Decentralized Control and Stability Analysis for Autonomous Microgrids

Abstract

In recent years, driven by the economic, environmental and sustainable incentives, there has been an increasing interest in the utilization of distributed generations (DGs) such as solar PV, wind turbines, fuel cells, microturbines, etc. A microgrid (MG), which combines DGs, energy storages (ESs) and a cluster of loads, is an enabling technology for high efficient and reliable utilization of DGs. MGs, especially operating at autonomous mode, encounter many operational challenges to be addressed, including the critical demand-supply balance under the intermittent renewable DGs, the economic operation requirement and the stability issues emerged from the high penetration of constant power loads.

Conventionally, centralized control methods are adopted to solve the above issues, which require a centralized controller and a communication network to coordinate the operation of local controllers. However, these methods encounter high communication and computation burdens as well as the single point of failure issues. Considering the distributed nature of the DGs in a MG and to increase system reliability and scalability, decentralized control strategies without central controllers and communications are explored in this thesis, to deal with the issues of power balance, economic operation and system stability.

First, a decentralized dynamic power sharing strategy for hybrid energy storage system is proposed. Hybrid energy storage system provides an effective approach to compensate the power unbalance caused by the intermittency of renewable DGs and uncertainty of loads. To fully exploit the advantages of different energy storages in the hybrid energy storage system, it is desirable that the access-oriented ES (e.g. supercapacitor) compensates fast power fluctuations and the capacity-oriented ES (e.g. battery) provides the low-frequency power at steady state. Unlike the most existing methods with central controllers and communications, an extended droop control scheme with a virtual resistance droop controller and a virtual capacitance droop controller is proposed for hybrid battery/supercapacitor(SC) system to achieve dynamic power sharing in a decentralized manner. In addition, considering the bus voltage deviation issue resulted from the droop-based control approaches as well as the SC state-of-charge (SoC) recovery issue to ensure secure operation, a decentralized power management is further proposed to achieve autonomous dynamic power sharing, SC SoC recovery and bus voltage restoration at the same time. A design guideline is also developed to ensure the desired dynamics.

Next, a decentralized strategy for economic operation of autonomous MGs is proposed. Conventionally, economic dispatch of DGs are solved by centralized control with optimization algorithms or distributed control with consensus algorithms. To improve the reliability, scalability and economy of MGs, an

incremental cost based droop control scheme is proposed. System operation cost is optimized when the incremental costs of all DGs reach equality. As frequency is a global state in an AC MG and DC bus voltage serves as a natural indicator in a DC MG, a frequency-incremental costs (*f-IC*) droop scheme is proposed for AC MG, a voltage-incremental cost (*V-IC*) droop scheme is proposed for DC MG and a normalization scheme is proposed for a hybrid AC/DC MG. By using the proposed technique, the total operating cost can be optimized without any communication or central controllers.

Finally, system stability issue is studied. Stable operation is a basic requirement for MGs. The high penetration of power electronic converter loads causes destabilizing effects in MGs, also known as the constant power load (CPLs) issue. Considering the increasing complexity and the requirement of system extension and reconfiguration of the MGs, a module-based approach is proposed for flexibly modeling and stability analysis. By this means, a complex system matrix can be easily integrated based on system configuration and overall system stability can be evaluated. The hybrid AC/DC more electric aircraft power system adopted by Boeing 787 is analyzed using the proposed technique as an example.

To further stabilize system with CPL, a composite nonlinear controller is proposed by integrating a nonlinear disturbance observer based feedforward compensation with backstepping design algorithm. Unlike existing active damping methods that can only ensure stability in small signal sense, the proposed controller not only ensures global stability under large variation of the CPL, but also features fast dynamic response with accurate tracking over wide operating range.