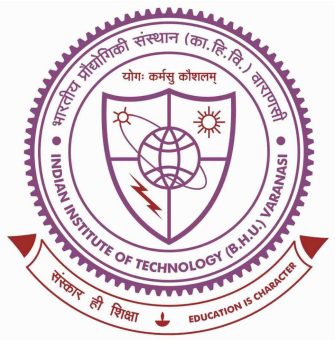
Multi-agent Energy Management Systems for Active Distribution System



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by

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Chapter 6

Conclusions and Future Scope

6.1 Conclusions

The emerging active distribution systems containing different energy resources promote the active involvement of multiple operating agents having some common and some conflicting goals. Energy management of such active distribution systems comprises of complex and challenging tasks, which requires proper and optimal economic decision-making. In this thesis, a couple of energy management frameworks have been developed for integrated scheduling of various energy resources, such as electric vehicles, battery energy storage, renewable energy resources, dispatchable distributed generations, and demand response. The thesis aimed toward developing electricity pricing models, planning and balancing between real-time consumption and energy production or purchase, minimizing energy costs, GHG emissions reduction, and minimizing real power losses and voltage deviations. The numerical investigations have been carried out to show the effectiveness of the proposed frameworks in achieving the different objectives by considering the distribution network constraints. The uncertainties associated with renewable generations, consumers' demands and the driving habits of owners of electric vehicles have also been integrated into the proposed frameworks.

6.1.1 Optimal Scheduling of DGs, PHEVs, and D-BESSs

A day-ahead joint scheduling of DGs, BESSs, and PHEVs in an active distribution system has been developed. The commonly used objective function in the literature was inves-

tigated for its suitability for centralized scheduling from utility point of view. Through the analysis, it was found that the existing formulations led to unnecessary charging and discharging of batteries due to canceling the effect of cost of charging. Thus the objective function needed reformulation in the context of centralized scheduling. The analysis reveals that re-formulated cost function effectively provides scheduling solutions thereby eliminating unnecessary charging and discharging of BESSs/D-BESSs and PHEVs. The modified objective function reduces the batteries discharging power by 91.5 % however, the operating cost of DU increases by only 1.2 %. The analysis through payoff tables reveals that the multi-objective problem of load flattening and cost minimization with high penetration of DGs cannot be effectively tackled by weighted-sum method. Various case studies and detailed analyses show that simultaneous optimization of four conflicting objectives, i.e. minimization of energy cost, CO_2 emission reduction, actual power loss minimization, and load flattening, can be appropriately dealt with the proposed method. This framework can assist the local distribution companies in assessing the aforesaid objectives. Also, a case study solved using a decentralized approach in which PHEVs and D-BESSs owners intend to maximize their profits, shows that increases utility cost is increased but prosumers who charge (discharge) from (into) the distribution network are benefited.

6.1.2 Decentralized Scheduling of Multi-Microgrid

A novel decentralized energy management system has been developed to maximize economic benefits among grid-connected MGs through cooperative scheduling. The Shapley value method based price signals have been used to coordinate all the MGOs and encourage them to exchange power among themselves for economic benefits. The numerical results show the efficacy of the proposed framework in reducing energy costs without any coupling constraints between MGOs. Therefore, the proposed energy management system eliminates (i) the need for mandatory information exchange between MGOs and (ii) joint scheduling of all MGs. The effectiveness of the proposed method has been validated by comparative analysis with the existing Nash bargaining method for power sharing among MGs. The developed framework reduces the average import price and increases the average export price for each MGO as compared to the tariff provided by DU. This updated energy price prompts MGOs to exchange power among themselves rather than with DU.

The different case studies demonstrate that cooperative operation in the proposed framework yields significant reduction in operational cost of MG as well as in their dependence on DU. In addition to the said power exchange mechanism between MGOs, the Dantzig-Wolfe decomposition has been used as an efficient tool to achieve the goals of MGOs, PL operators and D-BESSs aggregators in a decentralized manner with minimal information exchange. A time-variable tariff based on energy trading status of MGO has been used to emphasize the flexibility and contribution of PL operators and D-BESS aggregators in the MG's energy management. This method ensures the effective utilization of energy storage for energy management and provides an opportunity to PL operators and D-BESS aggregators to increase their profits.

6.1.3 Hierarchical Scheduling of Active Distribution System with Multi-Microgrid

A hierarchical decision-based multi-objective energy management framework for an active distribution system with multi-microgrid has been proposed. A game-theoretic dynamic pricing scheme has been used to model the interaction of DU-MGOs as well as MGO-EUAs, rather than pre-determined tariffs. The simulation results establish the effectiveness of the proposed framework in accommodating the active participation of multiple decision-making agents, such as DU, MGOs and EUAs, to realize their objectives. The numerical results show that the adoption of the developed participatory strategy increases the profits of MGOs and reduces the cost of DU, while lowering the peak demand maintaining the same average energy price, compared to the non-interactive approach. In addition, the net power exchange of MGO with DU decreases as import power decreases and export power increases, leading to an improvement in minimum voltage level and load profile after interaction of DU, MGOs, and EUAs. Similarly, electricity imports by DU from the main grid also come down. It has also been examined that the cost of DU increases with the level of tolerable uncertainty in risk-averse decision-making, whereas the cost of DU decreases with the level of uncertainty required in MGO's risk-averse decision-making.

Thus the proposed energy management frameworks would be beneficial to achieve various economic and technological aspects at the distribution level. In addition, the

frameworks developed in this thesis are capable of accommodating various DERs and pricing schemes based on the active participation of multi-agents with uncertainties in energy management.

6.2 Future Scope

The work presented in this thesis provided considerable effort to develop an energy management framework considering the different perspectives of multiple operating agents in an active distribution system, and to analyze different approaches for coordinating all energy resources owned by different operating agents. The present thesis work can be extended on aspects as discussed below.

The work presented in this thesis assumes that the power deficit/surplus of the MG (or distribution utility) can be met by power exchange with the main grid. This assumption is justified in normal operating mode. But, the failure of communication or physical connections between operating agents due to natural disaster or cyber-physical attack can jeopardize the balance of power, reduce stability and increase operating costs. Therefore, a contingency plan or reliability assessment using the probability of failures needs to be incorporated into the proposed energy management framework through which each operating agent can easily manage their energy requirement in island mode in an optimal manner. The proposed schemes can be scaled up with a market based stochastic model for managing a hybrid AC-DC distribution system as a multi-area control system with minimal dependence on the main grid. In this thesis, the demand for EVs is stochastically modeled using historical driving behavior considering only minimizing costs and achieving maximum storage levels at departure time. The probabilistic decisions of EVs' owners to participate in or opt-out of energy management and reliability improvements are not considered in this work. Further research is needed to investigate the stochastic models of EVs and PLs based on probabilistic decisions of consumers, and to examine the effect on market clearing and pricing as well as reliability.