Power System Bidding Tournaments for a Deregulated Environment

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Abstract

In this paper we describe certain tools for understanding and operating power systems in a deregulated environment. Many of the current models for this competitive market that employ an independent system operator (ISO) for controlling transmission, ensuring fair access and security, and providing a spot market for power will be studied. This centrally-dispatched power pool also ensures that generation meets demand based on bids submitted daily from independent generators (and from customers offering interruptible loads). Currently, most ISO bidding models allow only a single bid per day. In this paper, we present an asynchronous bidding scheme as a possible alternative. In particular, we examine the effects of including a feedback mechanism such that upon receiving generation levels from the ISO, independent generators (IGs) be allowed to modify their bid if they so desire. This competitive or 'sequential' bidding process should be allowed to take place each day for a predetermined period of time; in this way, IGs will have a chance to compete and hopefully optimize their profit margins. This paper also discusses the development tools necessary for examining the effects of different bidding processes on the ISO model and evaluating their capability of driving the market to an efficient state of operation.

1.0 Introduction

Recent proposals from FERC to deregulate the power industry are causing broad changes in how the industry currently operates. While there is no general agreement on how to restructure the industry for less regulation, there is agreement that pressures for greater competition in the generation sector should continue, consumer choice should be enhanced and access rights to the transmission system should occur in ways necessary to accommodate greater customer choice and supply competition.

In the recent past debates about coordinated operation of the deregulated system centered on two ends of a spectrum. On one end is the *bilateral model* where suppliers and consumers are allowed to independently arrange trades without involving a system operator. At the other end of the spectrum is the so-called Poolco model born of a necessity to coordinate trades. In the Poolco model all utilities combine to form a sort of super-utility. Suppliers and consumers offer price and quantity bids to an independent system operator (ISO) and the ISO exercises traditional scheduling and operating responsibilities in terms of ensuring power balance, reliability and security, and coordinating transmission access and services. In effect then, all trades are with a centralized pool that determines which trades to accept and which to reject.

At present, many ISO models involve a centrally-dispatched power pool from which generation meets demand based on bids submitted daily from independent generators (and from customers offering interruptible loads). Given this type of model, we suggest that a single bid submitted each day may not be the best mechanism to ensure the market is driven to an efficient operating condition. Instead, a more responsive feedback mechanism should be included in the model such that upon receiving generation levels from the ISO, the IGs be allowed to modify their bid if they so desire. Such a scenario could arise, for example, if an IG believes that it could increase its profit by changing its bid. This 'sequential bidding' process should be allowed to take place each day for a set period of time (e.g. - one hour); in this way, IGs will have a chance to haggle/bargain and hopefully optimize their profit margins.

2.0 Problem Formulation

To begin, suppose the system consists of a set of independent generators (IG), a set of independent consumers (loads) and an interconnected network controlled by an independent system operator (ISO). Next, assume each IG has submitted a bid function (in \$) to the ISO, $B_i(P_{gi})$, and a set of generation injection limits (e.g. P_{gi}^{min}, P_{gi}^{max}, Q_{gi}^{min}, Q_{gi}^{max}). The bid function conists of a set of coefficients (e.g. - defining a piecewise linear function, or an nth order polynomial) submitted to the ISO. Upon receiving these bids, the ISO determines a set of generation powers $\underline{P}_g = (P_{g1}, \ldots P_{gn})^T$ that satisfy the system economic, security and reliability constraints through application of a freely available and open

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algorithm. The ISO is assumed to provide information such as the load forecasting data used in their calculations to all participants. Finally, we assume that there is a maximum amount consumers are willing to pay so that $\sum_{i=1}^{n} B_i \leq B_T$ where B_T represents the total system cost. This simplification is not necessary but it helps simplify the problem so that the IG's bidding dilemma is more easily exposed. For this discussion we do not consider generator startup costs.

For the following description, the ISO is assumed to solve the following 'optimal power flow' problem:

$$\min_{P_{g_i}} \sum_{i=1}^{n} B_i\left(P_{g_i}\right)$$

subject to

Load Flow Constraints

$$P_g = f_1(d, V, \beta)\ Q_g = f_2(d, V, \beta)$$
$$P_d = f_3(d, V, \beta)\ Q_d = f_4(d, V, \beta)$$

Generator Constraints

$$P_g^{min} \leq P_g \leq P_g^{max}$$
$$Q_g^{min} \leq Q_g \leq Q_g^{max}$$
$$V^{min} \leq V \leq V^{max}$$

Network Constraints

$$P_{line}^{min} \leq P_{line} \leq P_{line}^{max}$$

Consumer Constraints

$$\sum_{i=1}^{n} B_i \leq B_T .$$

Upon solving this problem, the ISO then notifies each potential generator of the results. It is important to note that the ability to solve this problem for large-scale systems is an open question.

3.0 Sequential Bidding Model

Although the above formulation assumes that a bid is submitted to the ISO, it does not specify the information contained within the bid function, nor does it specify how often the bid is submitted. These details are reserved for what we define as the 'bidding model'. For instance, current ISO bidding models allow for a single bid per day. As an alternative, we now present a rudimentary version of an asynchronous or 'sequential' bidding model. Upon notification of ISO generation levels obtained from the formulation in section 2.0, IG's may then choose to hold or submit a new bid based upon subjective criteria. For example, a reasonable approach for a given IG is to maximize its own profit function:

$$\max_{B_i} d_i$$

where $d_i = B_i\left(P_{g_i}\right) - C_i\left(P_{g_i}\right)$.

Here $C_i(P_{gi})$ is the IG cost function which includes fuel and other costs necessary to operate the plant. The overall process is illustrated in figure 1. Clearly, each IG should not know the profit function of the other competitors. Since the bids in effect determine the amount of power each IG will be asked to generate, it is important to bid judiciously. The method used by a particular IG to generate a bid is defined as the bidding 'strategy'. It is important to note that the 'ith' IG's bidding strategy could be a (complicated) function of the overall system bidding history; hence, knowledge of such a relation might be critical.

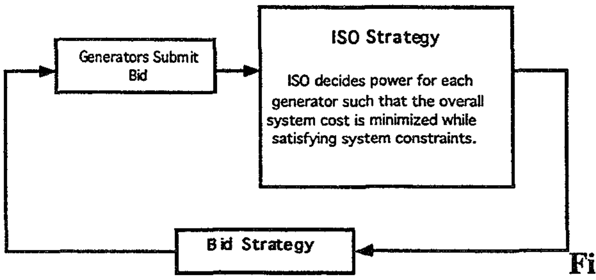


Figure 1: System block diagram for iterative bidding strategy

The sequential bidding process is an iterative mechanism that allows IGs, consumers and the ISO to enter into a competitive feedback process. Assuming the sequential process contains rules that encourage 'sensible', 'stable' behavior in the market, the possibility exists for participants to interact in a way that could drive the system toward market equilibrium. Such a formulation would then be equivalent to applying an iterative algorithm that could locate global minima.

4.0 Numerical Studies

For this discussion, a three machine, nine bus system is used to illustrate possible outcomes of the sequential bidding scenario when different algorithms are applied to the sequential bidding process. In the spirit of previous competitions ([2], [3], [5]), we have been formulating various bidding strategies to be applied to small and large-scale power systems. Given these strategies, it is possible to analyze their effects on market share, profit and system optimality. Such simulations are useful for developing realistic guidelines for the bidding process and measures of success in the restructured power market. For this presentation, we describe a strategy that attempts to predict the other generator bids based upon past power and bidding histories.

4.1 Learn and Predict Strategy

This method attempts to learn the history of past bids and generation levels in order to predict the outcome of the next bidding iteration. Several approaches such as Kalman filtering, Bayes decision or neural networks can be applied to implement this strategy. Denote the bid history $B^1, \dots B^k$ and generation history $Pg^1, \dots Pg^k$. There exists a relationship

$$P_g = h(B) \tag{4.1}$$

between bids and the generation patterns produced by them. While it is impossible to write function h(B) explicitly, it should be possible to approximate it given enough data.

Recall that the generator profit function being applied is the difference between revenues obtained based upon a specific bid and the cost of generation. For this discussion, let us assume that the bid function is linear; that is, for the 'ith' generator let

$$d_i = b_i P_{g_i} - C_i\left(P_{g_i}\right)$$

where P_{gi} is the power output of $(IG)_i$ and b_i is the bid coefficient submitted by the 'ith' IG in dollars/MWh and d_i is profit associated with $(IG)_i$ in dollars.

The bidding strategy applied in this example is for each generator to make its own estimate of the next system operating point, h*(b), based upon the past bidding and operating point histories broadcast by the ISO. Using the estimate the 'ith' generator can find a b_i that will maximize its own profit function

$$\max_{b_i} \; b_i h_i^*(b) - C_i\left(h_i^*(b)\right)$$

In the above equation, $h_i^*(b)$ represents the ith component of the estimate as function of the bids. Of course, in order for any one generator to estimate power and calculate the constraint equation, the other bids must be known. Since this information is unavailable, we suggest that each generator assume the other generator bids do not change drastically from one iteration to the next. Near an equilibrium solution of the iterative process, this assumption is not unreasonable; therefore, the 'ith' profit maximization procedure reduces to a one parameter search for which all other generator bids are held constant at their values from the previous iteration.

For the discussion at hand, we apply a radial basis function neural network [11] as the estimator. Training data for the network is obtained from the bidding and power histories. At each iteration the network is updated with the latest data so that it can continually learn the power as a function of the bid. After the network is trained, the bids can then be fed into the network to obtain a power estimate, h*(b) (see Figure 2).

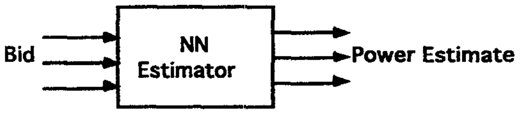


Figure 2: Neural network estimate of h*(b)

At bid time k and given the bid history $(IG)_i$ for the ith IG,

1) Let $P_{gi}^k = h_i^*(b^k, w^*)$ be an approximate relation for (4.1) parameterized by constants w*. Choose the w* to best approximate h (note that the predictor algorithm need not be a neural network, other function approximation approaches such as interpolation could also be used).

2) Since we want to determine b_i^{k+1} to maximize the profit function, d_i, given all other bids and generation histories, for the purpose of the algorithm assume

$b_j^{k+1} = b_j^k$ $\quad j \neq i$ (not a bad assumption near equilibrium)

Then

$$P_{gi}^{\,k+1} \approx h_i^*(b^{k+1}) \tag{4.2}$$

3) Substituting relation (4.2) into the profit function yields

$$d_i^{k+1} = b_i^{k+1} h_i^*(b^{k+1}) - C_i\,[h_i^*(b^{k+1})] \tag{4.3}$$

4.2 Numerical Experiment

This test involves the three generators running the learn and predict algorithm. The cost functions $C_i(p)$, i=1,2,3 for each generator are arranged so that $C_1(p) > C_2(p) > C_3(p)$. In this test, the bid constraint, b_T, is first set to a value of 20 for 25 iterations of the algorithm and then changed to 12 for another 20 iterations. This is done so that the system robustness and the estimation procedure can be examined as function of a particular step change (i.e. - the pool of funds available) in system conditions. Figure 3 clearly shows that the accuracy of the estimate increases as more data becomes available. Furthermore, after the change in bid constraint at iteration 25, the network is able to minimize the error in just a few iterations. Finally, figure 4 shows the bid histories for each IG along with the sum of all the bids. Observe that the sum of the bids approaches the system constraint. This result makes sense from a free market standpoint where all the generators are attempting to maximize their own profits. Finally, recall that this example has been set up so that $C_1(p) > C_2(p) > C_3(p)$. In figure 4, we observe that, in the limit, $b_1(p) > b_2(p) > b_3(p)$. This result is also consistent since a generator with higher costs must bid higher in order to maximize its own profit.

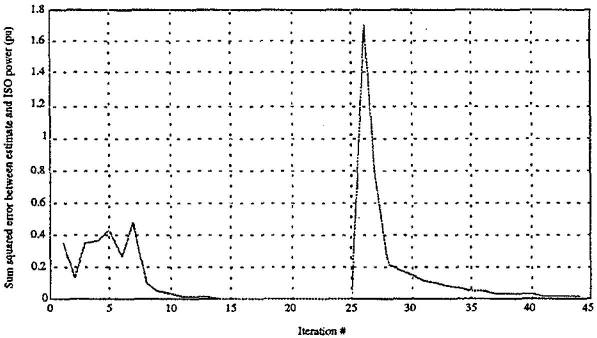


Figure 3: Sum squared difference between estimated power and the ISO

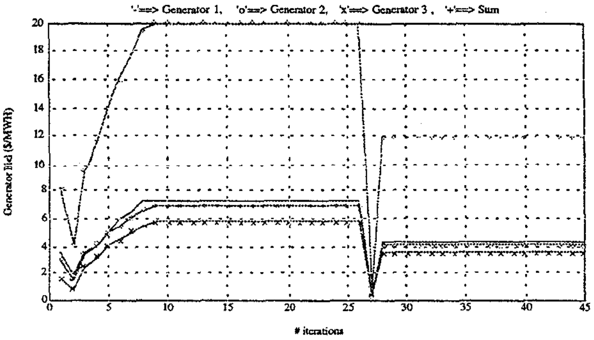


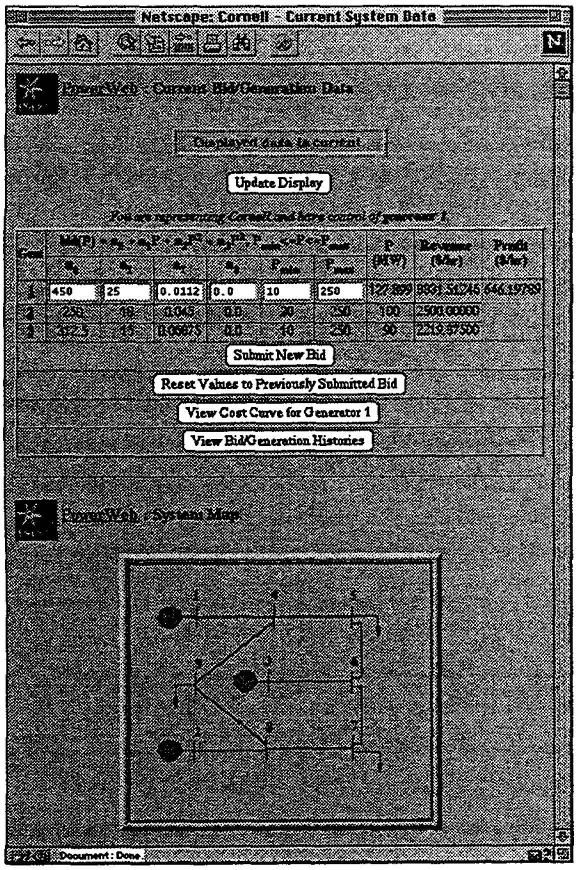
Figure 4: Generator bid histories

5.0 Open Internet Tournaments

In order to perform broader tests of the various bidding models, we have developed a distributed interactive test environment on the Internet, specifically on the World Wide Web (WWW). This test environment is a distributed system called PowerWeb that is being used to host real-time, interactive tournaments involving other researchers in the field. Figure 5 shows a sample page from the user interface which depicts a three machine, nine bus system used in preliminary Internet competitions.

The distributed nature of the environment allows participation from any location with a connection to the Internet, eliminating travel costs. The software is based on the standard WWW protocols, requiring only a web browser, which most participants already have. Since web browsers are freely available for all popular computer platforms, this WWW approach also has the advantage of being cross-platform, allowing each participant to use the computer and operating system of their choice. This eliminates the need for participants to buy a particular type of computing hardware or software. It also eliminates the need for distribution of any specialized software necessary for the simulation. The only cost to the participant involves the time spent in planning a strategy and playing in the tournament.

The real-time, interactive nature of the proposed test environment makes it possible to easily incorporate the 'human factor' in the bidding strategies. The participants are each given a particular generator in the system for which they are responsible. They each formulate their own bidding strategy which they employ throughout the tournament in an attempt to maximize their profit based on the system conditions and the bids of the other participants. Some may choose strategies which would be difficult to characterize as a set of rules for a computer program to follow. The tournament should also expose problems in the bidding models which may have been overlooked. It should also lead to further investigation of important issues surrounding the deregulated environment. For instance, questions regarding the feasibility of using the Internet as a conduit for communicating information in real-time and the necessity of developing standards and protocols will naturally arise as PowerWeb is further refined. Finally, the web based simulator will be a very useful tool in communicating our results and their significance to others



You are representing Cornell and have control of generator 1.

Gen	$MC(P) = a_0 + a_1P + a_2P^2 + a_3P^3, P_{min} <= P <= P_{max}$						P (MW)	Revenue ($/hr)	Profit ($/hr)
	a_0	a_1	a_2	a_3	P_{min}	P_{max}			
1	450	25	0.0112	0.0	10	250	127.899	9931.51245	646.19789
2	250	18	0.045	0.0	20	250	100	2500.00000	
3	312.5	15	0.00675	0.0	10	250	90	2219.37500	

Figure 5: Sample PowerWeb page for a three machine system

6.0 Conclusions

In this paper, we have presented a formulation for the sequential buidding model in a deregulated power systems environment. In particular, numerical experiments have been presented in order to demonstrate various issues in this new environment. In addition, an algorithm to predict competitors' bidding strategies has been presented. Future research will also involve using PowerWeb as a tool to experiment between various bidding models.

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