

Identifying the Potential for Market Power in Electric Power Systems in Real-Time

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Abstract

The analysis of recently restructured electric power systems has led to discussions concerning the ability of market participants to manipulate the market to their advantage. Indeed there are instances in which market manipulation has been convincingly established. In this paper we advocate a practical and objective approach to examine market power based on revenue sensitivities. Computing the sensitivities requires only currently available information together with the rules used to operate the electricity market and system. We specifically identify those suppliers with the ability to increase revenues by raising prices or withholding capacity. These suppliers may enjoy some measure of market power since such ability would not be possible in a competitive market in which their generation is easily substitutable. We present a visualization of relevant metrics that have the potential to allow those with the market monitoring function to observe opportunities for market power in real-time. Possible uses for the information are discussed.

1. Introduction

The high and volatile prices observed in some deregulated electricity markets have raised the concerns about abuse of market power by generating firms. The true costs of generation have become private information and are not disclosed by the generating firms to the market operators (e.g. Independent System Operator) except by special request. Therefore, it seems impractical to identify the abuse of market power by comparing the competitive prices and actual prices in deregulated electricity markets. In this paper, we employ an engineering approach to examine market power

based on revenue sensitivities. In a deregulated power system, market power exists when the degree of substitutability for the power generated at a particular zone (node) is low. Withholding capacity and/or raising offers to sell electricity at such zone is a way to exploit market power. If a small number of generating firms (GF) are located in a load-pocket due to transmission line congestion or outages, then any additional power required by the loads within this load-pocket must be provided by these local suppliers. In that case, there will be a reasonable concern that these local firms may exploit market power. In this paper we present a visualization of relevant metrics (revenue sensitivities with respect to offer price changes and to capacity withholdings) to allow those with the market monitoring function to observe opportunities for market power in real-time.

Competitive markets do not require that the participants' costs information become public. If a supplier raises his/her prices above competitive levels (his/her marginal costs), he/she will lose market share. Deregulated electricity markets should work the same way but due to the network topologies (reliability, stability and transmission capacity constraints) and the fact that electric power is not storable, market participants can occasionally gain and exploit market power.

The following is a list of a few standard metrics for measuring market concentration after the market is cleared (ex-post metrics):

1. Hirschman-Herfindahl Indices (HHI): Market shares, S_i ,

are used to determine market concentration: $HHI = \sum_{i=1}^n S_i^2$

HHI critical values:

- $HHI > 1800 \Rightarrow$ highly concentrated market,
- $1000 < HHI < 1800 \Rightarrow$ moderately concentrated market,
- $HHI < 1000 \Rightarrow$ market concentration is not a problem.

Weaknesses: *Opportunities for exerting market power can arise periodically in the short term, even when the HHI does not indicate a high degree of concentration in the market. Care must be taken to recognize instances of local concentration in network constrained areas even when total concentrations seem adequate. Also, there has been some debate about whether market share should be measured in capacity, residual capacity, or dispatch.*

2. Hedge Ratio: Calculates relative volatility of the spot versus forward markets,

$$h = \rho_{sf} \times \frac{\sigma_s}{\sigma_f}$$

where:

ρ_{fs} = Correlation between spot and forward prices,

σ_s = Monthly standard deviation of spot prices,

σ_f = Monthly standard deviation of forward prices.

Weakness: *Not useful for short-term analysis.*

3. Lerner Index on Price Setters:

Compares the Energy Clearing Price (ECP) to the marginal production cost (MC) using forward or spot fuel cost (generally gas). Calculation is performed for each price setter and results are plotted against load:

$$LI = \frac{ECP_t - MC_t}{ECP_t}$$

It examines a generator's behavior when it might anticipate setting price.

The main weakness of all the above-mentioned market metrics is that they are all ex-post metrics. This is due to the atypical characteristics of the electricity markets. In this paper we develop a real-time market monitoring metric. We propose a practical and objective approach to examine market power based on revenue sensitivities. Computing the sensitivities requires only currently available information together with the rules used to operate the electricity market and system. For example, an ISO has the actual supply offers and software tools to solve an AC Optimal Power Flow (OPF) in order to determine the nodal prices (Locational Marginal Prices or LMPs).

2. Problem Statement

In this paper we consider two sensitivity-base metrics, a substitutability measure of revenue/offer-price sensitivity and a withholding measure of

revenue/withholding sensitivity. If one or more suppliers can increase revenues while increasing price or withholding, it is likely that they have market power. In such cases we should flag these suppliers as potentially having market power that might warrant further investigation.

We calculate the revenue/offer-price and revenue/withholding sensitivities using a two-step process. First, we perform an initial detailed optimal power flow (OPF) to establish the operating point dispatches and locational marginal prices (LMPs). Second we construct matrices of sensitivities through subsequent perturbed OPFs. Using the perturbed OPFs we determine the effect of a small perturbation in offer price, and the effect of a small perturbation in quantity of power (withheld) on the GFs' revenues near the system operating point (equilibrium).

To get the sensitivities, recall that revenue is the product of price (λ) and dispatch quantity (q). For GF_{*i*} ($i=1, \dots, ng$) we have,

$$r_i = \lambda_i \cdot q_i \quad (1)$$

To arrive at the revenue price sensitivities we perform standard small perturbation analysis to obtain the following linear relation between the vector of changes in revenue (Δr) to incremental changes in offer price ($\Delta \lambda$):

$$\Delta r = A \cdot \Delta \lambda \quad (2)$$

The elements of matrix A [$ng \times ng$] are the revenue/offer-price sensitivities,

$$a_{ij} = \lambda_i \cdot \left(\frac{\partial q_i}{\partial \lambda_j} \right) \quad i \neq j \quad (3)$$

$$a_{ij} = \lambda_i \cdot \left(\frac{\partial q_i}{\partial \lambda_j} \right) + q_i \quad i = j$$

for $i, j=1, \dots, ng$

Likewise, we perform small perturbation analysis to form a linear relation between the vector of changes in revenue (Δr) to incremental changes in withholding (Δw):

$$\Delta r = B \cdot \Delta w \quad (4)$$

The elements of matrix B [$ng \times ng$] are the revenue/withholding sensitivities,

$$b_{ij} = \lambda_i \cdot \left(\frac{\partial q_i}{\partial w_j} \right) + q_i \cdot \left(\frac{\partial \lambda_i}{\partial w_j} \right) \quad (5)$$

for $i, j=1, \dots, ng$

Now we seek individuals or groups of generators that can increase revenues by increasing prices or practicing withholding. For example, a group of two generators, say 5 and 6, have mutual market power (potential) if:

$$\begin{bmatrix} \Delta r_5 \\ \Delta r_6 \end{bmatrix} = \begin{bmatrix} a_{55} & a_{56} \\ a_{65} & a_{66} \end{bmatrix} \times \begin{bmatrix} \Delta \lambda_5 \\ \Delta \lambda_6 \end{bmatrix} > 0, \text{ for } \Delta \lambda_5, \Delta \lambda_6 > 0 \quad (6)$$

and/or

$$\begin{bmatrix} \Delta r_5 \\ \Delta r_6 \end{bmatrix} = \begin{bmatrix} b_{55} & b_{56} \\ b_{65} & b_{66} \end{bmatrix} \times \begin{bmatrix} \Delta w_5 \\ \Delta w_6 \end{bmatrix} > 0, \text{ for } \Delta w_5, \Delta w_6 > 0 \quad (7)$$

These conditions ensure that in the absence of actions by other suppliers, generators 5 and 6 can both increase revenues by non-competitive behavior, raising prices or withholding capacity. If a single firm owns both generators, then it is only necessary that the sum of revenue increases is positive; that is,

$$\Delta r_5 + \Delta r_6 = [(a_{55} + a_{65}) \quad (a_{65} + a_{66})] \times \begin{bmatrix} \Delta \lambda_5 \\ \Delta \lambda_6 \end{bmatrix} > 0 \quad (8)$$

and/or

$$\Delta r_5 + \Delta r_6 = [(b_{55} + b_{65}) \quad (b_{65} + b_{66})] \times \begin{bmatrix} \Delta w_5 \\ \Delta w_6 \end{bmatrix} > 0 \quad (9)$$

We should note that these conditions are not sufficient to declare conclusively that these generators have market power. It may be possible that these actions may cause a reaction by the other suppliers to eliminate these gains. Nevertheless, the conditions are sufficient to identify generators that warrant market power investigation.

3. Numerical Example

In this section we present the applicability of the developed market metrics through a numerical example. Our market simulation environment is the POWER WEB software [4, 5]. For our example we use the IEEE 30-bus power system with six generators shown in figure 1.

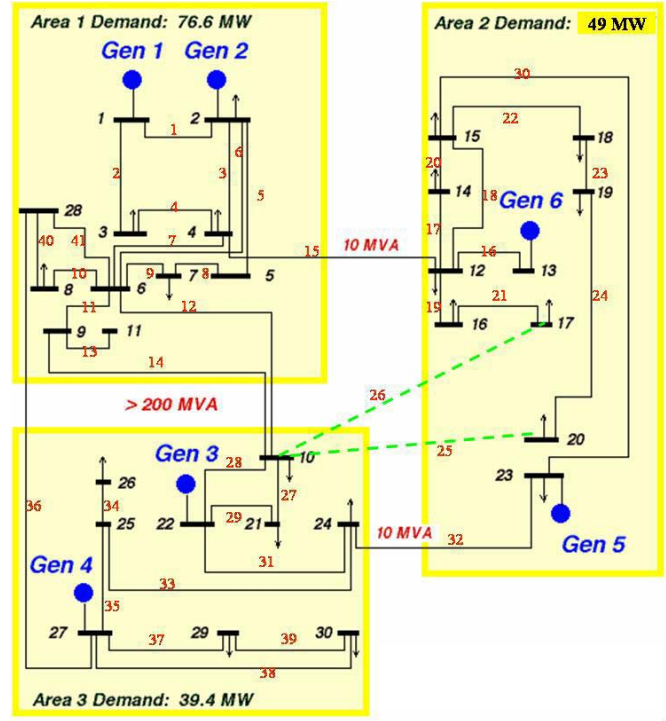


Figure 1. IEEE 30-bus, 6-generator power system

Each generator has a capacity of 60 MW which is offered into the market in three blocks. Marginal cost based block offers (our base case) for generators 1-4 comprise a 12 MW block at 20 \$/MWh, a 24 MW block at 40 \$/MWh, and a 24 MW block at 50 \$/MWh. Generators 5 and 6 are more expensive with marginal cost based blocks of 12 MW at 45 \$/MWh, 24 MW at 55 \$/MWh, and 24 MW at 60 \$/MWh. A uniform price auction is assumed.

The two tie lines that connect Zone2 to Zone1 (branch 15) and Zone3 (branch 32) have thermal capacity limits of 10 MVA each. With these assumptions, we run the first (base case) AC-OPF for the marginal cost based block offers to obtain the nodal prices (LMPs) and also the system operating points (equilibrium). In order to compute the market monitoring metrics (for substitutability and withholding) we run the second OPF by perturbing the generators' offer prices and quantities one at a time. We consider three generating firms competing with each other to sell electric power in the market. Firm 1 owns generators 1 and 2 (in Area-1), Firm 2 owns generators 3 and 4 (in Area-3), and Firm 3 owns generators 5 and 6 (in Area-2).

For each firm we calculate directed forms of our sensitivity metrics assuming firm-uniform perturbations:

$$\begin{aligned}
 m_{1\lambda} &= (a_{11} + a_{12} + a_{21} + a_{22}) \\
 m_{1w} &= (b_{11} + b_{12} + b_{21} + b_{22}) \\
 m_{2\lambda} &= (a_{33} + a_{34} + a_{43} + a_{44}) \\
 m_{2w} &= (b_{33} + b_{34} + b_{43} + b_{44}) \\
 m_{3\lambda} &= (a_{55} + a_{56} + a_{65} + a_{66}) \\
 m_{3w} &= (b_{55} + b_{56} + b_{65} + b_{66})
 \end{aligned} \tag{10}$$

In the visual display to follow, we color code the values of the metrics based on the scale shown in Table 1.

Table 1. Market metric ranges and their color codes

Market Metric Range	Color code
$mm < -500$	Blue
$-500 \leq mm < -1$	Cyan
$-1 \leq mm < 0$	Green
$0 \leq mm < 1$	Yellow
$1 \leq mm < 20$	Orange
$mm \geq 20$	Red

In order to present the metrics, voltages, and transmission lines flows, we developed the four-panel display shown in Figure 2 (page 6). In the upper left-hand quadrant the display shows the market metrics by firm and type (substitutability and withholding). For these system conditions, Firm 3 appears to have strong potential for market power in both withholding and price. Firm 1 also appears to have potential market power that deserves investigation. In the upper right hand quadrant we overlay the system plot with a color contour of LMPs. The displayed nodal prices do not indicate significant exercise of market power, which is not surprising since this base used marginal cost based block offers. There are some evident differences in prices related to the more expensive generators 5 and 6. Given their market power potential, they should be able to raise prices and increase revenues. This has been confirmed by experimental economic studies, in a few iterations, subjects representing generators 5 and 6 recognize and exploit their market power [1,2]. The lower left-hand quadrant shows a bar graph of bus voltages. The bars are color coded by the shadow price to relieve voltage levels from limits. Likewise the display in the lower right-hand quadrant shows the line flows relative to their limits and is colored related to the shadow price to relieve the capacity constraint. Note the two capacity limited lines effective create a load pocket in Area 2.

In figure 3 (page 7) we show the dynamics of the developed market power metrics versus system load.

We have simulated the electricity market for 24 rounds with a sinusoidal load profile (with average load of 164.8 MWh). It can be seen from figure 6b that at the 145 MWh system load, both tie lines (15 & 32) are congested. If we examine the substitutability metrics at this load (figure 6c), we will see that Firm 3's substitutability metric (red line) goes above zero at this load level and stays positive for all loads above 145 MWh. Figure 6d shows that at 130 MWh load level, Firm 3's withholding metric (red line) goes above zero and grows fast (positively) for all loads above 130 MWh. These figures (6c & 6d) confirm that in the power system under study (figure 4) generators 5 and 6 are non-substitutable at 145 MWh load level (and higher) therefore, Firm3 has market power at 145 MWh and above. These figures also suggest that Firms 1 and 2 may also have market power potential for certain operating conditions, and these conditions may deserve further investigation. It is worth noting that the metrics suggest that the system becomes vulnerable to withholding strategies at lower load levels than for offer price manipulation.

4. Conclusion

In this paper we proposed a practical and objective approach to examine market power based on revenue sensitivities. We showed that computing the sensitivities requires only currently available information together with the rules used to operate the electricity market and power system. We also presented a possible visualization of the developed metrics (revenue/offer-price and revenue/withholding sensitivities) in real-time.

Through a numerical example (IEEE 30 bus, 6 generator power system) we identified power suppliers with the ability to increase revenues by raising prices (or withholding capacities) in the market. Clearly these suppliers enjoy some measure of market power since such ability would not be possible in a competitive market in which their generation is easily substitutable.

With the aid of the developed market power metrics in this paper, electricity market operators (e.g. ISOs) can monitor these markets in real-time and investigate the non-competitive behaviors of the generating firms for further actions.

5. References:

- [1] C. Murillo-Sanchez, S. Ede, T. Mount, R. Thomas, R. Zimmerman, "An Engineering Approach to Monitoring Market Power in Restructured for Electricity", *Proceedings of the 24th Annual International Conference, International Association for Energy Economics*, April 2001, Houston, TX, USA.

[2] B.C. Lesieutre, R. Thomas, T. Mount, "Identification of Load Pockets and Market Power in Electric Power Systems", *Proceedings of the IEEE-PES Summer Meeting*, July 2003, Toronto, Ontario, Canada.

[3] Ali Keyhani, Ashkan Kian, Jose Cruz, Jr., Marwan A. Simaan, "Market monitoring and control of ancillary services", *Journal of Financial Economics, Decision Support Systems*, Vol. 30, No. 3, Jan. 2001, pp. 255-267.

[4] R. Zimmerman, R. Thomas, D. Gan, C. Murillo-Sanchez, "An Internet-Based Platform for Testing Generation Scheduling Auctions", *Proceedings of the 31st Hawaii International Conference on System Sciences*, Jan. 1998, Kona, Hawaii.

[5] R. Zimmerman, R. Thomas, D. Gan, C. Murillo-Sanchez, "A Web-Based Platform for Experimental Investigation of Electric Power Auctions", *Journal of Financial Economics, Decision Support Systems*, Vol. 24, No. 3 & 4, Jan. 1999, pp. 193-205.

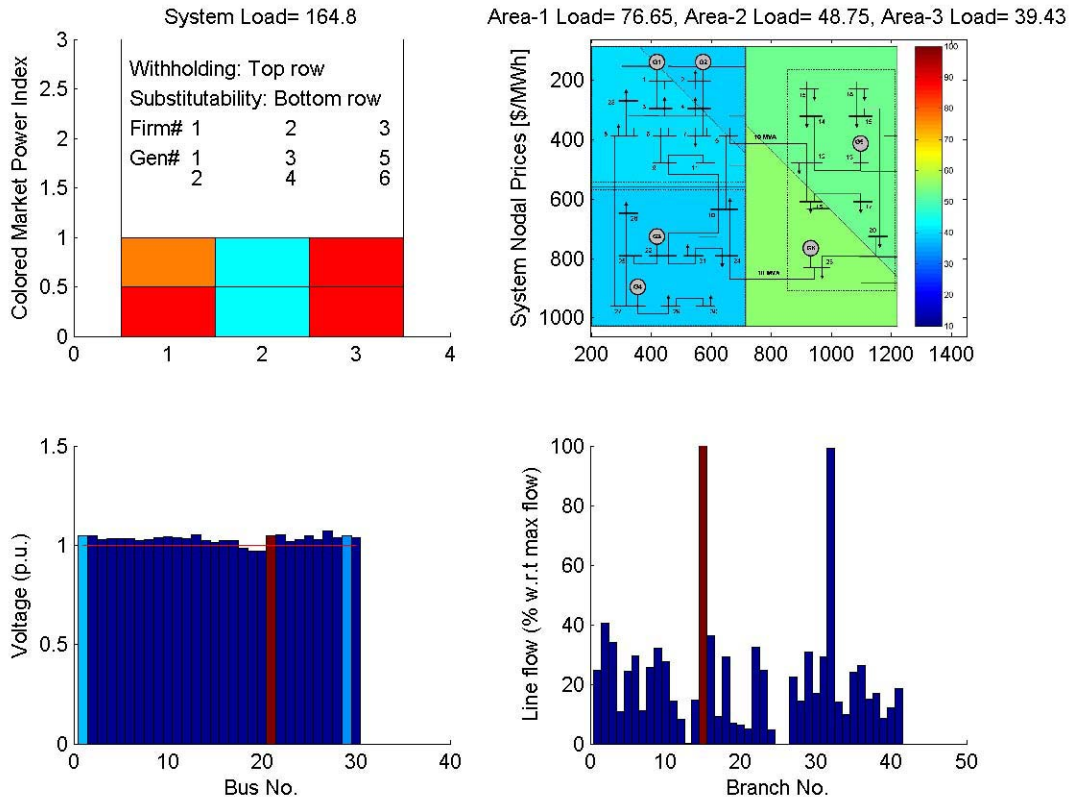


Figure 2. Power market simulation results for a system load of 164.8 MW.

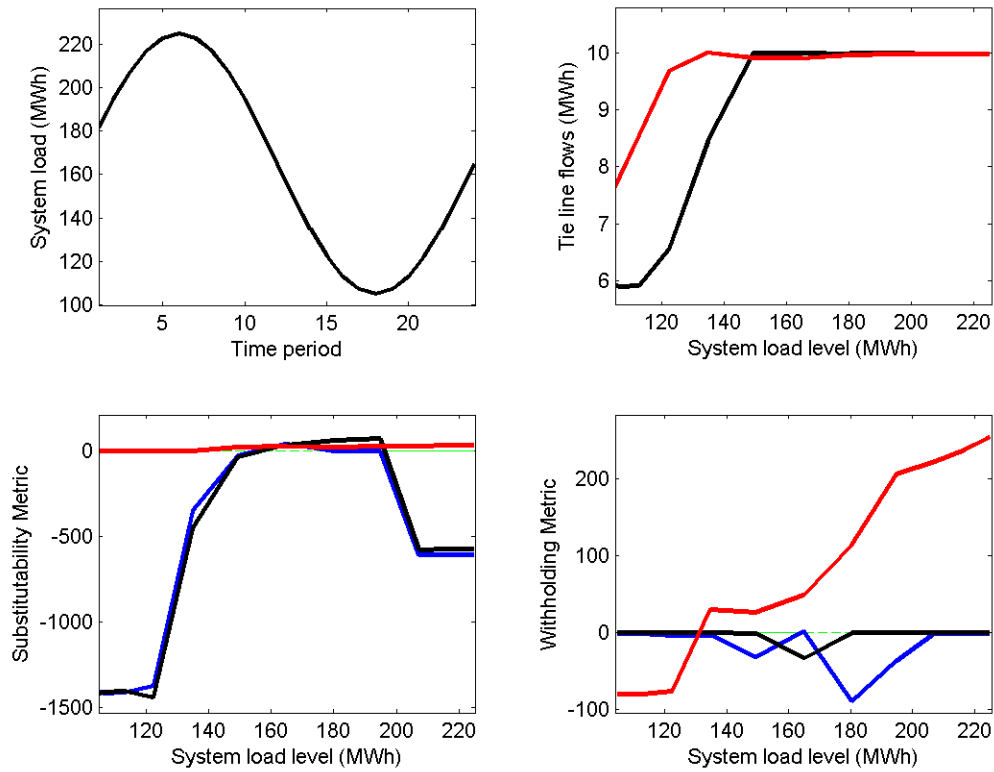


Figure 3. Dynamics of market power metrics

3a (top left): System load vs. time period [MWh]

3b (top right): Branch 15 flow (black) and Branch 32 flow (red) vs. system load [MWh]

3c (bottom left): Substitutability metric vs. system load, GF1 (blue), GF2 (black), GF3 (red)

3d (bottom right): Withholding metric vs. system load, GF1 (blue), GF2 (black), GF3 (red)