Distributed Secondary Control of DCMG for DC−link Voltage Restoration Considering System Price

Hieu Xuan Nguyen, Kyeong−Hwa Kim*
Dept. of Electrical and Information Eng., Seoul National University of Science and Technology

ABSTRACT

In this paper, a distributed secondary control is introduced to obtain the power balance and regulate the DC−link voltage in a DC microgrid (DCMG). An adaptive droop method is deployed in primary control to manage the power flow while the DC−link voltage is regulated by secondary control. Moreover, this paper proposes an optimal communication line topology not only to minimize the system price but also to reduce the communicational burden significantly. The simulation results are presented to verify the advantages of the proposed method under various conditions.

1. Introduction

In recent years, renewable energy sources (RES) have been considered as a superior replacement for fossil fuel because of their capacity to solve energy shortages and reduce greenhouse gas emissions [1]. The RES such as wind power, solar power along with energy store systems (ESS), utility grid, and local loads leads to the formation of microgrid systems.

Based on the common voltage bus, the microgrid can be classified as DC microgrid (DCMG) and AC microgrid (ACMG). Compared to ACMG, DCMG receives more attention because DCMG system not only removes redundant power conversion but also avoids control issues such as frequency, phase imbalance, and reactive power.

According to coordinated control, the microgrid is separated into centralized control, decentralized control, and distributed control. In centralized control, the central controller (CC) collects the data from each agent, processes and sends feedback command through digital communication links (DCLs) to manage the power flow and regulate the DC−link voltage. However, this scheme confronts many drawbacks related to single point of failure, flexibility, and scalability. Meanwhile, the decentralized strategy provides high flexibility and scalability because of the absence of CC and DCLs. However, it is difficult to obtain optimal power flow management due to the lack of exchange information among power agents. The distributed control is an alternative that combines the advantages and limits the disadvantages of the two above schemes.

Normally, the distributed control maintains the power balance and DC−link voltage regulation by the information exchanged between neighbor agents and droop method. However, the implementation of DCLs between each agent could cause the computational burden and increase the total system price.

In this paper, a distributed secondary control based on adaptive $V-P$ droop curves is proposed to achieve the system stability under various working conditions. The droop curve is changed due to the state of battery agent to enhance the efficiency of battery operation. In addition, the DCLs are minimized to reduce the system price and upgrade the system flexibility. Several simulations are conducted to demonstrate the performance of the proposed control scheme.

2. Proposed Control Scheme

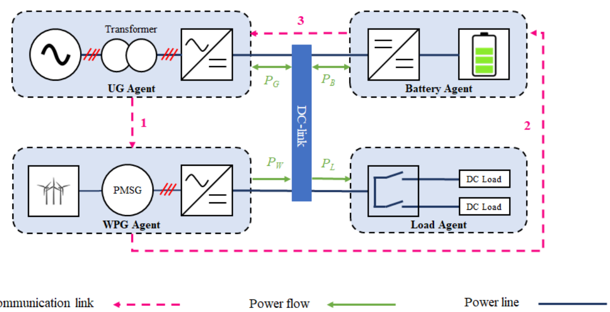

Fig. 1 Configuration of the proposed distributed DCMG.

Fig. 1 shows the configuration of the proposed DCMG which includes four agents: utility grid (UG), wind power generation (WPG), battery, and local load. The system communication is simplified by only three unidirectional DCLs between UG, WPG, and local load. Fig. 2 shows the overall block diagram for the proposed control scheme. In the proposed scheme, the secondary control is employed for voltage restoration as follows:

$$u_i = \frac{-K_i\left(\delta_i^V + \delta_i^u\right)}{s} \quad (1)$$

where K_i is the integral gain, $\delta_i^V = V_{DC}^{nom} - V_{DC,j}$ is the difference between the nominal DC−link voltage V_{DC}^{nom} and feedback DC−link voltage $V_{DC,j}$, and $\delta_i^u = u_i - u_j$ is the error between the secondary control output of agent i, u_i and the secondary control output of agent j, u_j that is sent via DCLs.

Secondary control is introduced to guarantee the DC−link voltage tracks to the nominal value while the system power

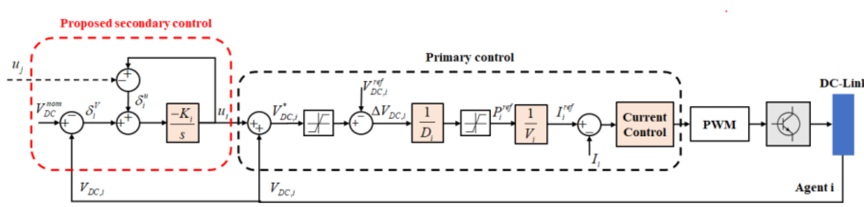

Fig. 2 Overall block diagram for the proposed control scheme.

balance is attained by adaptive $V-P$ droop control. The droop curves of each power agent are presented in Fig. 3. As can be seen, the droop curves are constructed by the high voltage value $V_{DC,i}^{*,H}$, the low voltage value $V_{DC,i}^{*,L}$, the maximum absorbed power $P_i^{A,\max}$, and the maximum surplus power $P_i^{S,\max}$ of each agent. From these values, the droop gain is calculed as follows:

$$D_i = \frac{\Delta V_{DC,i}}{\Delta P_i} = \frac{V_{DC,i}^{*,H} - V_{DC,i}^{*,L}}{P_i^{A,\max} - P_i^{S,\max}}. \qquad (2)$$

When the battery state of charge (SOC) is high, its droop curve is placed at Ⅰ to utilize the battery power. On the other hand, when the SOC is low, the droop curve is moved to Ⅱ to charge the battery agent optimally.

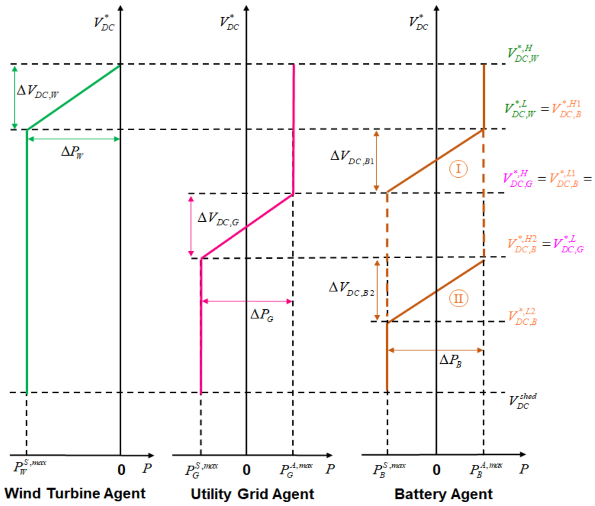

Fig. 3 *V-P* droop curves for distributed power management.

3. Simulation Results

To ensure the reliability of the proposed control scheme, several simulations are executed with PSIM software. Fig. 4 depicts the proposed DCMG system responses under various conditions. As can be seen in Fig. 4(a), the grid is connected to the DCMG at the starting instant and absorbs extra power supplied by the battery and wind power. At $t = 0.7$s, the power produced by WPG agent suddenly decreases, so the utility grid changes the operation to converter mode to compensate the deficit power. Then, as the battery SOC reaches 50% at $t = 2.2$s, the battery droop curve is adaptively changed to Ⅱ, which makes the battery operation is changed to charging mode, the grid supply power also rises immediately to keep the system stability.

Next, the grid is disconnected and the DCMG system switches to islanded mode at $t = 4$s as shown in Fig. 4(b). Consequently, the battery shifts to discharging mode to increase supply power to DC−link. However, despite that battery supplies power in $P_B^{S,\max}$, V_{DC}^* still decreases, which means that the sum of the power from battery and WPG is not enough to satisfy the load demand. Subsequently, V_{DC}^* reduces below the level of V_{DC}^{shed}, which triggers the load shedding process. As a result, V_{DC}^* increases, which indicates that the sum power of battery and WPG is more than the load demand. Then, the output power of battery declines until V_{DC}^* remains constant at nominal value.

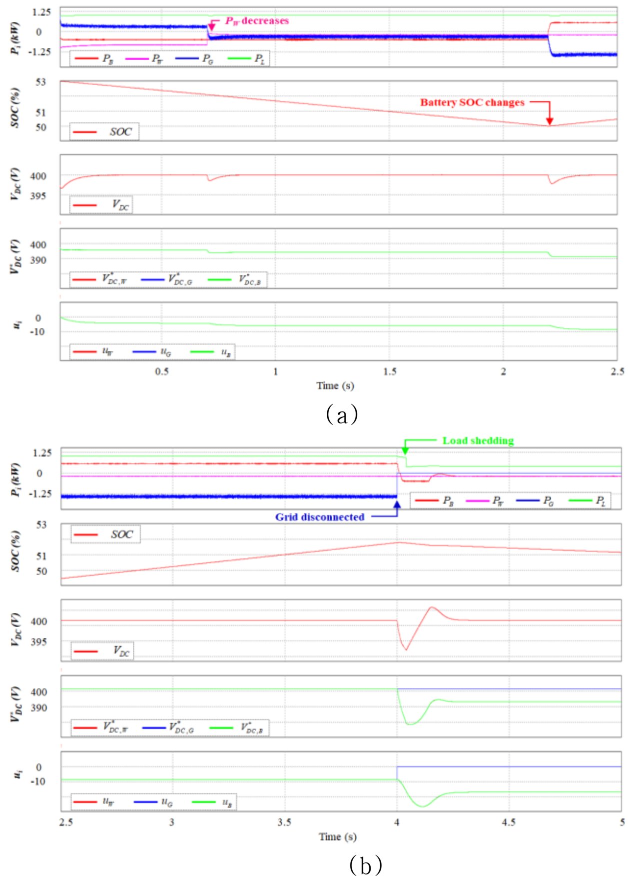

Fig. 4 System responses under various conditions. (a) In grid-connected mode. (b) Transition from grid-connected mode to islanded mode.

4. Conclusion

This paper has presented a secondary distributed control strategy based on adaptive droop method and minimum communication lines to improve the effectiveness and flexibility as well as to reduce the system price. The effectiveness of the proposed control is validated by simulations under various working conditions.

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