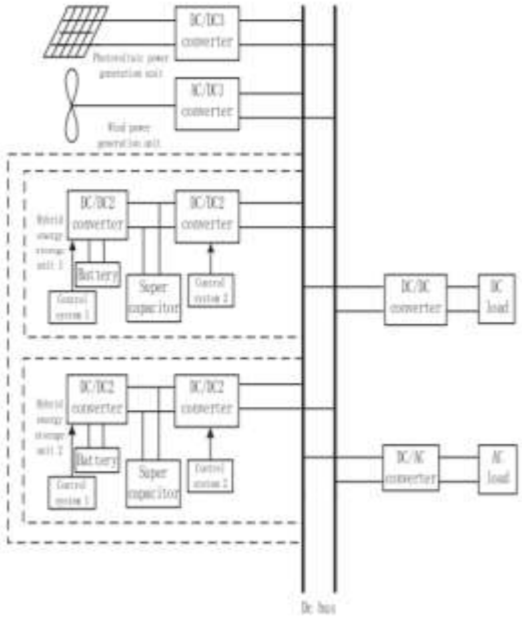

Figure 2. Simplified DC microgrid system structure

This article will battery via bi-directional DC–DC2 converter connected to the supercapacitor hybrid energy storage system, after the bi-directional DC–DC1 converter is connected to a DC bus. In an island mode, the stable operation of the microgrid is guaranteed by the hybrid energy storage system. When the power of microgrid of the power generation section provided is greater than the load demand, the extra power is absorbed by a hybrid energy storage system. On the contrary, hybrid energy storage system absorbs surplus power. As the supercapacitor is a powertype energy storage component, it can provide a higher power instantly, so the supercapacitor is connected to the DC bus by the bi-directional DC/DC converter 1 and fluctuations in the high-frequency part of DC bus power is balanced by charge and discharge of the supercapacitor. However, the response to lowfrequency power fluctuations will lead to the lack of capacity of the supercapacitor, so it cannot compensate for bus power fluctuations. Therefore, the battery is added for energy storage, and the charge and discharge of the battery are controlled according to the voltage of the supercapacitor in order to keep the supercapacitor voltage in normal working range, so the supercapacitor can indirectly compensates DC bus power fluctuations of the low-frequency part. At the same time, when the distributed power generation unit cannot provide power (such as a short period of time, there is no wind or solar energy), the power required for the load is provided by hybrid energy storage system alone to maintain the stability of the microgrid.

3 DESIGN OF THE DISTRIBUTED CONTROL SYSTEM

The overall system control diagram is shown in Fig. 4, in which the bandwidth of the DC bus control loop is 10 Hz, and the bandwidth of the ultracapacitor group SoC control loop is 0.04 Hz. Considering that the bandwidth of the DC bus control loop is much larger than the ultracapacitor group SoC control loop and ultracapacitors SoC equalising control loop, the effects of the other two control loops can be ignored when designing the DC bus voltage control loop. Ultracapacitors SoC equalising control loop is ignored when designing the ultracapacitor group SoC control loop. When designing ultracapacitors SoC equalising control loop, the influence of the other two loops should be considered. Therefore, it is reasonable to design the regulator of the DC bus voltage control loop first, then design the ultracapacitor group SoC control loop, and finally design the ultracapacitors SoC equalising control loop.

3.1 Design of the DC bus voltage control loop

Considering the charging and discharging characteristics of ultracapacitors, the bandwidth of the DC bus voltage control loop is set to 10 Hz. The control block diagram of the DC bus voltage control is shown in Fig. 5. The influence of ultracapacitors SoC equalising control loop to the DC bus voltage control loop can be calculated by

$$i_{uc}(s)H_i(s) + i_{uc}(s)G_{uc}(s)H_{vuc}(s)G_M(s) \simeq i_{uc}(s)H_i(s) \quad (1)$$

The influence of ultracapacitors SoC equalising control loop can be ignored in the vicinity of bus voltage loop with the cross-over frequency about 10 Hz. In (1), iuc(s) is the current of the ultracapacitor, Hi (s) is sampling coefficient of the current of the ultracapacitor, Hvuc(s) is the sampling coefficient of ultracapacitor voltage, GM(s) is regulator of ultracapacitors SoC equalising control loop, and Guc(s), as shown in (4), is the frequency-domain expression of the ultracapacitor current to its SoC and can be derived from (2) and (3)

$$\mathrm{SoC}(0) - \frac{\int i_{uc}(t)\mathrm{d}t}{Q} = \mathrm{SoC}(t) \quad (2)$$

$$Q = CU \quad (3)$$

$$G_{uc}(s) = \frac{\mathrm{SoC}(s)}{i_{uc}(s)} = -\frac{1}{sQ} \quad (4)$$

CONCLUSION

A distributed control strategy of HESS for the DC microgrid is proposed and designed in this paper. By setting the control bandwidth of the three control loops, it realises that ultracapacitors respond to high-frequency fluctuations and the battery responds to low-frequency fluctuations, which extends the life span of the batteries. The battery is used as bulk ES, which provides main and stable power supply of the system. And ultracapacitors are equivalent to low-pass filters, which filter the high-frequency power fluctuations. By controlling the equilibrium and stability of the SoC of ultracapacitors, the balance and stability of ultracapacitors' voltage are achieved indirectly, so that the ultracapacitors' states are stable or basically the same, which increases the stability of the system.

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