전력전자학술대회 하계학술대회 논문집 2024. 7. 1~4

Distributed Secondary Control for Voltage Restoration of DC Microgrid with Current Sharing based on Price−adaptive Droop Control

Muhammad Alif Miraj Jabbar, Kyeong−Hwa Kim*
Dept. of Electrical and Information Eng., Seoul National University of Science and Technology

ABSTRACT

This paper introduces a distributed secondary control strategy for voltage restoration in DC microgrids (DCMGs), incorporating power sharing mechanisms based on electricity pricing. The proposed method employs a price−adaptive droop control to dynamically adjust the contribution of each power unit within the microgrid based on the electricity prices of each unit. This adjustment ensures efficient distribution of power and optimizes operational costs while maintaining the voltage stability. Extensive simulations demonstrate the usefulness of the proposed control strategy to maintain the voltage stability and power sharing among different power units under varying wind power and price fluctuations. The proposed approach ensures not only a good voltage restoration but also economic operations and improved reliability of DCMGs.

1. Introduction

In recent years, DC Microgrids (DCMGs) have been crucial in the transformation of modern distributed energy systems. DCMGs are known to efficiently integrate renewable energy sources and provide enhanced reliability. However, despite their many advantages, DCMGs face significant challenges in voltage stability and economic efficiency. As load demands and energy prices fluctuate, the limitations of the existing control strategies become more apparent. The unpredictable and changing situation clearly highlight the important to develop new and flexible control technologies, which greatly enhances the sustainability of microgrids operatopn, creating new opportunities to make distributed energy systems more efficient.

This paper introduces a distributed secondary control strategy for DCMGs to improve the voltage stability and economic efficiency. The proposed method uses an internal price rate calculation for energy storage units within the DCMG. The energy storage unit continuously updates its internal price rate using the grid price value, grid unit power, and wind unit power. Secondary control and droop control mechanisms are used when the grid price information is absent due to a grid fault. The internal price rate for the energy storage unit is used as a droop constant for the droop control and secondary control. The combination of the droop and secondary controls provides the power sharing of energy storage systems in case of grid fault conditions. This approach not only aims to maintain the voltage levels, but also ensures the power sharing among power units.

The effectiveness of the proposed control strategy is shown by the simulation results, which illustrate its capability to maintain the voltage stability and achieve power sharing based on internal price rate of energy storage. The proposed scheme effectively responds to the grid faults, and adapts to fluctuations in wind power generation, ensuring seamless operation.

2. Proposed Control Scheme

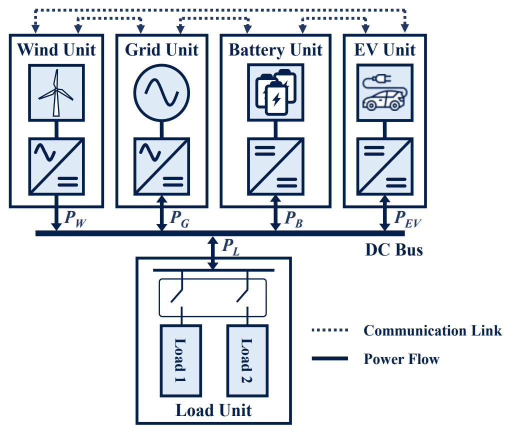

Fig. 1 Configuration of DC microgrid.

Fig. 1 shows the configuration of a distributed DCMG which consists of the grid unit, wind unit, battery unit, EV unit, and load unit. In the proposed distributed DCMG system, the communication links are used to transfer information such as power, price, and secondary control output. In this study, only the wind unit works in the maximum power point tracking (MPPT) mode.

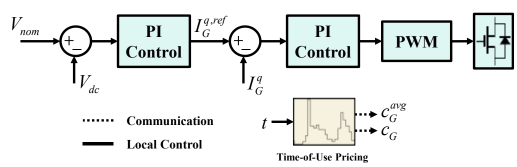

Fig. 2 Control scheme of grid unit.

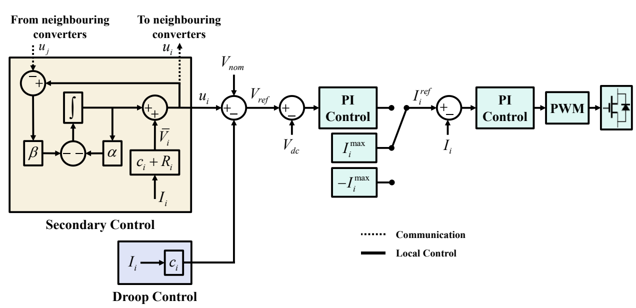

Fig. 3 Control scheme of battery and EV units.

Fig. 2 shows the control scheme of the grid unit that uses voltage control to maintain the DC bus voltage at the nominal value (V_{nom}). The grid unit also sends the current grid price (c_G) and average grid price of previous day (c_G^{avg}) to other power units.

Fig. 3 shows the control scheme of the battery and EV units, in which the current reference $\left(I_i^{ref}\right)$ is selected among the maximum current charging $\left(I_i^{\max}\right)$, the maximum current discharging $\left(-I_i^{\max}\right)$, and distributed control using the secondary and droop controls. The internal price rate $\left(c_i\right)$ is used in the droop and secondary controls to achieve the power sharing between the battery and EV units.

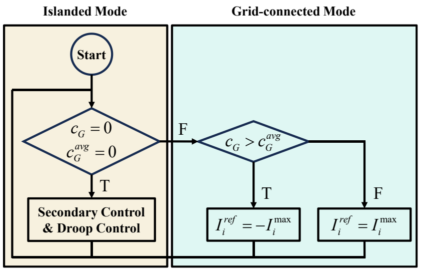

Fig. 4 Control modes of battery and EV.

Fig. 4 shows the control modes of the battery and EV units. In grid−connected mode, the battery and EV units select the maximum current charging if the grid price is lower than the average grid price of previous day. Conversely, the maximum current discharging is used when the grid price is higher than the average grid price of previous day. In islanded mode in which the grid price value is absent, the battery and the EV units use the secondary control and droop control methods to maintain the DC bus voltage at the nominal value and power sharing at once. As the battery and EV units work in charging or discharging, the internal price rate is continuously updated to a new value as

$$c_i = c_i^{new} \tag{1}$$

$$c_i^{new} = T_i^{new} / E_i^{new} \tag{2}$$

where T_i^{new} and E_i^{new} are the updated total energy price and updated stored energy of energy storage unit i, for battery or EV. The values T_i^{new} and E_i^{new} are calculated as

$$T_i^{new} = T_i + T_i^{add} \tag{3}$$

$$E_i^{new} = E_i + E_i^{add} \tag{4}$$

where T_i, T_i^{add}, E_i, and E_i^{add} are the total energy price, additional energy price, stored energy, and additional energy of the energy storage unit i, respectively. The values of T_i, T_i^{add}, E_i, and E_i^{add} are calculated as

$$T_i = SOC_i \times E_i^{\max} \times c_i \tag{5}$$

$$T_i^{add} = \int P_i(t) \cdot c_i^{add}(t)\,dt \tag{6}$$

$$E_i = SOC_i \times E_i^{\max} \tag{7}$$

$$E_i^{add} = \int P_i(t)\,dt \tag{8}$$

where SOC_i, $E_i^{\max}$, P_i, and c_i^{add} are the state−of−charge, the maximum energy capacity, output power, and additional energy price of the energy storage unit i, respectively.

The additional energy price in charging mode is calculated as

$$c_i^{add} = \int -P_G \cdot c_G dt \Big/ \left(\int -P_G dt + \int -P_W dt \right). \tag{9}$$

In discharging mode, the additional energy price is obtained as

$$c_i^{add} = -c_i. \tag{10}$$

3. Simulation Results

Fig. 5 shows the DCMG responses under various operation conditions. The DCMG system starts with the grid−connected mode and the grid price is lower than the average grid price of previous day. Therefore, the battery and EV unit start with the maximum current charging. The battery and EV unit reduce their internal price rates because they are charged with lower grid price. When the grid price is higher than the average grid price of previous day at t = 5s, the operation of the battery and EV units is changed to the maximum current discharging. In the discharging mode, the internal price rate of the battery and EV units remains constant, because there is no additional energy with different prices coming from other power units. When the grid fault occurs at t = 10s, both the operation of the battery and EV units is changed to secondary and droop control methods, in which the DC bus voltage is successfully maintained at the nominal value. The battery unit supplies more power than the EV unit because the internal price rate of the battery unit is lower than the EV unit. As the wind power is increased at t = 15s, supply power by the battery and EV units is reduced. In addition, the DC bus voltage can be maintained although the wind power is fluctuated.

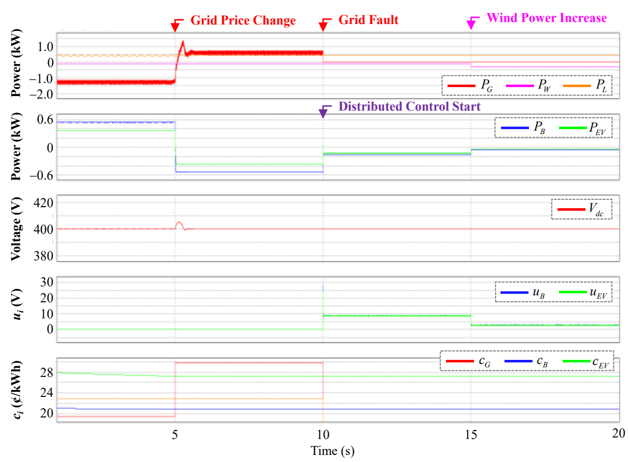

Fig. 5 DCMG responses under various operation conditions.

4. Conclusion

This paper has introduced a distributed secondary control strategy for DC microgrids by utilizing a price−adaptive droop control concept that adjusts power outputs based on the calculated electricity price of energy storage. The proposed approach ensures an effective voltage restoration and power distribution within DCMG system.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF−2022R1F1A1064350).

This study has been conducted with the support of the Korea Institute of Industrial Technology as "Development of core technologies of AI based self−power generation and charging for next−generation mobility (KITECH EH−24−0003)".

Following are results of a study on the "Leaders in INdustry−university Cooperation 3.0" Project, supported by the Ministry of Education and National Research Foundation of Korea.

References

[1] L. Xing, Y. Mishra, F. Guo, P. Lin, Y. Yang, G. Ledwich, and Y. −C. Tian. "Distributed Secondary Control for Current Sharing and Voltage Restoration in DC Microgrid," IEEE Trans. on Smart Grid, vol. 11, no. 3, pp. 2487−2497, 2019.