Autonomous Agents in Future Energy Markets: The Power Trading Agent Competition

Computer Science Colloquium
University of Minnesota

The business school that thinks
and lives in the future

Electric power enterprise heading into uncharted territory

Challenges

a few examples

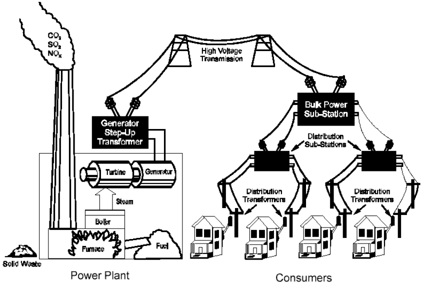
- Availability and externalities of fossil fuels
- Instability during peak loads
- High cost for unused (reserve) capacity
- Variable-output, non-dispatchable sources
- Market liberalization and restructuring
- Pricing of zero-marginal-cost sources
- Production resources in the distribution grid
- Electric vehicles
- Demand-side management and dynamic pricing
- Retail/business customers as active participants
- Policy issues: regulation, transparency, taxation, subsidies

Today's grid

Top-down control

The current system for delivering electrical power –

- Assumes power flows from large plants to end-users.
- Is controlled and monitored only at the top level.
- Must be closely balanced in real time.

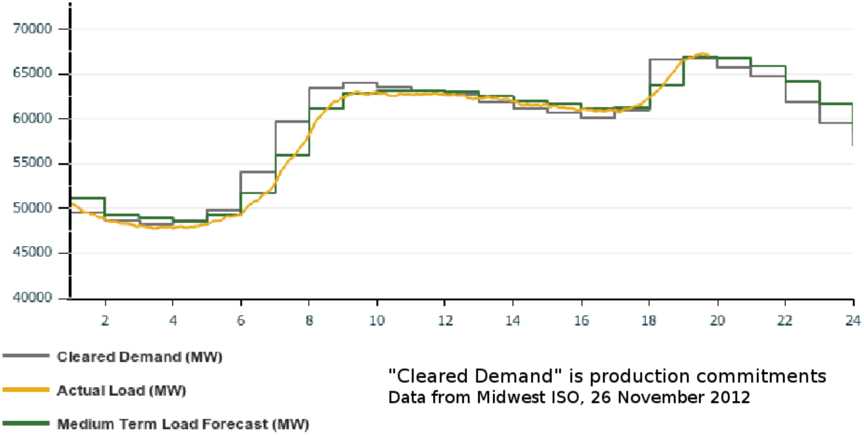


Tomorrow’s grid

Challenges

The Balancing problem

Making supply match demand



"Cleared Demand" is production commitments
Data from Midwest ISO, 26 November 2012

Reserve capacity

for balancing and reliability

up-regulation

- Ramp up spinning reserves
- Ramp down curtailable loads
- Maintain safety margin

Reserve capacity

for balancing and reliability

up-regulation

- Ramp up spinning reserves
- Ramp down curtailable loads
- Maintain safety margin

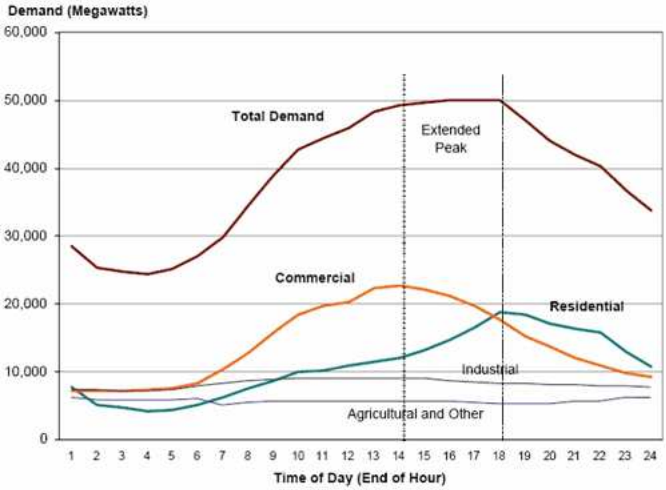
down-regulation

- Ramp down spinning reserves
- Ramp up curtailable loads

Reserve capacity

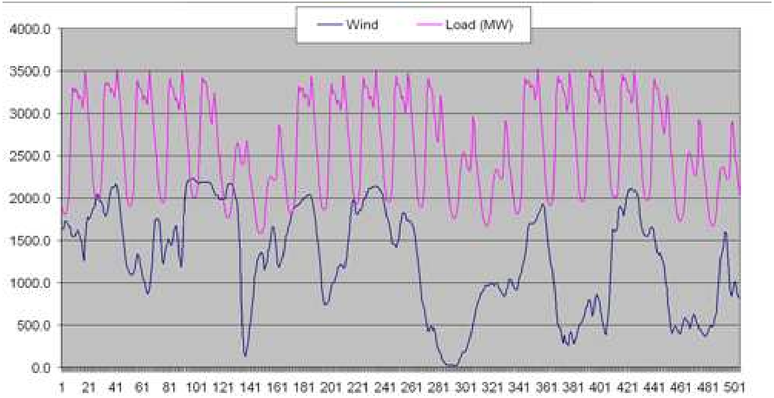
for peak demand

A hot day
in California



Reserve capacity

to integrate variable-output sources



Wind supply and total demand in Denmark, January 2005

Energy storage as reserve capacity

- Non-full battery for down-regulation
- Non-empty battery for up-regulation
- Can plugged-in Electric Vehicles be used?
- What about thermal energy storage?

What is the value per kWh of storage?
How much is available?

Retail competition

Why?

Remember Deutsche Bundespost?

- Regulated monopoly
- Rigid business model
- Broken up in 1996

Power markets?

- Wholesale markets were opened in the 1990s.
- Retail markets require near-real-time metering.

What is a market?

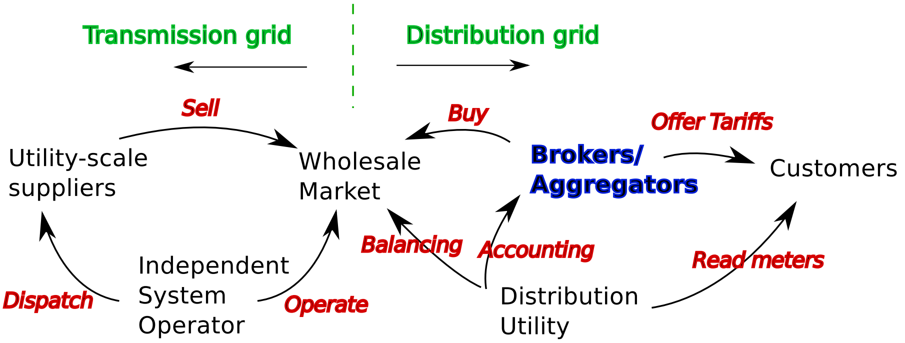
What can it do for us?

Our view: market is a general mechanism for distributed decision-making.

- Wholesale market minimizes cost of delivered power
  widespread adoption
- Energy prices can influence customer behavior
  early days, requires updated metering
- Balancing market involves retailers and customers in balancing
  active research area

Retail competition

How would it work?



Rough schematic showing markets and relationships; details vary

What can go wrong?

California, 2000

- Poor market design created opportunities for manipulation
- On the wholesale side, Enron and others discovered they could get higher prices by restricting supply.

Training simulations

- System management, fault response
- Trading in wholesale markets
- Project management
- Supply-chain management

System simulations

- Network dynamics
- Economic simulations (ACE)

Enabling research, when

- Self-interested agents (can) play a critical role
- Problem is too complex for formal game theory
- Cannot experiment with real organizations
- Competition can validate proposed solutions

Competitive Simulation

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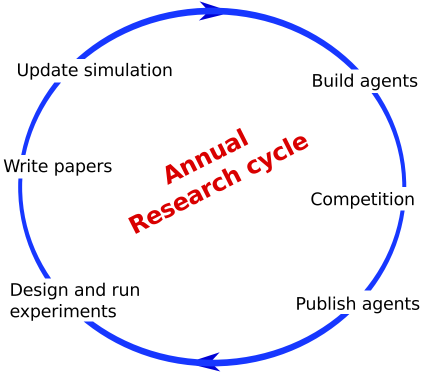
The “Game”

- Simulation model of real world scenario.
- Limited visibility, non-deterministic
- Uncertainty, imperfect information
- Balance real-world complexity with ease of analysis

Research model

Key Advantages

- Robust results
- Leverage the abilities of top research groups
- Annually updated research challenges (cf. Netflix)
- Tournament vs. research mode



Competitive Benchmarking

Open competitions

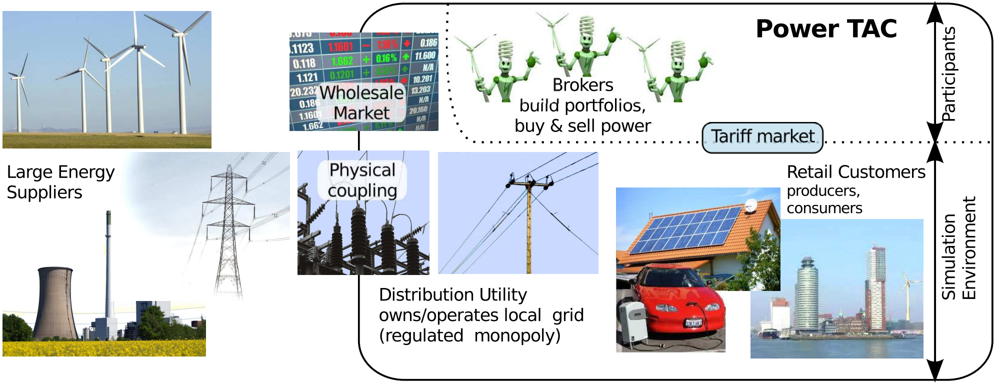
- Produce robust results
- Require significant investment
- Severe test of software quality
- Flexible architecture is key

Scenario criteria

- Balance abstraction and complexity
- Defeat trivial and unrealistic agent strategies
- Support repeatable experiments.

Power TAC Scenario

Modeling retail electricity markets



Time: The fundamental variable

Simulation time

- Basic unit:
  1-hour "timeslot"
- Typical sim:
  1440 timeslots (60 days)
- Time of day matters
- Day of week matters
- Date matters

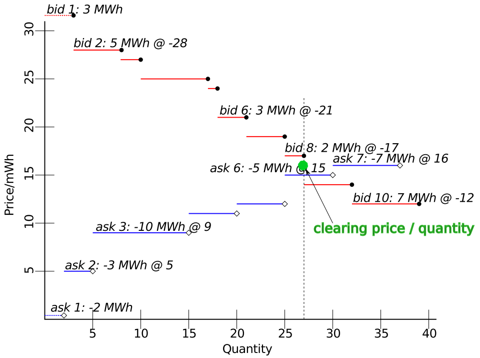
Time constraints

- Server and Broker must be in sync
- Broker must have sufficient time to build models, make decisions
- End of sim must not be predictable

$$simTime = base + (sysTime - start) * rate$$

Abstraction of FERC mkt

- Periodic double auction, cleared once/timeslot
- Bids and asks accepted any time
- Clearing price maximizes traded volume
- Brokers get clearing price and volume, uncleared bids and asks



Bottom-up models

- Detailed models of households and businesses
- People come and go, use their appliances & lighting, play video games
- Air conditioners, water heaters, refrigerators run as needed.
- Models validated against European consumption statistics
- Small populations < 100

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Top-down models

- Large populations, households and businesses, $10^4 - 10^6$
- Multiple small-scale solar and wind installations
- Statistics drawn from bottom-up models and public data

Tariffs and Rates

Tariff structure

- Standard fixed rates
- Time-of-use pricing
- Tiered rates
- Off-peak rates
- Subscription bonus
- Early-withdrawal penalty
- Fully-dynamic rates with realized-price tracking

Customer behavior

- New tariffs published every 6 hours
- Customers might pay attention: usually they do not
- If customer notices, it evaluates tariffs on offer
- Utility based on cost, convenience, risk attitude, reputation
- Customers not completely rational; utility is approximate guide

Current practice

- Supply-demand balancing is done at the top-level, by the ISO
- ... by up-regulation or down-regulation using reserve capacity
- Costs might be allocated to out-of-balance nodes

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Market-based balancing

- Retail brokers must be responsible for balancing their own customers.
  - by buying/selling in the wholesale market
  - by exercising controls among their customers
- Market must motivate brokers to achieve balance
- Market might reward brokers for offering balancing capacity to offset other brokers' imbalance

Default Broker

- Acts as the market "incumbent" at the time of market opening
- Retail arm of the Distribution Utility
- Puts a "floor" on the market by offering relatively unattractive, fixed tariffs
- At start of sim, all customers are subscribed to Default Broker's tariffs
- Competing brokers must attract them away
- Trades in the wholesale market to supply its own customers

Distribution Utility

Regulated monopoly

Distribution
- Owns & maintains distribution infrastructure
- Charges brokers for use of the system

Accounting
- Reads customer meters every hour
- Keeps customer subscription records
- Reports to brokers

Balancing
- Sees broker positions in wholesale market
- Exercises offered controls on customer supply/demand
- Runs the balancing market

Real-world weather

- Weather affects consumption and production
- Brokers need forecasts to guide trading
- Wind parks must make future sales commitments
- Current conditions: temperature, cloud cover, wind speed
- Forecasts: 24-hour forecasts updated every hour

Brokers

Goal: maximize profit

- Create and modify tariffs, adjust prices
- Buy and sell power in the wholesale market
- Sell controllable capacity in the balancing market

Public information

- Bootstrap data
- Broker identities
- Published tariffs
- Wholesale prices, orderbooks
- Weather data
- Consolidated supply & demand

Private information

- Transactions: tariff, market, distribution, balancing
- Portfolio supply and demand, market position, cash position

Brokers need basic domain info to support decisions

- Decisions typically driven by statistical models: market prices, customer behavior, weather
- Competitor identities
- Existing tariffs

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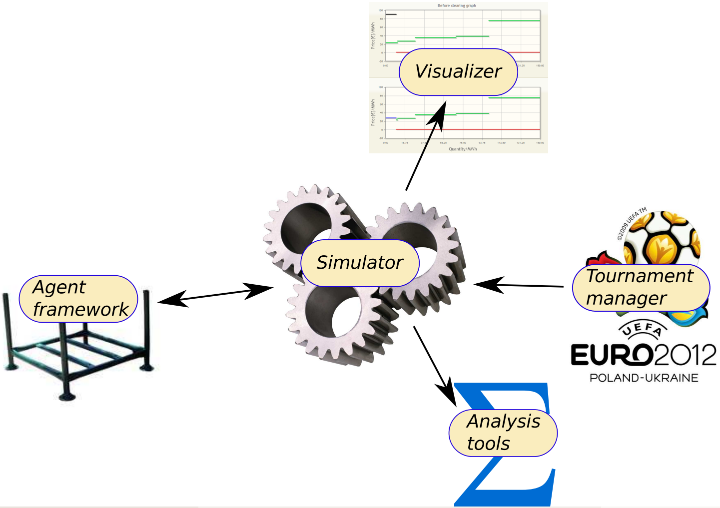
Every sim session requires a “bootstrap” dataset

- represents 2 weeks just prior to the start of the sim
- only the default broker is active
- weather history, wholesale market clearing prices
- customer production/consumption

Trading Agent Competition

Infrastructure



Tournament manager

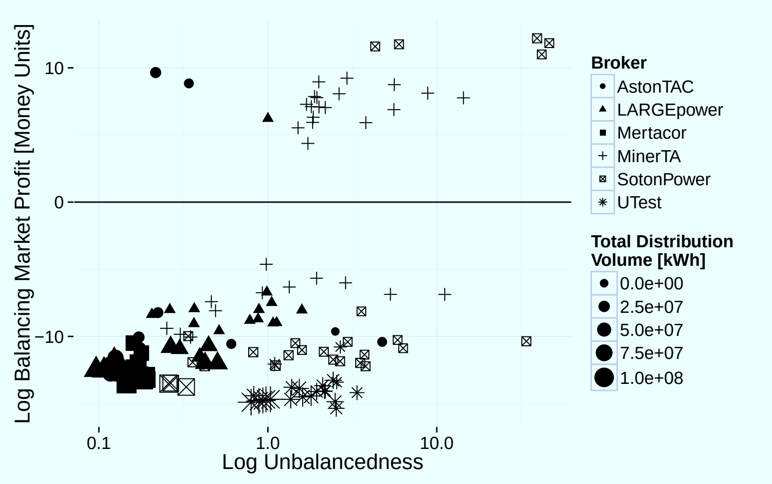
the scheduling problem

- Start with b brokers, game sizes $s_1, s_2, ..., s_n <= b$
- For each size s_n, each broker must see the same number of games
- So the number of games of size s_n must be $i \cdot \binom{b}{s_n}$
- Game length is non-deterministic; we cannot build schedule ahead of time
- Estimates of tournament duration must be generated by simulation.

Power TAC – Demonstration

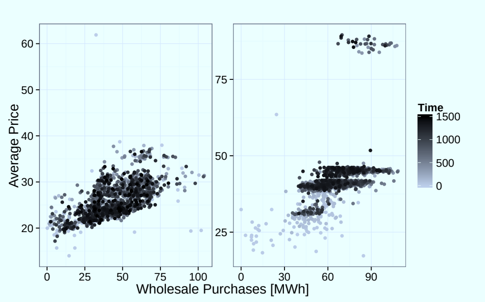
Results

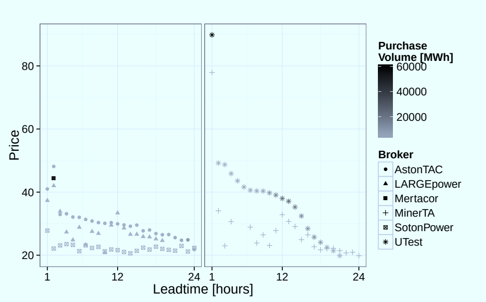
Agent balancing performance



Results

Prices and Leadtime effects in wholesale market





Building Power TAC

An international collaboration

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University of Minnesota, Minneapolis: John Collins, Travis Daudelin, Josh Edeen, Ryan Finneman, Nguyen Nguyen, Erik Onarheim, Shashank Pande, Kailash Ramanathan, Puthyrak Kang

University of Zagreb: Vedran Podobnik, Jurica Babic, Adis Mustedanagic

Aristotle University, Thessaloniki: Andreas Symeonidis, Antonios Chrysopolis

Carnegie-Mellon University: Manuela Veloso, Prashant Reddy

Ongoing research

enabled by Power TAC

- Effect of active management and variable pricing on grid stability
- Electric vehicles for grid balancing, peak shifting
- Effect of EV market penetration on energy cost, grid stability
- Machine learning to guide broker pricing decisions
- Effect of using cold-storage facilities and other large thermal loads as virtual batteries
- Business models that combine renewable production (wind, solar) with managed storage (EVs, cold-storage, domestic water heaters)
- Development and validation of balancing markets to offset traditional reserve capacity

Open Source

- License: Apache v.2
- Source, documentation, issue tracking on github
- Release packages hosted on Maven Central
- Java, Spring component framework, Maven build, JUnit tests
- Highly modular, designed to allow inexperienced students to be successful

You are welcome to join us and contribute to Power TAC.
You are also welcome to use it or extend it for your own purposes.
See `www.powertac.org` to get started.

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