Modeling the Restructured Illinois Electricity Market as a Complex Adaptive System

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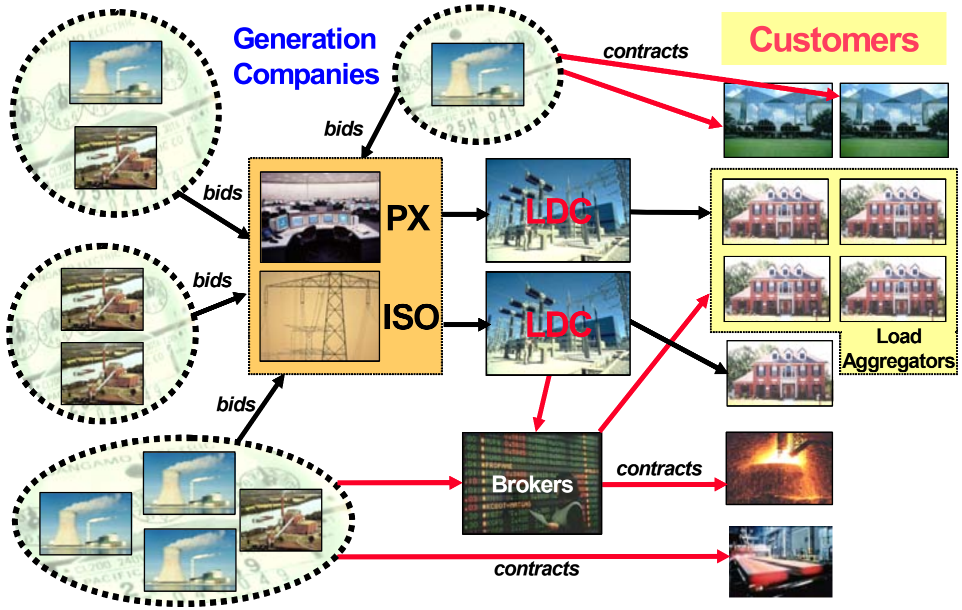
Outline

- Deregulated electric power markets and the agent modeling approach
- EMCAS model
- Investigations into market power
- Lessons learned

Electricity Markets Are Changing

- **The new deregulated electricity markets are founded on decentralized competitive decision-making**
  - Markets have greater complexity
  - Markets have more players
  - Participants have different (often conflicting) objectives and decision characteristics or risk preferences



- **Conventional modeling approaches must be extended to account for the new reality of decentralized competitive decision-making**

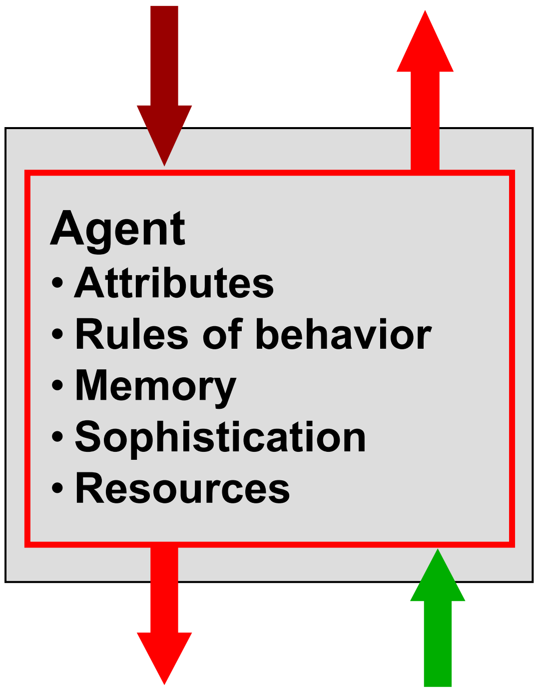
- **These extensions must be consistent with existing approaches and often include them in the larger modeling framework**

Why Agents?

- The rules of business and social interaction are at least as important as the rules of physics when it comes to the generation, sale, and delivery of electrical power
- Agents operating within an agent framework can be used to model decentralized competitive decision-making
- Agent frameworks allow groups of agents to interact in complex, dynamic ways
- Learning and adaptation of agent behavior can be modeled
- Transient conditions of the system can be studied in addition ot he long-run (equilibrium?) conditions
- Alternative market rules can be tested

Agents Are Autonomous, Self-directed, Decision-making Units

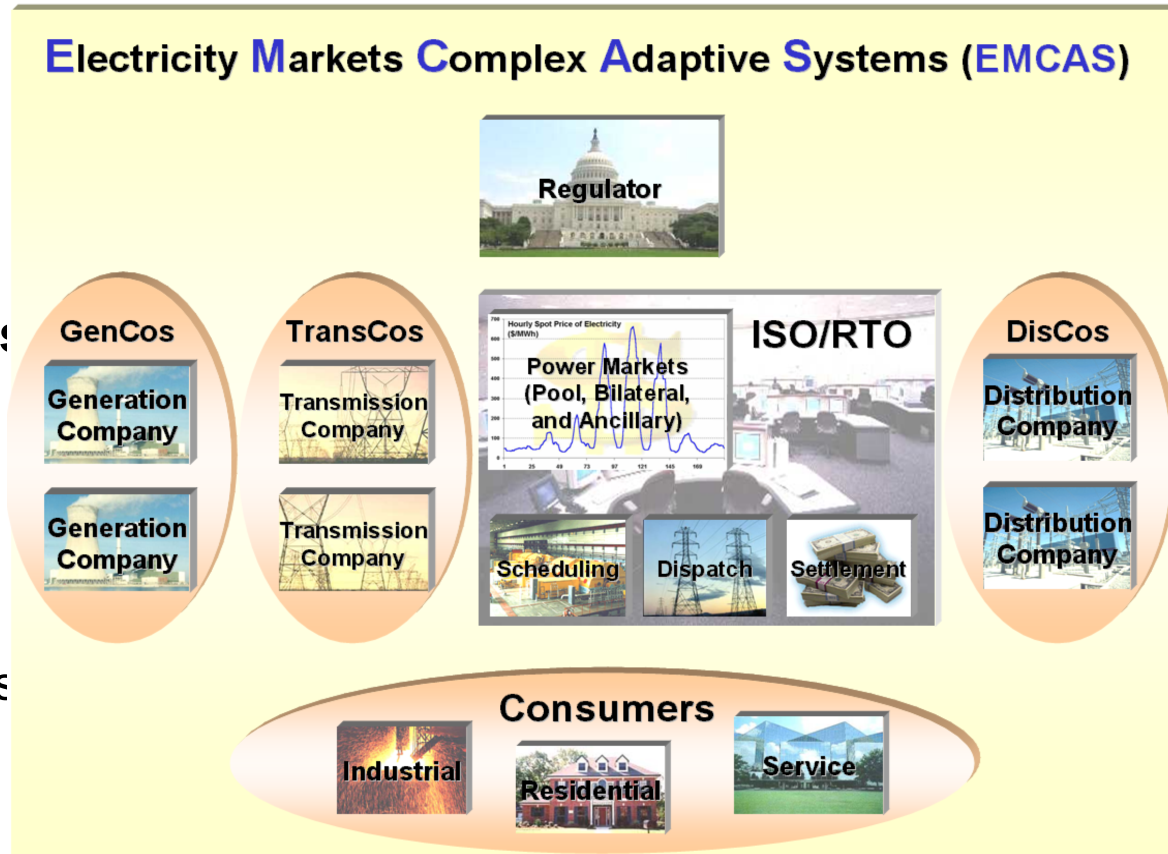
- **Agents are heterogeneous**
  - Goals
  - Behaviors
  - Attributes
  - Available accumulated resources
- **Decision rules vary by agent**
  - Sophistication of rules
  - Cognitive “load”
  - Internal models of the external world
  - Memory employed
- **What is the effect of individual agent behavior (rules) on the system?**
  - Do certain types of agents dominate?
  - Does the system evolve toward a stable mix of agent types?



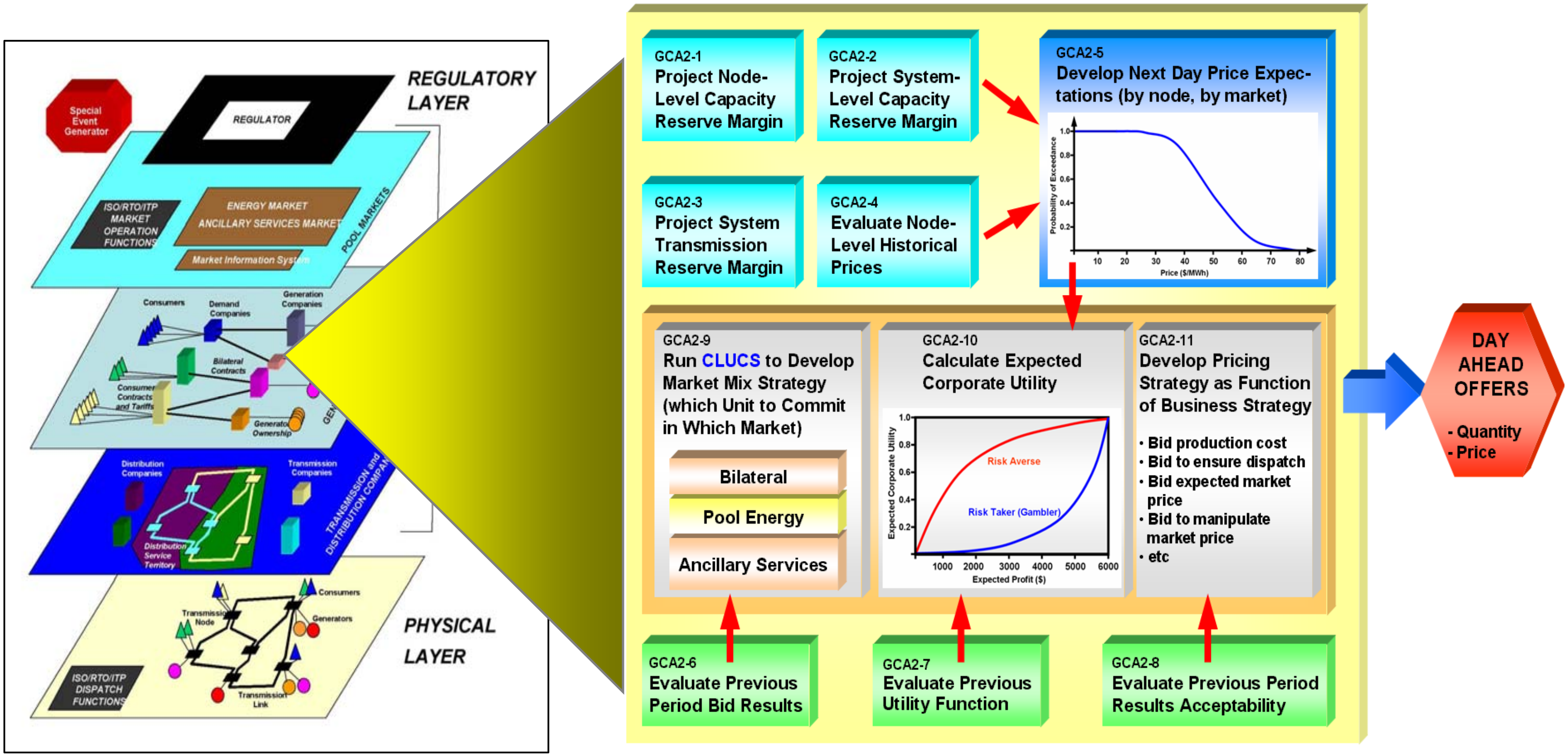
The EMCAS Model Uses A Variety of Agents to Model Decentralized Electricity Markets

- **Physical agents**
  - Generators
  - Transmission buses
  - Transmission lines

- **Decision-making agents**
  - Consumers
  - Demand agents
  - Distribution companies
  - Generation companies
  - Transmission companies
  - ISO/RTOs
  - Regulators



Generation Company Agents Consider Many Factors in Proposing Bids for the Day-Ahead Market



EMCAS Operates at Multiple Time Scales and Decision Cycles

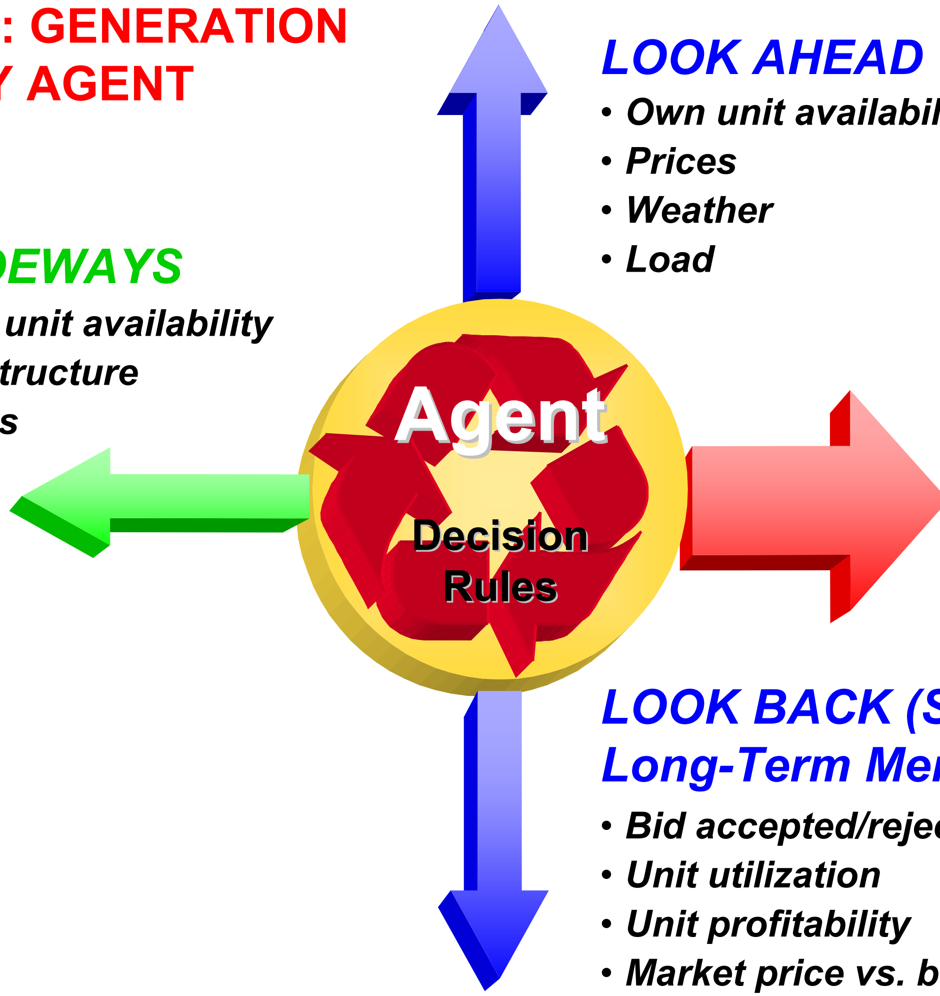
- ***Planning:***
  - *Day-Ahead Planning:*
    - Agents determine market allocations for selling products
    - Bilateral contracts are formed with individual demand agents, and energy bids are sent into the ISO
    - Agents make unit commitment schedules for the next day
- ***Dispatch: Hourly/Real-Time Dispatch:***
  - Power plants are operated as directed by the ISO in accordance with prior market arrangements made under bilateral contracts and in energy and ancillary service markets
- ***Weekly and Monthly Adjustments***
  - Bilateral contracts are made with individual demand agents and are sent to the ISO for approval
  - Marketing strategies are adjusted
  - Adjustments can be made to unit maintenance schedules

EMCAS Agents Make Decisions Based on Both Past Experiences and Future Expectations

EXAMPLE: GENERATION COMPANY AGENT

LOOK SIDEWAYS
- *Competing unit availability*
- *Own cost structure*
- *Market rules*

LOOK AHEAD
- *Own unit availability*
- *Prices*
- *Weather*
- *Load*

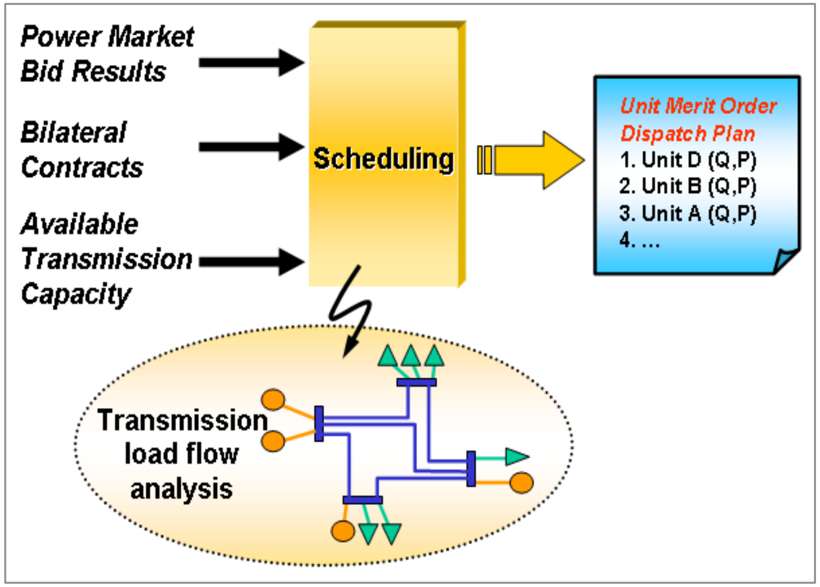


DECISION OUTPUT
- *Bid structure: capacity blocks for different markets*
- *Bid prices for each block and market*

LOOK BACK (Short and Long-Term Memory)
- *Bid accepted/rejected*
- *Unit utilization*
- *Unit profitability*
- *Market price vs. bid price*
- *Weather & Load*

The EMCAS ISO/RTO Agent Performs Several Functions

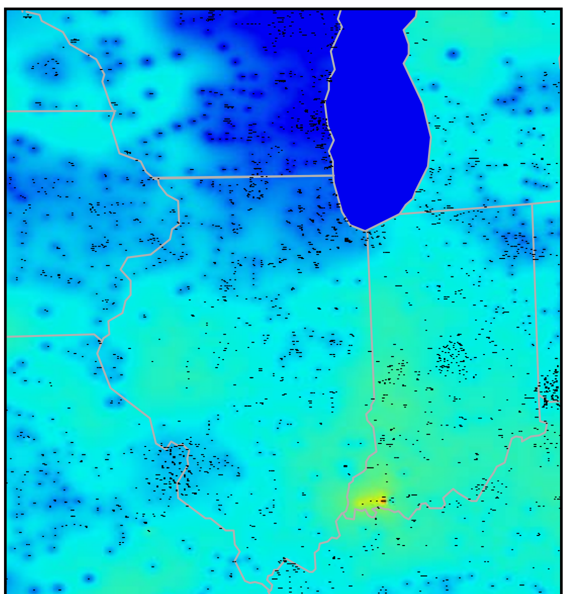
- ***Projection function***
  - Forecasts next day weather, system demand, and system available generation capacity
  - Makes information available to all agents
- ***Pool market function***
  - Operates the pool market for energy and ancillary services
  - Administers price setting rules such as LMP pricing or pay-as-bid pricing
- ***Scheduling function***
  - Accepts or rejects pool market bids and bilateral contracts using conventional load flow and optimization tools



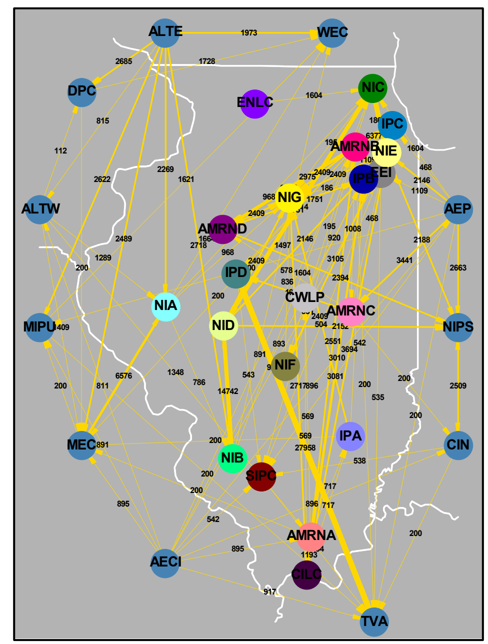
- ***Dispatching function***
  - Dispatches the generators in real time to match the demand
  - Maintains the necessary security requirements
- ***Settlement function***
  - Applies settlement rules selected by the user to calculate the payments to and receipts from the generating companies, demand agents, and transmission companies

The Physical System is Represented at the Bus/Branch Level While a Network Reduction Allows Zonal Market Simulation

- **Working with the University of Illinois and the PowerWorld AC power flow model, an equivalenced DC OPF (optimal power flow) model is derived and embedded in EMCAS**
  - In-state equivalenced network solved for 24-hour market
  - Includes equivalenced out-of-state representations
- **Major topology changes (e.g., substantial line outages) require network reduction to be rerun**

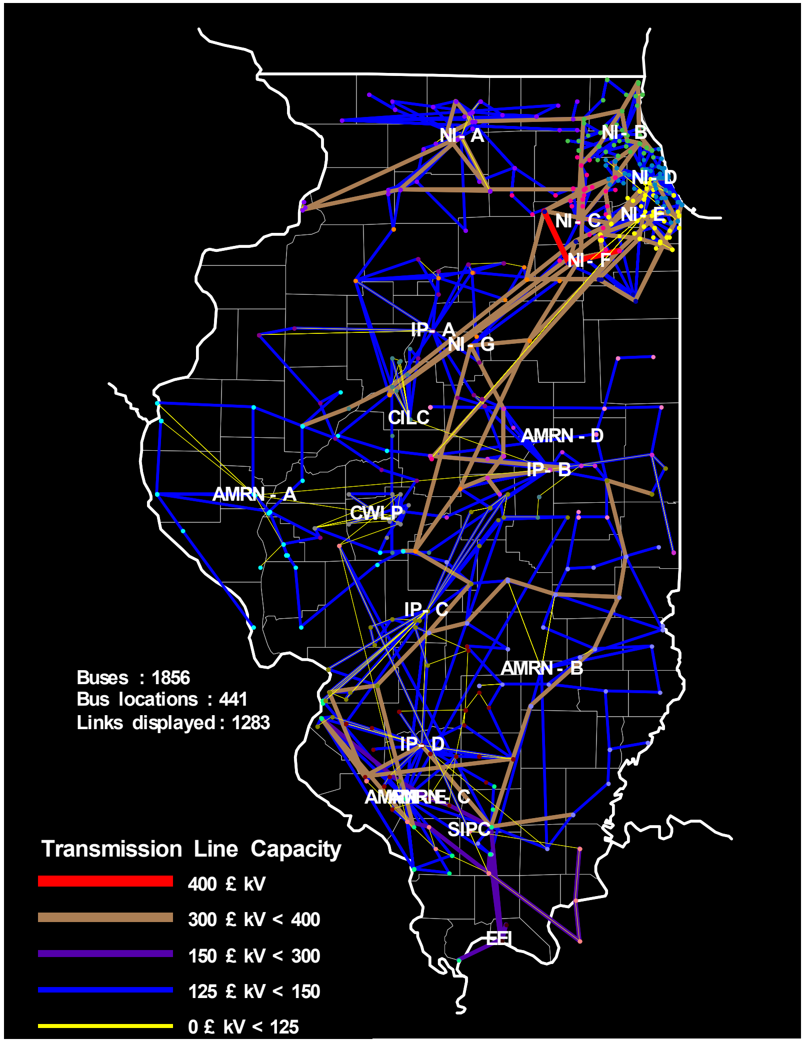


Network Reduction from Bus-Level to Zonal Level



Application: Electric Power Markets

How will Illinois fare under electricity deregulation: Jan. 1, 2007?



1. **Will power transmission capacity be adequate, or is congestion likely? Under what conditions?**
2. **Will transmissions constraints on the power grid create regional imbalances in supply and demand?**
3. **Will imbalances create pockets of market power and potentially drive up locational electricity prices?**

How Would We Go About Using Such A Model to Answer the Question of Whether There Is Market Power?

- **Establish a base case that excludes strategic behavior – bids based on production cost**
- **Establish reasonable assumptions on scenario variables**
  - Weather and effect on peak load
  - Unit outage assumptions
  - New capacity additions and transmission network adjustments
  - Agree on definitions (short-run, long-run), e.g., production cost
  - Identify credible strategies that agents might employ
- **Test the effect of these strategies incrementally with the model and compare with the base case**

Production-Cost Case Analysis

The following assumptions and market rules are assumed for the analysis year:

- Locational marginal prices (LMP) are paid to GenCos;
- DemCos pay the load-weighted average zonal price;
- There is a day-ahead market (DAM) administered by the ISO/RTO for both energy and ancillary services where GenCos and DemCos can participate;
- Bids are unregulated;
- Bilateral contracts between suppliers (GenCos) and purchasers (DemCos) are not allowed; all power is purchased in the spot markets;
- Generation companies sell electricity based entirely on the production costs of the generators, including fixed costs;
- Demand companies serve firm uninterruptible load; unserved energy is due only to forced outage conditions and not to any market considerations; consumers are assumed to have no response to electricity prices; and
- Transmission companies do not employ any strategic business behavior; their revenue comes in two forms: a transmission use charge of $3 per MWh and a transmission congestion payment.

Strategies for GenCo Agents

- **GenCo agents have various levers to base their strategies on**
  - Capacity to offer (bid) into the market
  - Price to offer the capacity
- **Witholding**
  - Physical Witholding
  - Economic Witholding
- **Price Probing: probe the market for weaknesses or flaws**
  - Discover if you are the marginal supplier
  - Discover who is the marginal supplier
- **A Host of Strategies:**
  - Dynamic incremental pricing
  - Fixed incremental pricing
  - Bid production cost
  - Bid low to ensure dispatch (EDF, for spot market only)
  - Bid high to increase the market clearing price
  - Bid last increment of capacity at high price
  - Adjust prices based on past performance (bid price based on moving average price)

Testing Strategies for GenCo Agents: Witholding

- **Physical Witholding: Capacity taken off line in order to improve business position**
  - Witholding capacity during periods of low prices, in which costs cannot be recovered
  - Witholding capacity for certain units increases LMPs for the system and the profits of other units in a companies generator portfolio
- **Economic Witholding: Generation capacity not taken off line – make available to the market at increased prices**
- **Fators to Consider in Implementing a Witholding Strategy**
  - *Unit capacity:* larger units tend to affect market prices more if witheld
  - *Unit location in transmission network:* units in areas of transmission congestion have larger impacts on the market if the transmission system cannot allow replacement capacity to be utilized
  - *Availability of replacement capacity:* Availability of replacement capacity and its price, will determine how the market will respond to physical witholding

Physical Witholding Experiments

- ***Experiment:*** ***GenCos physically withold units, observe affect on LMPs which results in changes in revenues. Which units to withold?***
- **Witholding a single unit of a company on peak load days,**
  - Preliminary results suggest that this strategy will not in general increase a company's profits
  - Loss of revenue from the unit witheld was not offset by higher prices paid to the company's units still operating
- **Witholding multiple company units, based on unit profitability (smallest profit potential)**
  - Preliminary results suggest that this strategy will not in general increase a company's profits
- **Witholding multiple company units, using system reserve and unit location as criteria**
  - Withholding done only when the system reserve was expected to be at a low point
  - Witholding units located at critical transmission network points (those with high LMPs)
  - Preliminary results suggest that this strategy can increase company operating profit and consumer costs considerably

Economic Witholding Experiments

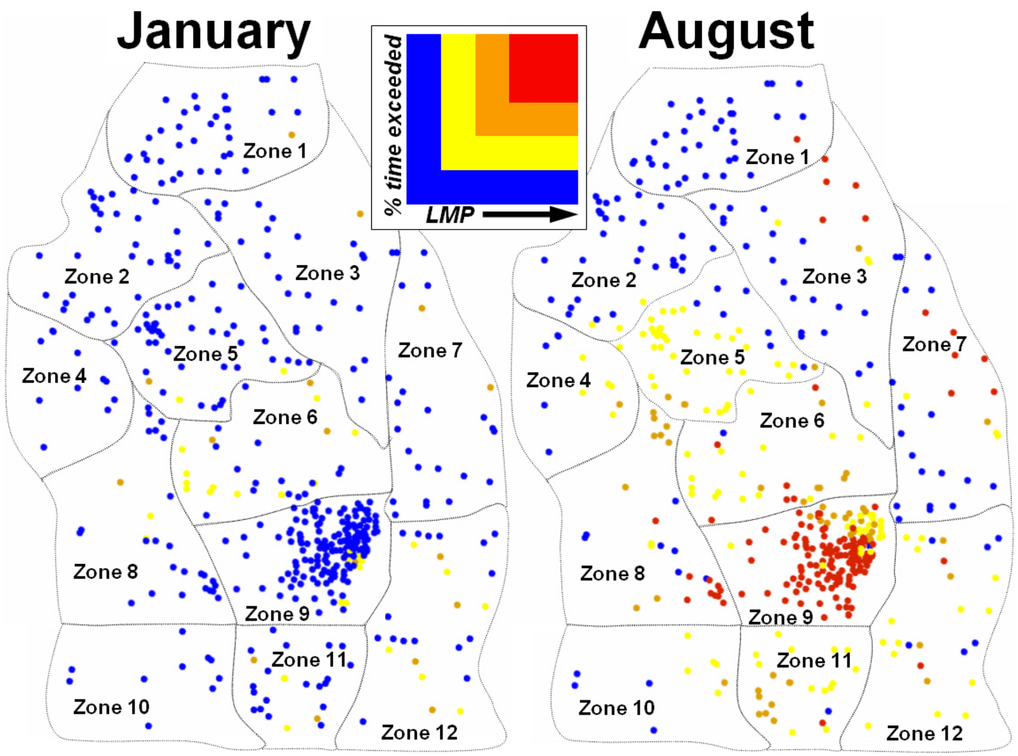
- ***Experiment:*** ***GenCos raise bid prices above production costs, observe affect on LMPs which results in changes in revenues. Which units to economically withold and for which hours?***
- **Company increases prices for a single unit of a company on peak load days**
  - Preliminary results suggest that this strategy will not in general increase a company's profits
  - Adequate generation and transmission capacity to bring cheaper units on line
  - A few units critical during peak hours provide small increases in operating profit
- **Company increases prices for all company units**
  - Preliminary results suggest that this strategy will not in general increase a company's profits if done for all units and all hours of a peak load day
  - May increase profits for a few larger companies if done for peak hours only

Testing Strategies for GenCo Agents: Price Probing

- ***Price Probing:* Test the bounds of the prices that can be offered in the market before competitors are able to capture market share**
- **Raising bid prices can result in increased profits if there is:**
  - Insufficient alternative generation capacity, and/or
  - Inadequate transmission capacity
- **Fixed Increment Probing**
  - A company raises prices by the same amount every day until its units are not selected and then retreats on prices
- **Dynamic Increment Probing**
  - Prices on units are raised by varying amounts depending on
    1. evaluation of a company's operating profit
    2. the projected system status, and
    3. whether specific units in their portfolio are located at critical points in the network

Base Case

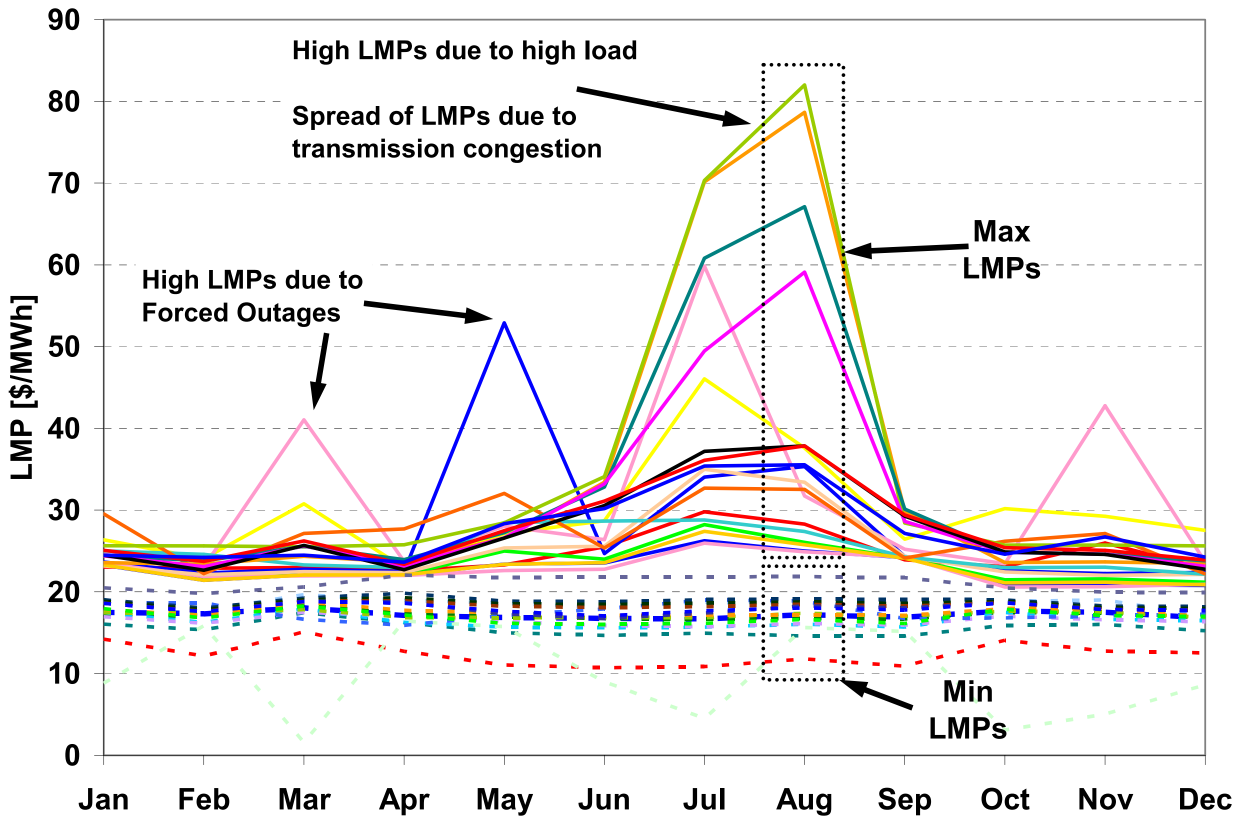
- Preliminary results suggest that higher LMPs are experienced through some portions of the study area
- Cheaper generation available in some areas does not help relieve the higher prices in other parts of the study area due to transmission limitations



Potential Future Load Pockets

Base Case

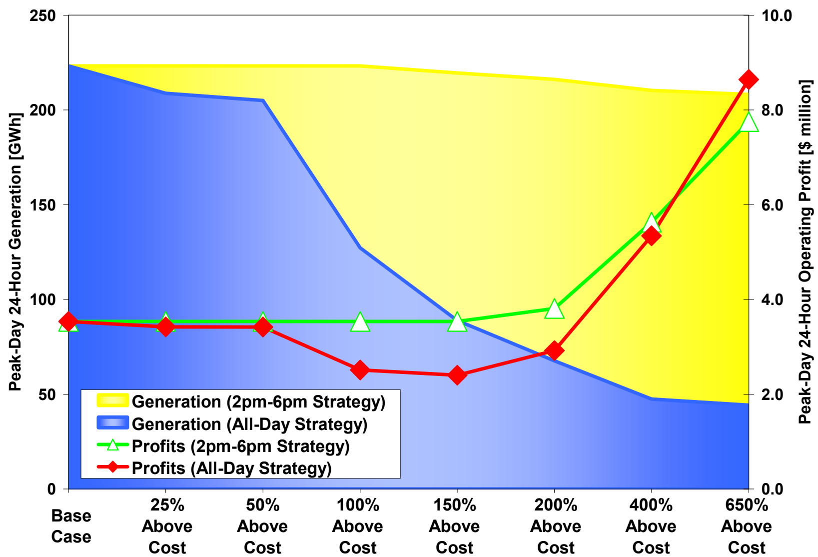
- **Congestion-related dispatch of units out of bid merit order leads to LMP differences across the system (note, no strategic bidding)**



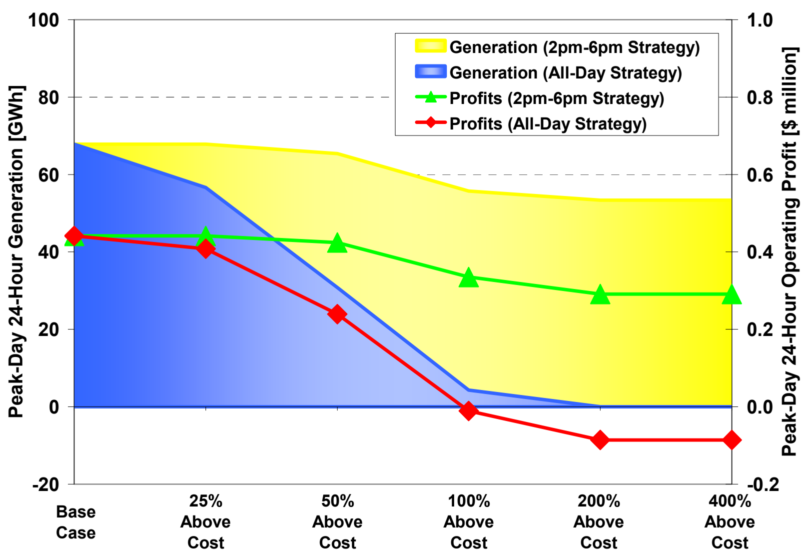
Projected Monthly Minimum and Maximum Hourly LMPs for All Zones

Identifying Market Power

- GenCo bid prices are increased to various levels above production cost
  - All-day
  - Afternoon only



GenCo with Market Power



GenCo with No Market Power

Lessons Learned from Agent-based Modeling of Electric Power Market

- **Agent-based modeling can be a useful adjunct to understanding the deregulated electric power market**
  - Important to have the agent model produce a base case that is comparable to what traditional modeling approaches would produce
- **Modeling (and validating) the interface/interplay between the physical system and the economic system is essential for credibility**
- **Agent strategies that are based on bounded rationality in lieu of a theory of agent behavior require special modeling approaches:**
  - Agent strategy hypothesizing, simplicity, screening, and support
  - Sensitivity analysis and parameter space exploration (lots of simulation runs)
  - Issue of non-attribution of agent behaviors to particular agents in the system (an agent could behave that way, but would they?)

Questions?

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