A Seamless Control Method for Supercapacitor to Compensate Pulse Load Transients in DC Microgrid

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ABSTRACT

This paper proposed a new control method for supercapacitor (SC) to compensate the pulse load transient and enhance the power quality of dc microgrid. By coordinating the operation frequency, the supercapacitor is controlled to handle the surge current component while the low-frequency current component is dealt with by remaining sources in the system. Based on the state of charge and dc bus voltage level, the SC unit operation mode is automatically decided. Meanwhile, the dc bus voltage level indicates the power demand of the whole system; by regulating the dc bus voltage, the mismatch of power demand is covered by SC unit. The effectiveness of proposed method is verified by experiment prototype formed by two distributed generation and one supercapacitor unit.

Keywords— Supercapacitors, ultracapacitor, pulse load, transient, dc microgrid

1. Introduction

The increasing of microgrids (MGs) recent years is the needle to achieve the better integration of various distributed renewable sources (RES) such as photovoltaic, wind turbine [1]. These are two types of MGs: DC MGs and AC MGs. AC MGs developed in the past due to the existent of ac distributed grid. However, most RES and storage system are inherently DC. Therefore, DC MGs are a better choice for integrating RES and storage system.

Fig. 1 illustrates the typical configuration of a DC MG, composed of different RES and energy storage system (ESS). Each unit is connected to a common dc bus via a DC-DC converter or AC-DC converter. ESS plays an importance role in DC MGs since the supporting in high-power transient, dispatching the fluctuation power of RES. For instance, the pulse current will cause a significant increase in the operation temperature of Li-ion batteries, which would lower the system efficiency and shorten the lifetime of battery [2]. Furthermore, fast load transient and low-frequency current ripples shorten the lifetime of the fuel cell and affect its long-term performance [3]. Supercapacitor (SC), which has medium power density, becomes the surge current compensator in DC microgrids due to its ability to supply surge current and long lifetime.

In this paper, we proposed a seamless control method that smoothly changes the operation mode and precisely controls the SC unit to compensate the load transient together with pulse load current. The calculation of design the system is carried out. The effectiveness of the proposed method is proved with a dc microgrid prototype.

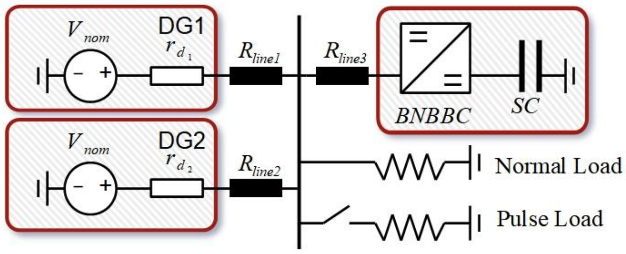

Fig. 1. Typical DC microgrid consists Super-capacitor

2. System Configuration

The considered system in this paper is shown in Fig. 1. Sources and loads are connected to a common dc bus. The SC unit will compensate the current mismatch between DGs output currents (i_{DG1} and i_{DG2}) and load current i_{load} to regulate the dc bus voltage. The SC is connected to the dc bus via Bidirectional Noninverting Buck-Boost Converter (BNBBC). The current relationship is

$$\begin{cases} i_{SC} = i_{load} - i_{DG1} - i_{DG2} \\ i_{load} = i_{ln} + i_{lp} \end{cases} \quad (1)$$

where i_{ln} and i_{lp} are normal load and pulse load currents. The DG is controlled by droop and its output voltage is expressed as

$$v_{out_i} = V_{nom} - r_{d_i} i_{out_i} \quad (2)$$

where V_{nom} is nominal voltage; v_{out_i} and i_{out_i} are output voltage and current of DG's converter. The droop coefficient or virtual resistance r_{d_i} is determined by DG rated current $i_{DG_{max}}$ and minimum allowable bus voltage V_{min}:

$$r_{d_i} = \frac{(V_{nom} - V_{min})}{i_{DG_{max}}} \quad (3)$$

Then, a DG can be modeled as a constant source V_{nom} connect serial with a resistant r_d.

In general, the DG output currents are limited by their rated power. Therefore, when a pulse load is connected to the system, the DG cannot supply current which should be compensated by SC.

3. Proposed Control Method

The cooperation of DGs and SC unit in DCMG is ensured by the dc bus voltage level. The DG converter is

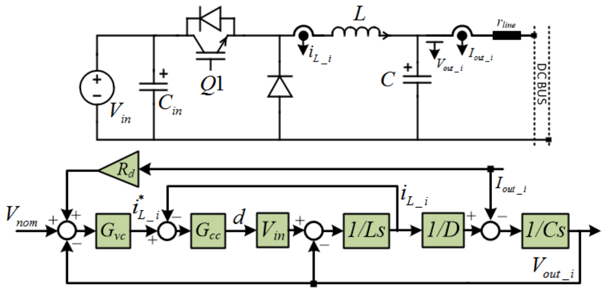

Fig. 2. Control diagram of DG converter with droop control.

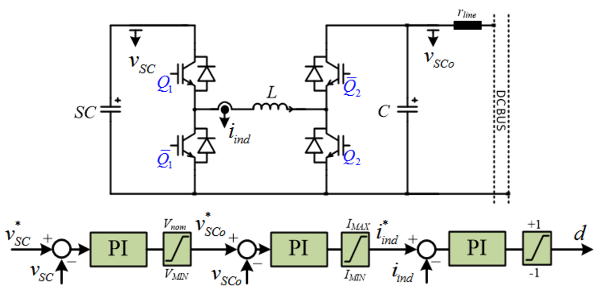

Fig. 3: Control diagram of Super-capacitor's converter.

designed so that its cut-off frequency of internal controller is low. Hence, the high-frequency current component is handled by SC unit converter. Dc bus voltage is used as a signal to coordinate the operation of SC and DGs. The SC will regulate the dc bus voltage to reduce the variation when loads change. By following the dc bus voltage, DGs will supply the power to the loads and regulate the SC voltage.

3.1. Droop control for DGs

The conventional droop controller is used to control the DG converter as shown in Fig. 2. The output voltage of droop control can be expressed as

$$V^*_{out_i} = V_{nom} - I_{out_i} r_{d_i} \qquad (4)$$

where r_{d_i} and V_{out_i} are the virtual impedance of droop control and output voltage of ith DG, V_{nom} is system nominal voltage. The DC bus level is used as a signal to share the load power between DGs. Therefore, it can be used to share the DG power and cooperate with SC unit. DG converter is implemented by a Buck converter with an inner controller as shown in Fig. 2.

3.2. Controller for Supercapacitor

The SC unit converter is implemented by a bidirectional non-inverting buck-boost converter (BNBBC) which controlled by dual-carrier modulator [4]. The proposed controller is shown in Fig. 3. There are three control loop: current loop, voltage loop, and SC voltage loop.

The SC voltage control loop regulates and keeps the SC voltage v_{SC} close to the deserved voltage. The output of this control loop is the output voltage reference v^*_{SCo} which can seem as dc bus voltage. Then, the output voltage of SC converter is controlled by a double loop voltage-current controller.

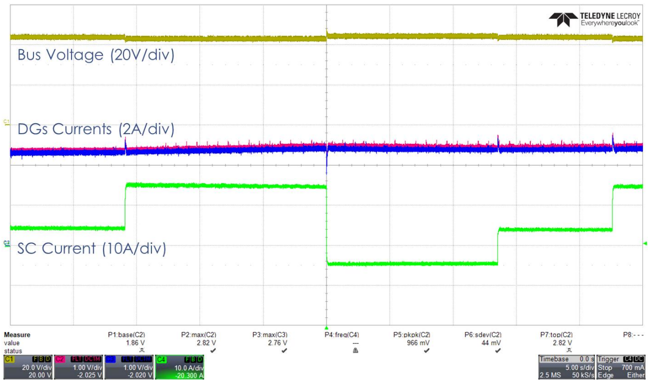

Fig. 4. Control diagram of DG converter with droop control.

4. Experimental Results

Two DGs is controlled by droop controller to share the load current while the SC is controlled to compensate the pulse load current and stabilize the DC bus voltage. The pulse loads sequentially connect to the dc bus. The experimental result is shown in Fig. 4. As shown in Fig. 4, the output current of DG1 and DG2 are constant at 5A regardless of the changes of pulse loads. DG1 and DG2 keep supply the current at rating power while SC unit handles the peak current of pulse load. The dc bus voltage is constantly regulated while the load changes and SC unit is in charge and discharge mode.

5. Conclusions

In this paper, a seamless control method is proposed to compensate the surge current caused by pulse loads by using the SC in dc microgrid. The coordinate frequency technical is used to incorporate DGs and SC unit. Based on the SC state of charge and available power of the dc microgrid, the operation mode of SC is controlled seamlessly. By using SC unit as a compensator, the system stability is significantly increased. The design procedure is presented. The experimental results show the effectiveness of the proposed method.

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