

# Predatory Gaming Strategies for Electric Power Markets

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**Abstract:** The recent deregulation of the electric industry in the United States opened some sectors of the power market to competition. Buyers and sellers of electric power are competing for limited resources. Although regulations exist attempting to limit such activity, when large amounts of money are at stake, the participants have incentives to engage in predatory behavior. The goal of this study is to model an agent driven bilateral power market auction where some of the players attempt to benefit from causing instabilities like brownouts and blackouts, as well as economic instabilities by applying different gaming strategies. The market structure is similar to the California power market. The network considered consists of six generators in three zones and two loads connected by a six bus power network. An independent entity takes care of the congestion management, as well of allocation of the available resources. One of the companies engages in predatory behavior, using the congestion management policies combined with carefully chosen bids to cut off one or more of the generators of the other company. Vulnerabilities associated with shutdown and start-up costs, minimum up and downtimes, ramp rate and generator limits for each generator, are utilized to achieve market destabilization. Customers may be negatively impacted by the predatory behavior, since reducing the power delivered to a customer is sometimes the best solution to the total congestion management optimization problem.

**Keywords:** *Power systems deregulation, congestion management, bidding strategies, auction gaming, market collusion.*

## I. INTRODUCTION

Throughout the world, the electric industry is in the midst of major changes designed to promote competition. No longer vertically integrated with guaranteed customers and suppliers, electric generators and distributors will have to compete to sell and buy electricity. The stable electric utilities of the past will find themselves in a highly competitive environment. Some countries and regions of the US (e.g., California, PJM) are already operating in a restructured environment. There does not yet appear to be a standardized final market structure that works for all areas, but each market that springs up adds to our experience and helps us make the next market implementation work a little better and more competitively. The authors believe that, to some degree depending on the market implementation, regional commodity exchanges will play a key role in buying and

selling electricity.

The deregulation of electric power industry opens the market to free trade. Although the rules may be designed to encourage what is perceived to be "fair-play", the opportunity for profits will push some to test the meaning of fairness. This work investigates the possibilities for such kind of gaming assuming there is a certain degree of freedom on the market about what could be perceived as "fair-play."

This research assumes a framework in which buyers and sellers negotiate contracts for trading electricity by submitting bids to a central entity. The buyers are energy service companies (ESCOs) and the sellers are generation companies (GENCOs). Prices and quantities are determined in an auction process after buyers and sellers have submitted bids to a power exchange. The power exchange works closely with an Independent Contract Administrator (ICA) to ensure that matched contracts are feasible, and that the electricity network is secure.

An important point in the deregulation of the electric power industry is that there is no longer a direct connection between cost and price. The generating companies are entirely profit driven and responding to the market demand. For example, in the California power market ICA is represented as the Independent System Operator (ISO). The California ISO is a nonprofit organization that remains neutral. In other words, it facilitates the power system operation without being paid directly by the market participants – the ISO's decisions do not affect its revenues. The role and responsibilities of the California ISO are as follows [1]:

- to operate the power grid
- to facilitate the transmission market
- to minimize involvement in forward energy market
- to maximize efficient use of the transmission system
- to provide comparable prices to all participants
- to prevent discrimination
- to minimize gaming opportunities

With an electricity market that promises to do nearly \$100 billion of business each year, competition is expected to be stiff. The number of market players will be larger than ever before, and it would be impossible to guarantee that all participants will be trustworthy. It is likely that participants in this market will attempt to gain a competitive advantage if a means to do so arises. Corporate espionage that reveals the strategies of competitors could provide valuable information in developing one's own strategies. Disruptive practices need not be illegal. Loopholes in the regulation may allow a market participant to engage in activities of a questionable nature. It is inevitable that some of the participants in the newly deregulated electric market will try to benefit by

employing techniques dealing with the financial aspect of markets like predatory pricing to eliminate competition or purposely inflating the prices. Other malicious actions may deal directly with the physical systems including causing congestion and blackouts/brownouts. In this work attention is paid to the study of the effects of malicious gaming behavior during bidding in agent based power markets.

The remainder of the paper is organized as follows. Section II presents the techniques and methods used to model the auction market and the participants. Section III describes a simple experiment that illustrates how malicious agents can affect the price and network congestion. Section IV presents the results of that experiment. Section V discusses the impacts of market power. Finally, Section VI presents some conclusion and possible extensions to this research.

## II. METHODS AND TECHNIQUES

To keep the effect of different strategies obvious the modeled system is fairly small and easy to understand. The model consists of two GENCOs and two ESCOs. Each GENCO owns three generators attached to a simple 6-bus network. Fig. 1 depicts the network. G1, G3 and G5 belong to GENCO\_1, and G2, G4 and G6 belong to GENCO\_2. ESCOs are represented as two loads, L1 and L2, belonging to ESCO\_1 and ESCO\_2, respectively. The characteristics of the power network are given in Table 1.

Table 1. Power network data

Bus Data					
Bus Number	Mw Load	Mva Load	Voltage High Limit	Voltage Low Limit	
1	0.0	0.00	1.05	0.95	
2	0.0	0.00	1.05	0.95	
3	0.0	0.00	1.05	0.95	
4	100.0	0.00	1.05	0.95	
5	100.0	0.00	1.05	0.95	
6	0.0	0.00	1.05	0.95	
Branch Data					
From Bus	To Bus	Line R	Line X	Charging	MVA Limit
1	2	0.01	0.01	0.01	1.0
2	3	0.01	0.01	0.01	1.0
3	4	0.01	0.01	0.01	1.0
3	5	0.01	0.01	0.01	1.0
4	5	0.01	0.01	0.01	1.0
5	6	0.01	0.01	0.01	1.0
6	1	0.01	0.01	0.01	1.0

Different models have been built to simulate the electric marketplace. In this study the scheme outlined in Richter, Sheblé and Ashlock [6] is used. A double-sided auction is constructed, with two buyers and two sellers of electricity. Computerized agents model the GENCOs and ESCOs as they participate in the simulated auction. The contracts for fixed amounts of electric energy are created for fixed time intervals. One of the trading agents uses a fixed set of rules to change the bidding strategy [8, 3]. The other is equipped with

an intelligent searching mechanism. The auction bid matching is performed by an independent entity, ICA, which handles the functions of the ISO.

Fig. 1 provides a flowchart that describes the market simulation. One round of bidding proceeds as follows. The selling agents determine a bidding scheme based on certain criteria, such as load forecasting, estimation of the available transmission, etc. Then they submit their bids. The ICA then calculates the amount of power offered that each generator can deliver to the customer while attempting to minimize the total cost and enforce all network constraints. Thus the ICA allocates transmission rights to the cost-effective users. The ICA also determines the cost of transmission used to price the transmission network. Each user pays the cost for using the network.

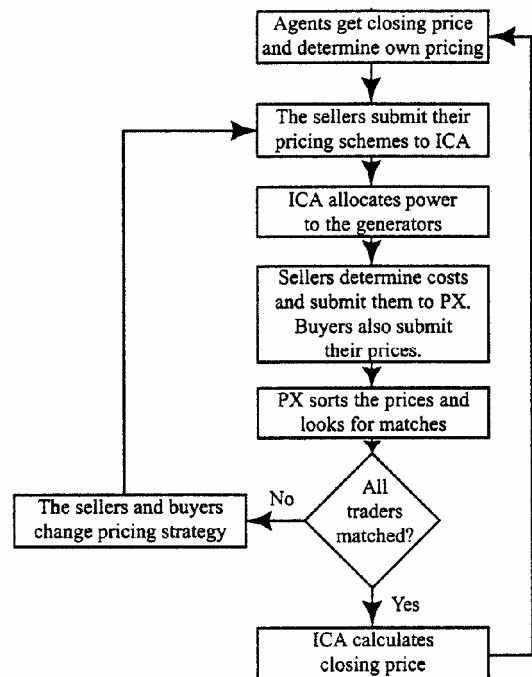


Fig. 2 Market flowchart.

A very simple example can illustrate the role ICA plays on the market. Let us consider the 2-bus network on Fig. 2 with 4 generators serving 2 loads [1]. Two GENCOs own two generators each with 10.0 MWh minimum and 100 MWh maximum load. The transmission limit of the line from bus 1 to bus 2 is set at 150 MWh. Each GENCO is serving a separate 100 MWh load. Both GENCOs produce bids for its generators and submit the bidding scheme to the ICA. If there were no limits imposed on the transmission line from bus 1 to bus 2, the ICA would allocate 100 MWh transmission to G1 and G3 each, because they are priced lower than G2 and G4 and this would minimize the total cost. Thus, the cost for L1 would be \$2500/h and the cost for L2 would be \$2000/h.

However, if there is 150 MWh transmission limit on the transmission line, ICA would allocate 50 MWh to G1, 50 MWh to G2, and 100 MWh to G3. Thus, the cost for L1 becomes \$2750/h, and for L2 is \$2000/h plus they have to pay for congestion transmission capacity.

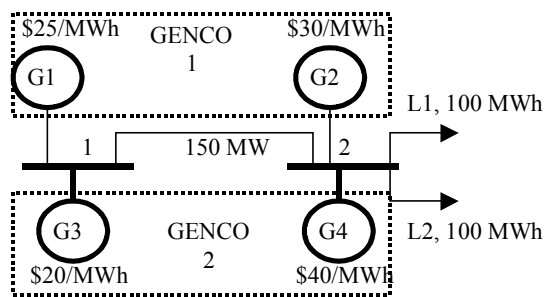


Fig. 2 Network with two GENCOs and two ESCOs.

The congestion transmission costs are transferred to the customers and included in the final price. They are calculated as follows. If ICA were to substitute 50 MWh from G3 with the same amount from G4, this would cost \$20/MWh to GENCO 2. Substituting 50 MWh from G1 with generation from G2 costs \$5/MWh to GENCO 1, therefore the transmission from bus 1 to bus 2 is much more valuable to GENCO 2, and ICA minimized the cost by rescheduling the generators of GENCO 1 instead of GENCO 2. Thus, GENCO 1 appears as the marginal user of the congested transmission line and sets the marginal cost of transmission at \$5/MWh. In that case GENCO 1 has to pay  $\$5/\text{MWh} \times 50\text{MWh} = \$250.0$  congested transmission costs for carrying 50 MWh over the congested line, and in the same fashion GENCO 2 has to pay \$500.0 for carrying 100 MWh over the congested line. These amounts are calculated in the total price the customer pays, and transferred to the transmission owner by the ICA.

This pricing scheme is very important because it unbundles energy and transmission costs, thus creating two separate markets. This allows the generation companies to properly arrange their pricing schedule in a way that minimizes costs and assures available transmission. The process of forecasting and managing the transmission by the ICA is called congestion management [1].

After the GENCOs submit their bids and are allocated transmission rights, they calculate the price and submit their offers. Respectively, the buyers submit their bids. An independent entity, a power exchange, matches the bids and offers using an approach which maximizes the profit, similar to Wood and Wollenberg [2, 7].

All bids and offers are sorted in descending and ascending order and juxtaposed. If a buy bid is higher than the corresponding sell offer, the two players are matched, a contract is approved and the players are notified. In the case where the buy bid is lower than the sell offer, the players are rejected and notified. The rest of the players are also notified that the market was not cleared and prompted to bid again. This is repeated until all players are matched and the market cleared, or it is deemed that enough bidding cycles have occurred and the matched players granted contracts. The rest of the players are rejected and notified.

Each cycle the sellers resubmit offers by providing the contract administrator with the new bidding scheme and it recalculates the congestion prices, reschedules generators if necessary and the players submit bids based on the transmission rights. A matched bid and offer average for each

contract, as well as an equilibrium price is calculated and the next round is called. Table 2 shows an example of 5 buyers and sellers after the bids and offers were matched by the power exchange. Different pricing techniques can be studied using the model described here. Midpoint prices are calculated, which is used if discriminatory pricing is desired, and if nondiscriminatory pricing is desired, the valid matches weighted by quantity are used to determine equilibrium price. Meanwhile the players update their strategy and the power exchange calls for the next round.

Table 2. An example of an auction matching scheme of with 5 buyers and sellers each submitting bids and offers.

Bid	Offer	Quantity	Match	Midpoint	Eq.Price
10.91	10.01	1 MW/h	Yes	10.46	10.48
10.76	10.07	1 MW/h	Yes	10.41	10.48
10.74	10.38	1 MW/h	Yes	10.56	10.48
10.26	10.53	1 MW/h	No	N/A	N/A
10.05	10.67	1 MW/h	No	N/A	N/A

Each player updates its strategy according to its own forecasting techniques like load prediction, congested transmission forecast, etc. The players know the outcome of its the past auctions (e.g. contract accepted/rejected), the bid/offer value, the congestion price and the closing price. If the offer was rejected, next time the seller lowers the price, choosing a pricing scheme it believes will bring maximum profit. Accordingly, the buyer bids are higher than the preceding round giving the agent a better chance to get a contract. If the offer was accepted, next time the seller offers a higher price, and the buyer bids are reduced. The players start trading around the previous round's closing price.

### III. EXPERIMENTAL DESIGN

A simple market was modeled with a simple six bus network serving as the transmission system. Two GENCO agents each having three generating units were modeled and are connected to a simple six bus network as shown in Figure 3. GENCO\_1 owns generators G1, G3, and G5. GENCO\_2 owns generators G2, G4, and G5. The model was implemented using C/C++ modules. Separate objects were created for the ICA, traders, and the power exchange. This allowed for quickly and conveniently changing the rules which the separate entities on the market have to follow. Real and reactive power flow was run to calculate the line transmission and the limit on the line from bus 3 to bus 5 was set on 30.0 MW. The ICA minimized the total cost of the amount of electricity sold subject to that line constraint. There was not limit set on the rest of the power lines. The algorithm for calculating the power flow followed the algorithm presented in Wood and Wollenberg [8].

At first both GENCO agents were equipped with similar bidding strategies. At the first step the agents get the closing price from the previous bidding round. Then the sellers set a bidding scheme that would result in a bid slightly below the closing price if all generators were allocated equal amount of power. In a real situation the bids for the separate generators of a particular GENCO would differ from each other due to

numerous reasons like amount of rainfall, current weather conditions, etc. This was modeled by perturbing the bids around an average bid that would be slightly lower (3% in this case) than the closing price from the previous round. In the same fashion the buyers set their bids slightly higher (3% again) than the closing price. After the power was allocated by the ICA and bids/offers matched, if there were no price discovery, the sellers would lower the offers with 1% proportionally. The buyers in the same vein would raise the bids proportionally with 1%. This strategy usually led to price discovery on the 2-nd call at most.

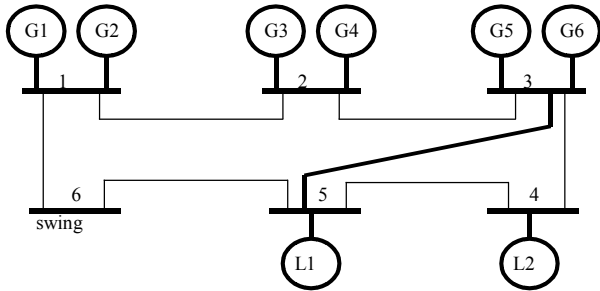


Fig. 3 Network with two GENCOS and two ESCOs.

After the round was completed, the ICA would announce the closing price calculated as the average of the two median prices of the contracts and call for the next round. Meanwhile the sellers would try to “forecast” the demand by repeating step one. The same was valid for the buyers. At first glance two randomly bidding GENCOS against each other do not provide much insight in the market behavior. Eventually, we could include results from previous runs, and employ elaborate forecast techniques, but in that case the model was kept simple. Later in this work it becomes clear that the random “forecast” and also randomizing the bidding scheme is very beneficial in sense that it allows for unbiased checking of different strategies when one of the GENCOS is trying to outsmart the other. Also the routines for determining the bidding strategy could easily be fed with actual data.

The described system fairly quickly reached equilibrium (Fig. 4, a), and the equilibrium price converged to a limiting value. Such seemingly simple market behavior is very similar to what was observed in experimental double auction markets played by people [2, 3]. It can be seen that the initial price remained stable, and each round the market got cleared after the first or second call. The system did not diverge even after simulating a few years of bidding rounds, assuming that each round lasted an hour and players traded fixed amounts of electric power.

#### IV. RESULTS AND DISCUSSION

After building a stable model of the market, simulations were run where one of the GENCOS misbehaved. A simulation was run where GENCO 1 tried to find such pricing schemes so that one of the generators of the other company would get less than 10.0 MW power allocated. Table 3 represents two such solutions. Solutions in most cases were easily found, while in others the pricing scheme of

the other company seemed practically intractable. In the case on Table 3, the targeted generator was G3 of GENCO 2. As we see, although it submitted the lowest bid from all 3 generators, it got almost no power allocated, due to the pricing scheme submitted by the other company.

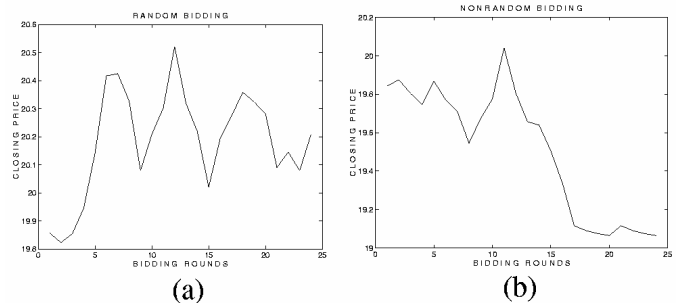


Fig. 4 Closing price as a result of random (a) and non-random (b) bidding after 24 bidding rounds.

Table 3. Two solutions where GENCO 2's generator G3 gets no power.

Solution 1			
GENCO 1	G1	G2	G3
Bid	19.77	19.54	19.65
Power	58.48	17.00	24.51
GENCO 2	G1	G2	G3
Bid	19.74	19.82	19.55
Power	67.70	31.22	1.068
Solution 2			
GENCO 1	G1	G2	G3
Bid	19.97	19.12	19.55
Power	61.94	33.31	4.743
GENCO 2	G1	G2	G3
Bid	19.77	19.64	20.07
Power	85.94	11.35	2.701

During such a bidding strategy, however, the equilibrium price was observed to drop and the equilibrium condition was violated (Fig. 4, b). For example, in the case on Table 3, the closing price dropped from \$20.03/MWh to \$19.41 /MWh in just 5 bidding periods. This was so because in order to get power allocated one of the generators had to consistently bid under the equilibrium price. On the other hand, this led to the need of 2, 3, and sometimes up to 4 bidding cycles to price discovery, depending on how difficult the other bidding scheme was. A way to partially compensate this could be to raise the bids of the other two generators, which was not done in this simulation.

Such behavior is justified in cases where the malicious GENCO may first cut down one of the generators of the other company, then apply pricing schemes which will benefit its own generators, while keeping down the generator of the other GENCO. It would be unprofitable for this GENCO to start-up and shut-down these generators frequently even if it can price it in a way that will ensure power allocation from ICA for a short time.

Another problem that arises is that the solutions are far from optimal. As we can see in Table 3, for both GENCOS the generators submitting the lowest offers get less power allocated than the ones submitting more expensive offers. Which means that such gaming behavior not only would hurt

the CENGO targeted, but also would rise the cost of electricity produced in very short run.

## V. MARKET POWER

Consideration should be given to assessing the market power of each seller. A seller is said to have unilateral market power if a unilateral deviation from a competitive equilibrium is profitable for that seller, given that all other traders continue to use the strategies that generated the competitive equilibrium [4]. The market power in this case is directly proportional to the market share. In a 10 seller market each seller has 10% of the market share, hence 10% market power, given that all sellers trade fixed amounts of electricity and all buyers are willing to buy regardless of the price. In this case both traders had equal market power (50% of the market share) which greatly simplified the modeling of the market and especially the congestion management of the power grid. However, in estimating the market power consideration here should be given to not only the market share of the company but also the information in possession of the company necessary to control a certain share of the market. If the malicious company did not possess information about the pricing schemes of the other company it would be impossible to come up with a solution leading to such devious behavior.

The situation would get complicated if unequal quantities of electricity are traded, if the buyers also have market power, if the number of buyers does not equal the number of sellers and each traded unit of electricity has different characteristics.

## VI. CONCLUSION AND FUTURE WORK

A realistic electric power market of two GENCOs and two consumers was modeled and different simulations were performed to model malicious behavior of one of GENCOs. Different scenarios were worked out and the effect of that behavior was studied.

As a future work, limit should be set on all transmission lines of the power network, and a day ahead and an hour ahead markets should be built. Also, the effect of the congested transmission price and congested transmission market should be taken into account, as well as incremental and decremental bids [1] from GENCOs should be implemented.

## VII. ACKNOWLEDGMENTS

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## IX. BIOGRAPHIES

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