A New Modeling Framework for Investigating: The Role of Flexible Demand in Electricity Markets

Electricity systems are currently facing the fundamental challenges of decarbonization and deregulation. Decarbonization introduces high variability from renewable generation and increasing demand peaks from the electrification of transport and heat sectors. In this setting, flexible demand technologies have attracted great interest as they can support renewables' integration and limit peak demand levels. However, their value in the low carbon energy future has been analyzed by the existing literature through centralized models, optimizing system objectives (e.g. maximizing social welfare) and assuming perfectly competitive behavior by market participants. The recent deregulation of the electricity industry though means that such models are not able to provide accurate and meaningful insights anymore, since they neglect that self-interested market players' actions are not generally aligned with social welfare optimization. This paper presents a new modeling framework which is capable of capturing the strategic, profit-driven behavior of self-interested players and identifying the market outcomes emerging from their interactions, accounting for the effects of demand flexibility. This framework is founded on bi-level optimization principles, capturing in a mathematically rigorous fashion the interactions between the strategic decision making of self-interested players (modeled in the upper level) and the competitive clearing of the electricity market (modeled in the lower level). The consideration of demand flexibility introduces complex time-coupling operating characteristics which are suitably incorporated in this modeling framework. The paper will apply this framework to investigate a number of highly interesting issues around the role of flexible demand, namely: a) its impact on the market power exercised by large generation companies, b) its impact on the pricing strategies and business case of electricity retailers and c) its impact on generation investment decisions. Finally, areas of future work in enhancing the capabilities of the proposed modeling framework will be identified and discussed.