EXPERIMENTAL TESTS OF COMPETITIVE MARKETS FOR ELECTRIC POWER

Simon Ede, Timothy Mount, William Schulze, Robert Thomas, Ray Zimmerman
Cornell University
sme11@cornell.edu, tdm2@cornell.edu, wds3@cornell.edu, rjt1@cornell.edu, rz10@cornell.edu

Abstract

Testing the performance of electricity markets using POWERWEB has already shown that relatively inexperienced players can identify and exploit market power in load pockets. When transmission constraints are not binding, however, auctions with six players have been shown to be efficient. There is evidence from operating electricity markets that prices can be driven above competitive levels when the largest supplier controls less than 20% of total installed capacity. This is accomplished by causing price spikes to occur. In experiments, uncertainty about the actual load and paying standby costs regardless of whether or not a unit is actually dispatched contribute to volatile price behavior. The objective of this paper is to investigate characteristics of a market that affect price volatility. The tests consider three different sets of rules for setting price when there are capacity shortfalls, and the following four market structures:

1. *Load is responsive to price*
2. *Price forecasts are made before market settlement*
3. *A day-ahead market and a balancing market auction*
4. *Suppliers are paid actual offers (a discriminatory auction)*

1 Introduction

This paper reports on the laboratory examination of the susceptibility of markets for electric power to price volatility and the allocative efficiency of market based institutions. Significant game theoretic examinations have been performed in both subject areas, primarily relating to the Californian and United Kingdom electricity markets**.** Both these markets possess simple radial transmission networks, the effect of which can be adequately analyzed through traditional transportation models to explain geographical variations in market performance (Hogan, 1997). Most electric power markets are far more complicated. To extend existing analysis to these markets (such as the northeastern United States), models must incorporate the laws of physics that govern the operation of transmission networks. At any point in time, hundreds of non-linear constraints bind the operation of any complicated power grid. The computational complexity of determining equilibrium strategies in a multi-player, multi-unit game is too intractable to derive analytical results (Klemperer and Meyer, 1989). Hence, testing market performance using experimental economics is a practical way to proceed.

Power system operators have long recognized these complexities when assessing the performance of the power grid. Using the same software that determines the commitment of generators, their allocation of load and the flow of power around the network, simulations are run to assess the effect of contingencies such as line and plant outages. While this approach was appropriate under regulation it does not deal with the effects of strategic behavior by suppliers in an auction that is subject to system uncertainties. Experimental economics is a parallel approach. Our software platform, POWERWEB, implements a "Smart-Market" first proposed by Vernon Smith and his colleagues at the University of Arizona (McCabe, et al., 1991). It simulates a thirty node AC network (that is a stylized representation of the New England market) and constrains an auction for allocation of load between generators to the operation of that network. By simultaneously solving the network and market solutions participants in the market can exploit characteristics of the network such as transmission constraints.

Earlier experiments have shown that players are able to exploit load pockets and drive up prices (Ede et al., 2000). For these experiments system load was fixed. When load is stochastic, other types of opportunities arise for raising prices above competitive levels. The objective of the new experiments is to understand the causes of price spikes in an auction. Average prices can be driven above competitive levels even when there are six players and no transmission constraints.

2 The POWERWEB Platform and Auction Experiments

2.1 Experimental Framework

A smart market was implemented to account for the operational constraints imposed by the physical transmission network. In this context, the sellers and the buyer's demands are connected by a transmission network which must be operated at all times in a manner consistent with the laws of physics governing the flow of electricity. The operation of the network is also constrained by the physical limitations of the equipment used to generate and transmit the power. This results in two phenomena that may affect an auction: (1) transmission losses and (2) congestion.

A small percentage of the energy produced by the generators is dissipated along transmission lines. The power lost depends on line flow and line length, among other things. To compensate for transmission, the buyer must purchase slightly more than the total demand. The exact amount is dependent on where the power is produced. The amount of electric power that can be transmitted from any given location to any other location is limited. These limits can result from either line capacity or from subtle system constraints arising from voltage or stability limits. When one or more of these network limits is reached, congestion occurs. Some inexpensive generation may be unusable due to its location. It is necessary sometimes, therefore, to utilize a more expensive unit in a different location.

Our experimental platform, POWERWEB, handles the effects of losses and transmission system constraints by adjusting all offers and prices by a location specific two-part transmission charge that represents the shadow price of transporting the electricity. This charge consists of a loss and a congestion component. It is associated with each line and is divided up between the various generators based on their individual contributions to the flow in the line. The value of the power dissipated by a transmission line is the loss component of the transmission charge for that line. The congestion component of the transmission charge is precisely the charge necessary to discourage overuse of the line. If there is no congestion, this component is zero. The transmission charges are dependent on the flow in each transmission line as well as each generator's contribution to that flow and cannot be computed before performing the auction. In this context, each generator receives a price which is specific to its location.

Generator units are chosen to satisfy fixed location specific demands in the least expensive manner while satisfying the operational constraints of the transmission system. An optimal power flow program computes the appropriate transmission charges for each generating station. Generators submit price/quantity offer curves to the system operator. The system operator adds the appropriate transmission charge to the price of each offer, and orders the offers from lowest to highest adjusted offer price. Units are included for sale, starting from the low priced units and moving toward the higher priced units, until the supply reaches the total buyer's demand plus transmission losses. The remaining, higher priced, units are excluded from sale. The reigning price is set to the adjusted offer price of the last (most expensive) unit chosen. The price paid for each unit produced by a given generator is the reigning price minus the corresponding transmission charge. In prior research when sellers have multiple units, Bernard et al. have shown that this last accepted offer mechanism (LAO) performs as well, or better, than the Vickrey Multiple Unit Auction and alternative uniform price auctions that set the price equal to the first rejected offer (Bernard, 1999).

2.2 Operation of Experiments

Subject Remuneration

It is important that the participants in the experiment received “salient” rewards that corresponded to the incentives assumed in the experiments. Performance related payment tends to reduce variability in performance and improve the quality of the results from the experiments. Davis and Holt (Davis and Holt, 1993) define saliency to require:

(1) subjects perceive the relationship between decisions made and the payoff outcomes
(2) induced rewards are high enough to dominate the subjective costs of making decisions and trades

Subjects received monetary rewards based on their profits in the experiments. During the experiment each of the subjects saw their earnings expressed in *experimental dollars* and their real dollar earnings. Real dollar earnings were calculated through the following formula:

*Real Dollars = Exchange Rate * Experimental Dollars*

The exchange rate can differ for each generator and across each experiment. The purpose of the exchange rate is to balance actual earnings across generators when different generators have different cost structures and therefore different profit making abilities. There was no limit on potential profits for subjects. Student subjects make on average $30-$50 for a two hour experiment while the utility executives might make $100-$200 for the same experiment. A single experiment might take 50-70 rounds of an auction to get to a stable pattern of prices.

2.3 POWERWEB

POWERWEB is designed to be a flexible web-based platform for performing economics experiments. To date the experiments implemented using this platform focus on examining the behavior of electricity markets using realistic modeling of the physical transmission network and real human decision-makers. Its Internet-based architecture eliminates the need for participants to be physically present in a specially equipped laboratory. The POWERWEB server handles application logic, data handling and computation. Users interact through a standard web browser.

In the electricity markets currently implemented in POWERWEB, each participant in a session plays the role of an owner of a generating plant offering to sell power through an independent system operator (ISO). An example offer submission page is shown in Figure 2-1.

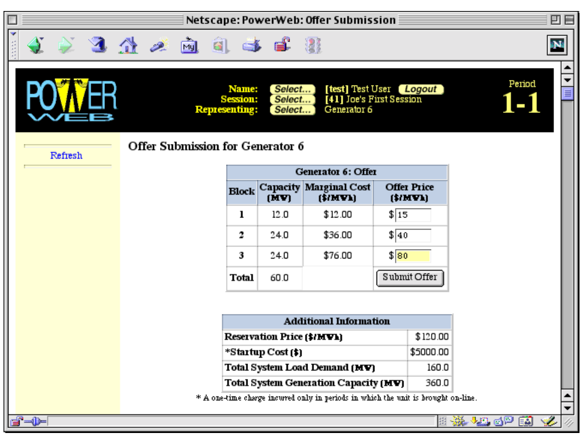

Figure 2-1: Offer Submission Page from PowerWeb

POWERWEB coordinates the offers from competing generators through a uniform price last accepted offer auction. It produces, via an optimal power flow simulation, the market clearing prices and the generation schedules which optimally meet demand (while respecting all of the physical limitations of the power system). The page shown in Figure 2-2 displays the results of a single auction.

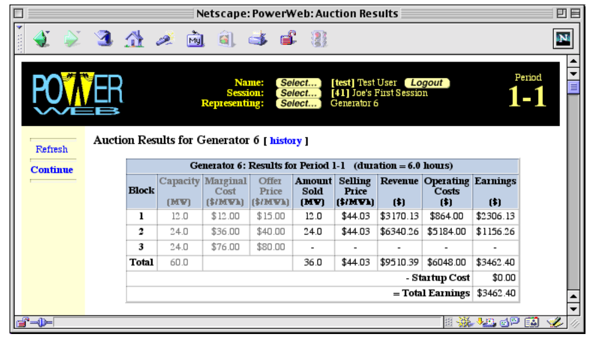

Figure 2-2: Auction Results Page from PowerWeb

Figure 2-3 is a diagram of a 30 bus, 6 generator power system whose (some 200) physical characteristics and constraints must be modeled by POWERWEB's "smart market".

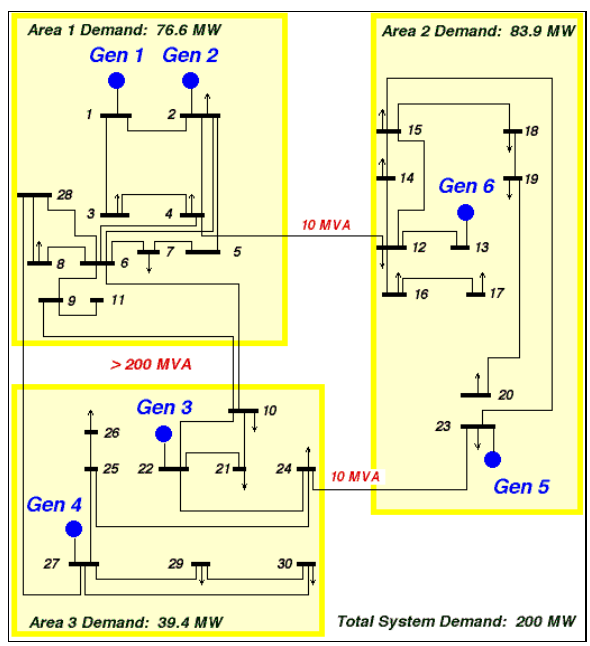

Figure 2-3: Underlying Simulated Power Grid for Market Power Experiments

3 The Experiments

Evidence from earlier experiments using POWERWEB have shown that uncertainty about load and paying standby costs contribute to volatile price behavior. Since standby costs must be paid regardless of whether or not a unit is actually dispatched, there is an economic incentive to withhold marginal capacity from the auction if the probability of being dispatched is low. Consequently, capacity offered into an auction may be much less than the total installed capacity.

The experimental results in Figures 3.1-4 show the total capacity offered into the auction and the corresponding clearing prices for experiments with and without standby costs. When no standby costs are charged, the total capacity offered into the auction remains relatively high even when players are told that the expected load is lower (see Figure 3.1). The corresponding prices are relatively close to the competitive marginal cost price throughout the 60 rounds (see Figure 3.2). When the final drop in expected load occurs in round 41, the efficient price drops substantially, but it takes a number of rounds before the market price reaches the efficient level. That is competition at work.

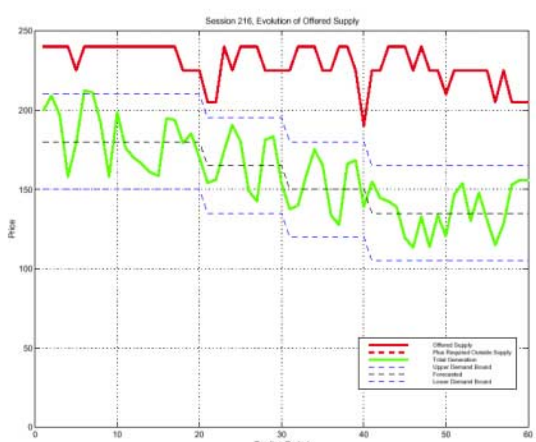

Figure 3.1: Capacity Offered into an Auction Without Standby Costs

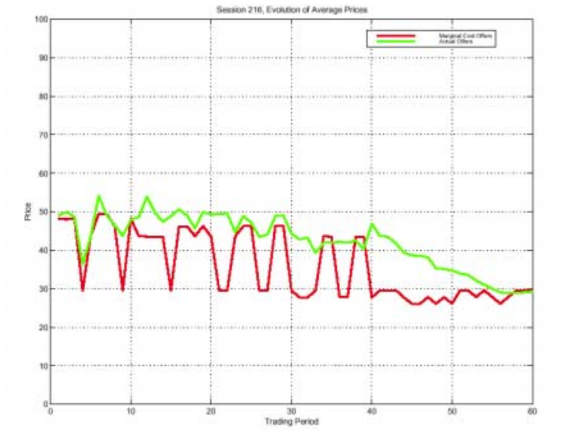

Figure 3.2: Market Prices Without Standby Costs

When standby costs are charged for all capacity offered into the auction ($2/MW), the total capacity offered into the auction drops when the forecasted load drops (see Figure 3.3). The effective or natural reserve margin remains about the same. For five rounds, actual load is above the total capacity offered. For one round, the forecasted load is higher than the capacity offered. In these circumstances when there is a shortfall of capacity, emergency capacity is provided at the price of the highest offer to avoid infeasible solutions. The interesting result for prices is that players speculate more with marginal units, and price spikes occur (see Figure 3.4). In one case, a price spike occurs when the load is relatively low because offered capacity is even lower.

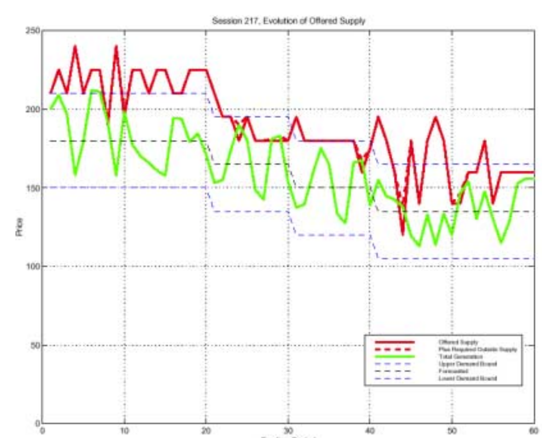

Figure 3.3: Capacity Offered into an Auction with Standby Costs

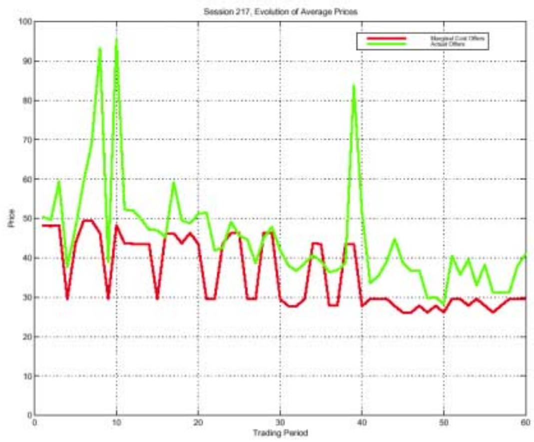

Figure 3.4: Market Prices with Standby Costs

For the new experiments, three different rules for pricing capacity shortfalls are investigated. These are:

1) The market price is set to the reservation price (maximum allowed)
2) The market price is set to the maximum offer submitted
3) The market price is set to the maximum offer submitted, and a two times standby cost is charged for recalling any capacity needed to meet load. This simulates the effect of having supply obligations in a capacity market to be available when needed.

Additional experiments will be run to determine whether the vulnerability of a market to price volatility can be reduced by changing the market structure. The following four structural changes will be considered:

1) Making load responsive to price
2) Forecasting price based on initial offers and allowing for new offers before settlement.
3) Using a two-stage market with a period-ahead settlement using forecasted load and a real-time balancing market
4) Paying suppliers actual offers in a discriminatory auction

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