



Agent Modeling for Integrated Power Systems

Final Project Report

Power Systems Engineering Research Center

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Power Systems Engineering Research Center

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Executive Summary

Countries around the world continue to refine their electricity market structures in various ways. There are ongoing debates over market design issues, such as how to design effective market power mitigation rules, how to incorporate ancillary service markets, and how to properly implement a retail electricity market to encourage customer participation. Although valuable experience has been gained, there is a lack of a robust analysis platform for evaluating the effects of a new market design from both engineering and economic points of view.

The difficulty in creating such a platform arises from the interactions among strategic behaviors of market players, various layers of market designs, and the underlying physical network. A multi-agent system with a corresponding software platform would allow for robust analysis of the complex phenomena of an electricity market with its human decision-making in the context of market rules and a physical electric system.

In this research, multi-agent electricity market simulation tools were designed and implemented. Three market design areas were investigated: market power mitigation, ancillary service market design, and customer participation.

Part I: Multi-Agent System Modeling of Electricity Market and Its Application in Evaluation of Market Power Mitigation (work done at Iowa State University)

Local market power is an issue for electricity markets due to transmission capability bottlenecks, lack of economical electric energy storage devices, and short-term inelasticity of the customer demand. The generators that possess potential local market power could leverage it to gain profits, such as by actually withholding or proposing to withhold supply. To address the issue of local market power, various market power mitigation rules have been proposed and implemented in practice. However, there has been no systematic analysis of the effectiveness of those rules against strategic bidding of market players with learning capabilities in the context of an electric power system.

An agent-based market platform was designed and constructed to incorporate energy and ancillary service markets with market power mitigation rules. The agents were designed to make decisions to maximize their reward through reinforcement learning. The platform is based on JADE, a widespread agent-oriented middleware, and was programmed in JAVA. As a result of these features, the platform offers a rich set of programming abstractions and libraries that can facilitate new analysis applications. Important constraints were incorporated, such as ramp rates, reserves, and regulation requirements. Heat rate and fuel price data were used to create quadratic cost curves for the thermal generators. A PJM-like local market power mitigation process was implemented in the simulation platform. The resulting platform includes a 225-bus system model that resembles the structure of the Western Electricity Coordinating Council (WECC) grid and electricity market. The platform allows for load serving entities (LSEs) to also be generation owners.

The simulation results showed that without market power mitigation rules, large generation owners learn to *implicitly* exercise market power without knowing each other's bidding data. The PJM-like market power mitigation rules performed reasonably

well against the supplier agents in enhancing market efficiency and discouraging the exercise of market power. The results also showed that generation resources owned by LSEs can counteract the exercise of market power by other suppliers during peak demand hours.

Part II: Effects of Ancillary Service Markets on Frequency and Voltage Control Performance of Deregulated Power Systems (work done at Washington State University)

The second research topic was the effect of different ancillary service market designs for frequency and voltage control on the control performance of power systems. Different market structures were created for the balancing (i.e., regulation) markets. The power system control used the standard automatic generation control (AGC) technique. Only the market structures were varied to study their effect on frequency control performance. By changing the market structure and incorporating generator ramp rates in the market design, a more desirable control performance was observed in the study.

Analyses showed that bilateral load following is viable within the conventional AGC framework. In this case, the control was modified to accommodate the market structure. Bilateral load following resulted in a faster frequency response as compared to separate, third party frequency control.

The feasibility of VAr markets was investigated. For voltage/VAr control, secondary control methods are still evolving and few markets are actually in operation. In this project, a new control method and new market structures were analyzed. In a comparative study of the feasibility of generator VAr markets, it proved difficult to avoid locational advantage (and hence, market power) for certain generators.

Part III: Power System Electricity Market Agent Model (work done at Cornell University and Smith College)

To examine the effect of active customer participation, the electricity market was modeled as a multi-agent system that included three types of agents: supplier, customer, and market. The market agent accepts and processes bids and offers according to market rules. The agents' responses to different market environments were simulated using Matlab.

The simulation results showed that suppliers and customers should learn as much as possible about the market environment and from historical data to maximize their benefits from participation. The simulation results also highlighted the importance of customer participation to deter the supplier market power, to lower electricity prices, to promote energy conservation, and to improve the system reliability.

The results emphasize the need for restrictive laws for the suppliers to protect customers as well as market integrity. In addition, customer participation was shown to be crucial from an environmental point of view. As customers become more familiar with the market mechanisms, they can indirectly improve overall market efficiency and energy conservation by simply minimizing their own expenditures.