

Locational Pricing and Scheduling for an Integrated Energy-Reserve Market

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Outline

- Background
- The framework for locational scheduling and pricing --- co-optimization
- Results
- Ongoing and future work

Introduction



- Ancillary Services (AS)

“Services necessary to support the transmission of Energy from generators to loads, while maintaining reliable operation of the power system in accordance with good utility practice and reliability rules.”
[NYISO]

- AS includes
 - Reactive Supply and Voltage Support Service
 - Black Start Capability
 - Frequency Response Service
 - Operating Reserve Service (traded in the wholesale market)

Introduction (Cont.)

- Operating Reserve Markets (e.g., CA, NY, NE Electricity Market)
 - Regulation (AGC, load following)
 - 10-min spinning reserves
 - 10-min non-spinning reserves
 - 30-min non-spinning reserves
- Fixed Reserve (FR) Requirements
 - A given percentage of forecasted peak load
 - To be able to make up the loss of the largest unit
 - Combinations of both

FR Market Examples



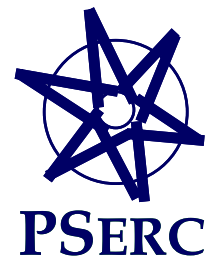
□ NYISO locational reserve requirement

http://www.nyiso.com/oasis/misc_pdf/nyiso_locational_reserve_reqmts.pdf

Table 2
Revised NYISO Reserve Requirements

	New York CA	Eastern New York	Long Island
Western=NY CA- Eastern-Long Island	A = most severe NYCA operating capability loss (1200MW)		
10 Minute Spinning Reserve	$\frac{1}{2}$ A = 600MW (I)	$\frac{1}{4}$ A = 300MW (IV)	$\frac{1}{20}$ A = 60MW (VII)
10 Minute Total Reserve	A = 1200MW (II)	1200MW (V)	$\frac{1}{10}$ A = 120MW (VIII)
30 Minute Reserve	$1\frac{1}{2}$ A = 1800MW (III)	1200MW (VI)	270-540MW (IX)

FR Market Examples (Cont.)



- ❑ PJM spinning reserve requirement (plan to enforce Dec. 2002)

The screenshot shows a web browser window with the address <http://www.pjm.com>. The PJM logo is in the top left corner. A vertical navigation menu on the left includes links for Home, Updated, Search, Who We Are, Energy Prices, Manuals & Documents, Committees, PJM Training, Emergency Conditions (marked with a red 'URGENT!' banner), Business eTools, PJM FERC Documents, and Contact. The main content area is titled 'Spinning Reserve Requirement' and contains a bulleted list of requirements. The third bullet point, 'MAAC Spinning Requirement', is circled in red and includes a sub-bullet '75%' which is also circled in red. The browser's status bar at the bottom shows 'Done' and 'Internet'.

Address <http://www.pjm.com>

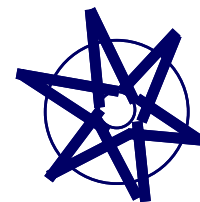
Spinning Reserve Requirement

- PJM Spinning Requirement is determined in whole MW for each hour of the operating day
- Defined as synchronized reserve that can be loaded in 10 minutes
- **MAAC Spinning Requirement**
 - **75%** of largest system contingency
 - Provided that double of the remaining 25% is available as non-synchronized 10 minute reserve
 - Additional reserves may be committed based on system conditions
 - Transfer limits
 - Conservative Operation

FR Market Cons

- Cons
 - Over-estimation of actually needed reserves
 - Actual reserves may not be locationally assigned as desired.
 - Consequences
 - Resources wasting: redundant reserves
 - Increased operating costs: some contingencies may not be covered but should have to, resulting in expensive solutions (expensive imports needed)
 - Potential market power problems: reserves in the load pocket

Proposed Market Alternative – Responsive Reserve (RR) Market



- No fixed forecasted reserve requirement
- Reserves required will cover a list of credible contingencies (unit failure, line-out, sudden load growth, etc.)
- The amount of reserves assigned varies with different system demands and energy-reserve offers – Responsive Reserves

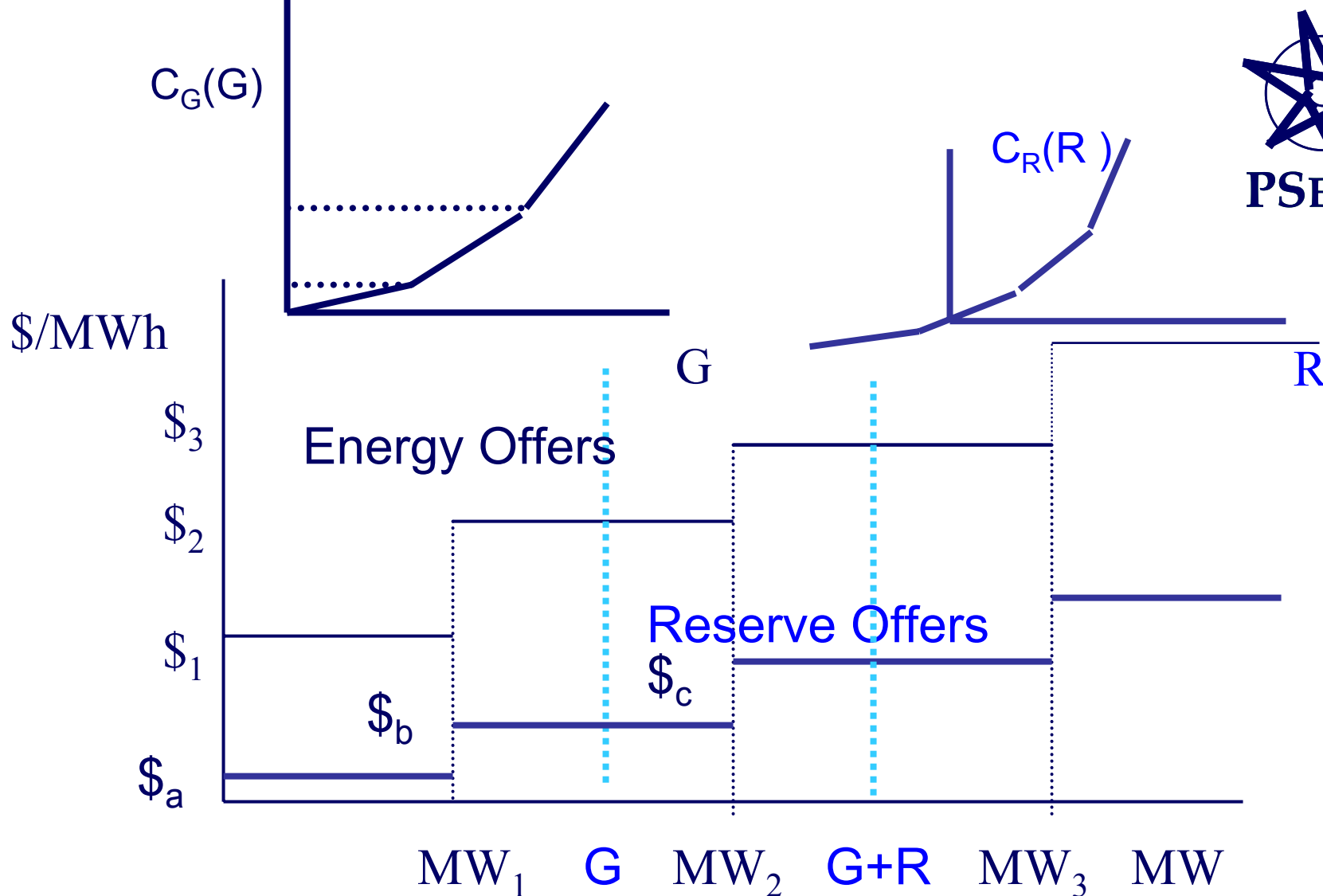
Underlying Scheduling Algorithm Co-optimization



- Objective
 - minimize the total expected cost (operating energy cost plus the spinning reserve cost) over the predefined base case and credible contingencies

$$S = \sum_{k=0}^K p_k \sum_{i=1}^N [C_{Pi}(G_{ki}) + C_{Ri}(R_{ki})] \quad \sum_{k=0}^K p_k = 1$$

- Subject to network and system constraints
 - Generation capacity limits
 - Voltage limits
 - Line flow limits
 - Ramping limits



We can clear a market with offers for both energy and reserves. We can compute locational prices for both energy and reserves

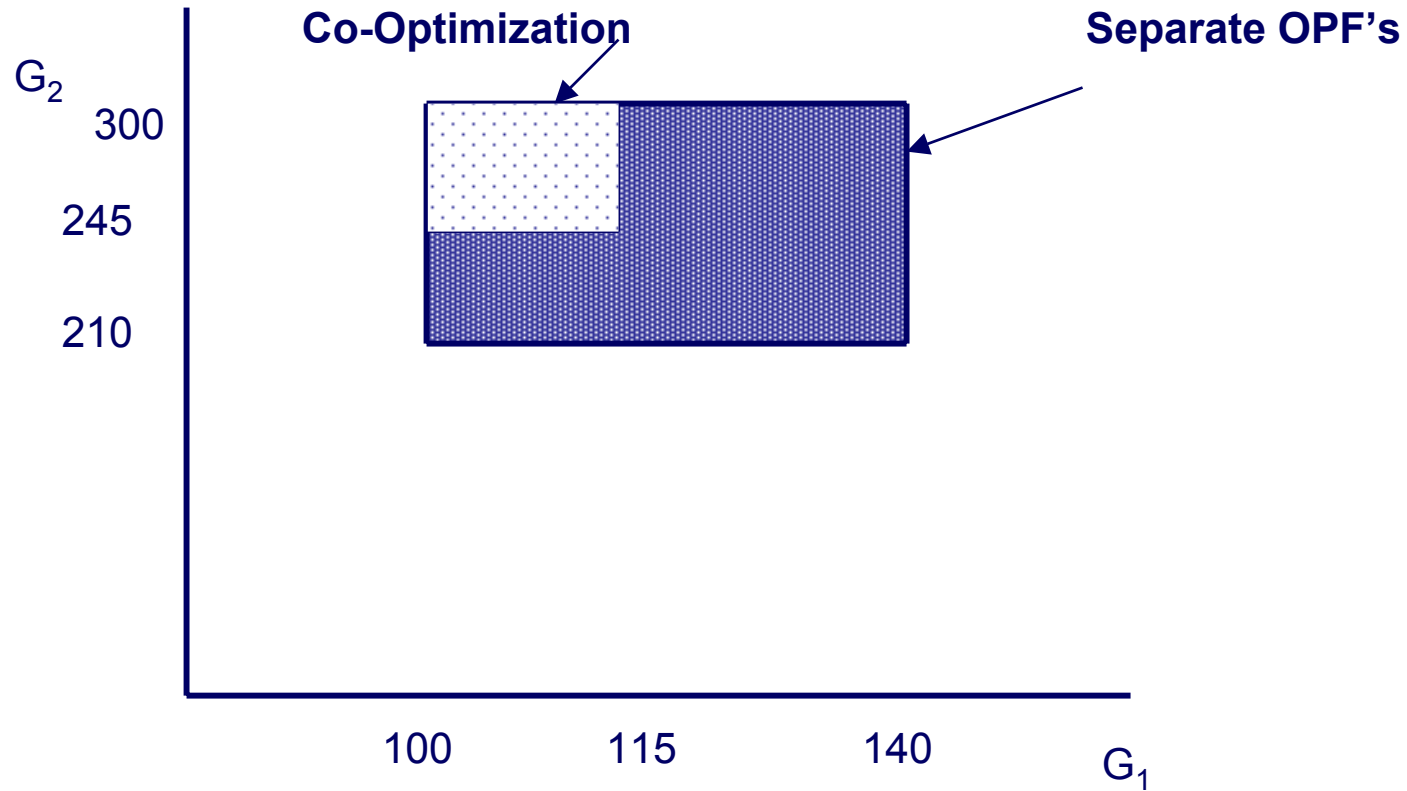
Co-optimization Solution Properties

- The co-optimization is K OPF's coupled by the reserve costs and the dependence of reserves on generation.
- The solution is generally different than K separate OPF's which do not consider the cost of reserves.
- The important features of the **solution** are the “Generator response intervals”

$$\hat{G}_{i\min} \leq G_{ki} \leq \hat{G}_{i\max}$$

- Not physical generator limits but the result of the co-optimization. K separate OPF's give large generator response intervals. Co-optimization reduces the size of the generator response intervals

“Generator Response Intervals”



Augmented Optimal Power Flow (AOPF)



- Cost-minimizing optimization for one of the specified K systems (base case or a contingency)

$$f_k = \sum_{i=1}^N [C_{Pi}(G_{ki}) + C_{Ri}(R_{ki})]$$

- Old system constraints from the Co-optimization apply Generation capacity limits, Voltage limits, Line flow limits, Ramping limits
- New (non-physical) generator constraints are added

$$\hat{G}_{i\min} \leq G_{ki} \leq \hat{G}_{i\max}$$

- Reserves are defined as

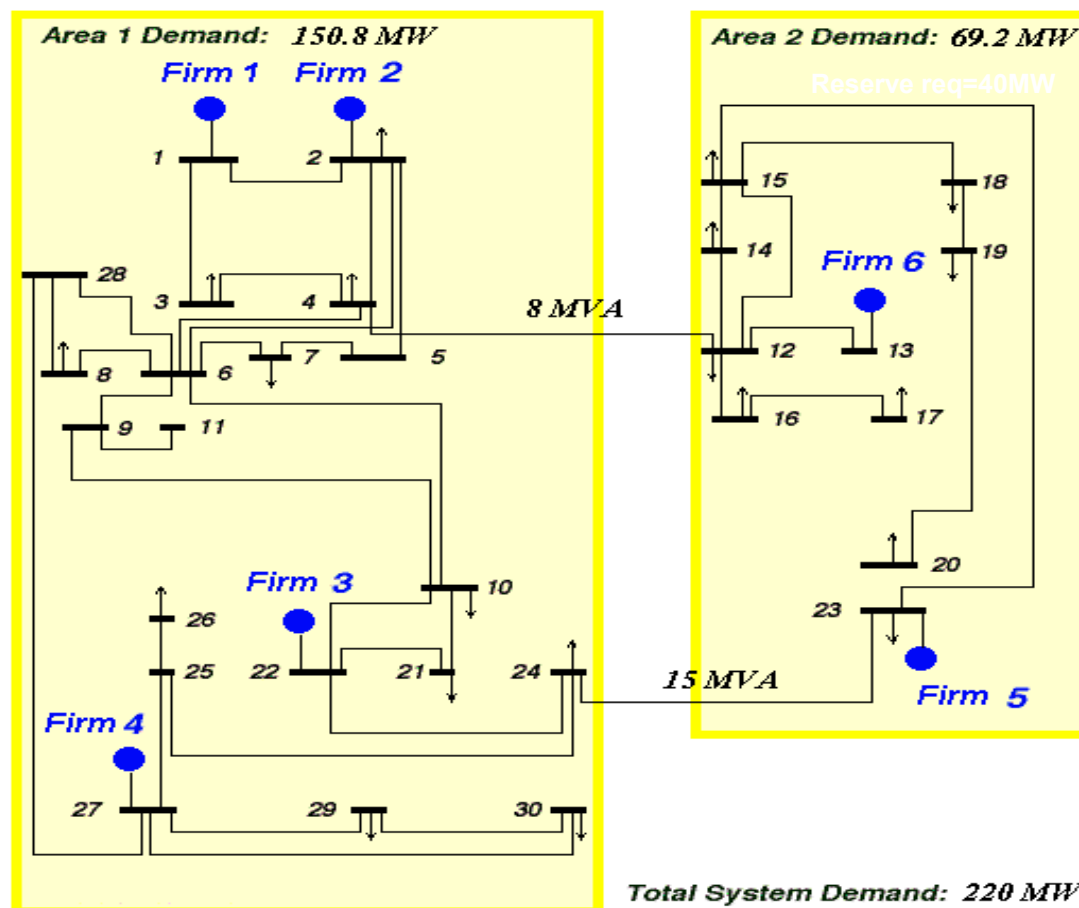
$$R_{ik} = G_i^{\max} - G_{ik}$$

Properties of AOPF

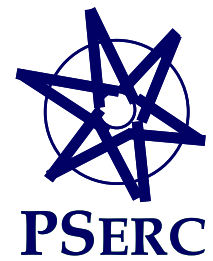
- If G_{ik} is the solution of the Co-optimization, it is also the solution of the k^{th} AOPF
 - Proof: like proof of principle of optimality
- Consequence:
 - if a new contingency can be met with the reserves from the co-optimization then the single AOPF gives the optimal solution.
 - Deals with forecast errors and unanticipated contingency. Prices from AOPF not Co-optimization
 - Only need to repeat the co-optimization when a new contingency can not be covered

Preliminary RR Market Results

- Test system



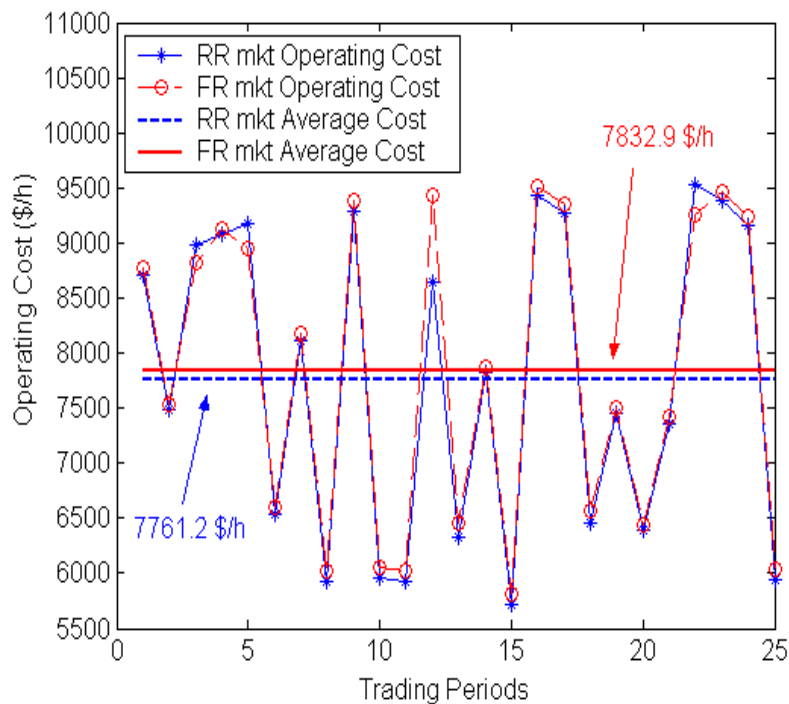
Preliminary RR Market Results



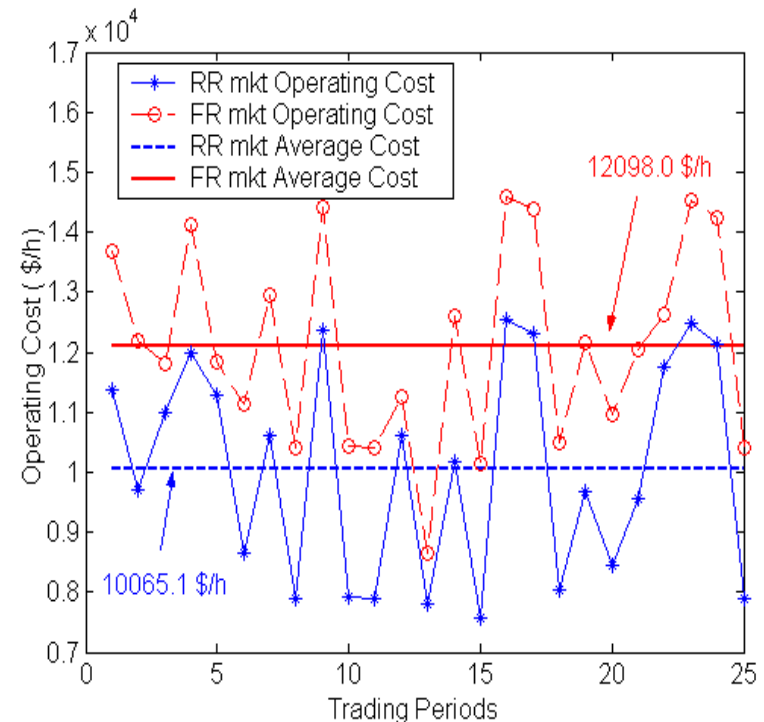
- Comparison of operating costs between Fixed and Responsive Reserve markets

- Reduced operating costs for the RR market

Marginal Cost Offers

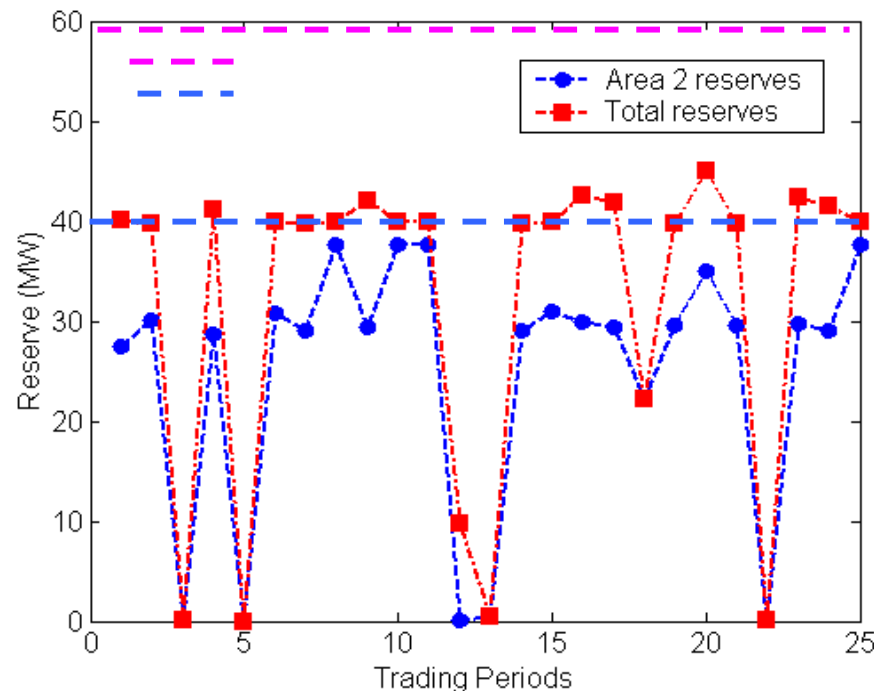


Simulated High Offers

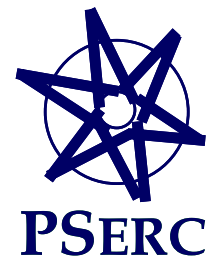


Preliminary RR Market Results

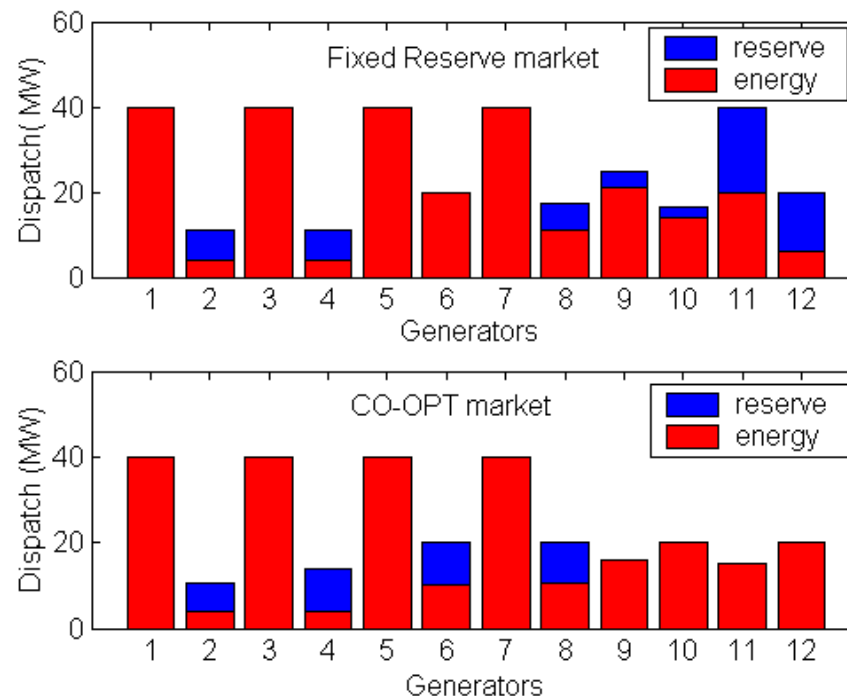
- Comparison of the amount of reserve requirement between FR and RR markets
 - Require less reserves in the RR market



Preliminary RR Market Results



- Reasons that the RR market outperforms the FR market
 - Aim at minimum reserve requirement to cover specified cases
 - Optimal way of locationally assigning reserves

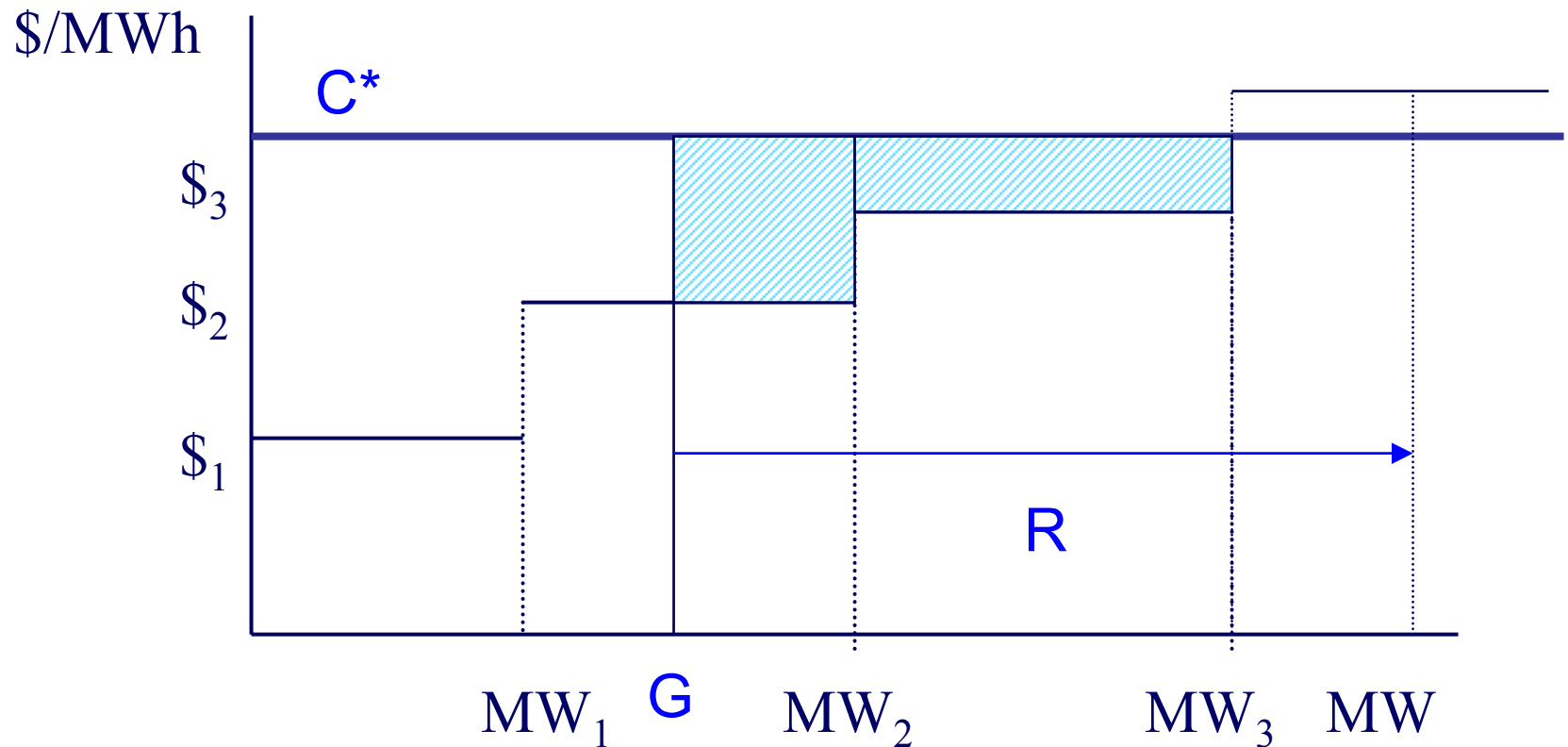
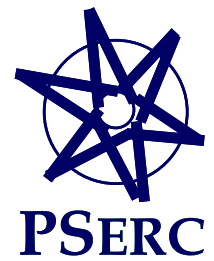


Experiments



- RR market experiments
 - Whether or not the RR market is more efficient in revealing true generator costs
 - Whether or not the RR market is more difficult to exploit when market power is a potential problem.

**Opportunity Costs: Attempt to lower energy offers.
Depends on energy offers and an energy price.
(possibly from the day ahead market)**



CONCLUSIONS

- The last results are preliminary.
- THIS IS A COMPLICATED MARKET.
- Some market solutions are NOT easy to interpret.
- Do participants need “tools” to improve their offer strategies?
- WE ARE NOW READY FOR SERIOUS TESTING.
- Using variable reserves (Co-optimization) is a promising way to reduce the market power that is inherent with fixed zonal reserves.
- Paying reserves the opportunity cost of forgone profits for energy is a promising way to mitigate speculative behavior compared to paying separate prices for energy and reserves. (Greedy suppliers who try to get high energy prices also provide low cost reserves.)

Testing Joint Markets for Energy and Reserves using PowerWeb II

Results from pilot tests conducted by graduate students during the fall of 2002 in course ECE551/AEM655 at Cornell University.

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Testing Joint Markets for Energy and Reserves: Basic Design

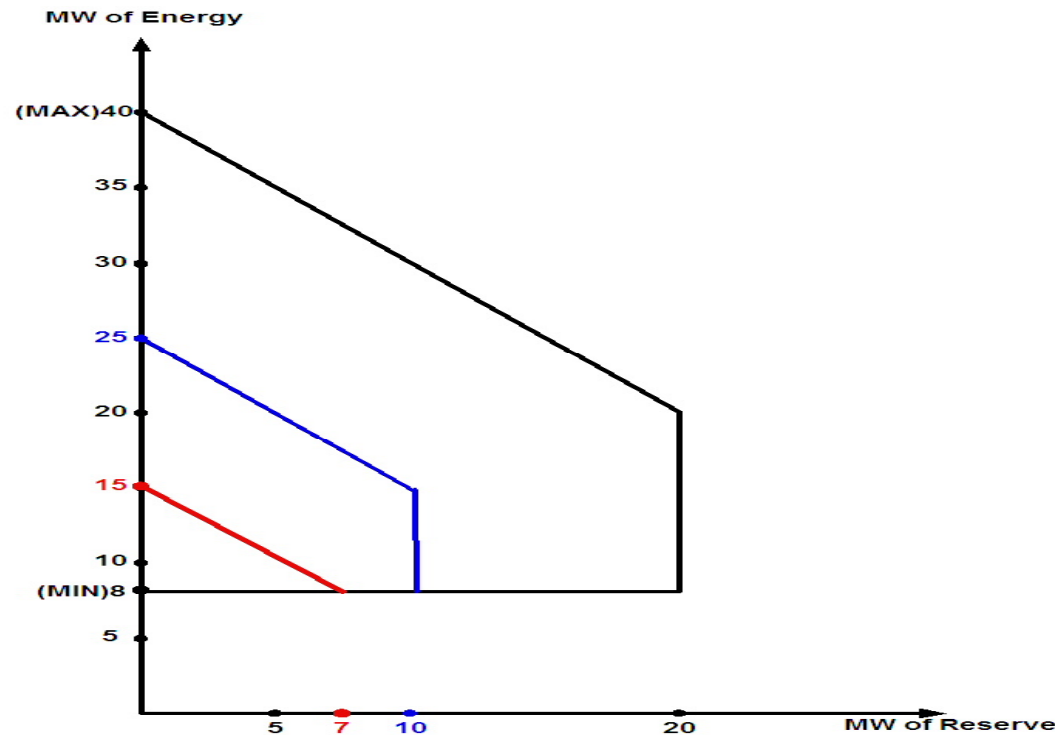


- The basic design is to have **two “firms” in a load pocket** interact with competitive suppliers in other regions to provide energy and reserves for the whole network. These two generators are relatively expensive, and are represented by different individuals in a centralized auction. A price cap is enforced, but withholding capacity from the market is allowed.
- The other **four generators outside the load pocket** are relatively inexpensive and they are price takers. Computer agents represent these four generators and submit “honest offers” for all of their capacity at the true cost in all periods.
- **Nodal prices** for energy and reserves are determined using a uniform price auction in a centralized “smart” market with a **full AC network**. The system load on the network is **price inelastic**, and it varies from period to period with no forecasting error.

Testing Joint Markets for Energy and Reserves: Types of Market

- TEST I: Fixed Reserves (Two Markets, “New York Rules”)
- Specify fixed MW amounts of reserves in the load pocket and overall to meet a specified set of contingencies. Minimize the cost of energy and reserves.
- TEST II: Responsive Reserves (Two Markets, Co-optimization)
- Minimize the expected cost of offers for energy and reserves over the same set of contingencies
- TEST III: Responsive Reserves (One Market + Opportunity Cost)
- Minimize the expected cost of offers for energy over the same set of contingencies. Pay reserves an opportunity cost for foregone “profits” on energy

Feasible Offers of Capacity for Energy and Reserves



Black – True capacity options for energy and reserves

$(8 \leq \text{Energy} \leq 40, 0 \leq \text{Reserves} \leq 20 \text{ and } \text{Energy} + \text{Reserves} \leq 40)$

Blue - Limit Reserves to ≤ 10 and $\text{Energy} + \text{Reserves} \leq 25$

Red - Limit $\text{Energy} + \text{Reserves} \leq 15$, implying that $\text{Reserves} \geq 15 - 8 = 7$ are not feasible

Offer Screen for PowerWeb II



Name: [user6] user 6 [Logout](#)
 Session: [2] Energy-Reserves Demo
 Representing: [12] Firm 6

Period

2

SYSTEM DATA	
Forecasted Load (MW)	221.5
Installed Capacity (MW)	360.0
Price Cap (\$/MW)	\$100.00

GENERATOR DATA	Gen 11	Gen 12
Min Generation (MW)	8.0	4.0
Max Capacity (MW)	40.0	20.0
Max Reserves (MW)	20.0	16.0
Standby Cost (\$/MW)	\$5.00	\$5.00
Fixed Cost (\$)	\$500.00	\$100.00
Energy Variable Cost (\$/MW)	\$45.00	\$55.00
Reserve Variable Cost (\$/MW)	\$0.00	\$0.00

Copy offers from previous period ? Copy		
MY OFFERS	Gen 11	Gen 12
Total Offered Capacity (MW)	40	20
Energy Offer (\$/MW)	\$45.50	\$80
Reserve Capacity (MW)	20	16
Reserve Offer (\$/MW)	\$20	\$35
Shutdown?	☐	☐
Submit Offer		
Standby Costs (\$)	\$200	\$100

MARKET HISTORY													
Period		System Load (MW)	Generation (MW)		Market Share	Reserves (MW)		Energy Price (\$/MW)		Avg Market Price (\$/MW)	Reserve Price (\$/MW)		Earnings (\$)
			Gen 11	Gen 12		Gen 11	Gen 12	Gen 11	Gen 12		Gen 11	Gen 12	
1	In	247.1	40.0	20.0	24%	20.0	16.0	\$45.50	\$55.50		\$20.00	\$20.00	
	Out	247.1	20.0	4.0	10%	20.0	16.0	\$60.00	\$60.00	\$48.64	\$35.00	\$35.00	\$680.00
1 - 1		Cumulative Earnings:											\$680.00
		Cumulative Earnings * Exchange Rate (1/2500):											\$0.27

Results Screen for PowerWeb II



Name: [user6] user 6 [Logout](#)
 Session: [2] Energy-Reserves Demo
 Representing: [12] Firm 6

Period

1

MARKET RESULTS [Test 1 : Fixed Reserve Requirements]			
Forecasted Load	247.1 MW	Contingency	none
Actual Load	247.1 MW		

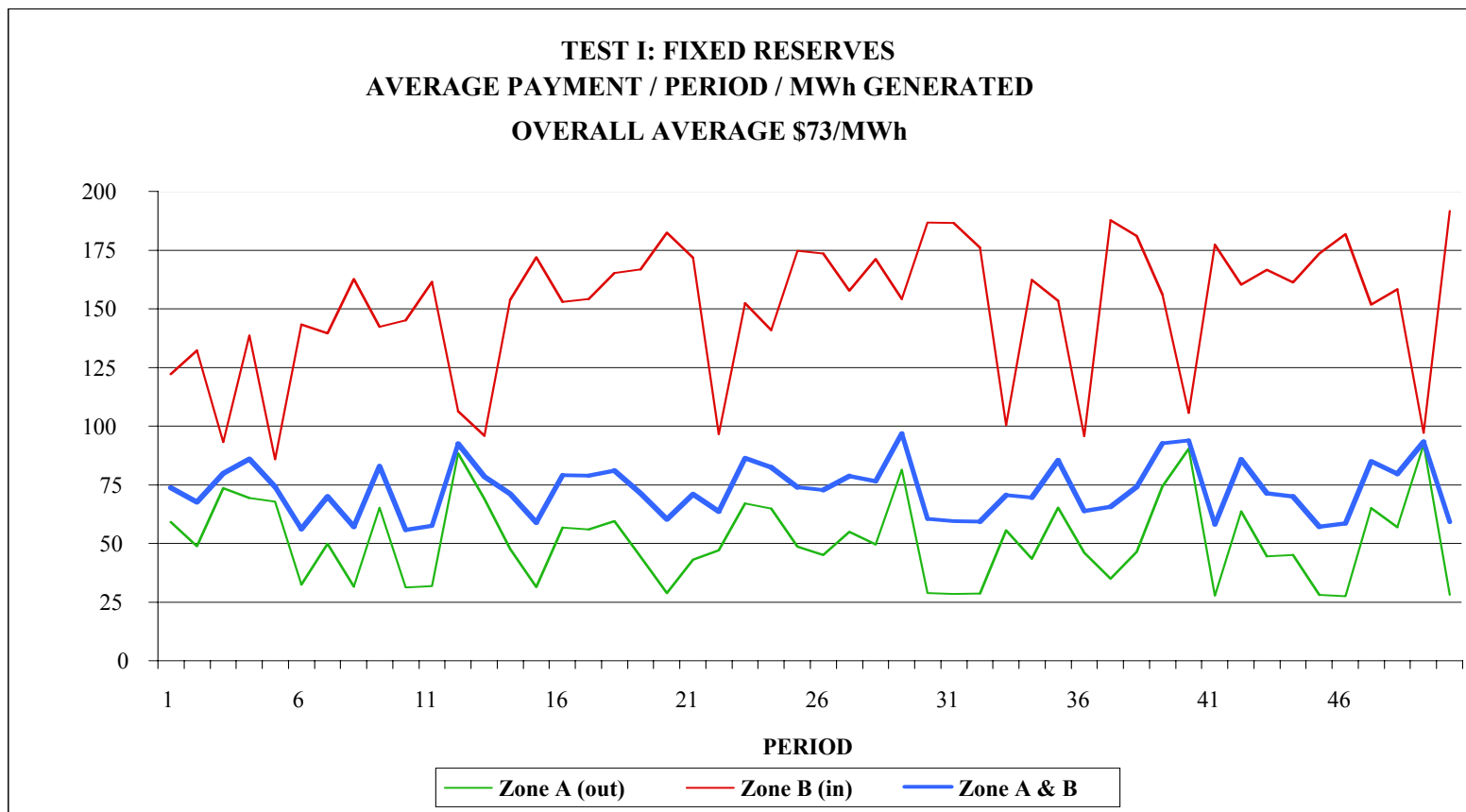
		Gen 11	Gen 12	Total
Total Capacity (MW)	Offered	40.0	20.0	60.0
Energy (MW)	Sold	20.0	4.0	24.0
Energy Price (\$/MW)	Offered	\$45.50	\$55.50	
	Paid	\$60.00	\$60.00	
Reserve (MW)	Offered	20.0	16.0	36.0
	Sold	20.0	16.0	36.0
Reserve Price (\$/MW)	Offered	\$20.00	\$20.00	
	Paid	\$35.00	\$35.00	

EARNINGS		Gen 11	Gen 12	Total
Revenue from Energy Sales (\$)		\$1200.00	\$240.00	\$1440.00
Revenue from Reserve Sales (\$)		\$700.00	\$560.00	\$1260.00
Standby Costs (\$)		\$200.00	\$100.00	\$300.00
Fixed Costs (\$)		\$500.00	\$100.00	\$600.00
Variable Costs (\$)		\$900.00	\$220.00	\$1120.00
Total Earnings (\$)		\$300.00	\$380.00	\$680.00

[Continue >>](#)

TEST I: Fixed MW Reserve Requirements (New York Rules)

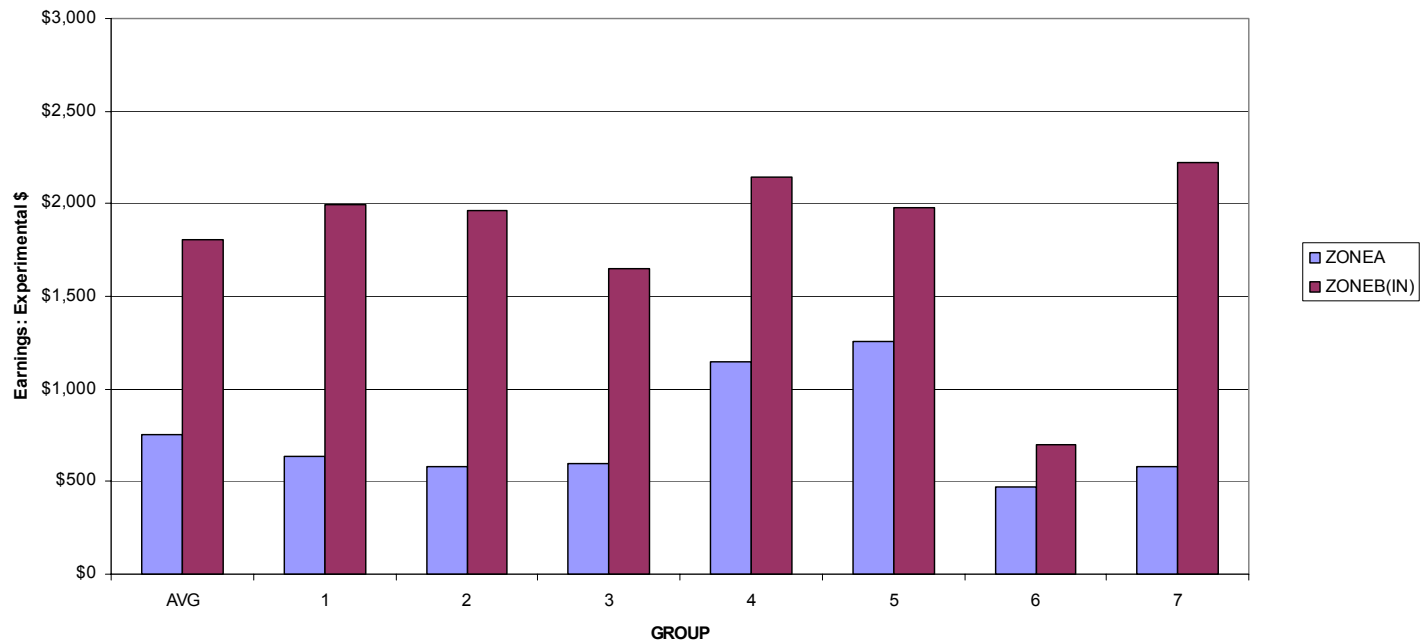
Average Payment / Period / MWh Generated



TEST I: Fixed MW Reserve Requirements (New York Rules) Average Payment / Firm / Period

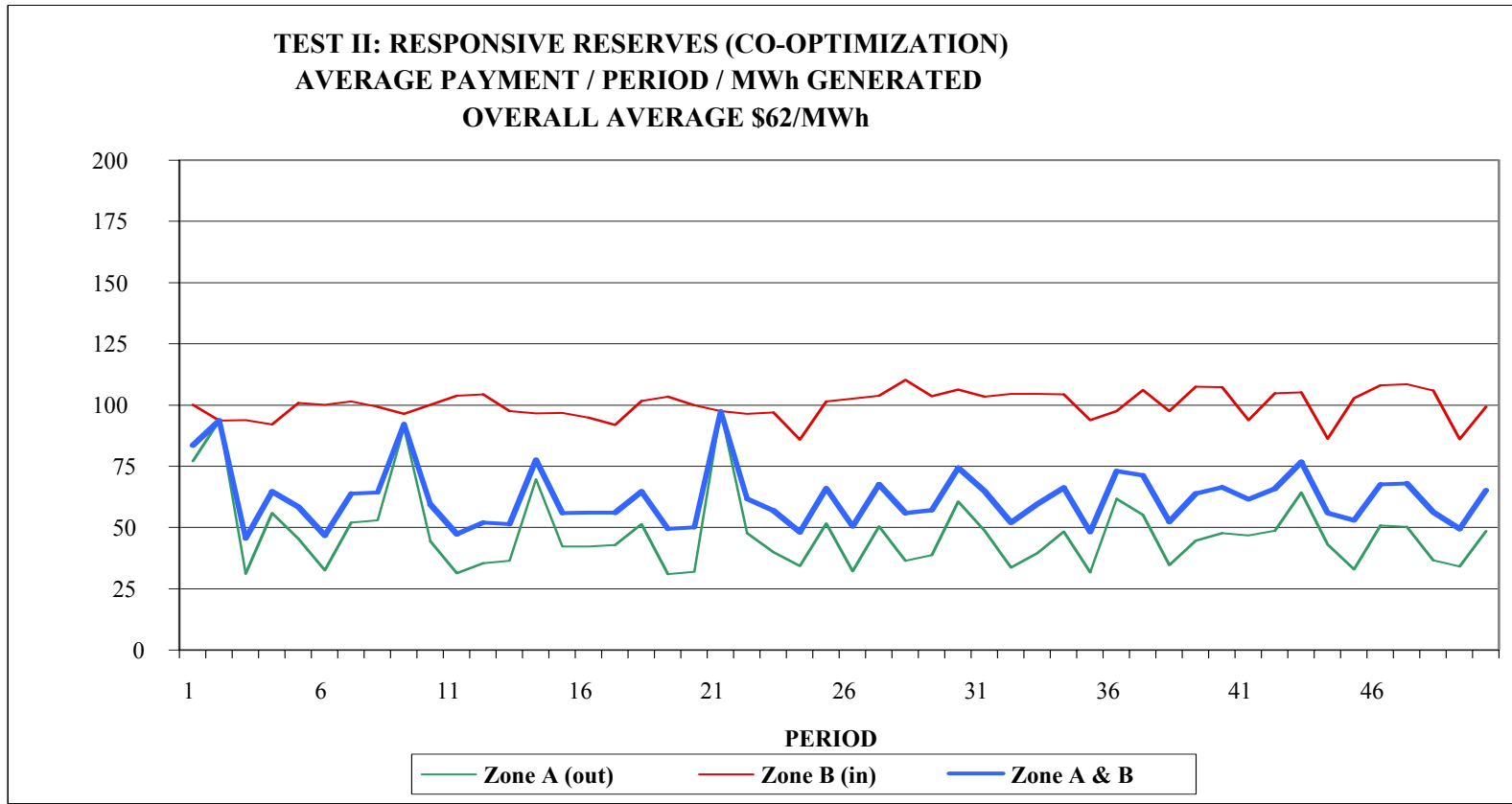


TEST OF JOINT MARKET FOR ENERGY AND RESERVES
AVERAGE EARNINGS PER FIRM PER PERIOD
TEST I FIXED RESERVE REQUIREMENTS, TWO MARKETS



TEST II: Responsive Reserve Requirements (Co-optimization)

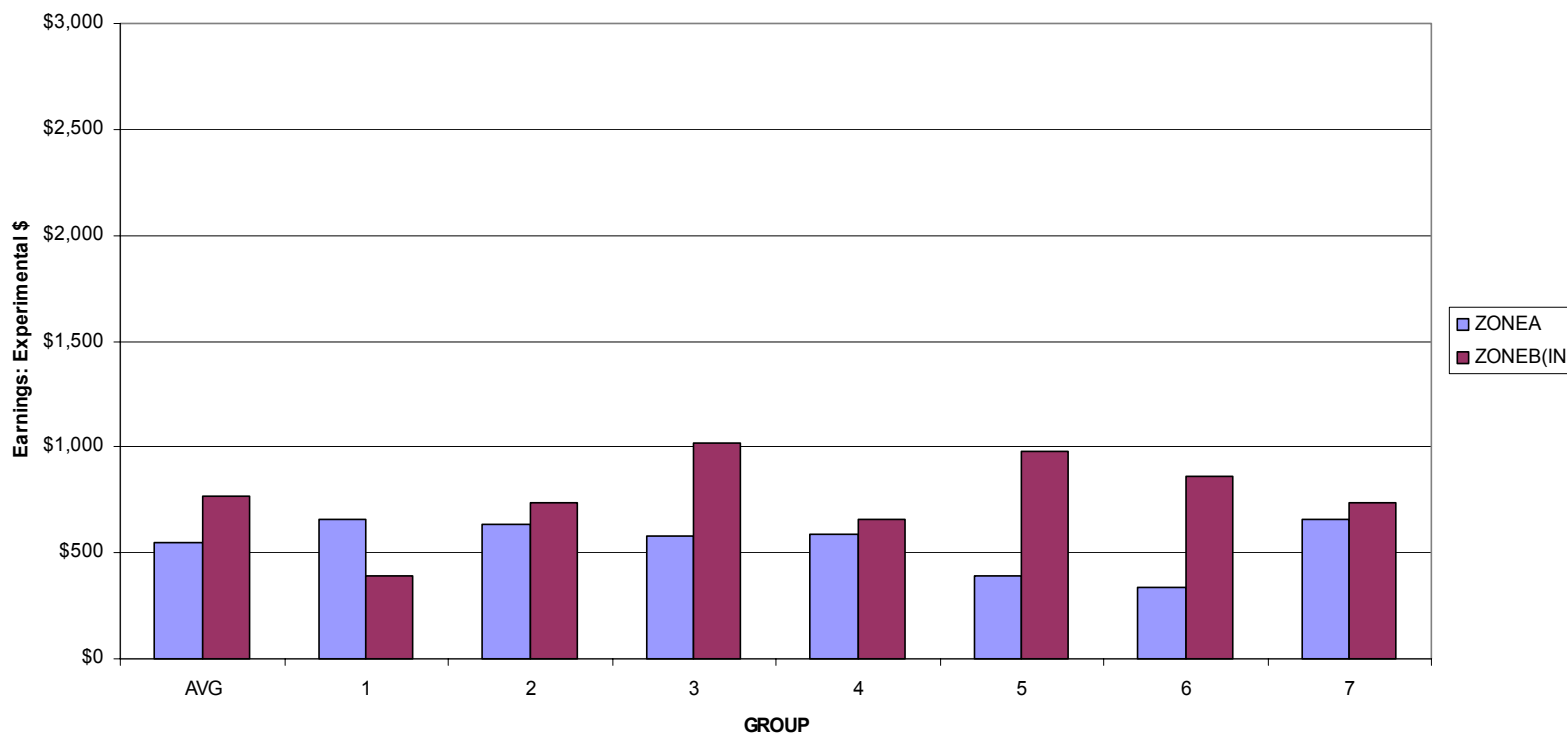
Average Payment / Period / MWh Generated



TEST II: Responsive Reserve Requirements (Co-optimization)

Average Payment / Firm / Period

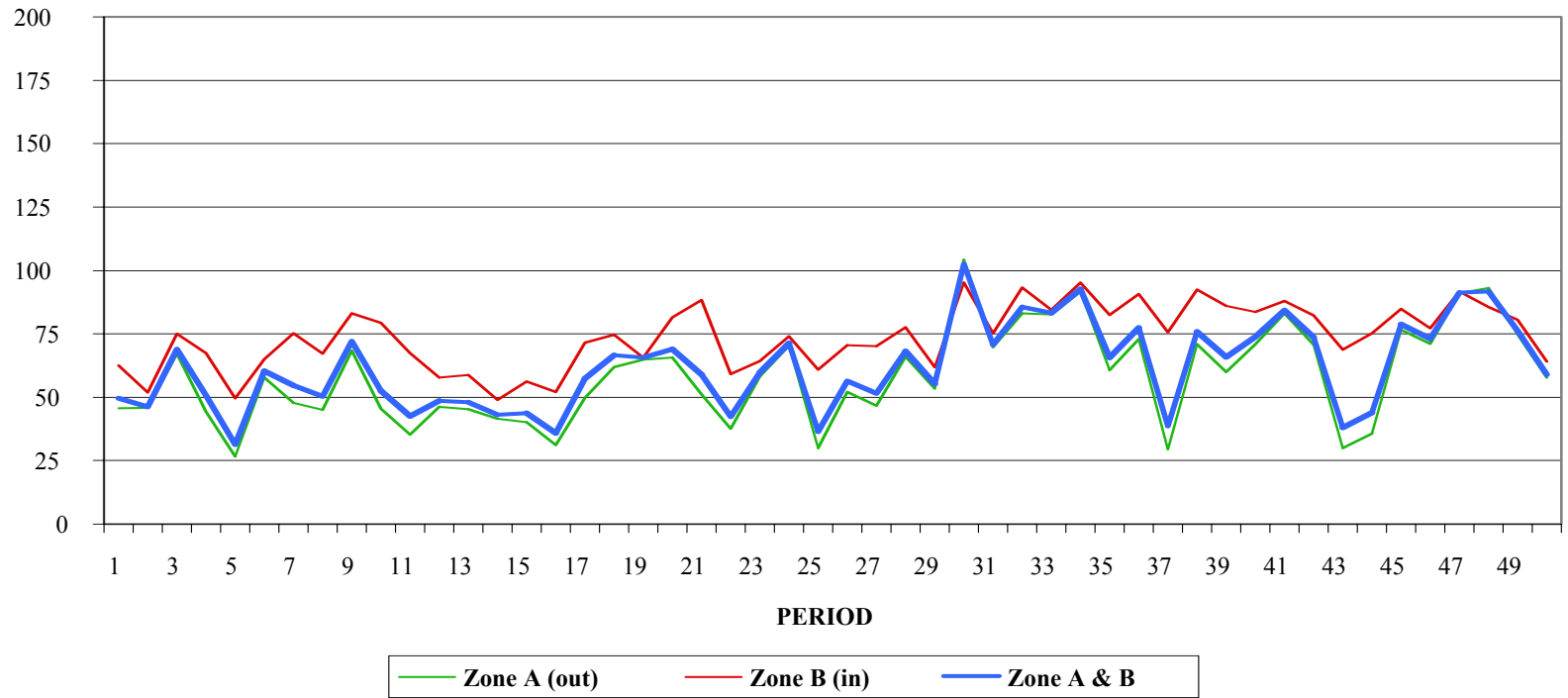
TEST OF JOINT MARKET FOR ENERGY AND RESERVES
AVERAGE EARNINGS PER FIRM PER PERIOD
TEST II VARIABLE RESERVE REQUIREMENTS, TWO MARKETS



TEST III: Responsive Reserve Requirements (Co-optimization & Pay Opportunity Cost) Average Payment / Period / MWh Generated



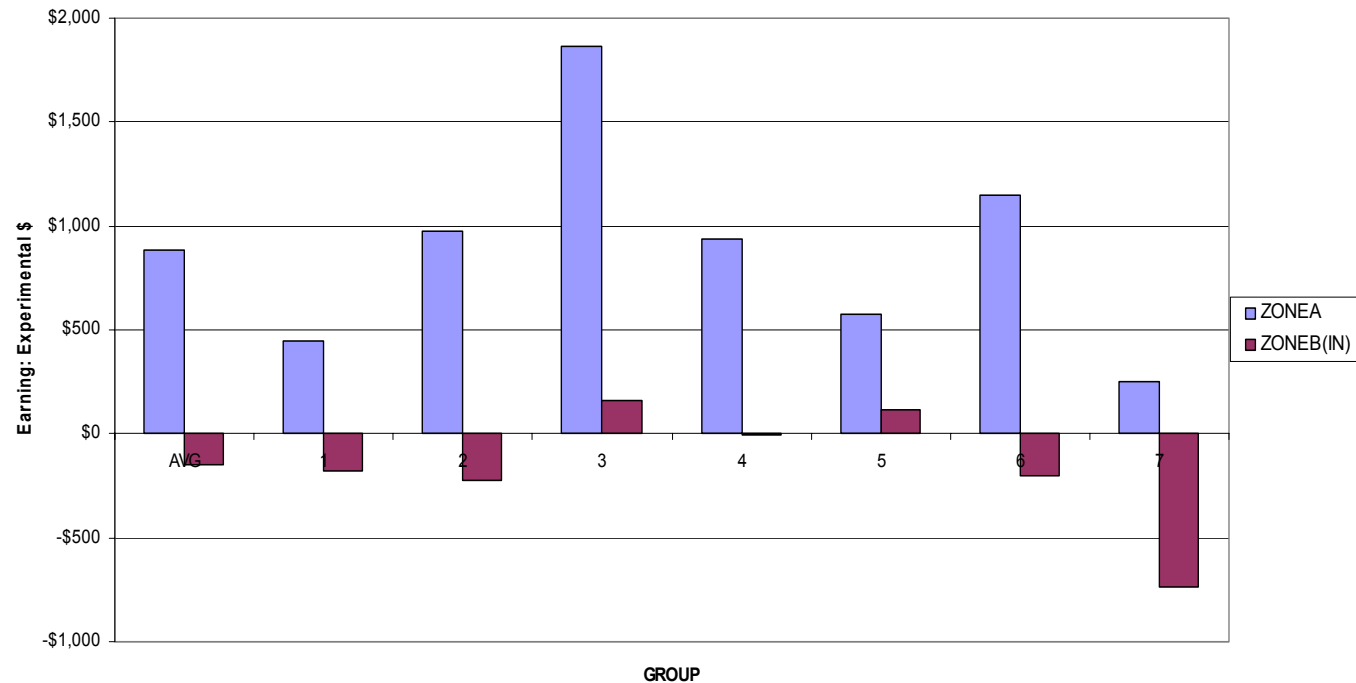
TEST III: RESPONSIVE RESERVES (PAY OPPORTUNITY COST)
AVERAGE PAYMENT / PERIOD / MWh GENERATED
OVERALL AVERAGE \$62/MWh



TEST III: Responsive Reserve Requirements (Co-optimization & Pay Opportunity Cost) Average Payment / Firm / Period



TEST OF JOINT MARKET FOR ENERGY AND RESERVES
AVERAGE EARNINGS PER FIRM PER PERIOD
TEST III VARIABLE RESERVE REQUIREMENTS, PAY OPPORTUNITY COST FOR RESERVES



CONCLUSIONS



- THESE RESULTS ARE PRELIMINARY
- The solution algorithm improved over time
- Fewer rounds are “infeasible”
- THIS IS A COMPLICATED MARKET
- Some market solutions are NOT easy to interpret
- Do participants need “tools” to improve their offer strategies?
- WE ARE NOW READY FOR SERIOUS TESTING
- Using variable reserves ([Co-optimization](#)) is a promising way to reduce the market power that is inherent with fixed zonal reserves
- Paying reserves the [opportunity cost](#) of forgone profits for energy is a promising way to mitigate speculative behavior compared to paying separate prices for energy and reserves. (Greedy suppliers who try to get high energy prices also provide low cost reserves.)