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An off-line design methodology of droop control for multiple bi-directional distributed energy resources based on voltage sensitivity analysis in DC microgrids

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ABSTRACT

The analysis and design of droop control applied to a bi-directional distributed energy resources in a DC microgrid are presented. The effects of line resistance on the power sharing and voltage regulation performance are analysed. To interpret a complicated line configuration, a voltage sensitivity analysis is derived based on a power flow analysis. Based on this analysis, the droop control design methodology is proposed to improve the power sharing accuracy and voltage regulation performance. Stability analysis is performed to analyse the influence of the control parameters and line resistance on the stability of the controller. The design method is applied to the 5-bus meshed line network model with three bi-directional distributed energy resources, three loads, and two non-dispatchable distributed energy resources. The improved power sharing accuracy and voltage regulation performance are verified using PSCAD simulations and the experimental system.

1. Introduction

As the power generation capacity of distributed energy resources (DERs) has increased globally, research on microgrids (MGs) has been carried out to utilize power effectively. An MG is a power system in which loads and DERs are interconnected, and the system is either connected to the ac grid or operated independently depending on the situation [1–5]. The DC MG delivers power through a DC line, so there are no reactive power and frequency synchronization issues. Therefore, DC MGs have relatively good power quality, high power conversion efficiency, and convenience of control compared to ac MG [6–10].

Various control strategies have been proposed for stable and efficient operation of DC MGs. Conventional control strategies can be classified into centralized control, distributed control, and decentralized control. A centralized control system acquires information on the DERs through a communication system, and uses an energy management system (EMS) to deliver the appropriate control commands [11–15]. However, this requires a high-speed communication system based on the single master-multiple slave structure, and the reliability of the system is impaired because there is a single point of failure in the communication system.

Distributed control and decentralized control have been proposed to overcome the limitations of centralized control. A distributed control consists of a primary controller based on droop control and a secondary controller using low-bandwidth communication (LBC). The output information of the DERs is exchanged by an LBC, and this is used as a control variable of the secondary controller to improve the control performance. A distributed control method can be classified into a voltage shifting method and a droop gain variation method. The voltage shifting method minimizes the voltage variation on the DC bus by compensating for voltage fluctuations due to the droop controller [16–18]. The droop gain variation method improves the power sharing performance of the DERs by varying the droop gain [19–24]. Also, robust distributed control methods considering delay effect and uncertainty of communication links have been proposed [25–27,53]. This distributed control has the advantage of avoiding a single point of failure in communication, but there is still a communication dependency in that the control performance is influenced by the communication state. In addition, the algorithm is complicated, and it is difficult to design the droop gain of the droop control.

In a decentralized control, only local information is used, a communication system is unnecessary, and the system generally applies

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