Abstract

In the recent decades, Renewable Energy Sources (RESs), mainly Wind Turbines (WT) and Photovoltaics (PV), have become increasingly attractive due to their environmental benefits. With the integration of RESs in the distribution network, the modern era is also witnessing the rapid integration of Electric Vehicles/Plug-in Hybrid Vehicles (EVs/PHEVs) in the power system. Energy Storage Systems (ESSs), either separately installed battery storage systems and/or EVs with Vehicle-to-Grid/Grid-to-Vehicle (V2G/G2V) facilities, accommodate high penetration of RESs by reducing the adverse effects of uncertainties in RESs. ESSs can be effectively used to reduce energy cost, reduce power loss and improve reliability. In addition, advances in Information and Communication Technology (ICT) and smart grid functionalities facilitate end users to participate in energy management through Demand Response (DR) programs. In the new scenario, the Time-of-Use (TOU) pricing offered by the utility based on the availability of RESs generation and wholesale prices influence the customers to change their consumption behavior. The distribution system can be benefited by achieving multiple objectives through optimal scheduling of Distributed Energy Resources (DERs), such as RESs, EVs, Battery Energy Storage Systems (BESSs) and DR programs. Nevertheless, the presence of various energy resource operators, consumers and prosumers with different needs and objectives increases the complexities in operational planning of distribution network. Therefore, an energy management with optimum decisions is needed for coordination of all production and consumption units and maximum utilization of available resources.

Considering the restructuring of the distribution network and the active involvement of multiple operating agents with some conflicting and some non-conflicting goals, integrated scheduling of different DERs controlled by different operators/aggregators is presented in this thesis. The following three aspects have been accomplished under this approach: 1) Day-ahead multi-objective integrated scheduling of DGs, PHEVs and BESSs

in the distribution system with centralized and decentralized approaches. 2) Cooperative scheduling of a network connected Multi-Microgrid (MMG) system with decentralized approach along with internal pricing approach to emphasize the flexibility of Parking Lot (PL) operators and BESSs aggregators. 3) Development of a three-level hierarchical decision making based energy management framework for a distribution system with Multi-Microgrid.

The first aspect is investigated as a multi-objective energy management framework that proposes a combined formulation of energy cost, CO_2 emissions, real power loss and load flattening by considering the integration of PHEVs (G2V and V2G modes), BESSs, and DGs. A ε-constraint method is used to obtain Pareto optimal front and optimal scheduling from the distribution utility point of view. A case of the decentralized multi-agent optimization problem in the ε-constraint domain has also been formulated.

The second aspect is investigated by proposing a decentralized approach to maximize economic benefits among network-connected Microgrids (MGs) through cooperative scheduling. The cooperative scheduling is based on price signals generated using Shapley value method to encourage MGs to share power among themselves for economic benefits. A microgrid operator (MGO) generates an energy trading status-based time-variable tariff for the PL operators and BESSs aggregators to promote the active participation of PLs and BESSs in the MG's energy management. The uncertainties related to load demand and RESs are modeled using scenario-based methods while the uncertainty associated with PHEV is modeled using copula theory-based estimation.

The third aspect is addressed through a three-level hierarchical decision based multi-objective energy management framework is developed through which multiple operating agents, such as Distribution Utility (DU), MGOs and End-User Aggregators (EUAs), actively engage in energy management to achieve their respective goals. This phase also examines the impact of risk-averse and risk-seeker decisions of MGOs on the operating cost of DU.