



PSERC

Electric Power Transmission: Research Needs to Sustain a Critical National Infrastructure

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Environmental Matters Conference
March 22, 2003
Washington, DC**

Power Systems Engineering Research Center



13 Universities partnering with 40 industry and government members in a NSF Industry/University Cooperative Research Center to:

- Engage in forward-thinking about the industry
- Conduct multidisciplinary research
- Facilitate interchange of ideas
- Educate the next generation of power industry engineers

Power Systems Engineering Research Center

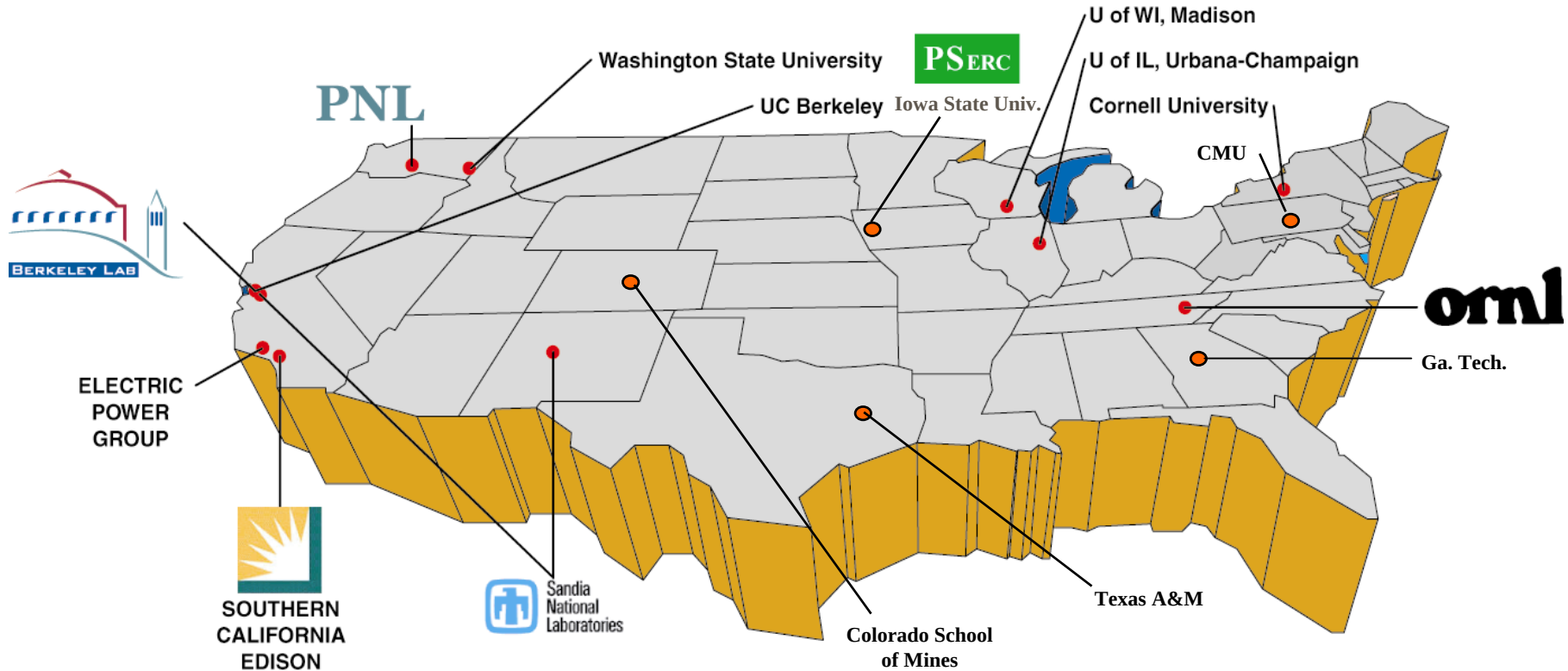


- Cornell University
- Arizona State University
- University of California at Berkeley
- Carnegie Mellon University
- Colorado School of Mines
- Georgia Institute of Technology
- University of Illinois at Urbana-Champaign
- Iowa State University
- Texas A&M University
- Washington State University
- University of Wisconsin-Madison

PSERC Resources

- Web site: <http://www.pserc.cornell.edu>
- Public documents
 - Papers
 - Presentations
- Internet seminars
- Short courses
- Tools and tutorials

Consortium for Electric Reliability Technology Solutions (CERTS)



...Our nation's transmission system over the next decade will fall short of the reliability standards our economy requires and will result in additional bottlenecks and higher costs to consumers.

It is essential that we begin immediately to implement the improvements that are needed to ensure continued growth and prosperity.

*Spencer Abraham, Secretary of Energy
National Transmission Grid Study (2002)*

Basic Technological and Cost Characteristics

- Predominantly high voltage AC (154,503 miles) with some DC (3,307 miles)
 - Flows governed by electrical properties
 - Divides among paths based on resistance to flow
- No “storage” so supply = demand + losses in real time (or frequency will rise/fall)
- Transmission constitutes about 10% of the total delivered cost of electricity.

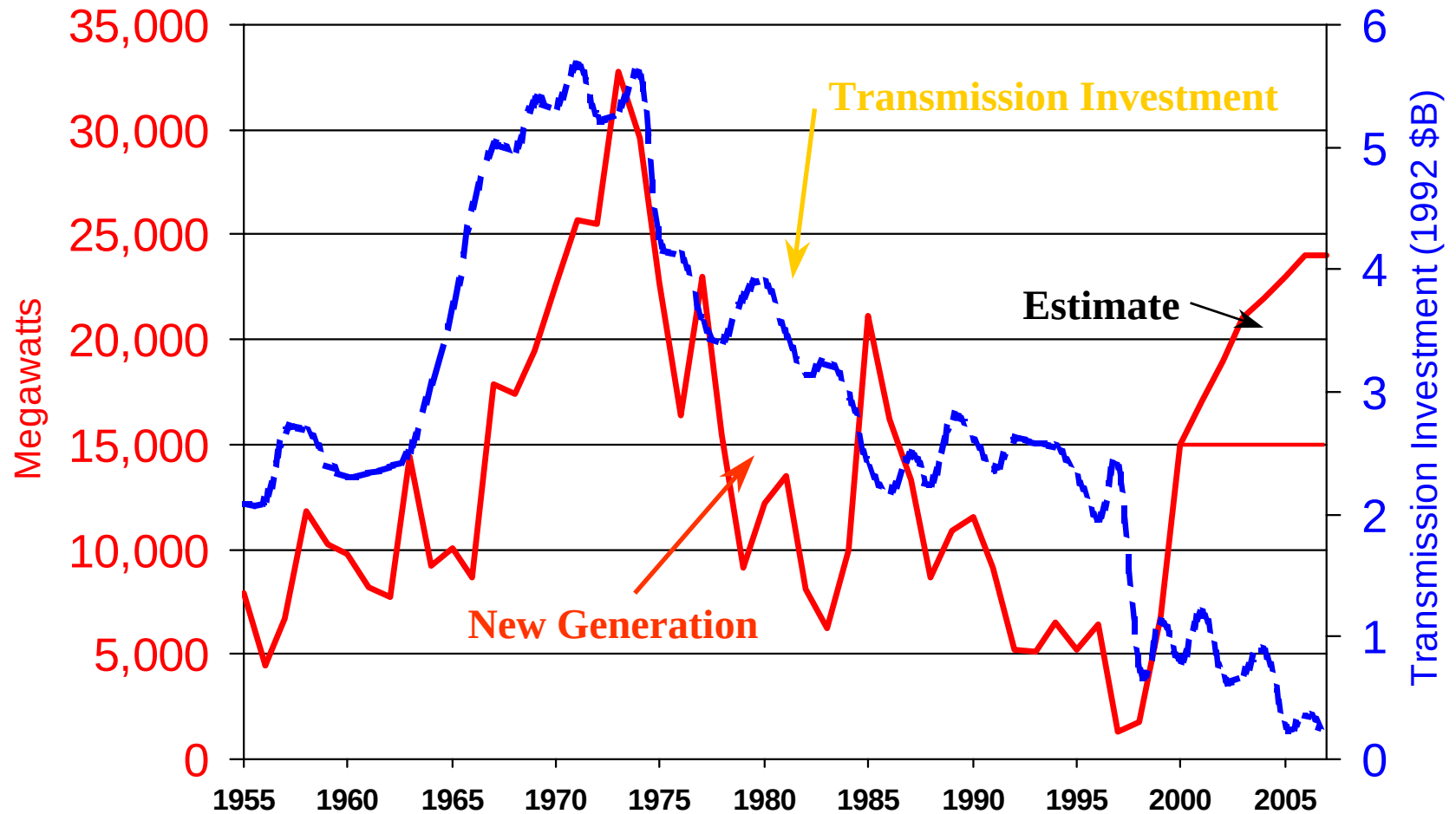
Operation

- 140 control areas in US
- 10 NA Electric Reliability Council regions
- Independent System Operators
 - California ISO
 - ISO New England
 - Midwest ISO
 - New York ISO
 - PJM Interconnection

Operational Objectives

- Thermal: no unacceptable overheating or line sags
- Adequacy: can meet load without voltage collapse through any single outage (N-1 criteria)
- Stability: no unacceptable power flow oscillations nor loss of synchronization after a contingency
- Transmission limits: thermal, voltage, stability

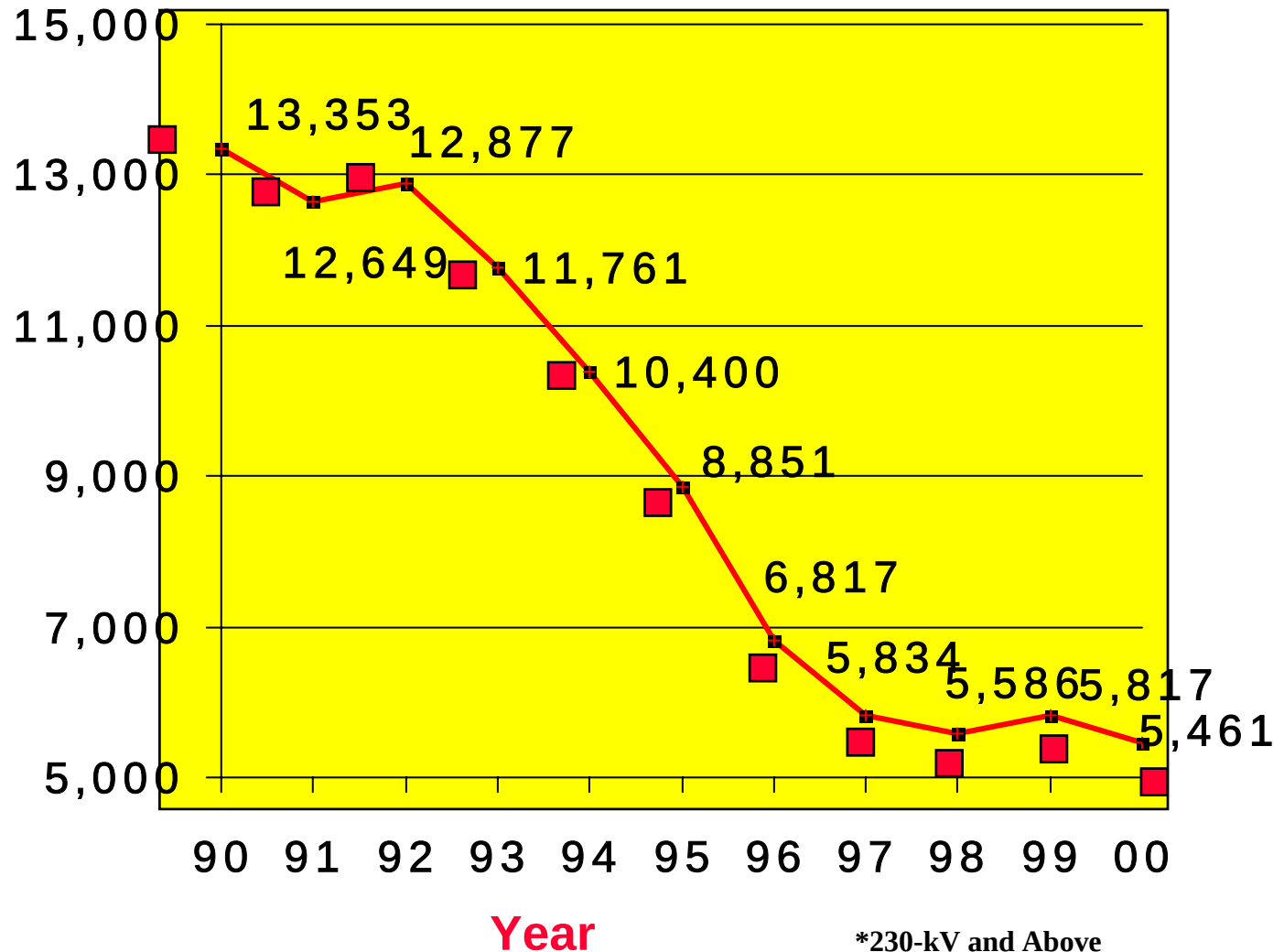
De-coupling of Investment in U.S. Generation & Transmission



Source: Cambridge Energy Research Associates, Electric Transmission Advisory Service, 2000

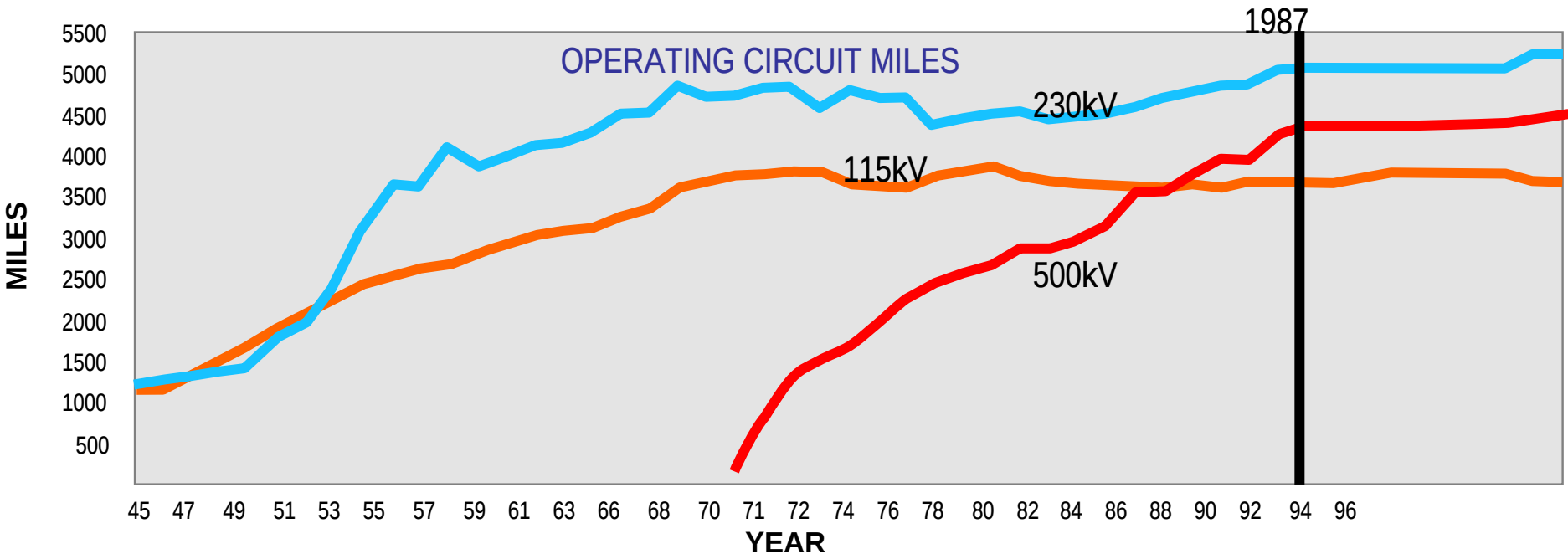
U.S. Transmission 10-Yr Plans*

Miles To
Be Added



Source: NERC Reliability Assessment Reports

Transmission Line Construction



Source: TVA. Data from BPA / May 2001

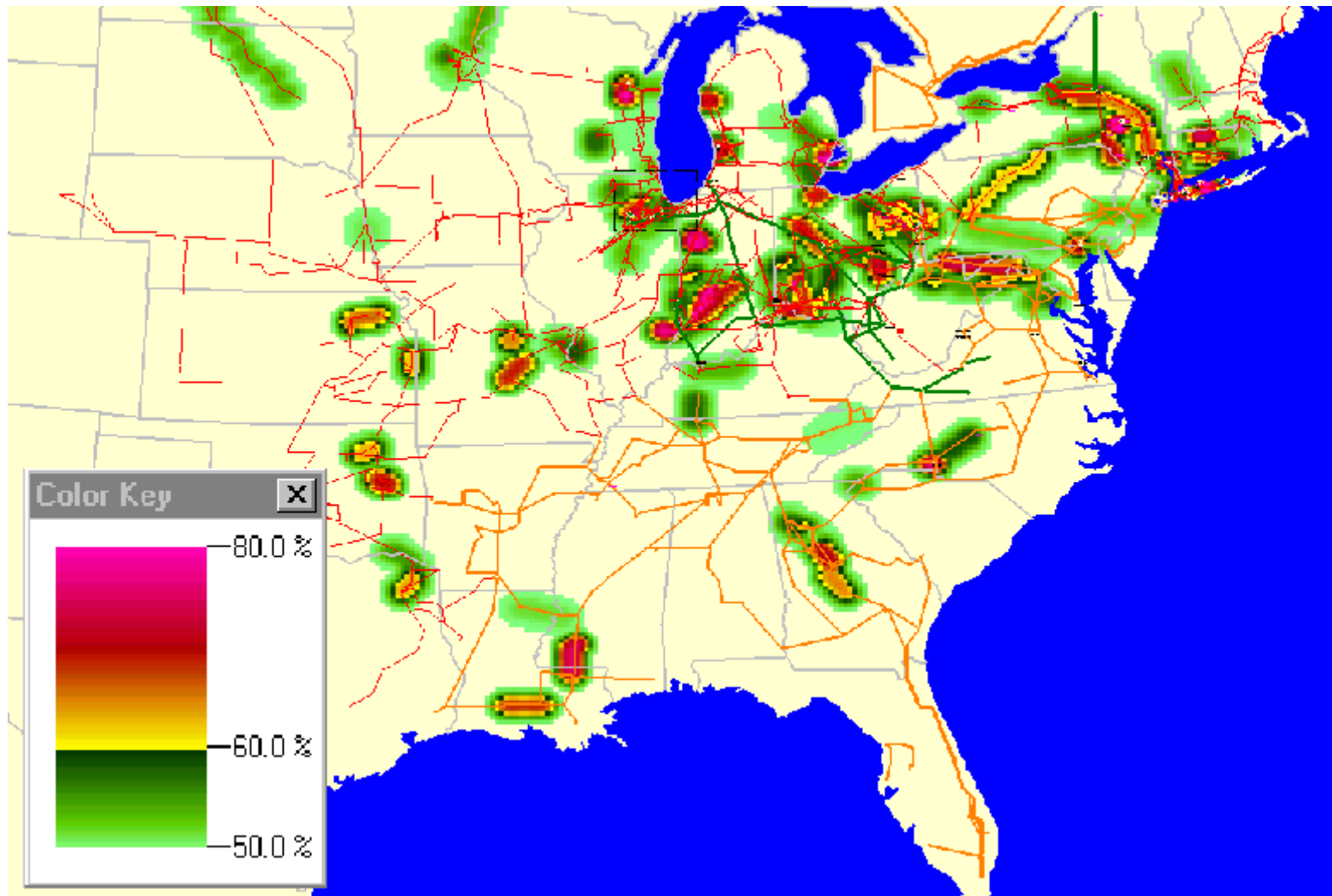
A System Under Stress

- Aging infrastructure
- Increasing loading of components and the calls for transmission loading relief (TLRs) are rising dramatically
 - A TLR requires changing scheduled transactions
- Investment has declined for the last 25 years
- Declining ability to isolate and remove components from service for maintenance
- More uncertain power flows due to wholesale merchant transactions resulting in a high percentage of major transmission lines to experience congestion

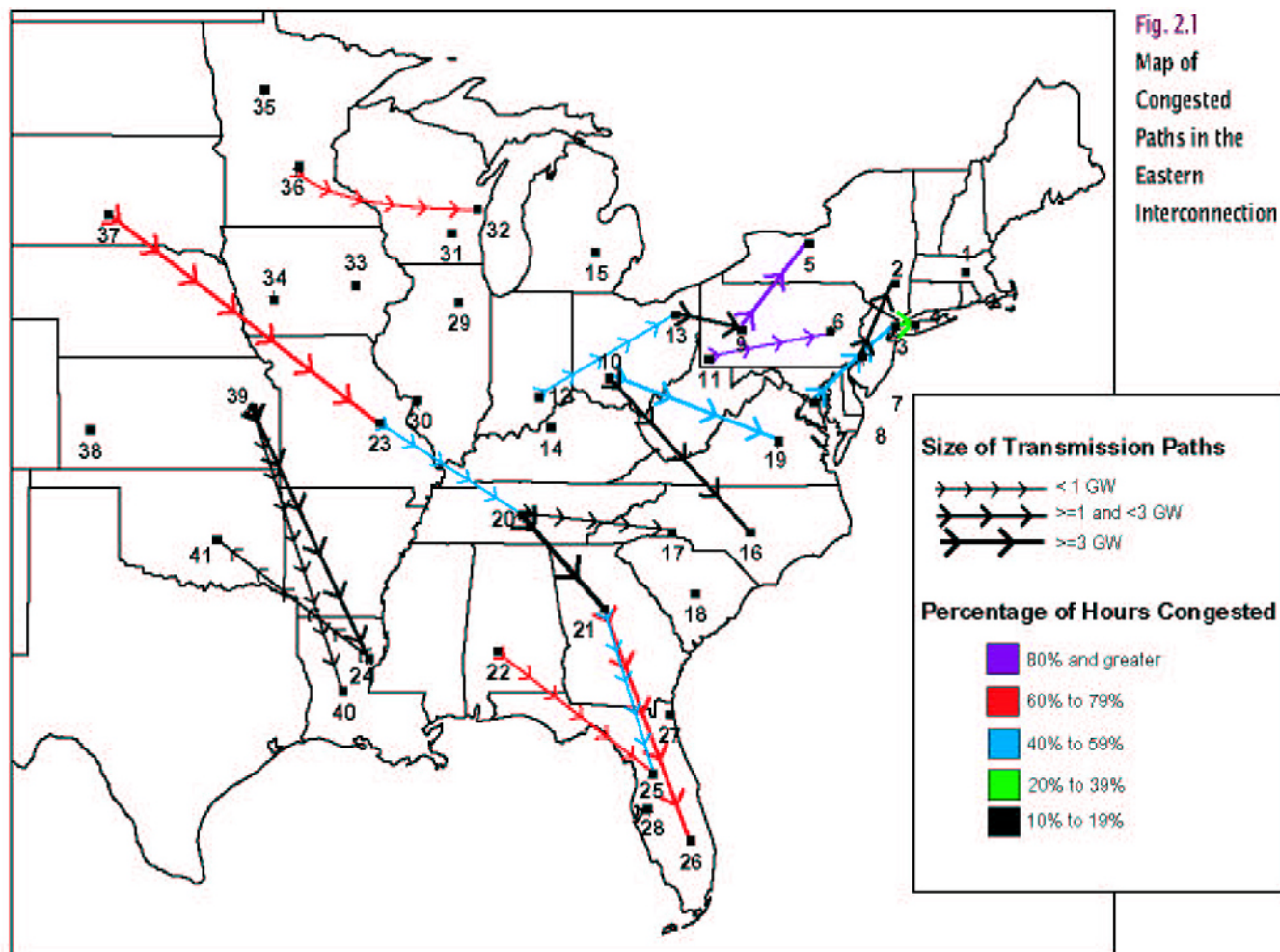
Effects of Transmission Bottlenecks/Congestion

- Barriers to economic transactions
- Higher prices in open markets
- Opportunities for excessive pricing
- Lower reliability
- Limits to economical emissions dispatch

Example of Line Loadings as % of Thermal Rating



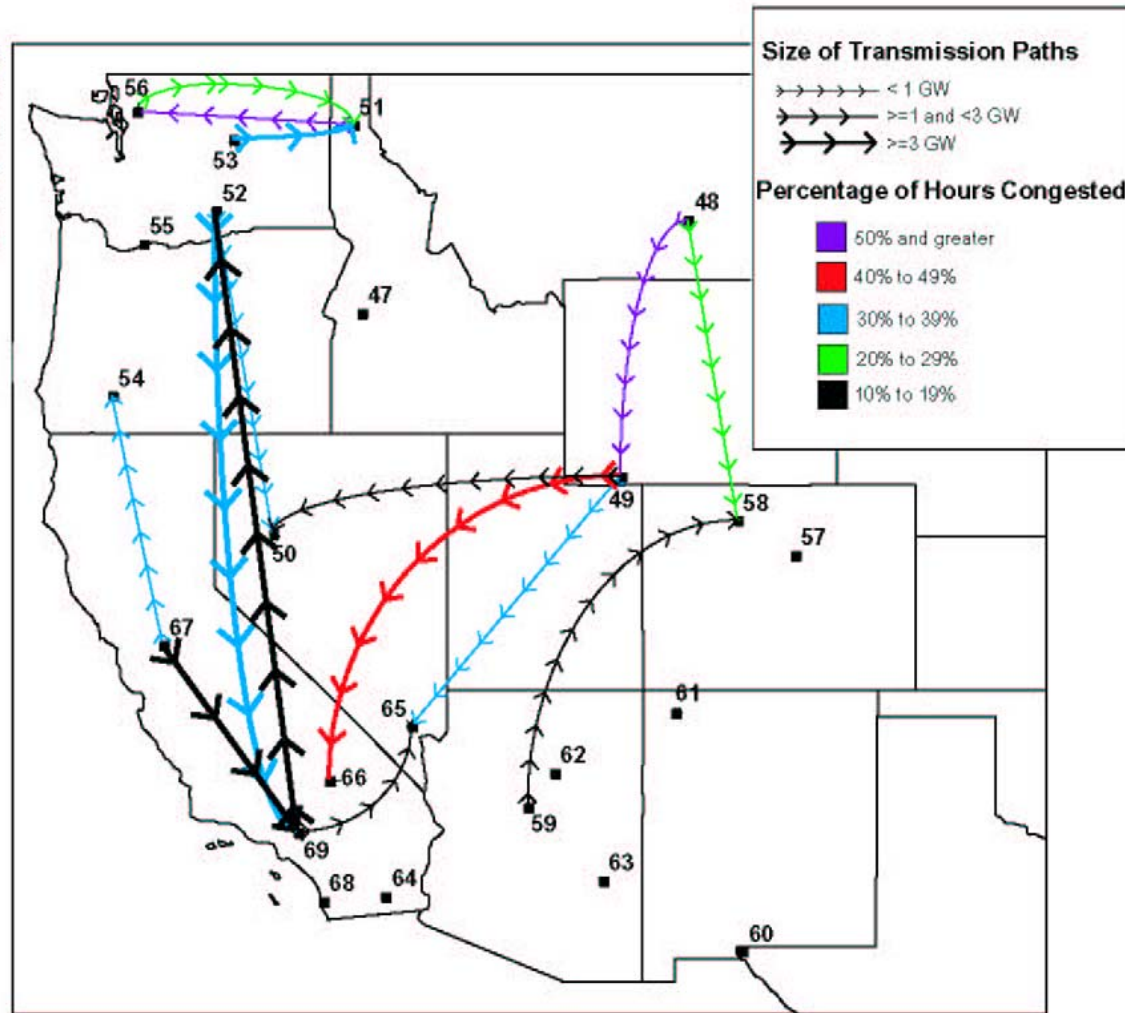
Major Corridor Transmission Congestion in the East



Source: U.S. DOE National Transmission Grid Study

Major Corridor Transmission Congestion in the West

Fig. 2.2
Map of
Congested
Paths in the
Western
Interconnection



Source: U.S. DOE National Transmission Grid Study

Costs of Congestion

- FERC study of 16 constraints: \$700 million for 6 summer months
- DOE study of 4 regions: \$447 million
- ISO New England: \$125-\$600 million
- California Path 15: \$222 million for 16 month period before Dec 2000

Source: U.S. DOE *National Transmission Grid Study*, May 2002

The background of the slide is a nighttime photograph of a city skyline, likely New York City, with numerous skyscrapers illuminated. A dark diagonal line runs from the top right towards the bottom left, dividing the image. The text is overlaid on this background.

Recent Major Blackouts

90% were Voltage Collapses

West Coast '96

Detroit '00

Chicago '99

New York '99

Northern California '01

San Francisco '00

Delaware '99

Atlanta '99

New Orleans '99

New Reasons for Building Transmission



- Previous: designed and operated for **reliability** (minimize outages while protecting equipment) and **economy** (everyone shares in the benefits of operating least cost generation)
- Today: also designed and operated to **support markets**.
- Note: More cost effective to build communication and control systems than overbuild transmission

New Reliability Management Needs

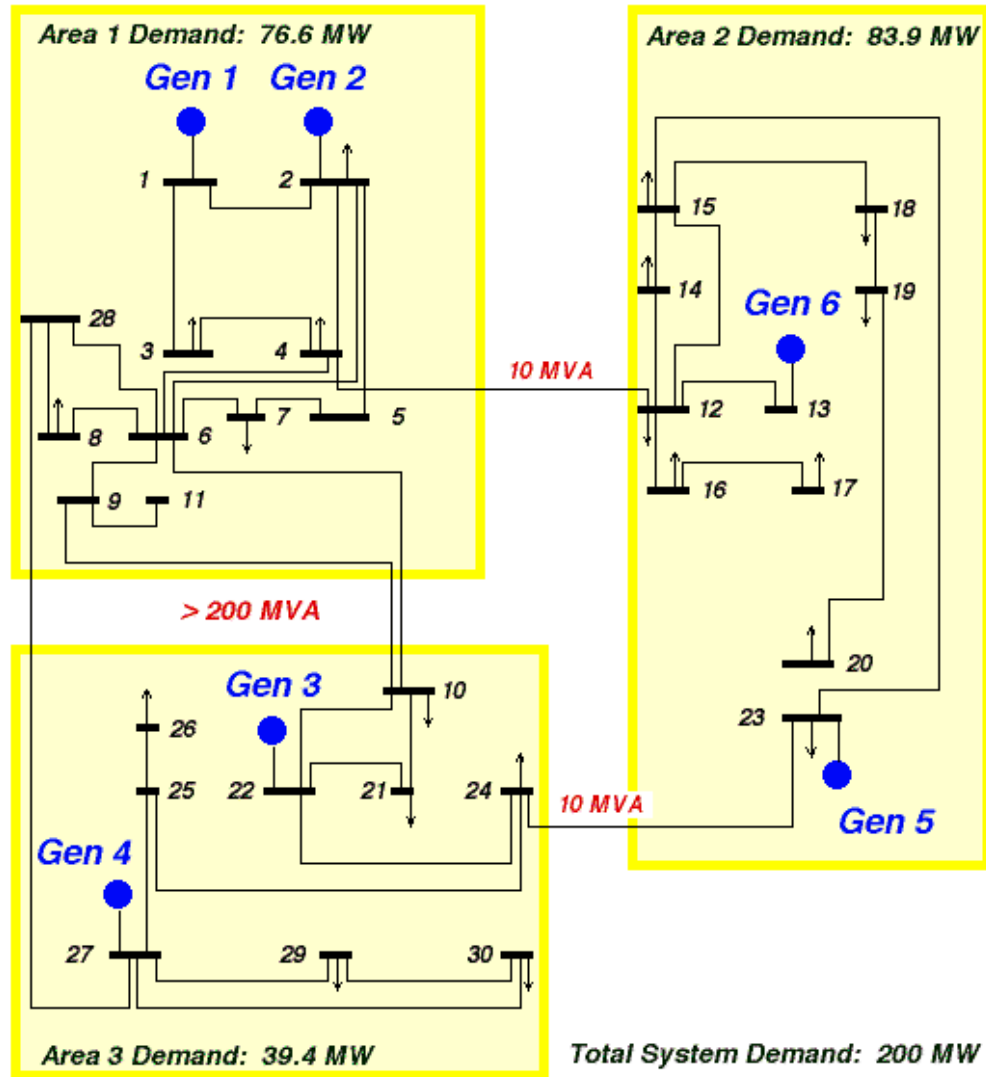


- Operators and planners need understanding of market behavior and its impact on grid systems.
- Operators need real-time information.
- Operators need tools to measure, monitor, assess, and predict both system performance and the performance of market participants.
- Grid needs to be enhanced to incorporate the latest advances in sensing, communication, computing, visualization, and algorithmic techniques and technologies.

Market Design Research

- Testing and validation of market designs before they are implemented.
- Experimental economics
 - Real people paid real money
 - Valid power systems model
- Studying current questions
 - Method of establishing payment (i.e., market price)
 - Integration of energy and reserves markets

PowerWeb



PowerWeb Offer Submission Page

Netscape: PowerWeb: Offer Submission

POWER WEB

Name: [Select...](#) [test] Test User [Logout](#)
Session: [Select...](#) [244] Example Session
Representing: [Select...](#) Generator 1

Period **1**

[Refresh](#)

Offer Submission for Generator 1

Generator 1: Offer					
Block	Capacity (MW)	Marginal Cost (\$/MWh)	Offer Price (\$/MWh)	Shut down?	Standby Cost (\$/hr)
1	50.0	\$20.00	\$ 20	☐	\$ 250
2	20.0	\$40.00	\$ 40	☐	\$ 100
3	10.0	\$48.00	\$ 48	☐	\$ 50
4	10.0	\$50.00	\$	☒	\$
5	10.0	\$52.00	\$	☒	\$
Total	100.0		Submit Offer		\$ 400

Additional Information	
Reservation Price (\$/MWh)	\$ 100.00
Interest Charged each Period (\$)	\$ 1200.00
Forecasted System Load (MW)	490.0
Total System Generation Capacity (MW)	600.0

Auction Results

Netscape: PowerWeb: Auction Results

POWER WEB

Name: [Select...](#) [test] Test User [Logout](#)
 Session: [Select...](#) [244] Example Session
 Representing: [Select...](#) Generator 1

Period **1**

[Refresh](#)
[Continue](#)

Auction Results for Generator 1 [[history](#)]

Generator 1: Results for Period 1 (duration = 1.0 hour)									
Block	Capacity (MW)	Marginal Cost (\$/MWh)	Offer Price (\$/MWh)	Quantity Sold (MW)	Selling Price (\$/MWh)	Revenue (\$)	Standby/Recall Cost (\$)	Variable Cost (\$)	Earnings (\$)
1	50.0	\$20.00	\$20.00	50.0	\$48.00	\$2400.00	\$250.00	\$1000.00	\$1150.00
2	20.0	\$40.00	\$40.00	20.0	\$48.00	\$960.00	\$100.00	\$800.00	\$60.00
3	10.0	\$48.00	\$48.00	10.0	\$48.00	\$480.00	\$50.00	\$480.00	\$-50.00
4	10.0	\$50.00	-	-	-	-	-	-	-
5	10.0	\$52.00	-	-	-	-	-	-	-
Total	100.0			80.0	\$48.00	\$3840.00	\$400.00	\$2280.00	\$1160.00
- Interest Charge									\$1200.00
= Total Earnings									\$-40.00

Auction History (Periods 1 - 1) [[results](#)]

Generator 1: History										
Period	Actual System Load (MW)	Offer Price (\$/MWh)					Quantity Sold (MW)	Selling Price (\$/MWh)	Standby/Recall Cost (\$)	Earnings (\$)
		Block 1	Block 2	Block 3	Block 4	Block 5				
1	464.0	\$20.00	\$40.00	\$48.00	-	-	80.0	\$48.00	\$400.00	\$-40.00
1 - 1		Cumulative Earnings: \$-40.00								
		Cumulative Earnings * Exchange Rate (0.0004): \$-0.02								

Experiment Objectives

Replicate the high price volatility observed in existing electricity markets using a “smart” market (POWERWEB)

- 30 Bus Network
- Human subjects (6) represent generators
- Pay real money proportional to profits
- Use various auction mechanisms
- Make load stochastic
- Standby charges for participation

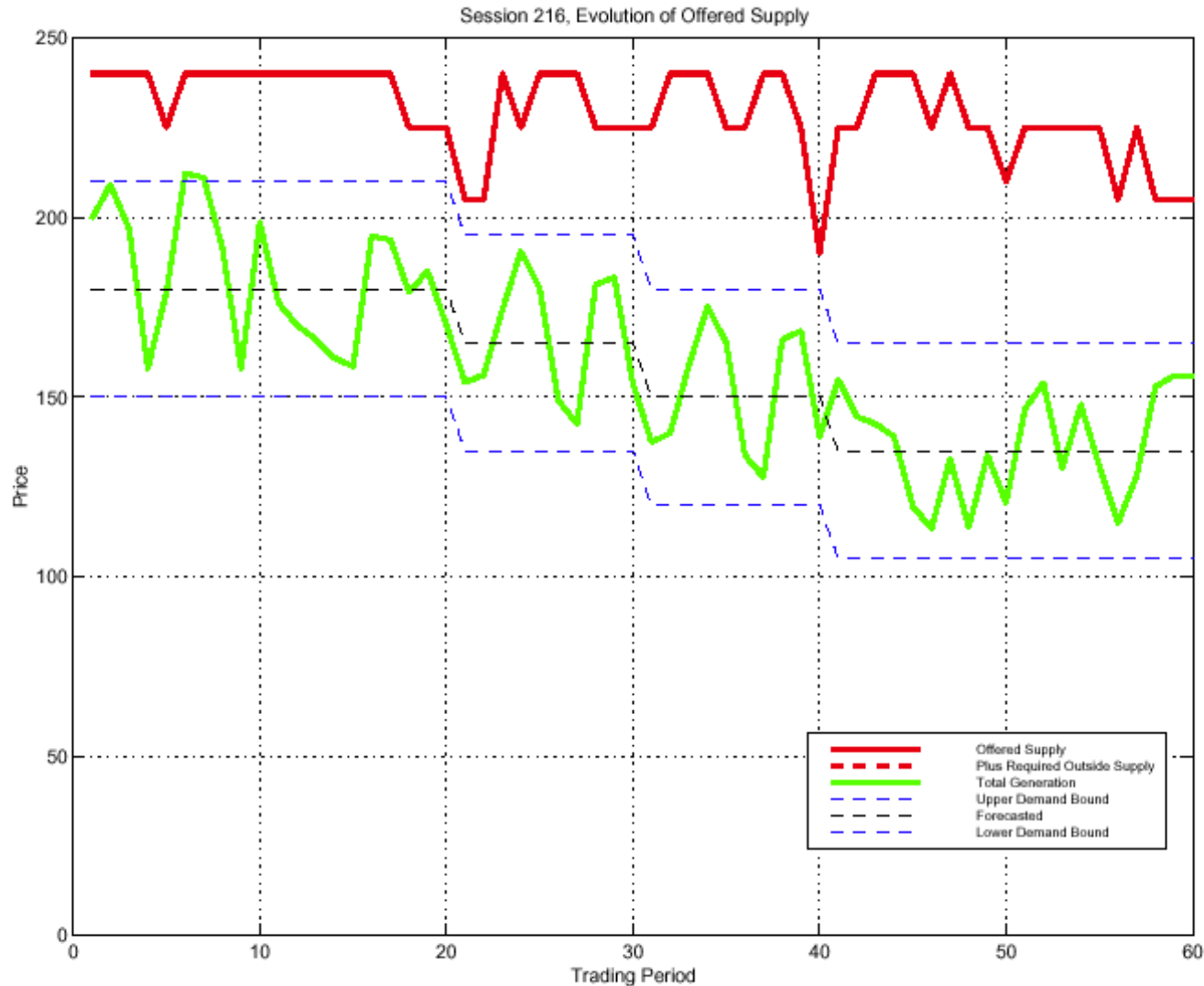
Test four different auctions

- Uniform price auction with price inelastic load (last accepted offer)
- Uniform price auction with price responsive load
- Discriminative auction (pay actual offers)
- Soft cap auction (uniform price below and discriminative price above)

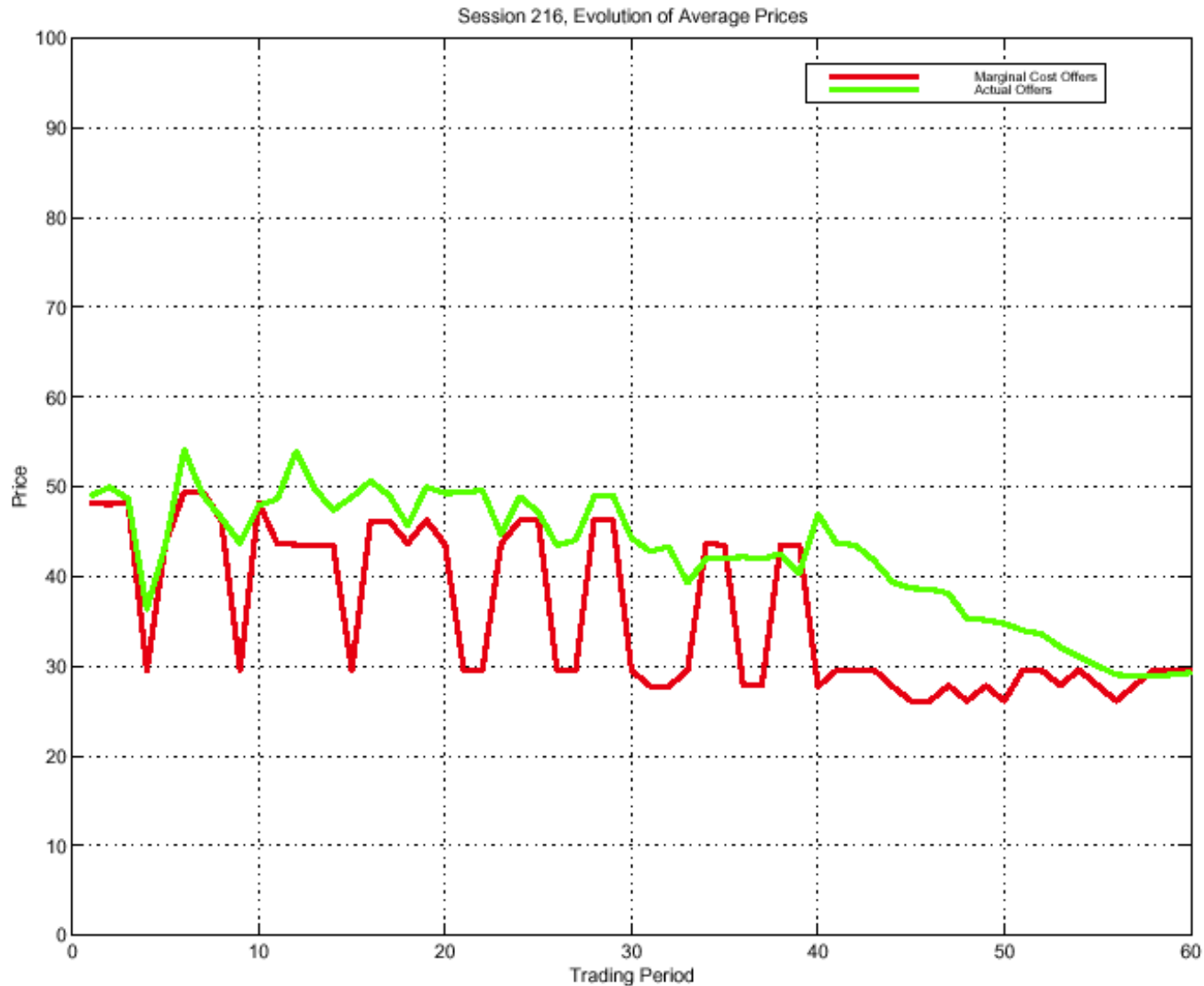
Capacity Offered into an Auction without Standby Costs



PSERC



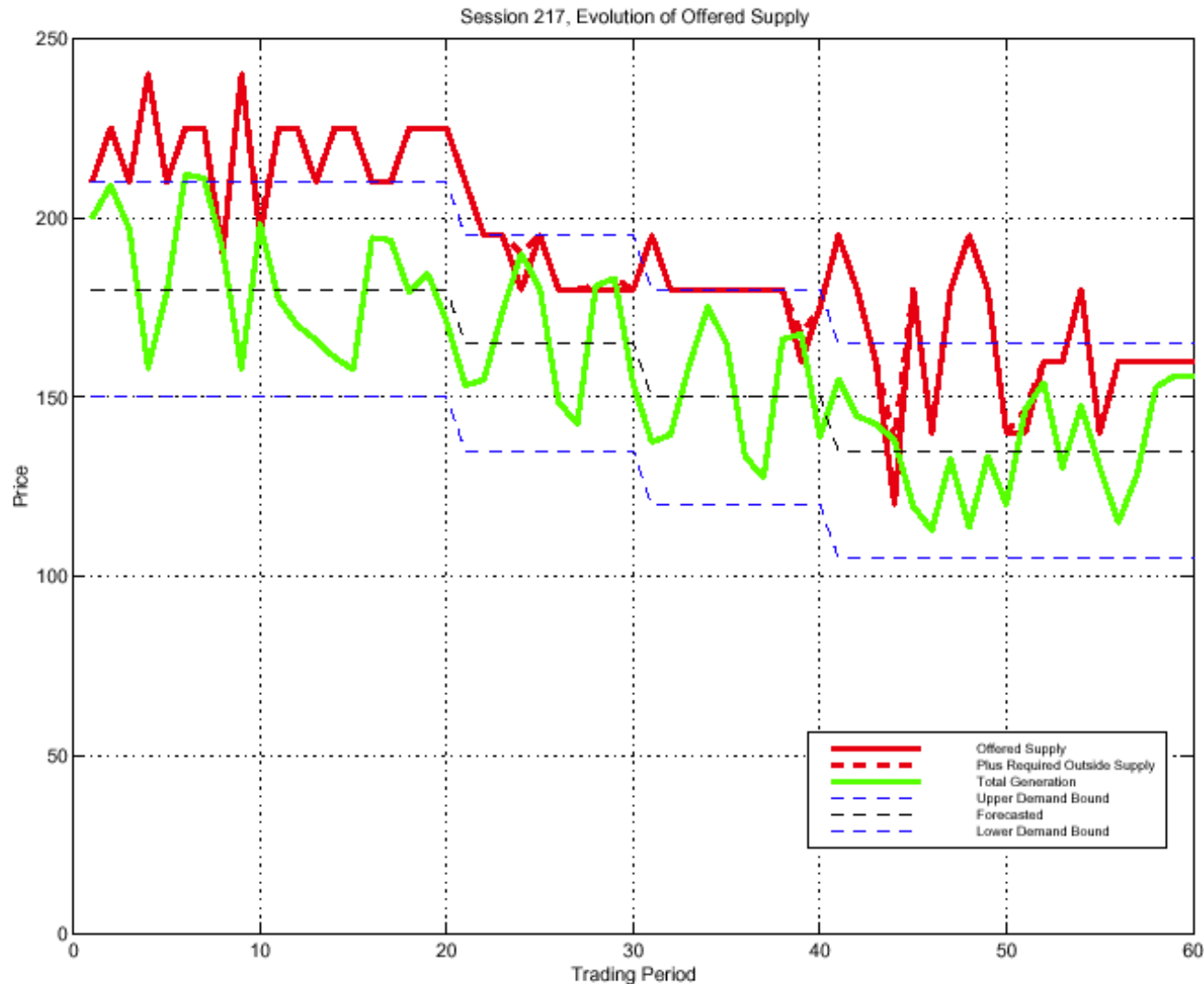
Market Prices without Standby Costs



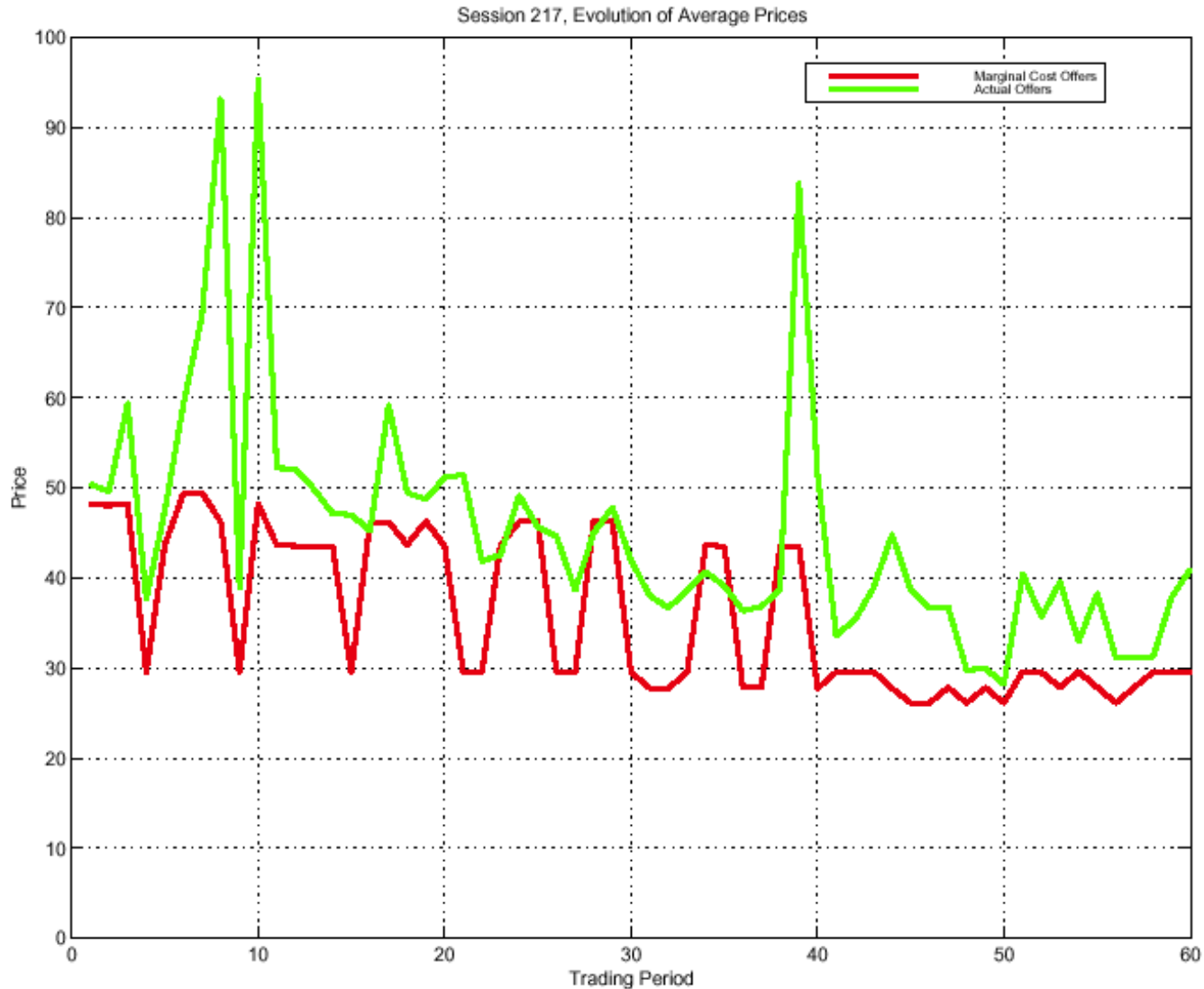
Capacity Offered into an Auction with Standby Costs



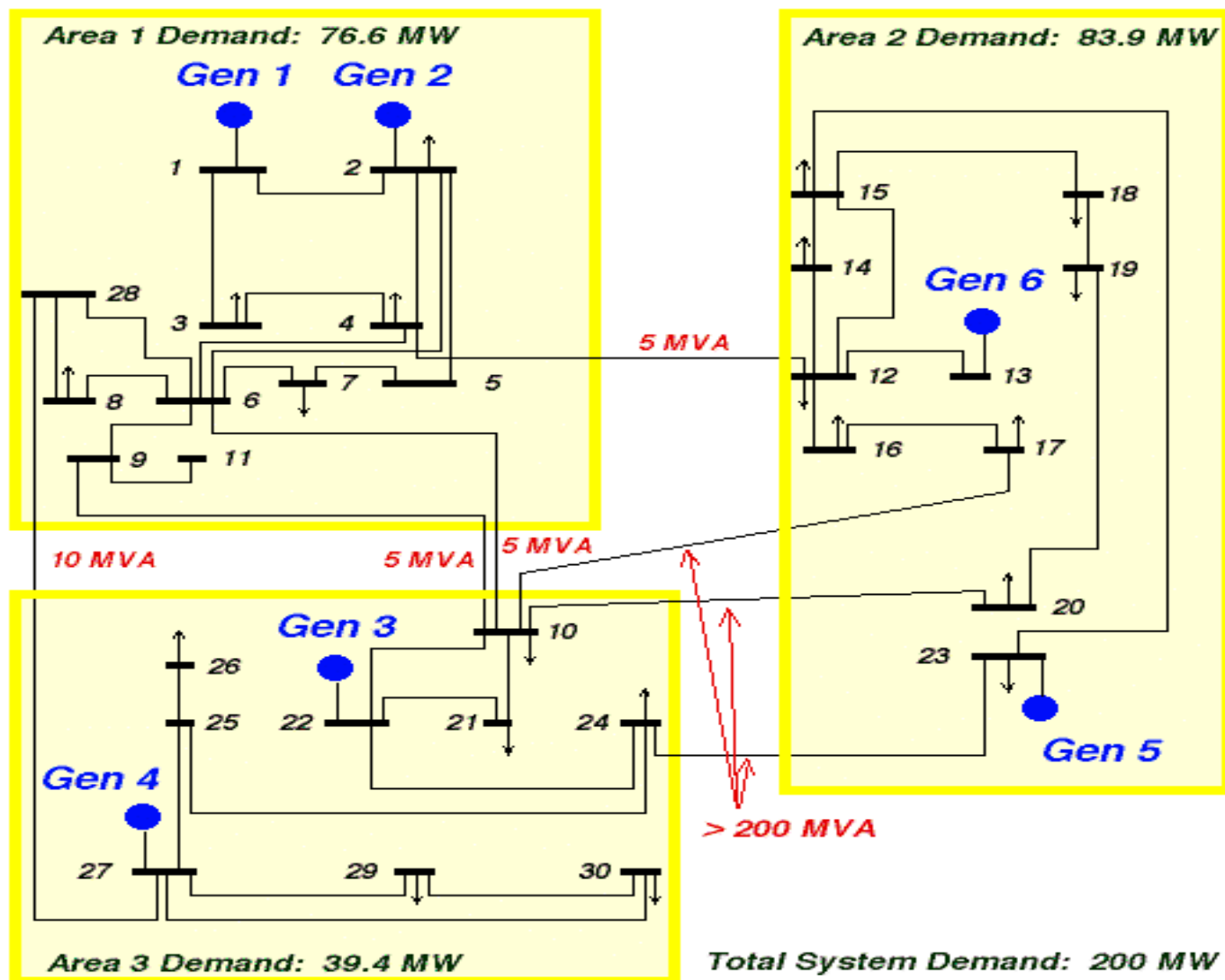
PSERC



Market Prices with Standby Costs



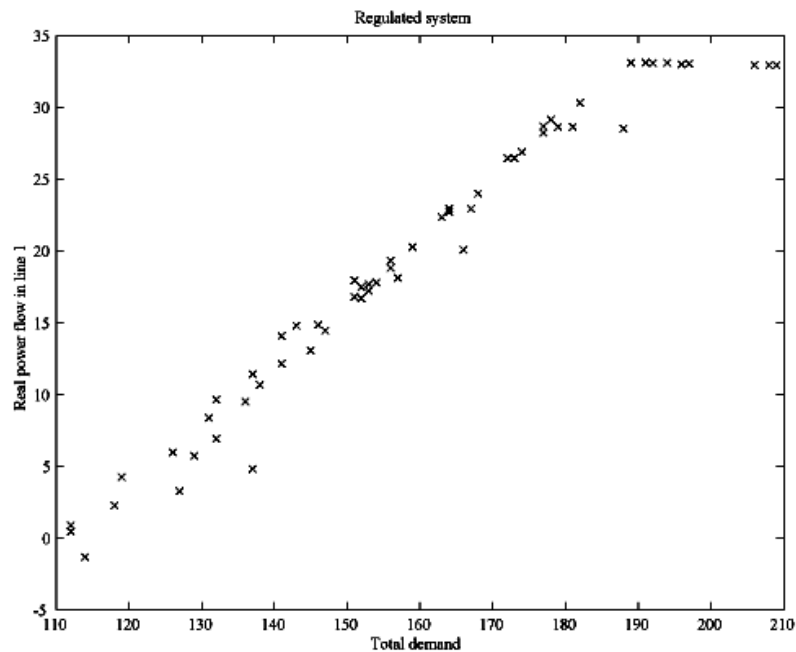
30 Bus Test System



Can Operators Predict Market Behavior?

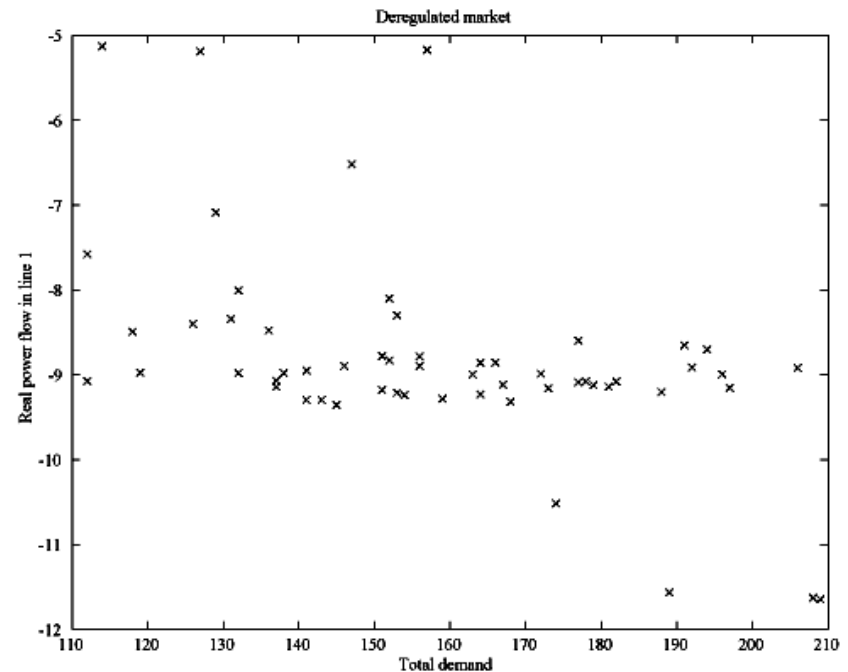
Results of Market Simulations Performed by PSERC

Regulated System



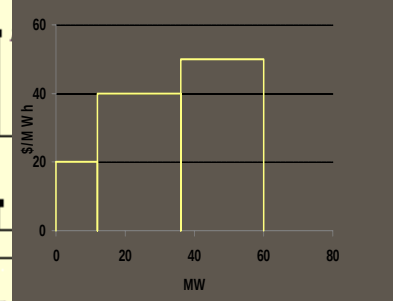
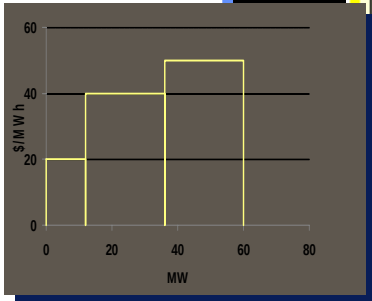
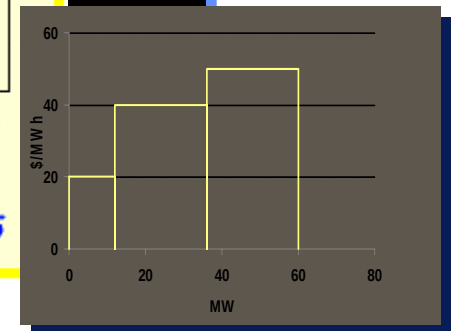
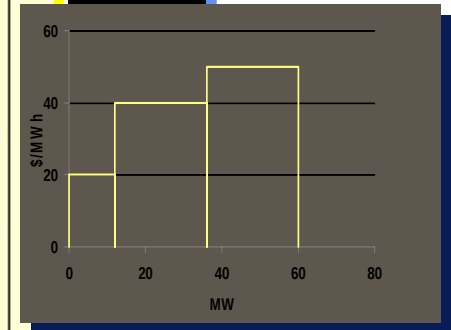
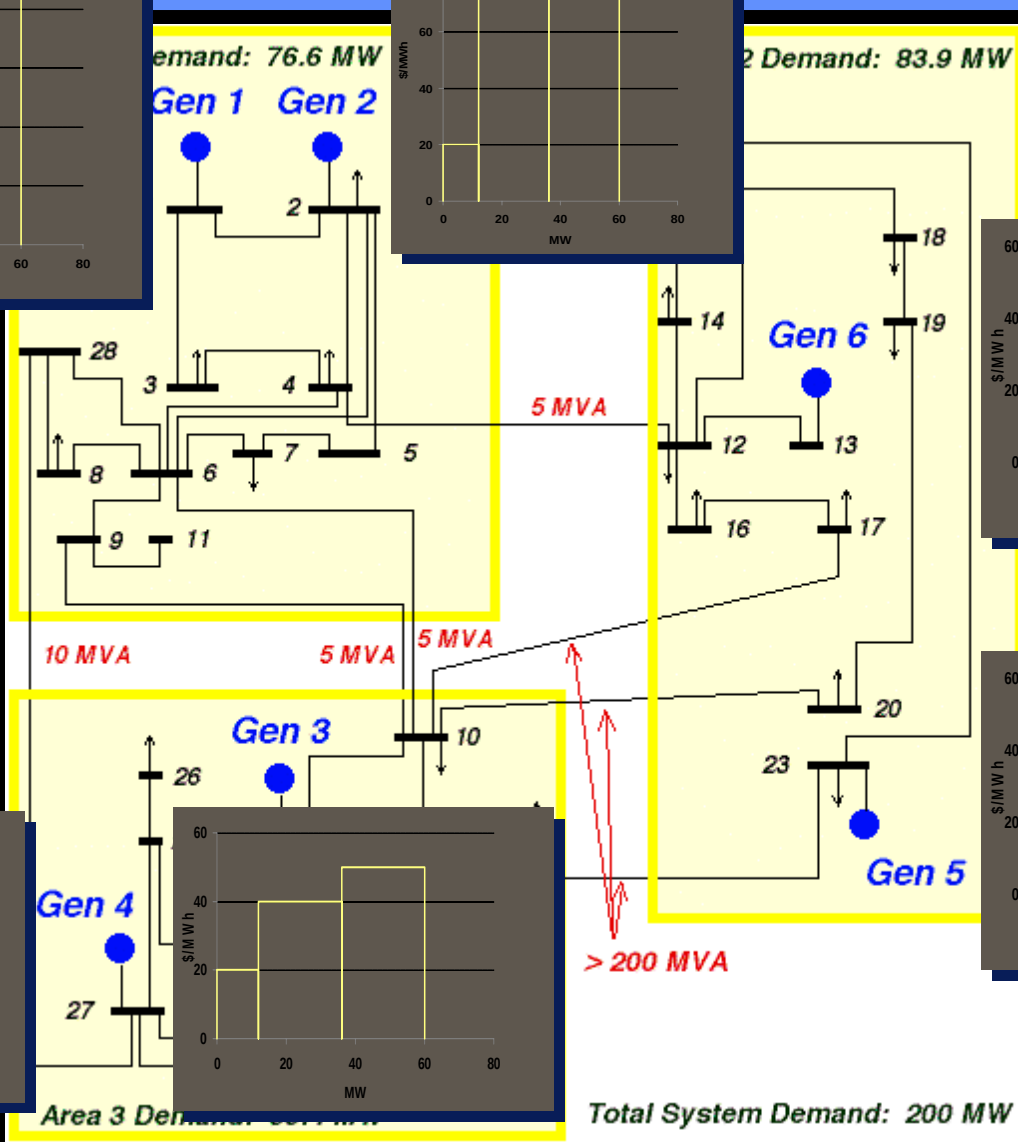
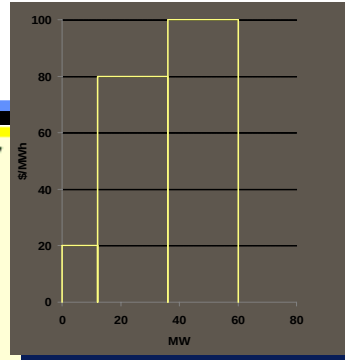
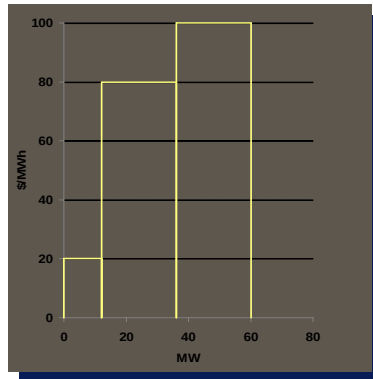
- Economic dispatch
- Strong correlation between power flow and demand

Market System

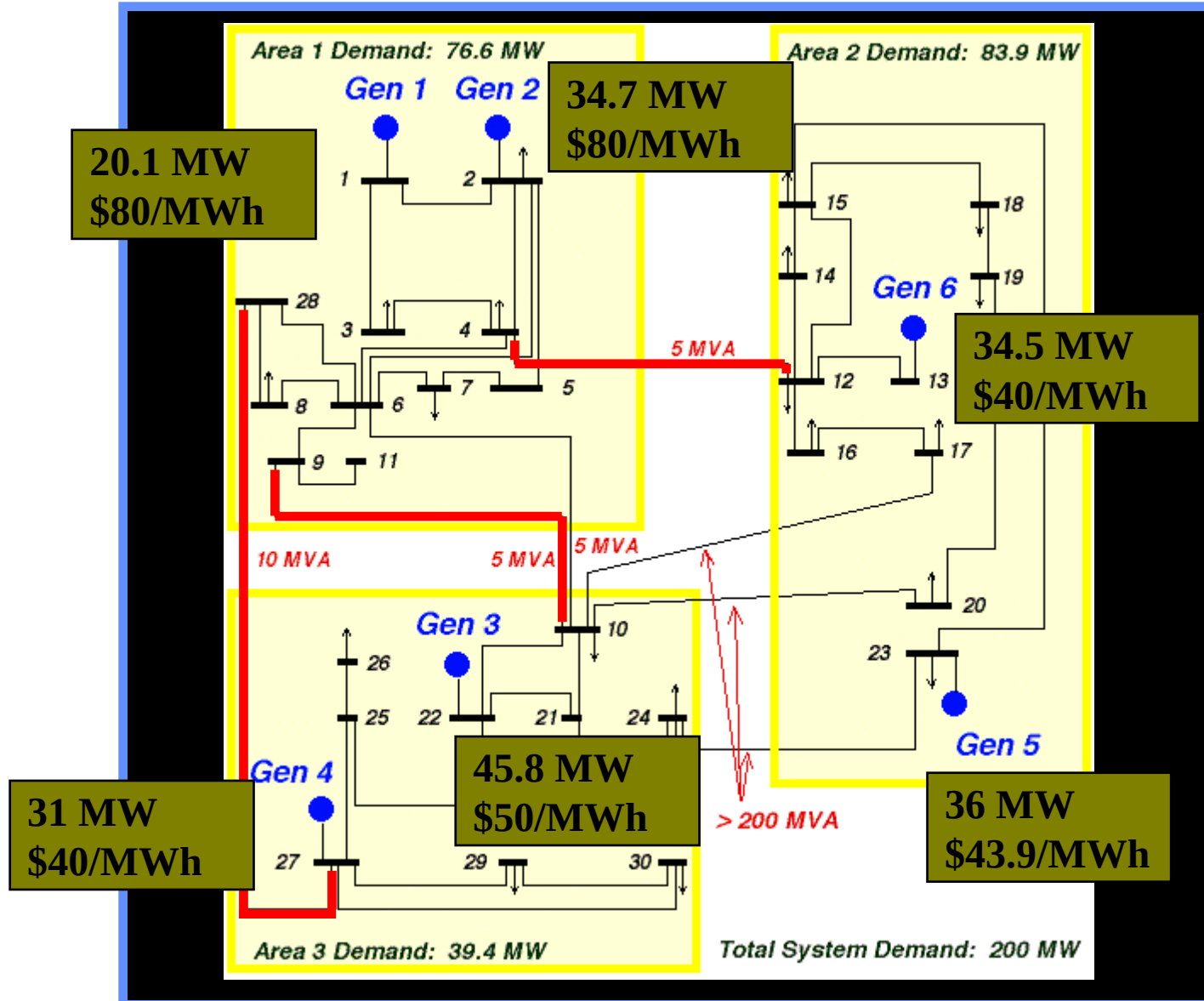


- Market-based dispatch
- Poor correlation between power flow and demand

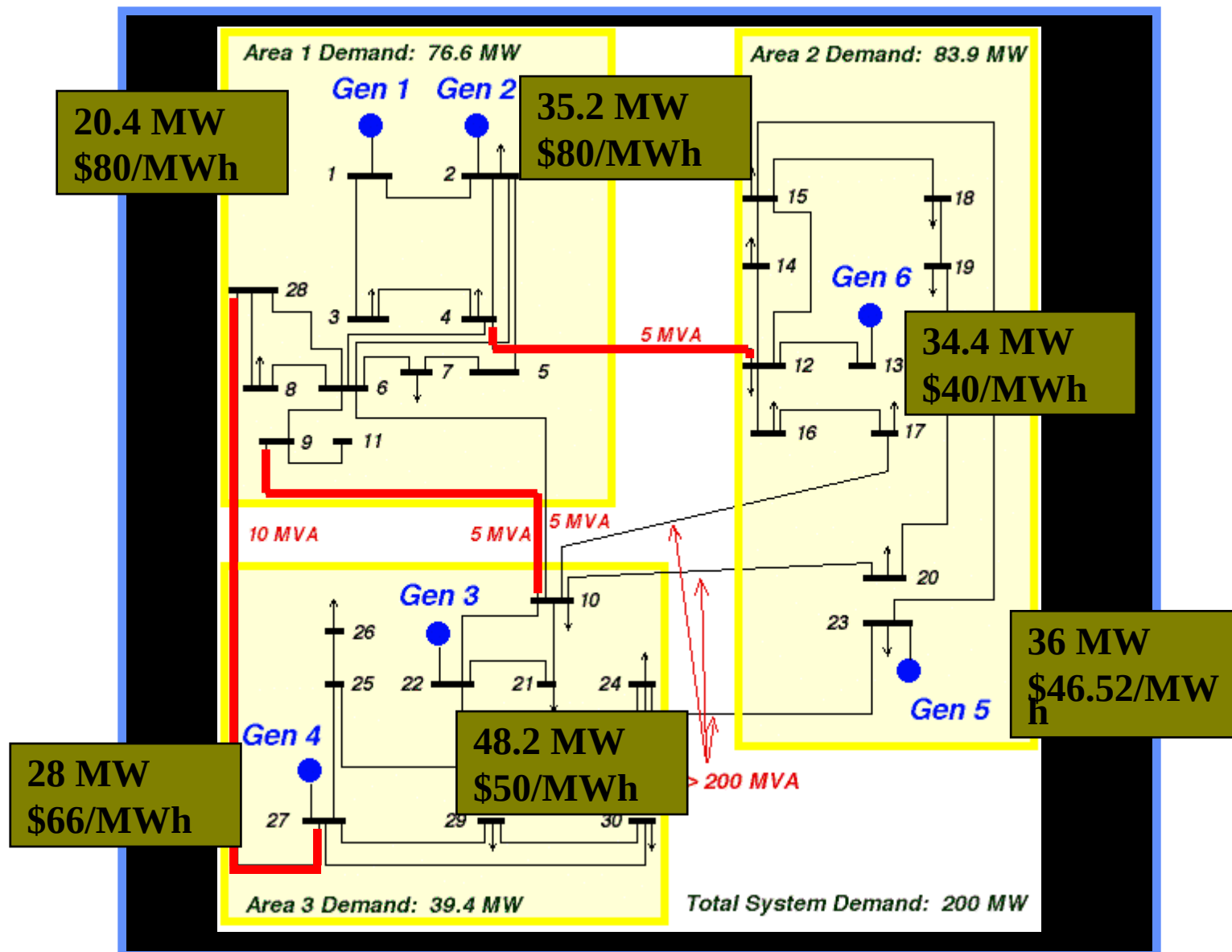
Tacit Collusion



Market Power (duopoly)



Cascading Market Power



What will it take to get the needed research done?

- A understanding of the problems
- National research need assessment: U.S. DOE's New Office of Transmission and Distribution
- Research and education funding
 - Research support has seriously declined since we began restructuring.
 - University and industry experts are graying.