Midwest ISO Unlocks Billions in Savings Through the Application of Operations Research to Energy & Ancillary Services Markets

Franz Edelman Award Presentation

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Before the Midwest ISO’s existence, each company operated independently.
What happens when a utility agrees to join the Midwest ISO?

**Utility**
- Maintains physical control of power plants and transmission lines
- Agrees to become a participant in a wholesale electricity market to supply or buy energy to meet demand

**Midwest ISO**
- Manages real-time balancing of energy to supply or buy based on demand
- Administers the market
- Maximizes total societal benefit

Through the use of operations research and the markets, we provide billions of dollars in value by efficiently utilizing the grid and improving reliability.
Richard Doying,
Vice President of Operations
Midwest ISO
The Midwest ISO transformed the Midwest electric utility industry

Markets

• Energy-only Market launched on April 1, 2005

• Energy and Ancillary Services Market launched on January 6, 2009
The Midwest ISO’s day-ahead market

- Financially binding
- Allows utilities to plan for the next day, knowing the amount of energy they have committed to generate.
- Especially useful for large power plants
The Midwest ISO’s real-time market

- Analyzes moment-to-moment conditions of the system
- Operators rely on precise technology to keep the system balanced and reliable
The Midwest ISO transformed the Midwest electric utility industry

Markets

• Energy-only Market launched on April 1, 2005
  • Energy

• Energy and Ancillary Services Market launched on January 6, 2009
  • Energy
  • Regulation
  • Contingency Reserves
Regulation has one main objective – to keep the frequency of the grid at 60 hertz.

Demand is greater than Supply - Midwest ISO regulates energy by dispatching units to provide more power.

Supply is greater than Demand - Midwest ISO regulates energy by dispatching units to provide less power.
Contingency reserves meet system demand in the event of sudden loss of power plant or transmission line.

**Unexpected loss:** A coal plant is forced to go offline due to malfunctioning boiler.

**Contingency reserve online** meets demand within 10 minutes of an unexpected loss.
The Ancillary Services Markets has resulted in improved efficiency and reduced contingency reserve and regulation requirements.
Market challenges

- Stakeholder confidence
- Communication
- Technology
Could operations research techniques handle the scale and performance required?
Mingguo Hong,
Principal Market Engineer
Midwest ISO
Before the Midwest ISO, each company operated independently.
The Midwest ISO determines which supply offers and demand bids are cleared at the least societal cost.
The Midwest ISO market footprint includes 57,000 miles of interconnected transmission lines.
Our energy-only market employed 2 sequentially solved optimization algorithms

Commitment
- Commits power plants to be on or off

Dispatch
- Determines power plant output levels and prices

Transmission facilities can only be asked to carry electricity flows within their physical limits, to avoid overloading and damaging expensive equipment.
Solving the two optimization problems, commitment and dispatch, is essential to our day-ahead market.
Our real-time market clears offers by solving the dispatch problem every 5 minutes on a 24/7 basis.
Commitment problem for the energy-only market

Method Chosen: Lagrangian Relaxation Method

Main Decision Variable Type: Binary

Output
  • When each plant should be on/off
Dispatch problem for the energy-only market

Method Chosen: Linear programming

Variable Type: Continuous

Output
- Primal solution – power plant dispatch output levels
- Dual solution – energy prices
The Midwest ISO transformed the Midwest electric utility industry

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  - Energy
  - Regulation
  - Contingency Reserves
Co-optimization results in minimized total production costs

Separate Energy and Ancillary Services Markets

- Smaller optimization models for each market
- Less challenging in regard to operations research
- Solution is locally optimal

Co-optimized Energy and Ancillary Services Market

- Bigger optimization model
- More challenging in regard to operations research
- Solution is globally optimal
A New Algorithm for our commitment problem

Langrangian Relaxation method would be too slow for solving the Ancillary Service Market Commitment problem

Advances made since 2005
  • Computing speed increased following Moore’s Law
  • Optimization algorithms improved

Mixed Integer Programming (MIP) algorithm has gained substantial improvement in modeling capability and convergence rates due to work in operations research

The Midwest ISO’s option for solving the commitment problem: **MIP**
MIP formulation with main decision variables

Binary Types
- On\((p,h)\)
- Startup\((p,h)\)
- Shutdown\((p,h)\)
- Regulating\((p,h)\)

Continuous Types
- EnergyOutput\((p,h)\)
- RegulatingReserve\((p,h)\)
- ContingencyReserve\((p,h)\)

- \(p\): Plants \(P_1, P_2, P_3\)
- \(h\): Hours 1, 2, 3, ..., 24
Objective cost function

\[ \sum_{p,h} \text{EnergyOutput}(p,h) \cdot \text{EnergyOfferCost}(p,h) \]

\[ + \sum_{p,h} \text{Startup}(p,h) \cdot \text{StartupCost}(p,h) \]

\[ + \sum_{p,h} \text{On}(p,h) \cdot \text{NoLoadCost}(p,h) \]

\[ + \sum_{p,h} \text{RegulatingReserve}(p,h) \cdot \text{RegulatingReserverOfferCost}(p,h) \]

\[ + \sum_{p,h} \text{ContingencyReserve}(p,h) \cdot \text{ContingencyReserverOfferCost}(p,h) \]
Maximum and minimum capacity constraints

\[
\text{EnergyOutput}(p,h) + \text{RegulatingReserve}(p,h) + \text{ContingencyReserve}(p,h) \leq \text{On}(p,h) \cdot \text{EconMax}(p,h) + \text{Regulating}(p,h) \cdot (\text{RegMax}(p,h) - \text{EconMax}(p,h))
\]

\[
\text{EnergyOutput}(p,h) - \text{RegulatingReserve}(p,h) \geq \text{On}(p,h) \cdot \text{EconMin}(p,h) + \text{Regulating}(p,h) \cdot (\text{RegMin}(p,h) - \text{EconMin}(p,h))
\]
Minimum run time and down time constraints

\[ \text{Startup}(p,h) - \text{ShutDown}(p,h) = \text{On}(p,h) - \text{On}(p,h-1) \]

\[ \sum_{h_1=h-\text{MinUpTime}(p)}^{h} \text{Startup}(p,h_1) \leq \text{On}(p,h) \]

\[ \sum_{h_1=h-\text{MinDownTime}(p)}^{h} \text{ShutDown}(p,h_1) \leq 1 - \text{On}(p,h) \]
Maximum ramping rate

\[ |\text{Energy Output}(p,h) - \text{Energy Output}(p,h-1)| \leq \text{MaxRamp}(p,h) \]
Transmission flow constraints

\[ \sum_p \text{EnergyOutput}(p,h) \times \frac{\partial \text{Flow}(l,h)}{\partial \text{EnergyOutput}(p,h)} \leq \text{FlowLimit}(l,h) \]
Total energy production meets system demand

$$\sum_{p} \text{EnergyOutput}(p, h) = \text{SystemDemand}(h)$$
Online reserve procurement meets reliability requirement

\[ \sum_{p} \text{RegulatingReserve}(p,h) \geq \text{RegReserveRequirement}(h) \]

\[ \sum_{p} (\text{RegulatingReserve}(p,h)+\text{ContingencyReserve}(p,h)) \]

\[ \geq \text{RegReserve Requirement}(h)+\text{ContReserveRequirement}(h) \]
Enhancement 1: pre-processing

• Reduce decision variables
• Eliminate infeasibilities
Enhancement 2: identify strong model formulation

**Capacity Constraints**
One way to formulate

**Minimum Run Time Constraints**
Two ways to formulate

**Transmission Constraints**
One way to formulate

- Formulation 1: Solves Slowly

- Formulation 2: Solves Quickly -- **Stronger**
Example: minimum run time constraint

**Formulation 1**
Must be On between $t$ and $(t + \text{MinRunTime})$

**Formulation 2**
At most 1 startup between $t$ and $(t - \text{MinRunTime})$
Enhancement 3: model specific cuts

Plant $P_1$ Hourly Ramping Constraints

$$|\text{EnergyOutput}(P_1,h) - \text{EnergyOutput}(P_1,h-1)| \leq \text{MaxRamp}(P_1,h)$$

If $\text{MaxRamp}(P_1,h) \leq \text{Demand}(h) - \text{Demand}(h-1)$, then add cut (a constraint):

$$\frac{\text{EnergyOutput}(P_2,h)}{\text{EconMin}(P_2,h)} + \frac{\text{EnergyOutput}(P_3,h)}{\text{EconMin}(P_3,h)} \geq 1$$
A cut reduces feasible region

Feasible Region Before Cut

Feasible Region After Cut
CPLEX solver parameters tuning
A successful team effort
John Bear,
CEO and President
Midwest ISO
The Midwest ISO provides value in several areas

Quantitative Benefits

• Improved Reliability
• Dispatch of Energy
• Unloaded Capacity
• Regulation
• Spinning Reserves
• Wind Integration
• Footprint Diversity
• Generator Availability Improvement
• Dynamic Pricing
• Direct Load Control and Interruptible Contracts
• Midwest ISO Cost Structure

Qualitative Benefits

• Price/Informational Transparency
• Planning Coordination
• Seams Management
• Regulatory Compliance
Value Proposition studies conducted for 2007 through 2010 revealed that the Midwest ISO region realized between $2.1 billion and $3.0 billion in net cumulative savings driven by O.R.

We project a future value of $6.1 to $8.1 billion through 2020.