Evaluation of wholesale electric power market rules and financial risk management by agent-based simulations

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Abstract
As U.S. regional electricity markets continue to refine their market structures, designs and rules of operation in various ways, two critical issues are emerging. First, although much experience has been gained and costly and valuable lessons have been learned, there is still a lack of a systematic platform for evaluation of the impact of a new market design from both engineering and economic points of view. Second, the transition from a monopoly paradigm characterized by a guaranteed rate of return to a competitive market created various unfamiliar financial risks for various market participants, especially for the Investor Owned Utilities (IOUs) and Independent Power Producers (IPPs). This dissertation uses agent-based simulation methods to tackle the market rules evaluation and financial risk management problems.

The California energy crisis in 2000-01 showed what could happen to an electricity market if it did not go through a comprehensive and rigorous testing before its implementation. Due to the complexity of the market structure, strategic interaction between the participants, and the underlying physics, it is difficult to fully evaluate the implications of potential changes to market rules. This dissertation presents a flexible and integrative method to assess market designs through agent-based simulations. Realistic simulation scenarios on a 225-bus system are constructed for evaluation of the proposed PJM-like market power mitigation rules of the California electricity market. Simulation results show that in the absence of market power mitigation, generation company (GenCo) agents facilitated by Q-learning are able to exploit the market flaws and make significantly higher profits relative to the competitive benchmark. The incorporation of PJM-like local market power mitigation rules is shown to be effective in suppressing the exercise of market power.

The importance of financial risk management is exemplified by the recent financial crisis. In this dissertation, basic financial risk management concepts relevant for wholesale electric power markets are carefully explained and illustrated. In addition, the financial risk management problem in wholesale electric power markets is generalized as a four-stage process. Within the proposed financial risk management framework, the critical problem of financial bilateral contract negotiation is addressed. This dissertation analyzes a financial bilateral contract negotiation process between a generating company and a load-serving entity in a wholesale electric power market with congestion managed by locational marginal pricing. Nash bargaining theory is used to model a Pareto-efficient settlement point. The model predicts negotiation results under varied conditions and identifies circumstances in which the two parties might fail to reach an agreement. Both analysis and agent-based simulation are used to gain insight regarding how relative risk aversion and biased price estimates influence negotiated outcomes. These results should provide useful guidance to market participants in their bilateral
Further details about market market rules, clearing process, and insights on the market dynamics are documented in El-Baz et al. (2019). In order to perform the scenario analysis and generate the most accurate results, the market model is co-simulated on two independent platforms: SimulationX and Matlab. SimulationX, a Modelica based software, is used to model all the physical systems such as the user’s building model, heat pump, micro-CHP, EV, batteries, or PV system. Although the user behavior can be evaluated based on different variables, fixed load consumption is used as an indicator of the user behavior and lifestyle. Three categories define the user consumption level: low, average and high. The range of each level is explained in the next section. Electricity markets (EMs) are a relatively new reality and also an evolving one, since both market rules and market players are constantly changing. Market participants can purchase and sell...