Battery State of Charge Balancing Based on Low Bandwidth Communication in DC Microgrid

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Abstract

This paper presents a load sharing method based on the low bandwidth communication (LBC) applied to a DC microgrid in order to balance the state of charge (SOC) of the battery units connected in parallel to the common bus. In this method, SOC of each battery unit is transferred to each other through LBC to calculate average SOC value. After that, droop coefficients of battery units are adjusted according to the difference between SOC of each unit and average SOC value of all batteries in the system. The proposed method can effectively balance the SOC of battery units in charging and discharging duration with a simple low bandwidth communication system.

Key words – State of charge (SOC); DC microgrid; low bandwidth communication (LBC).

1. Introduction

In recent years, DC microgrids have become a promising and efficient solution to integrate intermittent renewable energy sources, energy storage devices and loads. In these systems, energy storage devices play an important role to balance power and energy, and to enhance system stability. Among the energy storage technologies, the battery receives much attention because of high efficiency, high energy density and independence on the geographical condition. In actual operation, multi-battery units are installed and generally operate in parallel to ensure power sharing as well as distribution requirements. However, battery units may have different state of charge (SOC) during their operations with different amount of stored energy. In order to guarantee a stable battery operation, the SOC of the different battery units should be equalized, which means that the unit with a higher SOC discharge more amount of energy than those with lower SOCs, and vice versa.

There are many studies about the battery SOC control. In [1] and [2], a distributed droop control method based on the SOC was proposed, which used the droop coefficient inversely proportional to the SOC^n. However, it is very hard to select properly the coefficient n to reach quickly the desired SOC value and satisfy the stability requirement. Another strategy to implement the secondary level control was applied in [3] to balance the SOC of the battery units used in the residential building DC microgrid. In this method, the authors try to multiply the droop coefficient of battery unit with an exponential function of ΔSOC which means the difference between SOC of each unit and average SOC value of all units, and the difference between the output currents of each unit is minimized. However, the SOC balance compensation is only actuated when the imbalance degree is out of a certain limit. Therefore, during operation, the SOCs of batteries are not totally equalized in some extent.

In order to remove these problems, we propose a SOC balancing method based on the low band width communication (LBC). The proposed method is efficient and easy to be applied to the distributed battery units in DC microgrid.

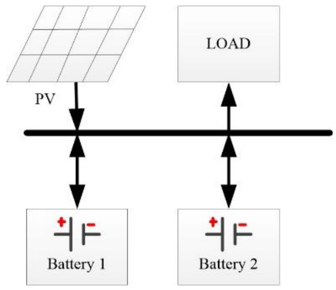

Fig. 1. Configuration of DC microgrid

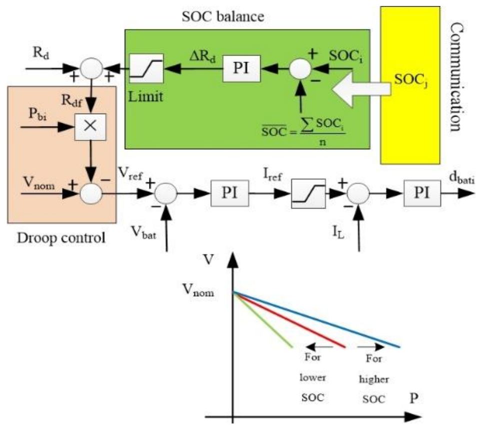

Fig. 2. Proposed control strategy

2. Proposed control strategy

For simple analysis, let us consider a simple DC microgrid in Fig. 1 including two battery units, a PV source and a load. In this system, the PV source operates according to MPPT algorithm to extract maximum power from the solar irradiation, and it is regarded as a constant power source. Meanwhile, the battery units are connected with a common bus via bidirectional buck-boost converters and operated by the voltage droop control to regulate DC bus voltage.

The SOC of each battery unit is estimated through the basic Coulomb counting method in (*1*).

$$SOC = SOC(0) - \frac{1}{C}\int I dt$$
$$SOC = SOC(0) - \frac{1}{C.V_{bat}}\int P_{bat} dt \qquad (1)$$

where SOC(0) is the initial SOC of battery unit, C is rated capacity, I is the output current of battery, P_{bat} is battery power, and V_{bat} is output of DC-DC converter connected to the battery.

In order to balance the SOC of battery units, an improved droop control method based on the LBC is proposed in this paper. The overall control scheme is shown in Fig. 2. It can be seen that the LBC system is applied to transmit each battery SOC. And, the average SOC is calculated and compared with the SOC value of each battery unit and applied to the PI controller to generate the adjusted droop coefficient in the local control systems. By using the droop control, power sharing according to the SOC is achieved by regulating the droop coefficient as shown in (2):

$$V_{refi} = V_{nom} - (R_{di} + \Delta R_i)\, P_{bati} \quad (2)$$

where V_{refi} is the reference output voltage of DC-DC converter connected to the *i-th* battery; V_{nom} is the nominal voltage of DC microgrid; R_{di} is the droop coefficient of the conventional droop control loop, ΔR_i is the adjusted droop coefficient, and P_{bati} is the output power of the *i-th* battery.

Fig. 2 shows how to regulate the droop coefficient in the discharging period. As can be seen in Fig. 2, the droop coefficient of the lower SOC battery is adjusted to share the lower discharging power. On the other hand, the droop coefficient of higher SOC battery is regulated to share higher discharging power. In case of charging period, the procedure is similar as discharging period. Eventually, the proposed control method assures that the battery units having higher SOC discharges more amount of power than those having lower SOC in discharging period, and vice versa in charging period. Consequently, the SOC of battery units can be equalized.

3. Simulation results

The parameters used in simulation are shown in Table 1.

In order to evaluate the effectiveness of the proposed method, the discharging and charging period are taken into consideration. In case of discharging period, if the output power of PV source is lower than the load power, two batteries have to discharge to compensate the power mismatch between the load and the PV source. In this case, the initial SOC of two battery units are assumed to be 80% and 70%. On the other hand, during charging period, the PV source injects higher power than the load power, and the batteries have to absorb surplus power to balance power in microgrid. In this instance, the initial SOC of two battery units are assumed to be 60% and 50%. The simulation results for two cases are shown in Fig. 3 and 4, respectively. As can be seen from Fig. 3, the battery unit that has higher SOC (initially 80%) tends to discharge more amount of power than the other one. After the SOC is equalized, two battery units share the same discharging power at around 200W. Similar to discharging period, Fig.4 shows the simulation results to charge more amount of power than the other one in charging period with the battery unit that has lower SOC (initially 50%). When the SOC is balanced, two battery units share the same charging power at around 200W.

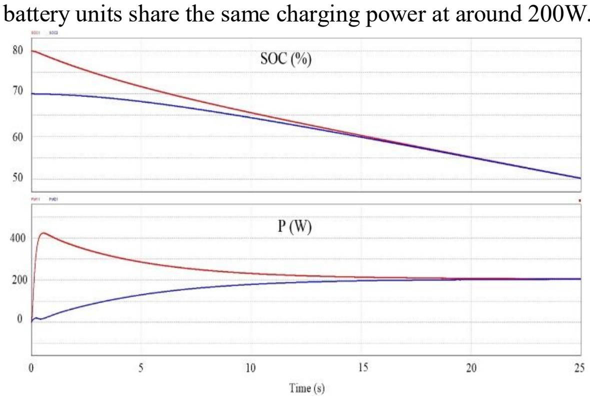

Fig. 3. SOC and output power of batteries during discharging

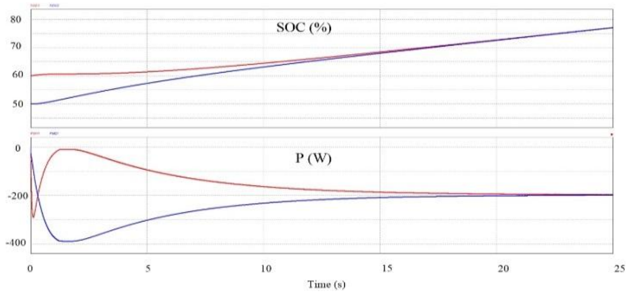

Fig.4. SOC and output power of batteries during charging

Table 1. System parameters

Load	20Ω
Rated bus voltage	100V±10%
Battery rated power	500W
Battery rated capacity	0.1Ah
Communication	200Hz
Switching frequency	10kHz

4. Conclusion

In this paper, a droop control strategy based on the LBC is proposed to share the power between the parallel battery units with different SOC levels in a DC microgrid. In the prosed control method, only LBC is used to transmit the information, so, the communication burden is reduced. Additionally, in terms of the droop control, the proposed control method regulates the droop coefficient of each battery unit to adjust the power sharing in charging and discharging period according to each battery SOC level; the battery with higher energy should provide higher discharging power. Inversely, the battery with the lower energy should be charged with higher power. The simulation is carried out to investigate the performance of the proposed control method, and it is verified that the control strategy has each SOC balanced effectively.

Acknowledgment

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