Abstract

Recent advancements in renewable energy (RE) technologies, along with reduced installation costs, have led to their widespread adoption. However, challenges arise due to the intermittent nature of RE influenced by variable weather conditions, impacting its reliability. Irregular human behavior and the widespread adoption of high-demand loads, like electric vehicles (EVs), lead to significant energy demand fluctuations. To address these challenges, the integration of energy storage systems (ESS) emerges as a crucial solution. ESS provides fast response times, managing surplus energy during off-peak periods and discharging stored energy during peaks. Strategic deployment of ESS, combined with energy sharing and demand-side management, enables smart grid communities to balance supply and demand, mitigating fluctuations, and reduce reliance on costly and environmentally harmful peak power plants.

This dissertation aims to explore the integration of various forms of ESS into the hierarchical multiple levels of the electrical grid by proposing a framework called "hierarchical multi-communities energy-sharing management framework (hMESH) to provide efficient energy sharing management through three schemes: energy-sharing management for non-moving energy storage (eNMES), critical hour energy sharing management for partially-moving energy storage (ePMES), and inter-community energy sharing management for fully-moving energy storage (eFMES).

The first scheme, energy-sharing management for non-moving energy storage (eNMES), focuses on a smart home environment, comprising multiple REs, home appliances, and multiple ESS units. This chapter proposes a novel scheme to address the challenge of minimizing energy loss in ESSs and optimal ESS capacity design. It utilizes distributed power-flow assignment with a load-shifting algorithm, and the optimal energy storage capacity is determined using linear programming techniques.

The second scheme, critical hour energy sharing management for partially moving energy storage (ePMES), focuses on EVs with predictable usage patterns, specifically electric school buses (ESBs), often deployed at specific times and remaining idle for extended periods, making them practical for delivering vehicle-to-grid (V2G) ancillary services. It introduces a V2G model centered on ESBs in various schools within a single community, formulating the problem as a noncooperative game where the utility company (UC) determines the optimal incentive price for schools to discharge energy, minimizing additional costs during the peak demand period. Schools negotiate for the optimal discharged energy to maximize benefits during the peak period. The optimal energy-price (OEP) algorithm is also introduced to achieve equilibrium, which is proven to be unique and always existent.

The third scheme, inter-community energy sharing management for fully moving energy storage (eFMES), proposes a three-level energy-sharing model: utility company (UC) level, community energy aggregators (CEAs) level, and electric vehicles (EVs) level. In the smart grid, multiple communities exist, each with EVs inside. EVs possess the unique capability to travel between communities and engage in energy sharing through charge/discharge activities. The model is a three-level game, where UC at the upper level, supplies/buys electricity to/from the multi-community system and sets the multi-communities energy sharing price. CEAs, in the middle level, set optimal community energy sharing prices within their community. At the bottom level, each EV determines optimal charging and discharging energy, responding to energy sharing prices. All players aim to maximize their utility functions by choosing their best strategies. The scheme presents the optimal three-level energy-price (3OEP) algorithm to obtain an equilibrium that is proven to be unique and always existent.

The evaluation studies for the proposed three schemes of the hMESH framework were performed through simulations using MATLAB. The simulation results demonstrate the effectiveness of the proposed framework. The simulation on eNMES shows a reduction in energy loss and a significant decrease in energy storage capacity. Furthermore, the simulation on ePMES shows a reduction in the peak-to-average ratio and the bills for schools possessing ESBs, which help discharge energy to the grid during peak periods. Finally, the results for the eFMES scheme indicate a reduction in the peak caused by charging EVs, with a significant decrease in the peak-to-average ratio and the electricity bills of EV owners. This also leads to a much flatter load profile compared to the original charging profile, where there is no multi-communities energy sharing management system.

Keywords: Renewable Energy, Energy Storage System, Electric Vehicle, Energy Sharing Management, Smart Grid