Electricity Markets with Strategic Agents Possessing Asymmetric Information

Mohammad Rasouli
EECS Department, University of Michigan
rasouli@umich.edu

1 Background

New cyber-physical systems are emerging which are governed by specific physical laws, strategic decision makers and asymmetric information among the decision makers. Restructured electricity industry is one example of these new cyber-physical systems.

Power networks are sophisticated large systems the control of which needs a deep and synergistic integration of new design ideas, computational algorithms and physical components. The difficulty in the control of the electricity networks comes from their special features, such as the integrated flow of electricity governed by the KVL and KCL laws, the inability to store electrical energy, the inelasticity of demand which needs to be met in real time, network transmission limits, and unpredictability of demand. Furthermore, with the growth and integration of renewable sources of energy into the system, the wind and solar, the supply has become unpredictable.

Traditionally, energy networks have been under the control of a centralized planner who could decide for dispatch of energy, expansion of the network and price of electricity as well as other parameters of the system. In this traditional setting, the producer side is a cost-minimizing entity. The restructuring of the industry has emerged around the idea of introducing energy markets; therefore, it enables producers and consumers to make decisions in the system.

New ideas and algorithms are required to run the restructured electricity network optimally. The main question here is which services (control decisions) should be transferred to the markets and for each of them, how the market should be designed. Beside the physical constraints in the control of traditional power networks, there are two new features for the service providers in the restructured power networks: They are strategic self profit maximizer and they possess asymmetric information.

As a result of the new environment, we need new market mechanisms for the electricity market. There are some experiences with market mechanisms including California ISO/PX, British and Australian electricity restructuring. The California experience that resulted in California electricity crisis shows that the common practices of the markets do not necessarily fit into the electricity industry. The current markets and market mechanisms proposed for the industry also do not provide a theoretical analysis of the performance of the system considering the above-mentioned features, especially strategic behavior and asymmetric information.

Developing a theory/methodology for designing electricity markets and studying their performances under strategic agents with asymmetric information is the goal of this research.

2 Proposed Research/Work

The goal of this research is to provide an analytical approach to the design of electricity markets in the restructured industry considering strategic behavior of the producers and asymmetric information they possess. We use control theory, the theory of incentives and game theory for this purpose and proceed according to the following steps:

First we consider a hypothetical central controller who knows all the information in the system and makes all the control decisions. The goal of this hypothetical controller is to maximize the social welfare. We solve the optimization problem of this centralized planner using control theory to find the best performance we can achieve under any market designed for the system. Such a performance provides the benchmark we wish to achieve with our market design.

In the second step, we consider the strategic behavior of the agents and their asymmetric information. We use the theory of incentives and mechanism design to find under what condition the centralized best performance is achievable. Next, the theory of mechanism design provides us with guidelines to design market mechanisms that achieve the best performance. These markets should satisfy other desirable features from the market including budget balance, incentive compatibility and individual rationality. In case the best possible centralized performance is not achievable, mechanism design provides guidelines on how to design good mechanisms. We will use these guidelines in our designs.

The main markets that we propose to study are electricity trade markets, and markets for generation expansion planning. We will start studying these markets in static form. Afterwards, we consider dynamic markets, i.e. markets which are repeated over time or evolve dynamically over time. The actions in an earlier market, can have effect on the information of the agents about other agents and therefore affect agents' strategic behavior. Dynamic mechanism design and dynamic game theory are theories we will use for this type of problems.

3 Potential Impact in/to CPS

The research proposed in this position statement provides new approach and new methodologies to design markets for the restructured electricity industry where the agents are strategic and possesses asymmetric information. It provides a theoretical ground to study the performance of the markets and identify the best possible market designs. In particular, we will consider markets for trade of electricity and markets for the generation expansion both in static and then in dynamic forms.

The results of this research can be used in other cyber-physical systems where we have strategic agents with asymmetric information, and other sets of physical laws governing the system behavior and evolution.