Transmission Reliability Program Review

Market Monitoring Tools

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Overview

Approach: Revenue sensitivity approach to identify market participants with market power potential.

2003 Technical Work:

- **Extend sensitivity analysis to consider "withholding."**
- **Take into account generation ownership by firm.**
- **Enhanced visualization of market power metrics.**
- **Publication and presentation of results.**

2003 Papers and Presentations

Papers

- "A Revenue Sensitivity Approach for the Identification and Quantification of Market Power in Electric Energy Markets," B.C. Lesieutre, R.J. Thomas, and T.D. Mount, IEEE Power Engineering Society General Meeting, Toronto, CA, July 2003.
- "Real-time Monitoring of Electricity Markets," A. Kian, R.J. Thomas, R. Zimmerman, B.C. Lesieutre, T.D. Mount, 37th Annual Hawaii International Conference on System Sciences, January 2004.
- "Identification of Load Pockets and Market Power in Electric Power Systems", B. C. Lesieutre , R. J. Thomas, T. D. Mount, to appear in the Elsevier Journal on Decision Support Systems Special Issue on Competitive Electricity Markets.

2003 Papers and Presentations

Presentations

1. EIA, January 2003
2. FERC, April 2003
3. MIT, April 2003
4. NYISO, May 2003
5. CAISO, May 2003
6. ESCA, June 2003
7. CAISO, June 2003
8. IEEE PES, July 2003
9. HICSS, January 2004

Market Power: Substitutability

"Market power is the ability to raise prices above the competitive level." (FERC SMD §393)

Market power boils down to the issue of

substitutability

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Electric markets are:

1. **Dynamic in that they are repeated hourly, daily, monthly, etc. so learning takes place**

2. **Enabled by a network that obey laws of physics, not economic incentives**

3. **Necessarily incomplete so that some monitoring and mitigation is necessary**

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On the supply-side

Non-substitutable $\Leftrightarrow$ must-run

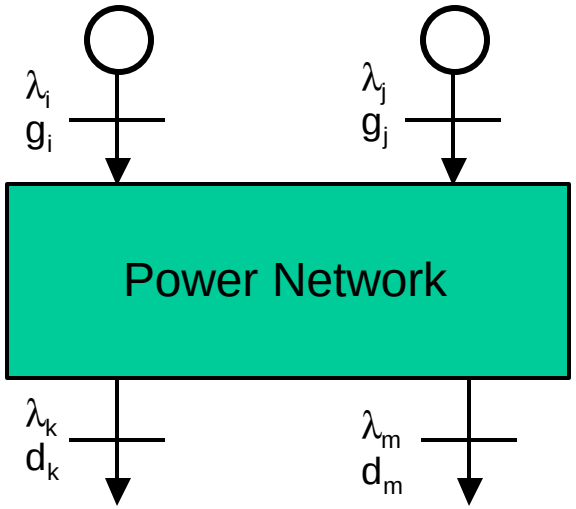
e.g.,

a. **Must-run on load (load pocket, line-flow constraint)**
b. **Must-run on Var's (engineering constraint)**
c. **Must-run on reserves (contingency constraint)**

Create/exploit market by

- **Locational advantages**
- **Witholding**
- **Strategic offers**

A Typical Power System

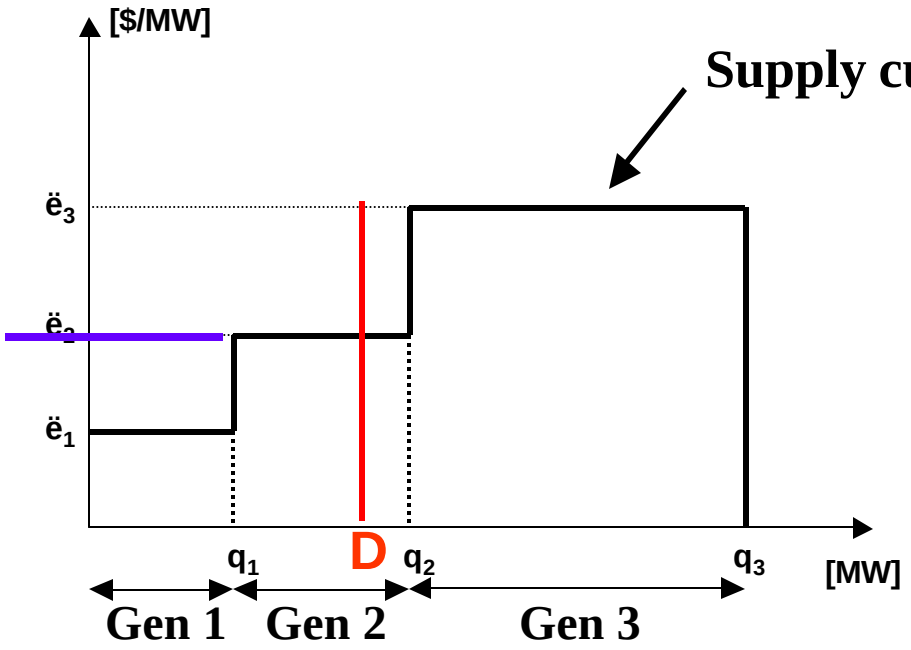


Revenue for Gen_i : $R_i=\lambda_i x g_i$

Payment by LSE_k : $P_k=\lambda_k x d_k$

Consider a uniform-pricing market clearing mechanism – inelastic demand

λ_2 = Market clearing price (MCP)

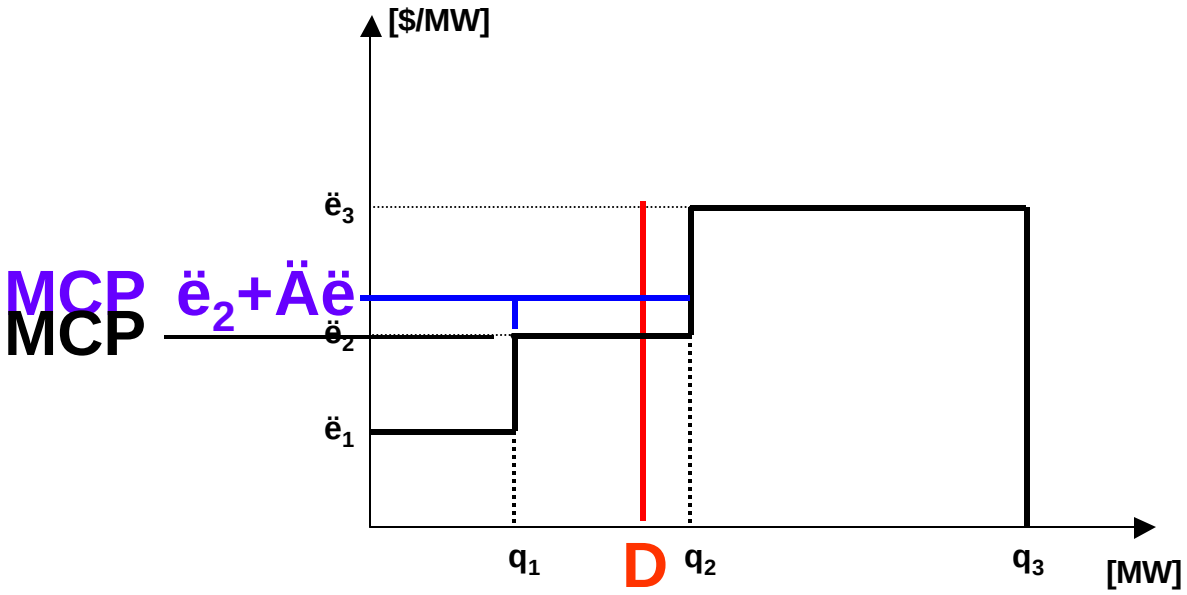


D=Market Demand

Substitutability

Gen 2 can increase MCP by increasing offer price.

So can Gen 1.



Gen_1: $\Delta R_1 = q_1 \cdot \Delta l > 0$

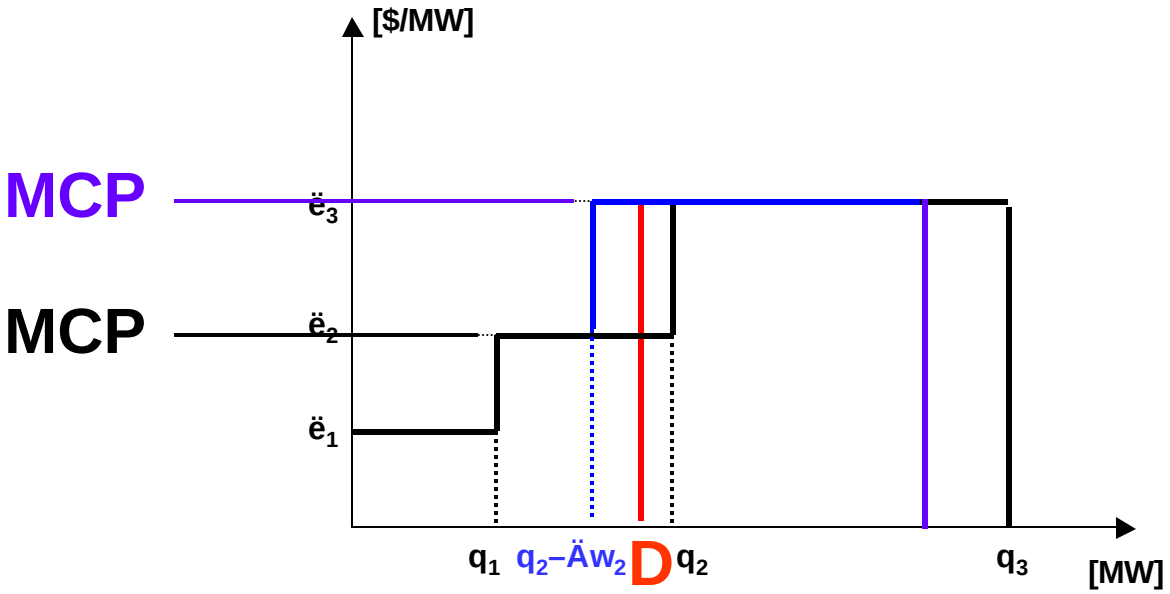
Gen_2: $\Delta R_2 = (D - q_1) \cdot \Delta l > 0$

Gen_3: $\Delta R_3 = 0$

Withholding

Gen 2 can increase MCP by withholding supply.

So can Gen 1.



Gen_1: $\Delta R_1 = q_1 \cdot (l_3 - l_2) > 0$

Gen_2: $\Delta R_2 = (q_2 - \Delta w_2 - q_1) \cdot l_3 - (D - q_1) \cdot l_2$

Gen_3: $\Delta R_3 = \Delta w_2 \cdot l_3 > 0$

Revenue Sensitivity Approach

Revenue/Offer-price sensitivity computation

$$a_{ij} = l_i \cdot \left(\frac{\partial q_i}{\partial l_j} \right) + q_i \cdot \left(\frac{\partial l_i}{\partial l_j} \right)$$

For i,j=1,…,ng

$$\Delta r = A \cdot \Delta l$$

Revenue/Withholding sensitivity computation

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

For i,j=1,…,ng

$$\Delta r = B \cdot \Delta w$$

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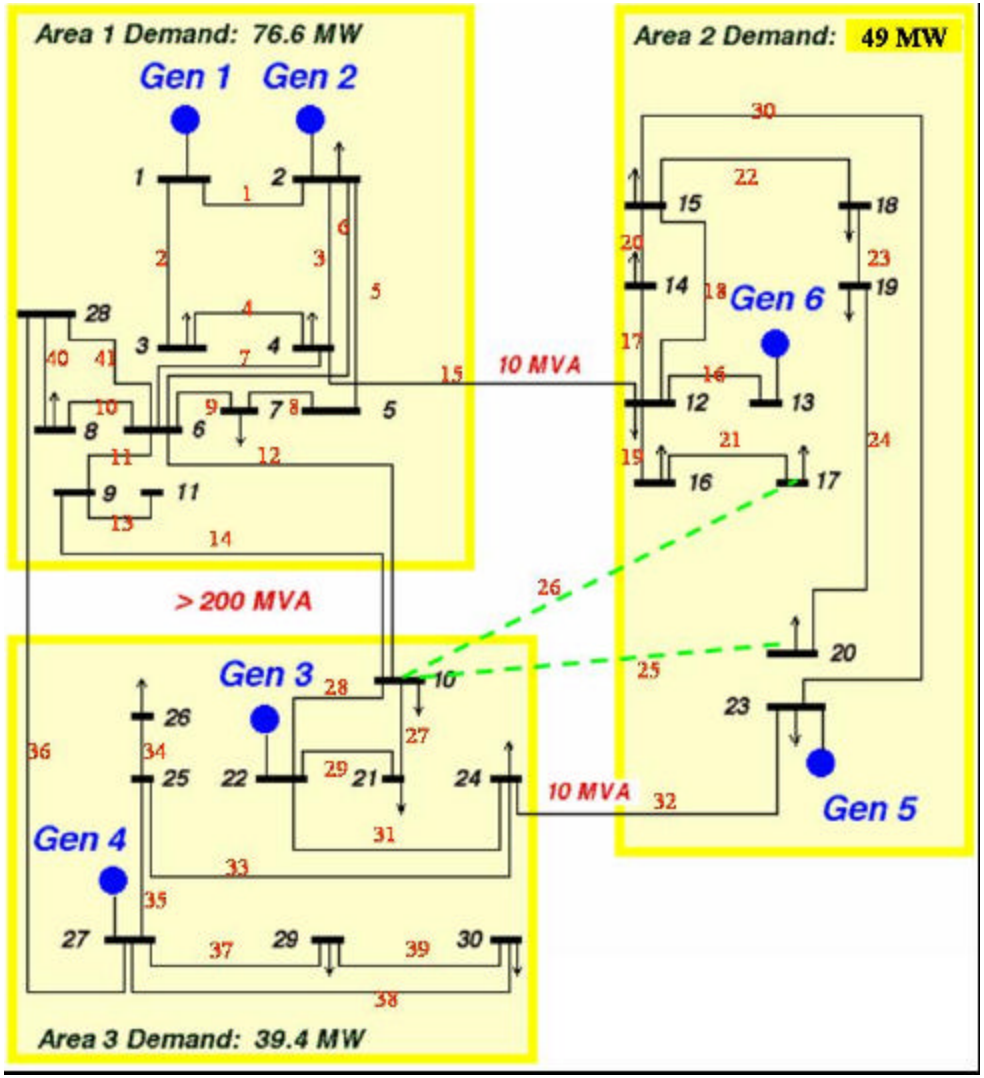
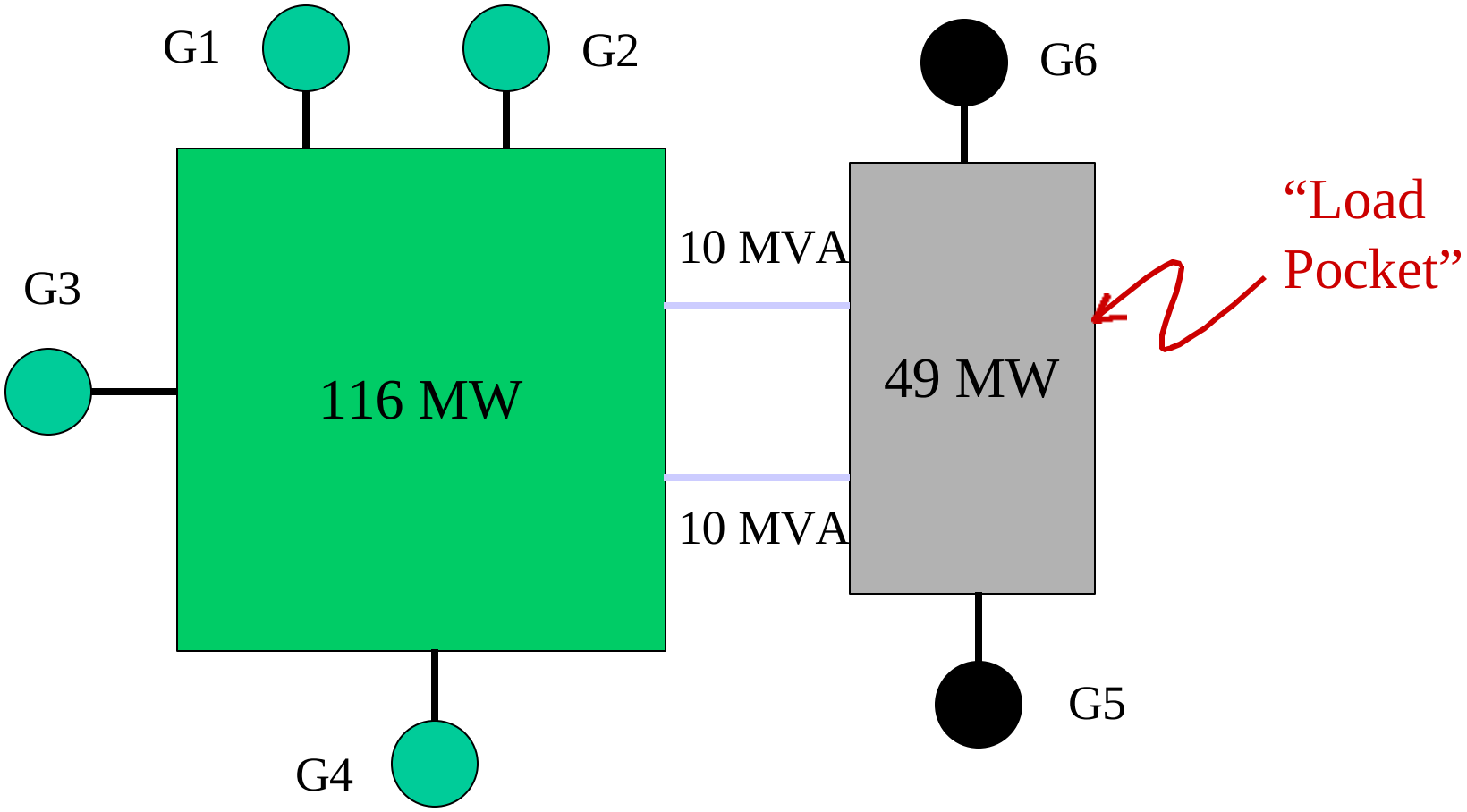
Observations

1. **Sensitivities are operating point dependent. Therefore, one outcome is that a unit or group of units may have market power for certain operating conditions and not others.**
2. **If a firm owns two units it could withhold the output of one unit in order to provide increased revenue for the pair under, say, certain load conditions.**
3. **Network constraints are captured by the sensitivities**

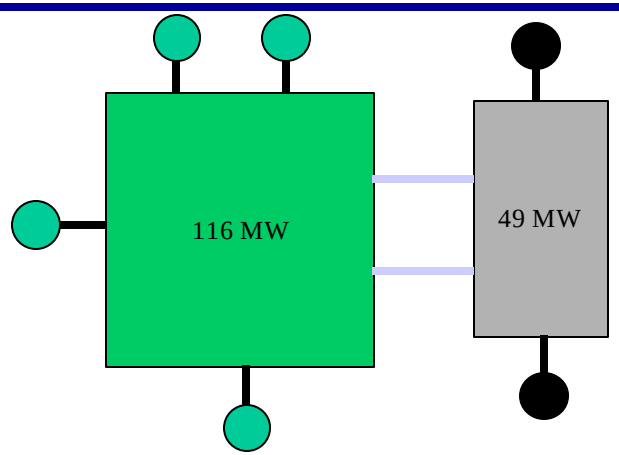
Numerical Example



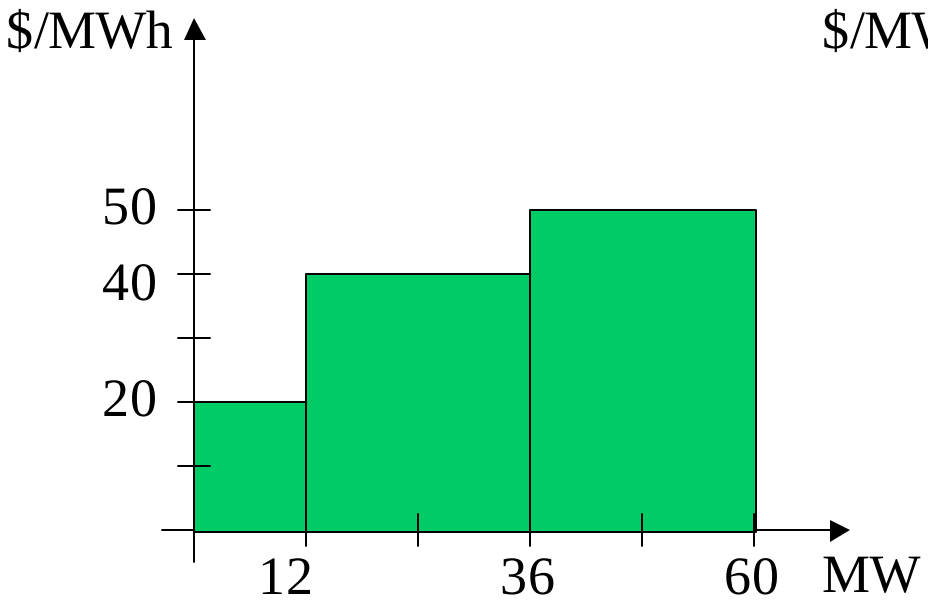
Six Supplier Example (Market Power)



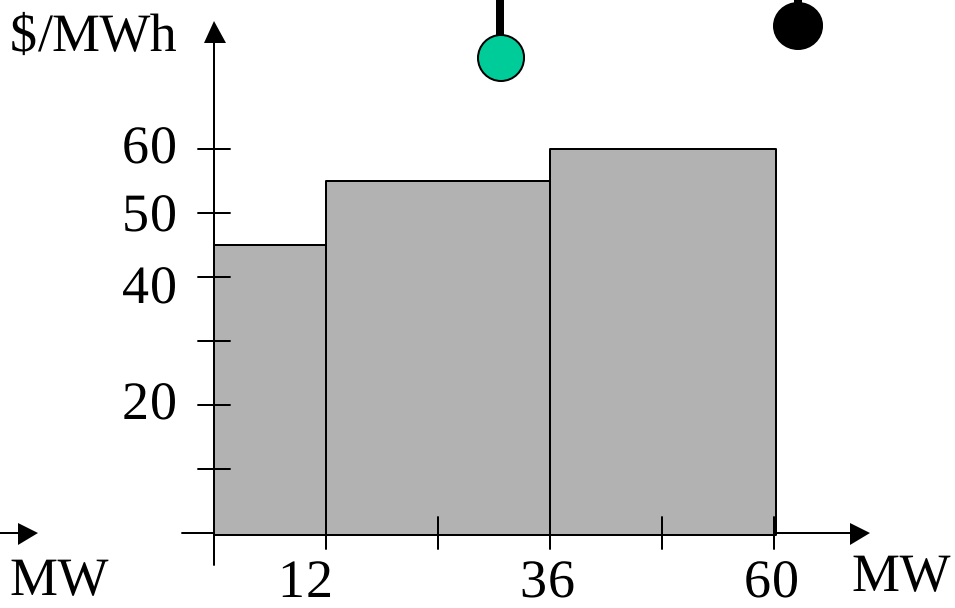
Six Supplier Example (Market Power)



Competitive Offers:



Generators 1-4



Generators 5-6

Higher to create load pocket

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Results (75 round experiment)

Competitive Solution

	G1	G2	G3	G4	G5	G6
Dispatch (MW)	31.7	36.0	34.0	36.0	17.6	12.0
Price ($/MWh)	40.0	40.1	40.0	40.1	55.0	54.3

Actual Experiment*

* 80 $/MWh price cap

	G1	G2	G3	G4	G5	G6
Dispatch (MW)	37.9	34.9	30.1	34.9	14.9	14.6
Price ($/MWh)	48.5	48.7	48.5	48.6	72.0	70.0

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Results: Experiment

Generators in the load pocket were able to raise prices well above competitive levels (and would have increased them further with a longer experiment).

Matrix of Revenue/Offer Sensitivities

Competitive solution

$$\begin{bmatrix} \Delta r_1 \\ \Delta r_2 \\ \Delta r_3 \\ \Delta r_4 \\ \Delta r_5 \\ \Delta r_6 \end{bmatrix} = \left[\begin{array}{cccc|cc} -3298 & 3231 & 31 & 65 & 52 & -49 \\ 3219 & -3695 & 244 & 263 & 315 & -310 \\ 31 & 244 & -544 & 308 & -234 & 229 \\ 65 & 263 & 307 & -597 & -127 & 125 \\ \hline 38 & 230 & -170 & -93 & -160 & 173 \\ -36 & -229 & 169 & 92 & 175 & -159 \end{array}\right] \begin{bmatrix} \Delta l_1 \\ \Delta l_2 \\ \Delta l_3 \\ \Delta l_4 \\ \Delta l_5 \\ \Delta l_6 \end{bmatrix}$$

Observations:

- If any supplier, acting alone, raises its (offer) price, that supplier will lose revenue.
- If all suppliers, acting together, raise (offer) prices, everyone's revenue increases.

Matrix of Revenue/Offer Sensitivities

Competitive solution

$$\begin{bmatrix} \Delta r_1 \\ \Delta r_2 \\ \Delta r_3 \\ \Delta r_4 \\ \Delta r_5 \\ \Delta r_6 \end{bmatrix} = \left[\begin{array}{cccc|cc} -3298 & 3231 & 31 & 65 & 52 & -49 \\ 3219 & -3695 & 244 & 263 & 315 & -310 \\ 31 & 244 & -544 & 308 & -234 & 229 \\ 65 & 263 & 307 & -597 & -127 & 125 \\ \hline 38 & 230 & -170 & -93 & -160 & 173 \\ -36 & -229 & 169 & 92 & 175 & -159 \end{array}\right] \begin{bmatrix} \Delta l_1 \\ \Delta l_2 \\ \Delta l_3 \\ \Delta l_4 \\ \Delta l_5 \\ \Delta l_6 \end{bmatrix}$$

Observations:

• If the load pocket generators (5 and 6) raise their (offer) prices together, *their own revenues increase* with almost no effect on the revenue of others.

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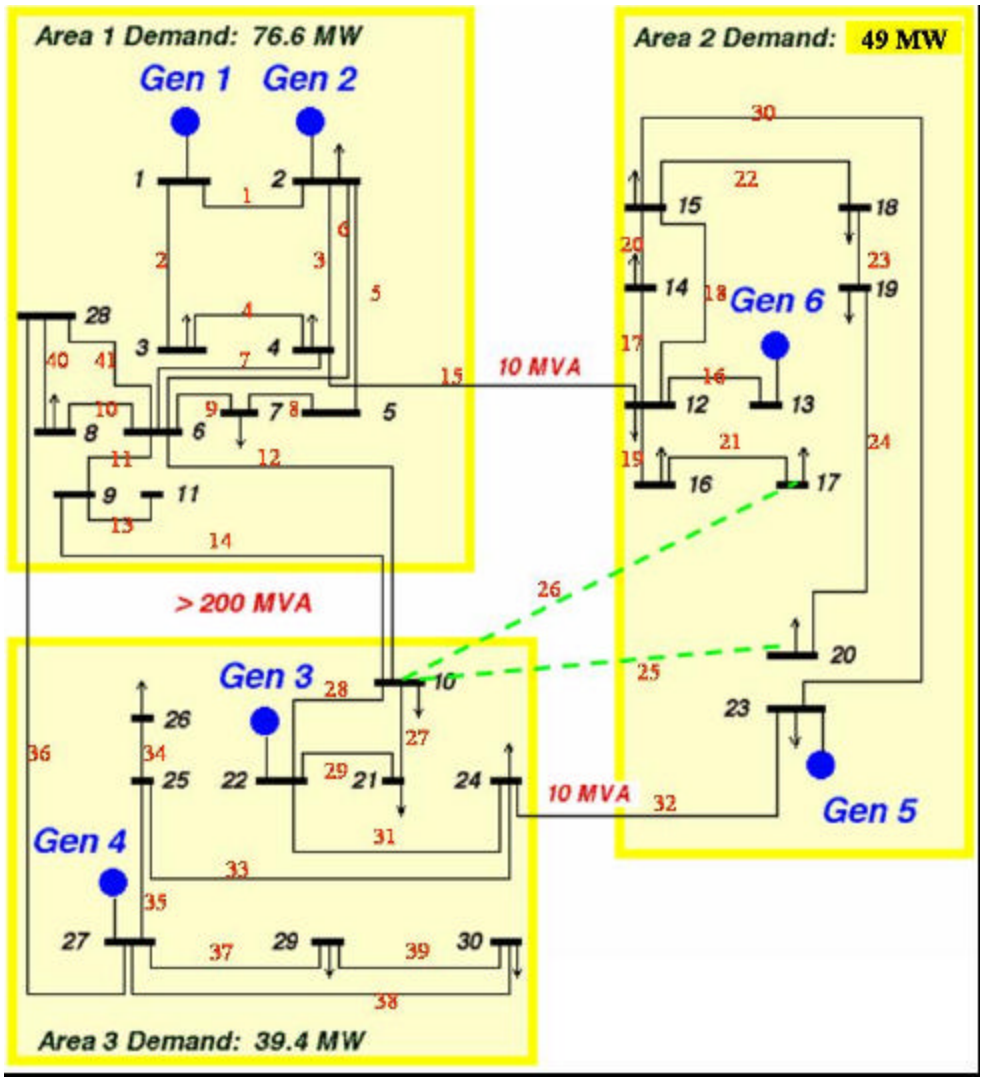
Load Pocket Market Power

Generators 5 and 6 have the potential to exercise market power when the load is above 145MW

Experiments show that they do exploit this potential.

Market Power Opportunities for Firms

Firm 1



Firm 2

Firm 3

Group Generators into Firms

$$\begin{bmatrix}\Delta r_5\\ \Delta r_6\end{bmatrix}=\begin{bmatrix}a_{55} & a_{56}\\ a_{65} & a_{66}\end{bmatrix}\times\begin{bmatrix}\Delta l_5\\ \Delta l_6\end{bmatrix}>0 \qquad \text{For } \Delta l_5,\ \Delta l_6 > 0$$

Generators 5 and 6 belong to the same firm.

$$\begin{bmatrix}\Delta r_5\\ \Delta r_6\end{bmatrix}=\begin{bmatrix}b_{55} & b_{56}\\ b_{65} & b_{66}\end{bmatrix}\times\begin{bmatrix}\Delta w_5\\ \Delta w_6\end{bmatrix}>0 \qquad \text{For } \Delta w_5,\ \Delta w_6 > 0$$

$$\Delta r_5+\Delta r_6=\begin{bmatrix}(a_{55}+a_{65}) & (a_{65}+a_{66})\end{bmatrix}\times\begin{bmatrix}\Delta l_5\\ \Delta l_6\end{bmatrix}>0$$

Firm revenue/offer sensitivity

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

Firm revenue/withholding sensitivity

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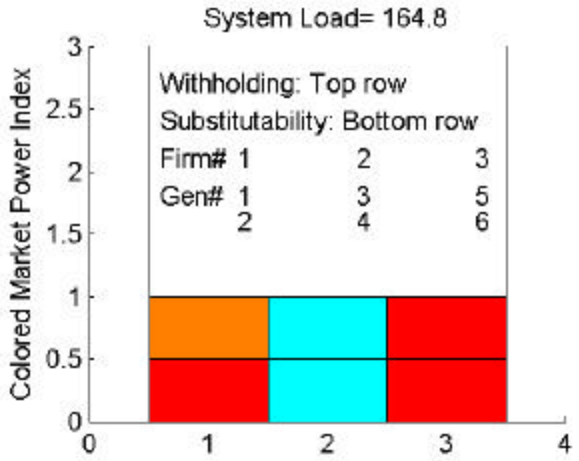
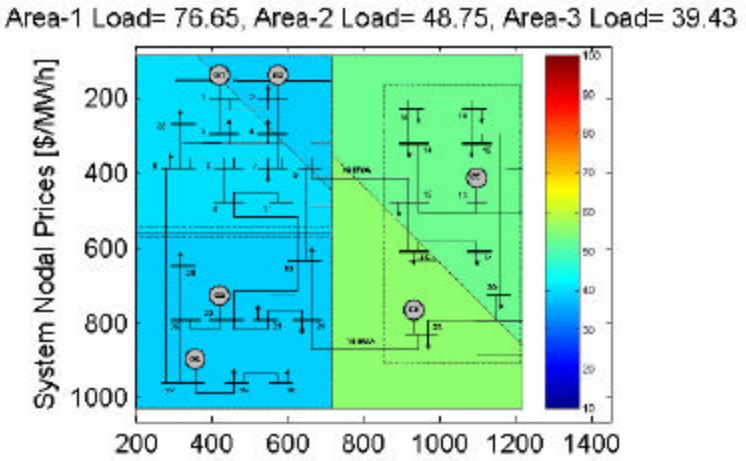
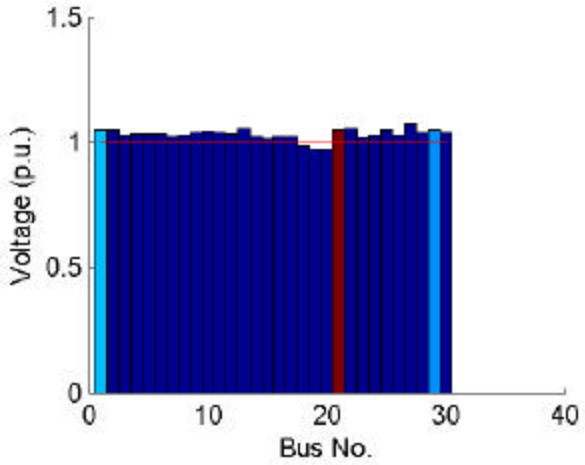
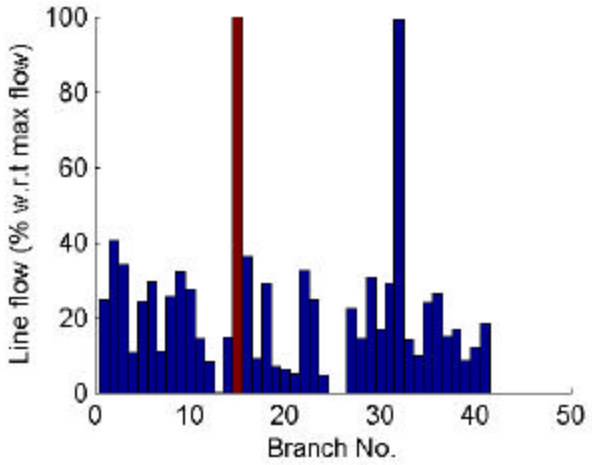
Visualization of Market Simulation Results









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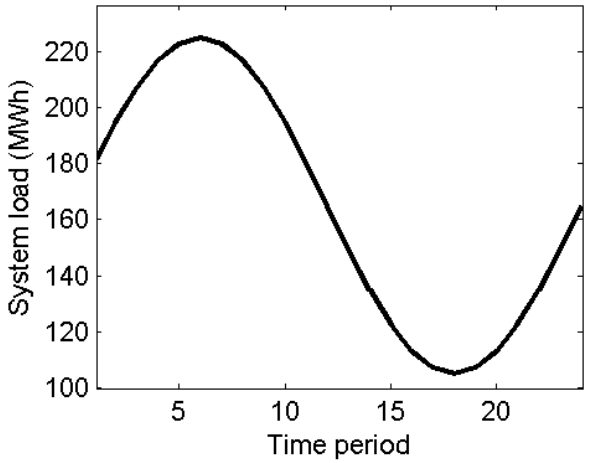
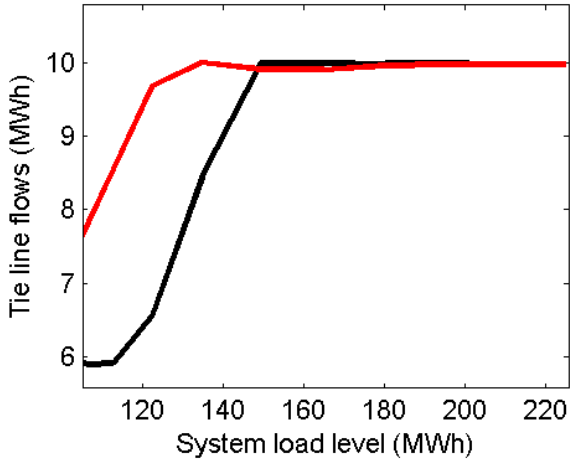
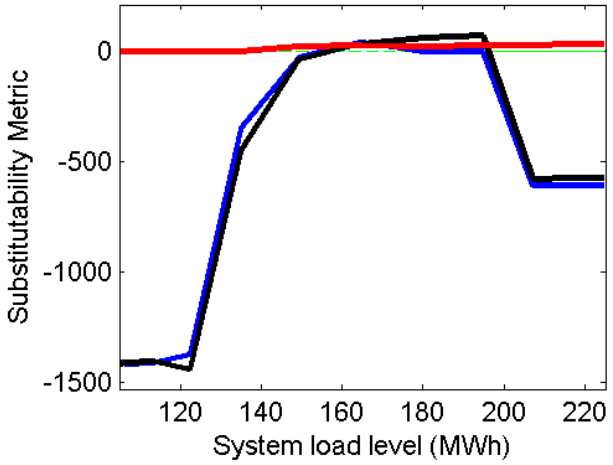
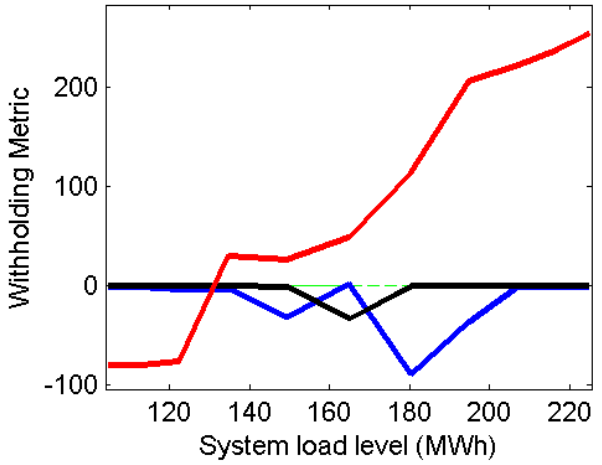
Market Power Metrics





Red-branch 15
Black – branch 32





Blue – Firm1
Black- Firm2
Red - Firm3

Note

Firm 3's (generators 5 and 6) withholding metric (red line) goes above zero and grows fast (positively) for all loads above 130 MW. Firm 3 generators are non-substitutable for load levels of 145 MW (and higher). Firm 3 appears to have strong potential for market power in both withholding and price.

Firms 1 and 2 have market power potential for certain operating conditions based on voltage congestion (limits).

The metrics suggest that the system becomes vulnerable to withholding strategies at lower load levels than for offer price manipulation.

The nodal prices shown for the example do not indicate significant exercise of market power, which is not surprising since marginal cost offers were used.

Conclusions

- Practical real-time sensitivity-based metrics that accounts for the network
- Computing sensitivities requires only currently available information together with the rules used to operate the electricity market and power system,
- Visualization of the metrics is needed for Real-time Monitoring of Electricity Markets

Future Work

- Apply this analysis to large system models (eg. MISO).
- Application of this market monitoring technique to real bulk power markets (i.e. New York power system), by Integrating into real-time monitoring tools being developed by CERTS
- Development of market monitoring metrics for two-sided markets.
- Examine several metrics derived from the price/revenue sensitivities (e.g., eigenvalues, max singular value, RMP, others)
- Apply a visualization of the metrics to PowerWeb and monitor them during experiments

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