Abstract

Over the past few years, Renewable Energy Sources (RES), especially Wind Turbines (WT) and Photovoltaics (PV), have experienced increasing popularity owing to their environmentally friendly characteristics. Their integration into the distribution network and the energy market can be regarded as a primary transition to resilience and sustainability in the global energy systems. The major challenge in this integration is the intermittency of the RESs. One solution to this is using Battery Energy Storage Systems (BESSs). The BESSs can be either separately installed for each consumer or shared among a certain number of consumers. However, implementing battery energy management is again a challenge in the real-time energy market. The adaptation of RES has encouraged the development of innovative trading mechanisms and energy markets. In such a scenario, peer-to-peer (P2P) energy trading has emerged as a crucial approach for harnessing the benefits of integration of RES and dealing with its intermittency.

The traditional centralized energy generation models have now become obsolete and environmentally unsustainable. Thus, there is a growing need to explore decentralized approaches to energy management. With the smart grid functionalities and the advancement in Information and Communication Technology (ICT), consumers can participate in energy management through the Demand Response (DR) programs. Also, the P2P energy trading approach enables consumers to exchange surplus energy directly to other consumers in the energy market. Through the optimum scheduling of distributed energy resources (DERs), such as RESs, BESSs, P2P energy trading, and DR programs, the distribution system also receives benefits. However, with the availability of such heterogeneous resources, including the consumers and prosumers, each with different objectives and needs, the complexities in energy management increase. In such cases, the Game Theory proves to be an excellent tool for dealing with such complexities. This thesis presents a comprehensive analysis of Game Theory-based P2P energy trading frameworks, each addressing the critical aspects of such mechanisms. These aspects are as follows.

The first aspect deals with the Cooperative game formulation for incentivizing P2P energy

sharing within building communities. The participants are motivated by minimization of their cost using Generalized Nash Bargaining and Alternating Methods of Multipliers (ADMM) optimization techniques. The uncertainties related to renewable generations are also handled in this work through stochastic modelling.

The second aspect is about optimizing the economic benefits of P2P energy trading among buildings that are geographically distant from each other. This framework reduces the number of transactions by organising the buildings into virtual communities (VCs) based on their geographical locations. This reduces the computational complexities and enhances the efficiency of the energy management system. The decentralized framework ensures the privacy of each participant. The Non-Cooperative game facilitates decentralized energy exchange, load shifting, and cloud computing-based algorithms for pricing and energy profiling.

In the third aspect, the P2P energy trading framework ensures the economic benefit to each participant without violation of any network constraints with the help of dynamic network utilization charges. The Cooperative Game Theory is used to obtain the equilibrium strategies in a decentralized way.

The fourth aspect focuses on implementing the large-scale P2P energy trading framework with a more realistic building model and DGs participating actively in the energy market. A modified Nash Bargaining-based Cooperative game approach is proposed for a fairer incentive distribution among hypothetical virtual community aggregations, and dynamic network charges are used to maintain the network variables within their limits. The cloud-computing-based algorithm is proposed for decentralized energy management and enhancing computational efficiency.

The fifth aspect deals with a virtual community-based P2P energy trading framework, utilizing a modified Nash Bargaining solution for fair incentive distribution. The effect of integration of distribution network constraints is also analysed in this framework. This privacy-preserving algorithm also deals with the uncertainties related to the RES and considers the shareable battery energy storage systems. Apart from day-ahead scheduling, the energy management in this framework focuses on real-time implementation of this framework, including the usage of BESSs based on the day-ahead scheduling results.

Hence, the proposed framework as a whole encompasses the above aspects in an integrated manner in this thesis. A range of models for addressing the complexities associated with P2P energy trading, RES and BESSs is presented here in a decentralized energy landscape. This thesis contributes valuable insights toward sustainable and adaptive energy systems that align with the future of smart grids and local energy markets.