Abstract

Microgrids (MGs) are characterized by their decentralized, dynamic, flexible, and user-responsive frameworks due to the growing integration of distributed energy resources (DERs), including demand response (DR) programs, electric vehicles (EVs), battery energy storage systems (BESS), and renewable energy sources (RES). However, the optimal planning and operation of MGs face significant challenges due to the inherent uncertainties associated with renewable power generation, user load demand, and system coordination complexities. This dissertation addresses the necessity for a cost-effective and user-centric planning and operation approach for MGs under uncertainty and varying load conditions. A stochastic planning framework is proposed for the optimal placement, sizing, and scheduling of BESS and RES-based distributed generators (DGs), such as solar and wind, to ensure an economical and reliable incorporation of DERs into MG. For effective utilization and user-friendly EV charging station infrastructure, the queueing theory is applied to minimize waiting time, and the charging/discharging priority-based function is formulated to identify their participation in DR schemes. In the operational stage, advanced energy management strategies are formulated for grid-connected and islanded MGs, integrating BESS, EVs, and DR strategies. The proposed model ensures financial benefit for both the MG operator and end-users while considering operational reliability and user satisfaction. A two-level Stackelberg game-theoretic framework is proposed to model the strategic interaction between aggregators (leaders) and end-users (followers) in the contexts of both EV and non-EV DR participants. The optimized load demand resulting from this game-theoretic model serves as input for the second stage, which addresses the economic-emission generation scheduling of dispatchable DGs. The proposed methodologies are validated for efficacy on a 33-bus microgrid test network across various scenarios. The suggested strategies enhance microgrid resilience, reduce operating costs, improve voltage and frequency stability, and increase participation among energy users. The proposed MG model demonstrates flexibility and sustainability in addressing the needs of future decentralized power networks.