Control of Power Electronic Converters for Efficient Operation of Microgrid Consisting of Multiple DG Units and ESS

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Abstract. To construct a reliable and efficient microgrid system which consists of multiple DG units, local loads, and ESS, this paper presents a control methodology of power electronic converters and their dynamic behaviors. Microgrid often exchanges the active and reactive power with main grid and needs to operate with a high degree of smartness and flexibility. In microgrid operation, the electrical power flow is mainly dependent on the generated power of DG units, load power demand, and ESS state. As main constituting elements of microgrid, this paper presents a control strategy of power electronic converters. Through the integrated simulation studies, the dynamic behaviors of power electronic converters are investigated in detail.

Introduction

Recently, there has been a gradual interest on the integration of the renewable energy resources into the electrical power system because of the worldwide energy crisis created by the depletion of fossil energy and the greenhouse gas emission limit [1]. Because renewable energy sources are usually distributed in a wide area and have an intermittent output nature, the conventional centralized generation and distribution schemes of electrical power system are not sufficiently efficient and effective. The recent trend constructing the electrical power grid is to share distributed generation (DG) units based on renewable energy sources with electrical power systems, which has a significant impact on the operation of electric distribution networks [2]. As a result, an innovative concept of microgrid began to emerge in modern electric distribution networks.

Microgrid normally consists of multiple DG units, local loads, and energy storage systems (ESSs). This demands an efficient operating strategy and a smart control approach to integrate multiple DG units in the electrical network. Also, microgrid can provide more technical benefits and control flexibilities to both utility grid and microgrid participants as compared with the conventional electrical power system. It gives benefits of scale for the utility, and moreover, it can deliver the power with better power quality and high reliability for consumers [2]. The essential function of microgrid is to have the ability to operate either in grid-connected or autonomous mode in case of the absence of the main grid [3]. Another requirement is to handle effectively the exchange of active and reactive powers between the microgrid and main grid. To provide smartness and flexibility to microgrid in addition to satisfying the above requirements, the control strategy for microgrid operation has been developed based on three levels of hierarchical structure, which includes the primary control, the secondary control, and the tertiary control [4].

In microgrid, a grid-connected inverter is generally employed to link microgrid with the utility grid. To exchange the power between microgrid and utility grid, a grid-connected inverter should be able to operate in bidirectional mode. To overcome the inherent output fluctuation of DG units in microgrid configuration, the ESS is normally combined for the purpose of improving the stability in electrical power system supplying local loads. The ESS can contribute to mitigate the power unbalance in microgrid caused by the inherent intermittent power output of DG units. For this reason, various researches have been conducted regarding on the ESS techniques such as the bidirectional power conversion, battery management, battery scheduling, and estimation of state of charge (SOC) [5,6].
This paper presents a control methodology of power electronic converters for efficient operation of microgrid which consists of multiple DG units, local loads, and ESS. Through the integrated simulation studies based on the PSIM software, dynamic behavior of power electronic converters constructing microgrid are investigated in detail.

Configuration and Operation of Microgrid

Fig. 1 shows a typical configuration of microgrid connected with multiple DG units, ESS, and local load. Microgrid has ESS as well as various DG units from the renewable energy resources such as the solar panels and wind turbines. Microgrid is electrically connected at the point of common coupling (PCC) to connect it with utility grid.

Control of Power Electronic Converters

Fig. 3 shows a configuration of the power electronic converters for a grid integration of DG units, which is composed of the three-phase voltage source converter and grid-connected inverter. When the wind turbine is considered as a DG unit, the voltage source converter is interfaced to deliver the developed power of generator to DC link bus. The speed and torque of the generator are generally controlled in order to draw the maximum power from the wind turbine by generating the proper current references [1]. Using these current references, the current controller is designed on the synchronous reference frame by the PI decoupling control to generate the voltage references of three-phase voltage converter.

Because the developed powers from different renewable energy resources such as photovoltaic and wind power generation systems are assembled on the DC link bus, the grid-connected inverter is used
as an essential conversion interface to connect the grid as well as to deliver the collected powers in the DC link to the grid. When the grid-connected inverter is employed to deliver the developed power from DG units to grid, it should be able to regulate the DC link voltage in order to maintain the power balance within microgrid. This is achieved by the DC link voltage control loop, which generates the current references for the grid-connected inverter. The supplied power to grid can be adjusted by controlling the inverter output currents in the inner current control loop.

To exchange the power with ESS, the bidirectional DC-DC converter is employed as power electronic interface, in which the charge and discharge of ESS are controlled according to the SOC level, load power demand, and generated DG power.

Simulation Results

In this section, the dynamic behaviors and control performance of power electronic converters constructing microgrid are presented through the integrated simulation works based on the PSIM software. As main constituting elements of microgrid, the wind power system, ESS, and local loads were considered and the test was conducted under the operating condition as in Fig. 2, in which the DG unit and ESS supply the power to both the local loads and grid.

Fig. 4 through Fig. 6 shows the dynamic behaviors of the grid-connected inverter, the bidirectional DC-DC converter and ESS, and the voltage source converter and DG unit. Fig. 4 shows the transient and steady-state control performance for the grid voltages \( e_a, e_b, e_c \) and output currents \( i_a, i_b, i_c \) of the grid-connected inverter. Fig. 5 shows the responses of the DC link voltage \( V_{DC} \), the ESS current \( i_{ESS} \), and the SOC level of ESS \( (ESS_{SOC}) \). Fig. 6 shows the responses of the generation voltages of the wind turbine \( (v_{ab}, v_{bc}, v_{ca}) \) and the \( q \)-axis and \( d \)-axis currents \( (i_q, i_d) \) and three-phase currents \( (i_a, i_b, i_c) \) of the voltage source converter. From these figures, it is clearly confirmed that all the power electronic converters are properly controlled to perform a necessary operation algorithm of microgrid.
Summary

Control methodology of power electronic converters and their dynamic behaviors have been presented in this paper to construct a reliable and efficient microgrid system. Through the integrated
simulation studies for microgrid which consists of a DG unit, local loads, and ESS, the control performance and dynamic behaviors of power electronic converters have been investigated.

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