PowerWeb Testing of Various Auction Clearing Mechanisms for Electricity

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Abstract

Testing auction mechanisms using humans in a controlled environment provides an excellent and inexpensive means for evaluating their relative merits. This paper describes a framework for testing the efficacy of various supply-side auctions including one with price-responsive load and a soft-cap market. These are compared to a non-uniform price discriminative auction also inappropriately termed a "pay-as-bid" auction. Experimental evidence to date based on uniform price market testing has shown an ability of price responsive load to mitigate high volatility and average price.

The Experimental Setup

The Cornell group developed PowerWeb as a flexible web-based platform for performing economic experiments on various electricity market designs. In the experiments discussed in this paper each participant plays the role of a power plant owner offering to sell electric energy into a market. Each participant is assumed to have a strong profit motivation. Normally, up to six participants play in each session, and their bidding behaviors are recorded. These data are later analyzed graphically and statistically for attributes such as a correlation between observed bidding behavior and market rules. This is done in order to use the information for the development and refinement of bidding agent models. Different market rules are evaluated in terms of price spikes and average price. This approach has the following advantages:

- The effects of specific market characteristics can be isolated and tested, while it is difficult to study the actual, complex market rules analytically.
- PowerWeb experiments are inexpensive compared to real-life experiments on the public such as "California experiments".

Paying participants of experiments on the basis of their performance duplicates bidding agent behavior and market behavior effectively. The payment design is critical for meaningful experiments.

An Overview of POWERWEB

Because of operational constraints on a power system, it is necessary to have a central agent acting as an independent system operator (ISO). In previous implementations of POWERWEB, the ISO received offers to sell power from independently owned generation facilities. Based on a forecasted demand profile for the next day and the information gathered from the generator's offers, the ISO computed the optimal generator set points along with a corresponding price schedule which will allow the system to meet changing demand while satisfying all operational constraints.

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As a web-based tool, the current version of POWERWEB may be used in several capacities. It can be utilized in a tightly controlled setting where a well-defined group of subjects are used for a very specific set of market experiments. It can also be used in a more open environment in which anyone on the web can log in and "play" as a generator competing against other generators, controlled by other humans or computer algorithms (agents), to generate power profitably. In either case, since POWERWEB is web-based it is accessible at all times to anyone with proper authorization, as long as the servers are up and running.

A Typical Session

To eliminate the need to coordinate accesses (via phone, e-mail, etc.) and to prevent one user's actions from interfering with another's, all accesses occur in the context of a given "session". The session specifies which power system is being simulated, who "owns" which system resources (generators, etc.), and what market mechanism is in use. Multiple sessions can be active at any given time and activity in each is completely independent of the others. Typically, a user in a session will "own" one or more generating plants.

After logging in as a generator in a simple auction session, for instance, the user is taken to the *Offer Submission* page such as shown in Figure **1**, which displays the cost and capacity information for their generator. Here they can enter offers to sell power to the ISO.

When all participants have submitted their offers, POWERWEB's computational engine runs the auction according to the rules specified and reports back the results to the user. The *Auction Results* page is shown in Figure 2.

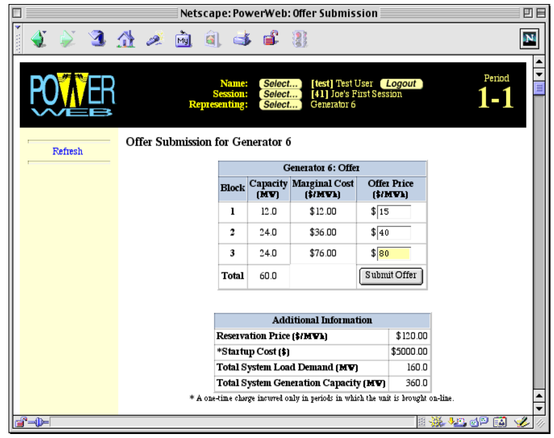

Figure 1: *Offer Submission* Page

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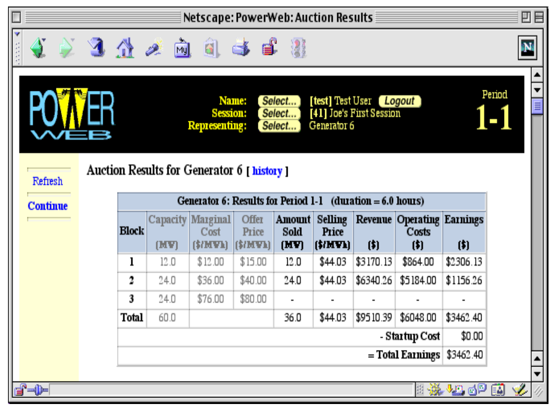


Figure 2: *Auction Results* Page

PowerWeb also has the capability to provide differing levels of information to the players, as specified by the experimenters. In a full information setting, each user would have access to the system information area, which gives tabular summaries of the system operation conditions as well as a "live" one-line diagram of the power system. Figure 3 shows the one-line diagram of a 6 generator, 30 bus system in POWERWEB's database. This diagram is generated dynamically by a Java applet from information retrieved from a relational database server. The diagram can be panned and zoomed and it is interactive in that clicking on an object such as a line, bus, generator, or load will query the database for information about the object. For example, selecting a bus will display the current information about real and reactive flows into and out of the bus as well as information about the current voltage level of the bus.

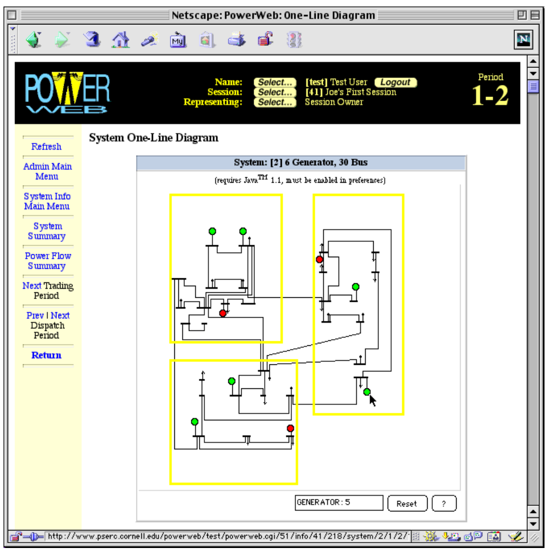


Figure 3: PowerWeb one-line diagram display, showing 30-bus system

The PowerWeb User's Manual, available from the PowerWeb home page at <http://www.pserc.cornell.edu/powerweb/> has more details regarding PowerWeb's functionality.

The Underlying Optimal Power Flow

At the heart of the PowerWeb computational engine is an optimal power flow (OPF) program that is executed by the ISO in response to offers submitted in an auction. The market activity rules determine what offers are valid, but it is the ISO's role to ensure the safe and reliable operation of the network. By using an OPF, the ISO can legitimately allocate generation in an "optimal" way while respecting line flow constraints, voltage magnitude constraints, VAr constraints and any other constraints that are necessary to ensure safety and reliability. As a by-product, the OPF also produces the shadow prices associated with locationally based marginal pricing (LBMP) of power. These prices can be used as determined by the market mechanism being employed.

In the context of a market in PowerWeb, the OPF may be subjected to widely varying costs and therefore dispatches which are far from typical base case operation. It is important in such an environment that the OPF be extremely robust. The latest release version of the Matlab OPF solvers used in PowerWeb and more detailed documentation of the algorithms employed are available at no cost at <http://www.pserc.cornell.edu/matpower/> as part of the MATPOWER package.

PowerWeb has so far been used to examine the effectiveness of day-ahead electricity markets. Over 200 people have participated in electricity market experiments using this software platform. It has allowed for simple variation in the market mechanism being examined and also variation in the type of generators in the market. Two important series of experiments were conducted that examined the ability of generators to sustain prices above marginal cost in the presence of network constraints and the ability of generators to self-commit when faced with start-up costs. Current experiments, described elsewhere, are being conducted on multi-dimensional market designs where energy and ancillary services such as reserves and voltage support are co-optimized.

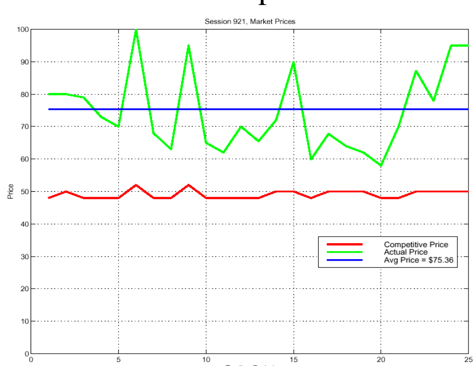
PowerWeb Experiments

In this section we describe an interesting collection of six experiments that were run in order to observe differences in cognitive behavior in response to six different market mechanisms. Specifically, the experiments are:

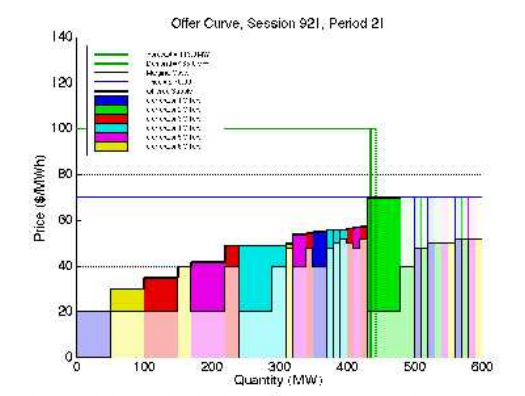
A. An Uniform Price Auction with Inelastic Load
B. An Hybrid Price Auction with Inelastic Load
C. An Hybrid Price Auction with Elastic Load
D. An Uniform Price Auction with Elastic Load
E. An Hybrid Price Auction with Variable Generation Costs and Inelastic Load
F. An Hybrid Price Auction with Variable Generation Costs and Elastic Load.

Experiment A

The plot below shows the typical price spikes produced in a uniform price auction when load is price inelastic.

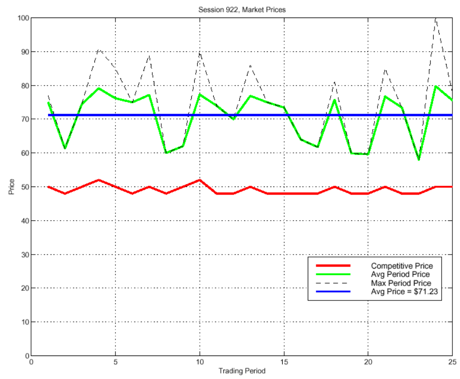


In a uniform price auction, it is generally sensible to offer inexpensive capacity at cost and to speculate in some way with the marginal units (submitting high offers or withholding units from the auction). This is the type of behavior seen in a market like PJM leading to a supply curve shaped like a "hockey stick". The offer curve below shows some speculation with inexpensive units, which is risky, and modest speculation with the marginal units. The participants in earlier tests tended to speculate more with their marginal blocks. (Note, the pale colors correspond to the true costs.



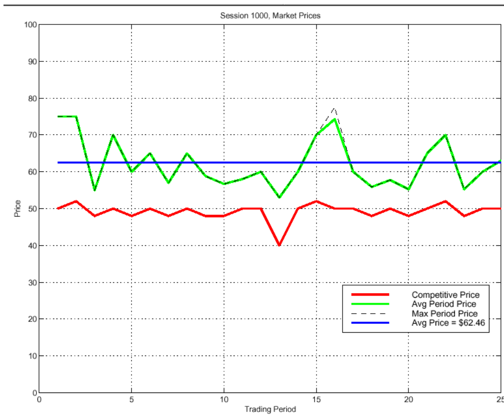
Experiment B

The dotted line in the plot below shows the highest price paid for a block. When this line is higher than the average price paid (solid green line), the hybrid auction is doing what is supposed to do and stopping high offers setting the price for all blocks. However, it also represents a situation when participants are accepting a high price for some units at the same time as a low price for other units. Why not try to get the high price for all units? This requires making a reasonably accurate forecast of the highest price paid in the next period.



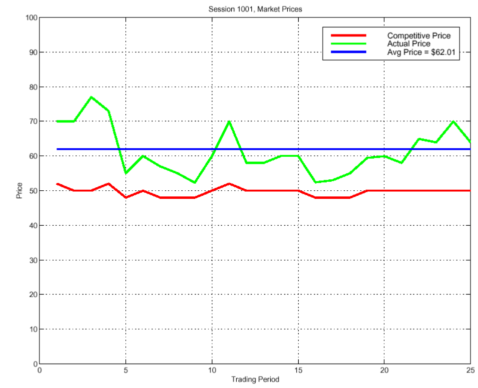
Experiment C

Making load price responsive eliminates most of the purchases of blocks above the soft cap. Hence, the highest price and the average price are equal because all blocks are paid using the uniform price auction. Period 16 is the only exception.



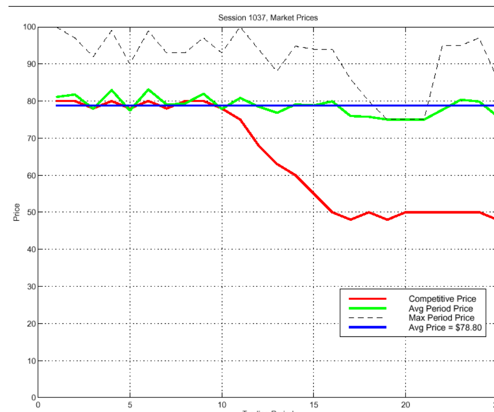
Experiment D

The plot below shows that it is difficult to get price spikes when load is price responsive even though all of the participants had been successful at getting price spikes in the earlier test with inelastic load.

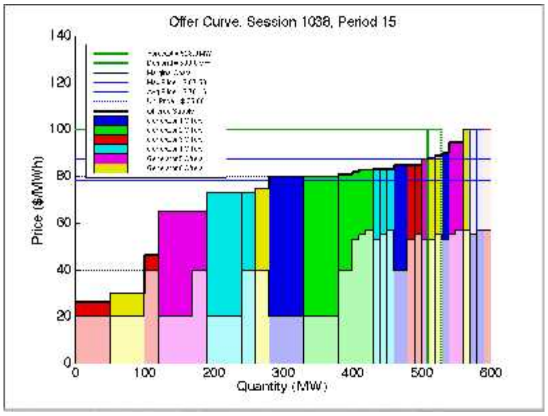


Experiment E

The high initial costs of the marginal blocks make the competitive price above the soft cap and make it easier to sell more blocks in the discriminative auction. This reduces the volatility of the average price substantially, but the difference between the highest offer accepted and the average price is still large. Money is still being left on the table. However, the high average price is sustained after the competitive price falls. This confirms earlier results showing that high prices set in a discriminative auction are harder to dislodge than high prices in a uniform price auction.

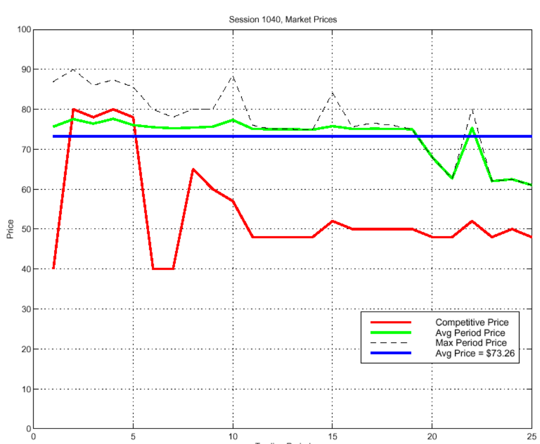


Even though the competitive price has fallen to $50/MWh, over half of the capacity offered is still above the soft cap of $75/MWh. The offer curve is relatively flat where the price is set by the load --- definitely not like a hockey stick. Hence, even if load is price responsive the price of the highest accepted offer will not be lowered by much. Prices set in a discriminative auction tend to be relatively persistent.



Experiment F

The high prices are still quite persistent when load is price responsive. It takes over 10 periods to get a noticeable reduction of the average price after the competitive price falls below the soft cap. This could be a contributing factor in an explanation of what happened in the California-type market a couple of winters ago.



Conclusions

Various electricity market designs have been and continue to be investigated through PowerWeb experiments. The results of these experiments indicate that:

1) In a uniform price auction where all the successful bids are uniformly rewarded at the clearing price,
   - Infrequent high price spikes are typical.
   - Speculating with a few units is rational behavior.
   - The supply curve looks like a hockey stick.
   - Price responsive load serves to mitigates price spikes.
2) In the hybrid auction where the hard limit on the bidding price in the uniform price auction is replaced with a soft limit (i.e., the auction becomes discriminatory for the bids exceeding the limit),
   - Persistent high prices may occur.
   - Speculating with many units is rational.
   - The supply curve is relatively flat.
   - Price responsive load does not mitigate high prices.
3) Price spikes are mitigated with an increased number of bidders for uniform price auctions even when the load is inelastic (i.e., price insensitive). The average prices are still above the competitive levels even with as many as 24 bidders.
4) Price spikes occur if the spot price affects the price of renewing the fixed price contracts when those contracts constitute 50% of the total system capacity.

5) When bidders are reasonably well compensated for offering generation capacity into the auction, much less capacity is withheld from the auction, but price spikes continue to occur.
6) Much less speculation occurs if successful firms are allowed to buy out the firms that have very low earnings. Keeping market share is perceived to be more important than making profits.
7) The prices go to the reservation price when collusions are not strictly prohibited.

Acknowlegments

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