

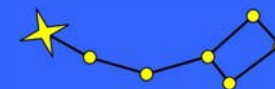


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Probabilistic Modeling to Support Planning and Operational Decisions in the Power Industry

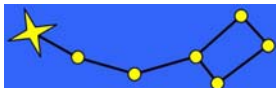
Alex Rudkevich, Newton Energy Group
Russ Philbrick, Polaris Systems Optimization

Federal Energy Regulatory Commission
Workshop on the Next Generation of Transmission
Planning Models
Washington, DC
20 March 2012



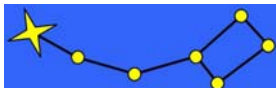
Presentation outline

- Probabilistic modeling in industry planning and operation: current practice, challenges and opportunities
- Example 1. Probabilistic modeling and system expansion planning
- Example 2. Probabilistic modeling and procurement of operating reserves



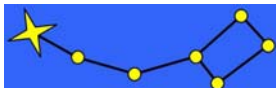
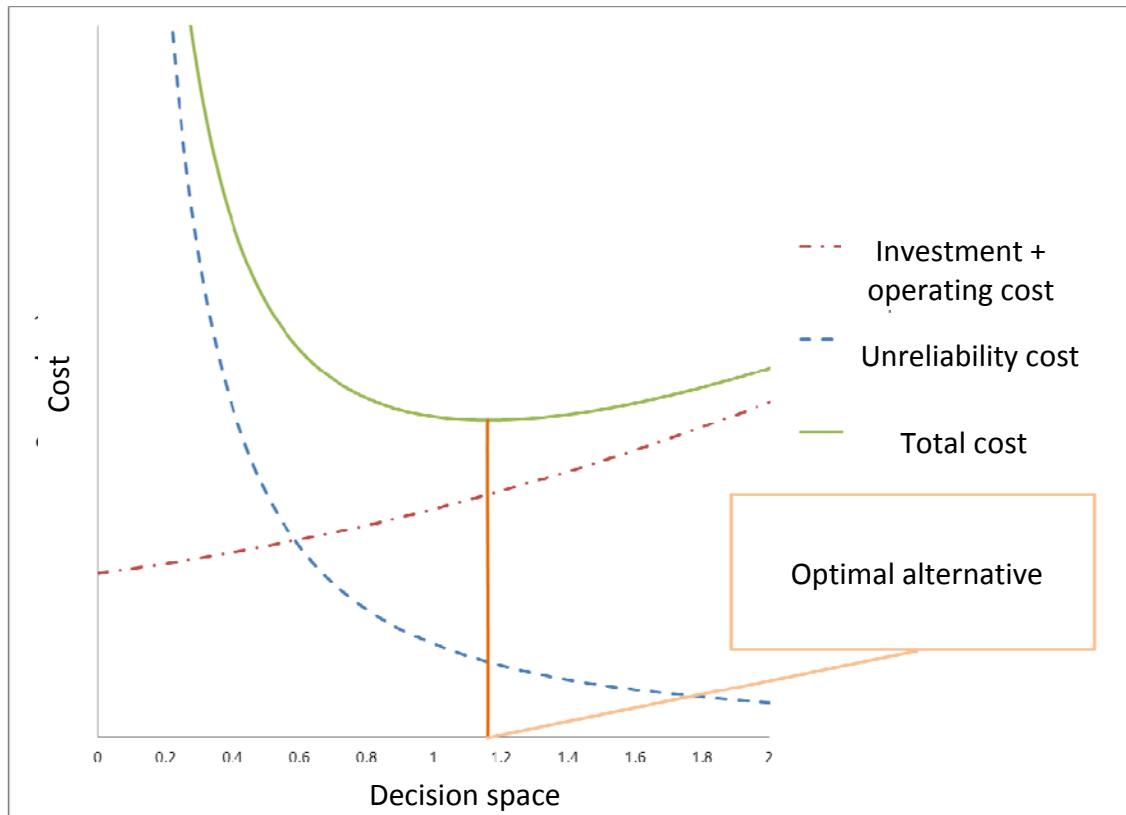
Evaluation of probabilistic events...

- ... either implicit or explicit, is an essential element of every aspect of the power industry. The probability that something will deviate from our expectations equals 1
- Recognized since the first half of the last century, as reflected in publications of that time
 - W.J. Lyman “Fundamental Considerations in Preparing Master System Plan” (1933)
 - P.E. Benner “The use of theory of probability to determine spare capacity” (1934)
 - S.M. Dean “Considerations involved in making system investment decisions for improved service reliability” (1938)
 - G. Calabrese “Generating reserve capability determined by the probability method” (1947)
- Practical methods of evaluation of probabilistic events for the purpose of making planning and operational decisions are typically based on a two-step approach:
 - “Off-line” probabilistic analyses translated into deterministic planning or operational parameters
 - Solution of deterministic planning or operational problems utilizing these parameters as constraints or adjustments to optimization criteria



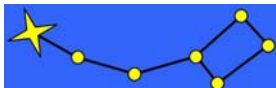
The Total Cost Approach

- The best alternative must achieve the lowest total cost
- Total cost = investment cost + operating cost + unreliability cost



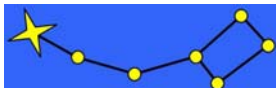
Key Drivers that Make Probabilistic Modeling Necessary and Possible

- Relevant technological advancements of the last two decades:
 - Increased computational and algorithmic power allows to address more complex and computationally intensive problems. Commercialization of High Performance and High Scalability Computing
 - Advancement in metering technologies and development of customer information systems geared toward SmartGrid – improved information on the economics of electricity use
 - Growing penetration of variable resources and energy limited resources, among them resources in the form of demand response, create significant challenges to old concepts
 - Development of transmission control technologies, ability to co-optimize generation, load and transmission topology
- Institutional advancements
 - Emerging competitive market mechanisms for energy, capacity and ancillary services, virtual power plants auctions, energy procurement auctions, derivative mechanisms (futures, FTRs, virtual bidding)
 - Development of sophisticated market infrastructure supporting optimal operation of electricity markets over large footprints
 - Active participation of demand response in markets for energy, ancillary services, capacity
 - Emergence of diverse and highly sophisticated market participants
- Theoretical advancements
 - Theory of spot pricing of electricity, nodal economic theory of power systems
 - Application of real option methods in decision-making
 - Use of auction theory and applications in design and operation of various power markets



Challenges of Probabilistic Modeling of Power Systems

- Rely on advanced mathematical concepts and complex computational algorithms that are not well understood by decision-makers
- Require new software and hardware architecture
- Economic theory lags behind: need appropriate understanding of “products,” “services” and “prices” that are consistent with the probabilistic representation of power systems and markets
- As new methods and tools are being developed, it is important to make sure that:
 - the problems addressed are correctly formulated
 - solutions are communicated in terms that are understandable to decision-makers
 - methodologies, market structures and business practices are aligned
- Lack of “good” probabilistic tools inhibit the development of advanced market models and business practices. But outdated market structures and business practices do not encourage development of advanced tools
- Breaking this vicious circle takes a lot of work. Need to demonstrate that:
 - the way things done today are not perfect,
 - the new tools are feasible
 - the improvements are worth the effort of both developing new tools and changing business practices





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Example 1. System Expansion Planning



Reliability of the bulk power system. CIGRE Definition

System reliability

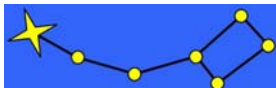
A general term encompassing all the measures of the ability of the system, generally given as numerical indices, to deliver electricity to all points of utilization within acceptable standards and in the amounts desired.

Resource adequacy

A measure of the ability of the power system to supply the aggregate electric power and energy requirements of the customers within component ratings and voltage limits, taking into account planned and unplanned outages of system components. Adequacy measures the capability of the power system to supply the load in all the steady states in which the power system may exist

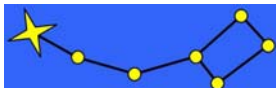
System security

A measure of power system ability to withstand sudden disturbances such as electric short circuits or unanticipated losses of system components together with operating constraints. Another aspect of security is system integrity, which is the ability to maintain interconnected operations. Integrity relates to the preservation of interconnected system operation, or the avoidance of uncontrolled separation, in the presence of specified severe disturbances

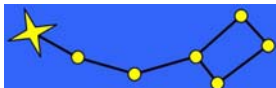
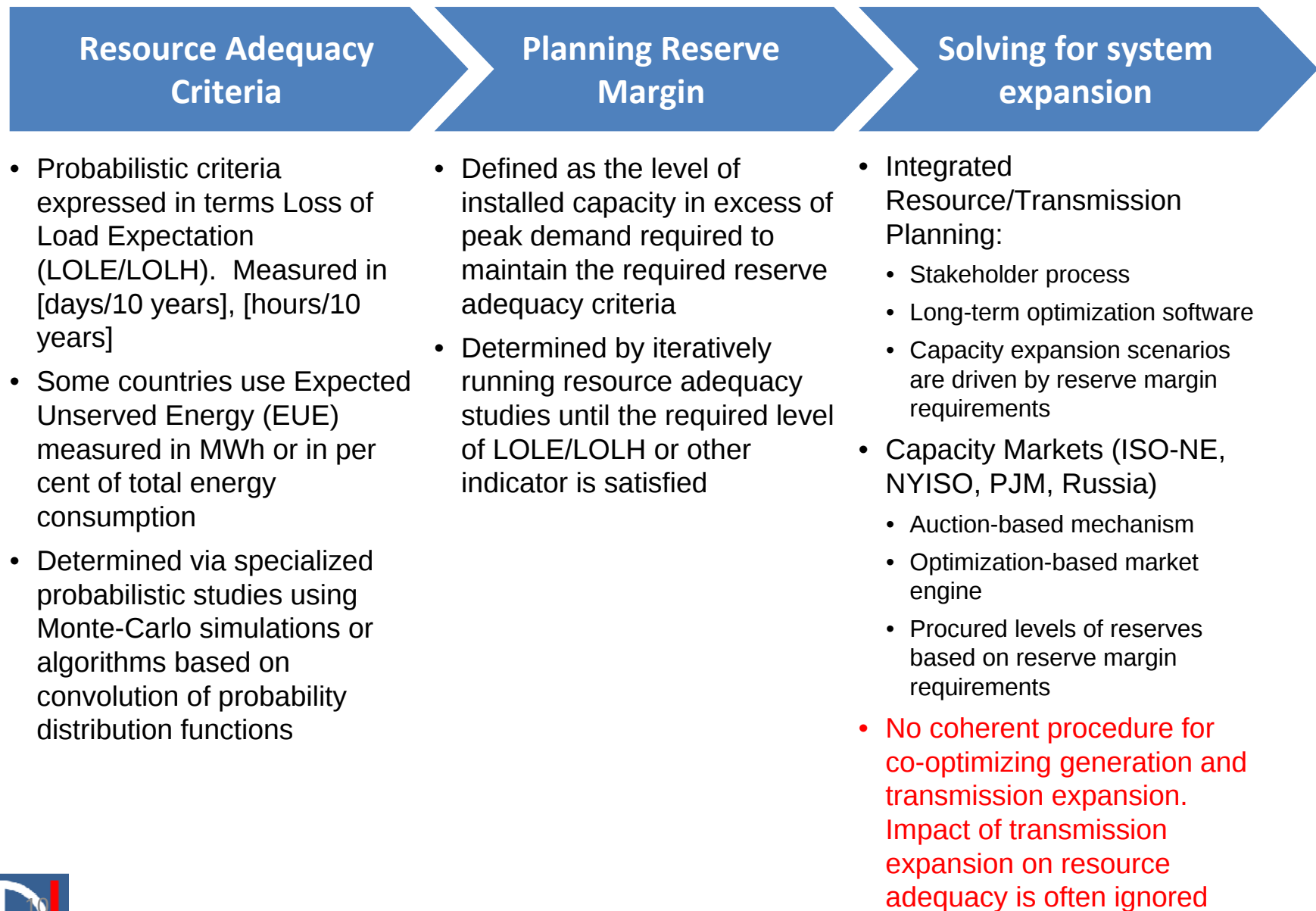


Resource Adequacy is measured by probabilistic criteria

- Resource adequacy criteria express *the expected value frequency, expected value duration and/or expected magnitude* of possible capacity deficiency (loss of load)
- Expected number of days per year of loss of load a.k.a. Loss of Load Expectation, **LOLE**) [days/yr]
- Expected number of hours per year of loss of load a.k.a.(Loss of Load Hours, **LOLH**) [hrs/yr]. In USSR/Russia the standard was set as the probability of uninterrupted operation
 $P = 1 - \text{LOLH}/8760 = 0.996$ (LOLH=36 hours per year)
- Expected value of unserved load in MWh/yr or % of annual energy use (**EUE, RUE** – other abbreviations **EENS, LOEE**)
- Another term often used is Loss of Load Probability (**LOLP**). However, most of the time it means either LOLE or LOLH

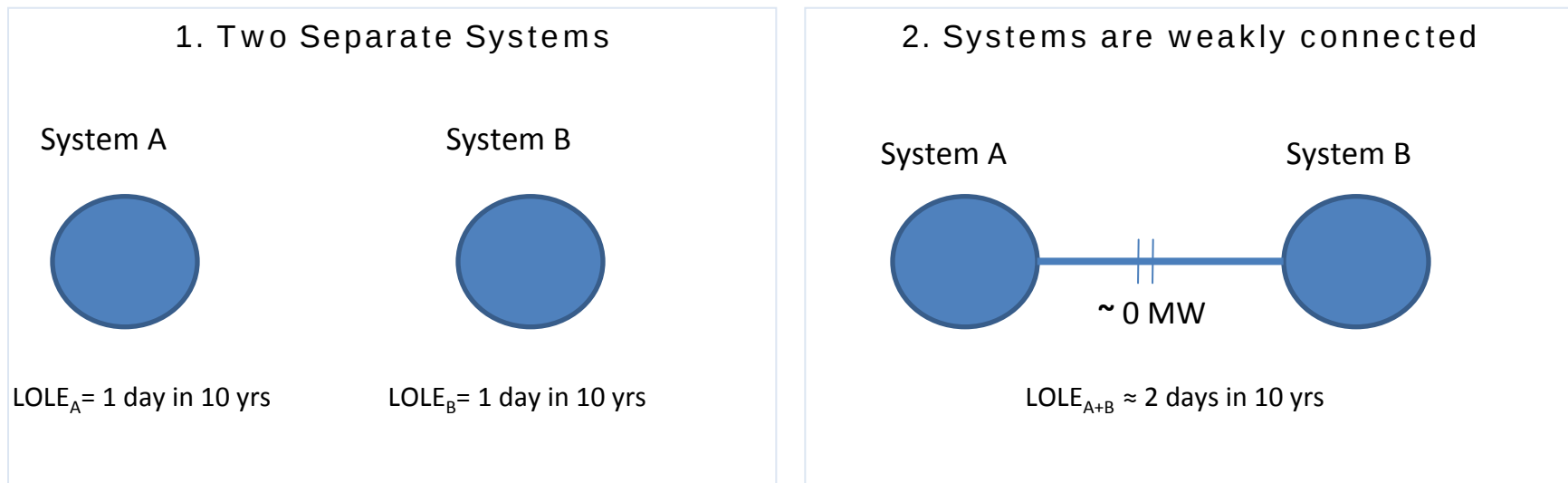


High Level Schematic of the System Expansion Planning Process

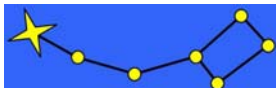


System-wide LOLH/LOLE criteria may not be applied to transmission constrained systems. Lazebnik's Paradox

- ❑ LOLH reflects the average frequency of the loss of load in the system as a whole
- ❑ But LOLH for the system with transmission constraints no longer reflects marginal cost of unreliability
- ❑ LOLH provides no signal on the location of added capacity
- ❑ Setting adequacy criteria in terms of LOLH for the system yields paradoxical results



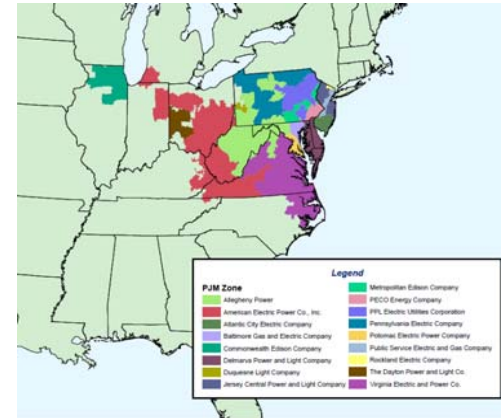
In the second case the frequency of interruption of individual end users is practically the same as in the first case but the LOLE no longer meets the 1 day in 10 years standard. In the first case, no investments are necessary. In the second case, new reserves must be added to meet the 1 day in 10 years criterion



Are we getting it right?

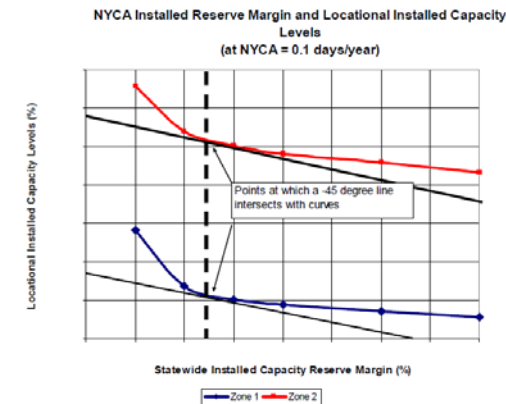
- Example 1: PJM

- Sets system-wide LOLE requirement of 1 day in 10 years and local LDA requirements at 1 day in 25 years
- Effectively determines installed capacity requirements by zone on the basis of 1 day in 25 years LOLE criteria (subject to 100% availability of imports)

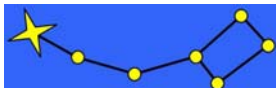


- Example 2: NYISO

- Sets up system-wide LOLE requirement of 1 day in 10 years. Upstate/downstate split in capacity requirements are set on the relative trade-off basis: increasing downstate reserve margin by 1% while reducing system reserve margin by 1% must preserve the LOLE of 1 day in 10 yrs

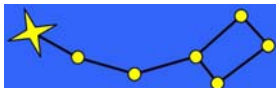


Neither of these methods are optimal



Stochastic Modeling for Resource Adequacy

- 2011 methodology developed jointly by Charles River Associates and Melentiev Energy Systems Institute of Russian Academy of Sciences (Irkutsk, Russia) for the Market Council of Russia
- Systematically applies the total cost approach
 - Develops locational indicators of resource adequacy using expected values of shadow prices associated with the optimal reliability dispatch
 - Identifies the need for new capacity additions at the nodal level
 - Identifies the need for transmission reinforcements
 - Identifies optimal tradeoff between transmission upgrades and generation additions to maintain resource adequacy of the system
- All this is fully applicable to power systems in the US and in other countries
- However, there exists no tool, neither in Russia, nor in the US, capable of supporting this methodology
- Implementation of this approach, especially at the nodal level, would require substantial changes to the market structure and to business decision processes employed by industry stakeholders



Locational Indicators of Resource Adequacy Derived from Stochastic Optimization Approach

$MLOLH_n$ – expected number of hours in which loss of load in the system can be reduced by load reduction at location n

$RLH_{n \rightarrow m}$ – expected number hours in which loss of load in the system can be reduced by increasing transfer capability from location n to location m

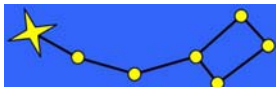
$BRLH_{nm} = RLH_{n \rightarrow m} + RLH_{m \rightarrow n}$ – bidirectional expected number of hours in which transfer between locations n and m is reliability limiting

Optimal locational criteria

$$MLOLH_n = \frac{CONE_n}{VOLL}$$
$$BRLH_{nm} = \frac{COTR_{nm}}{VOLL}$$

Important implications:

- Enforceable criteria should be locational, not system-wide
- Resource adequacy value of transmission is significantly higher than the difference in capacity prices between two locations
- By consistently implementing stochastic optimization approach to system expansion, the industry could reliably operate at lower reserve margins and avoid significant capital expenditures in system expansion





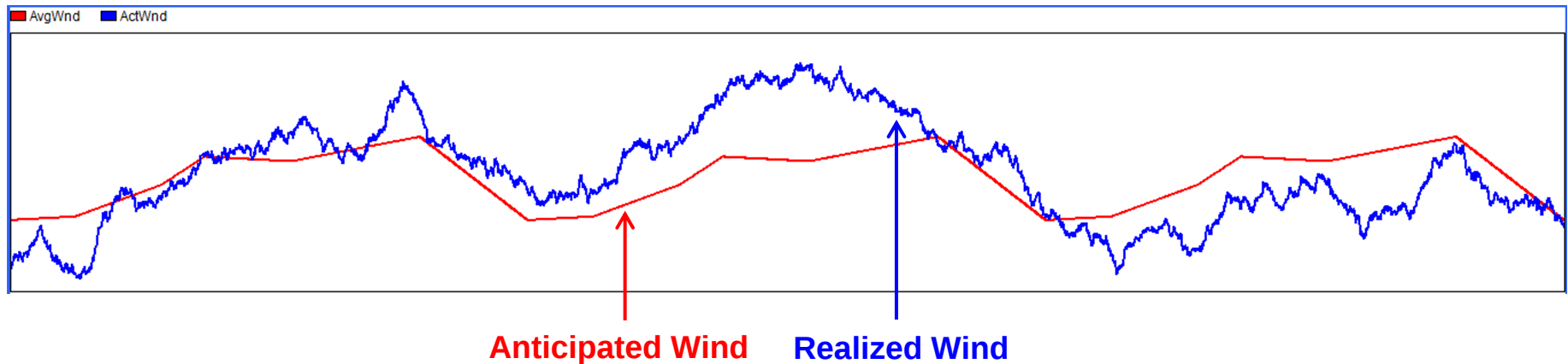
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Example 2. Procurement of Operating Reserves



Need for Cautious Operating Policies

- Forecasts are uncertain



- Uncertainty from load, variable generation, outages, interchange, generator and load dispatch errors
- Need policies for procuring reserve that support reliable system operations
- Cost matters

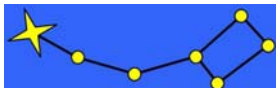
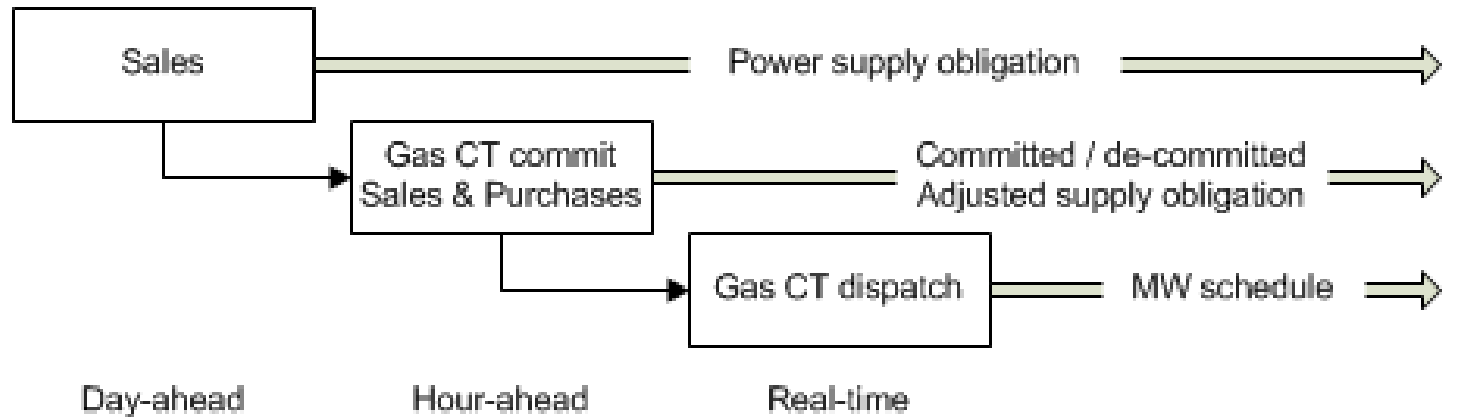
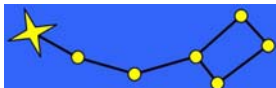


Illustration: Trading with 3 Units



- Uncertain output from wind unit (other uncertainty ignored).
- Day-ahead sales must be honored, with potential for hour-ahead incremental purchases/sales and CT re-commitment.
- 50MW ramp up/down reserves enforced Day Ahead and Hour Ahead



Day-Ahead Commitment and Dispatch



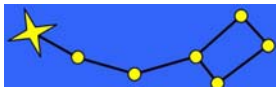
anticipated
wind

gas held back to
provide reserves

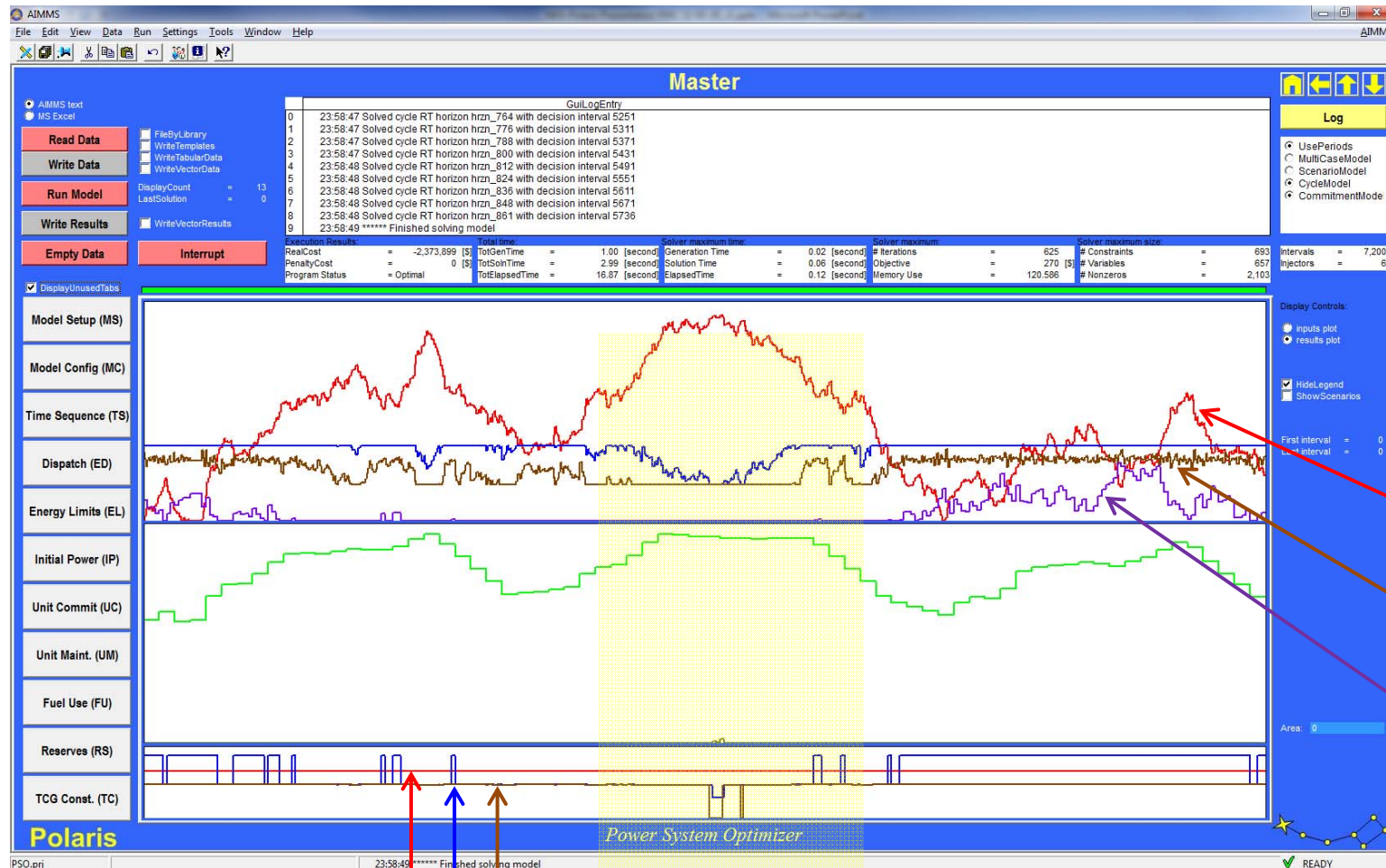
quantity sold
day ahead.

price taker
(\$60/MWh)

Marginal Cost: Wind < Gas 1 < Gas 2
 (Red < Blue < Brown)



Hour-Ahead and Real-Time Operations



Realized wind

reserves deployed

HA purchases to meet DA sales

day-ahead prices

hour-ahead prices

real-time prices

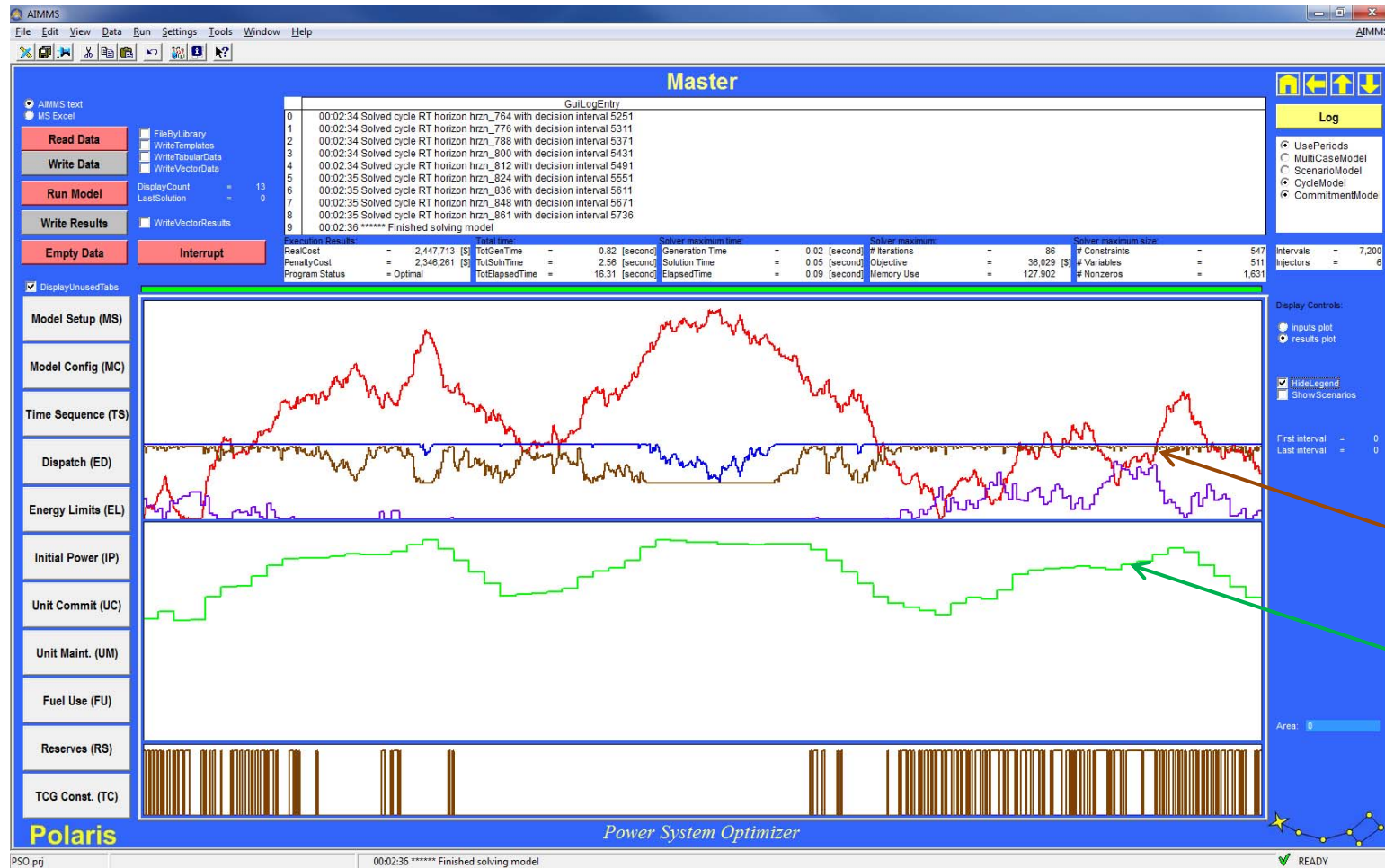
higher than expected wind: min-gen & wind curtailment

Hour-ahead sales at lower price (\$26/MWh)

Hour-ahead purchases at higher (\$79/MWh)



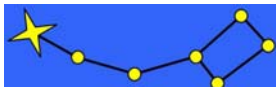
Impact of No Reserve Procurement



not held back for reserves

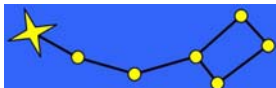
larger DA sales

Generation Shortages



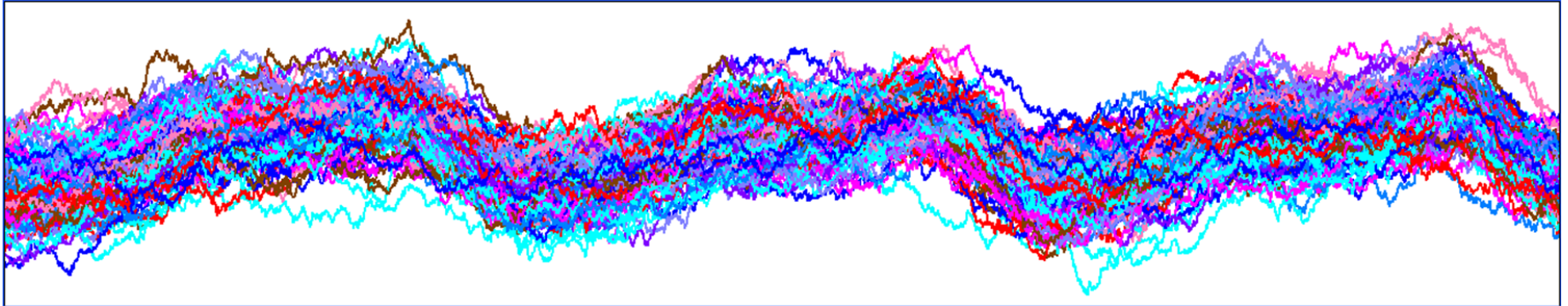
Reliability and Economics

- In operations, reliability trumps economics. Or does it? Is there a tradeoff between the cost of carrying reserves and the cost of unreliability?
- By using stochastic optimization it becomes possible to internalize economic trade-offs in operation as well as in planning
- Traditional methods and rules of thumb adapted to traditional issues:
 - Uncertain load → Regulation requirements (small and frequent)
 - Unscheduled outages → Contingency reserves (large but infrequent)
 - Unscheduled interchange → ACE procedures (small are frequent, large are infrequent)
- Relatively static issues for 50 – 100 years
- New challenges:
 - Variable generation (wind and solar)
 - Load response
 - Energy storage
 - New transmission / distribution controls
 - New uncertainties **are large and frequent**
- New challenges call for new tools, new market structures and new business practices

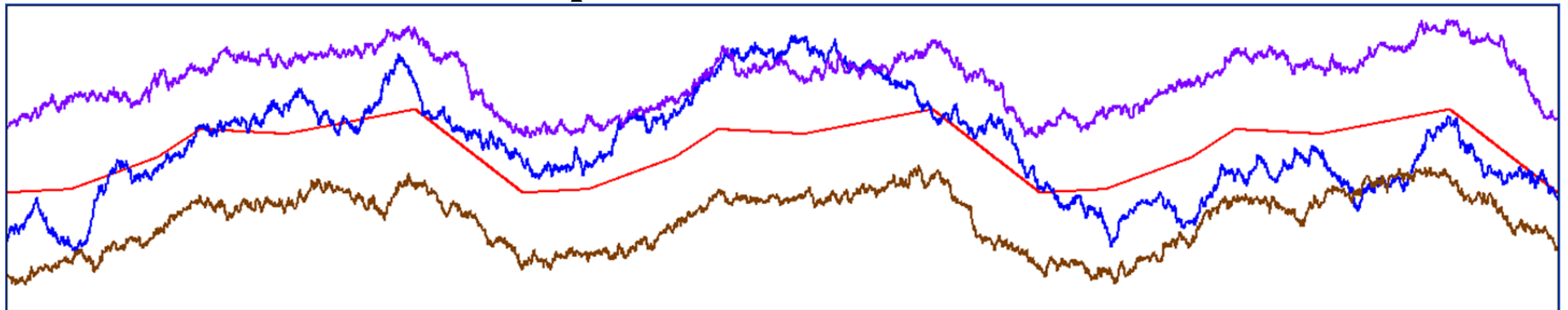


Back to basics

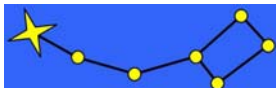
- Identify the possibilities



- Focus on what's important



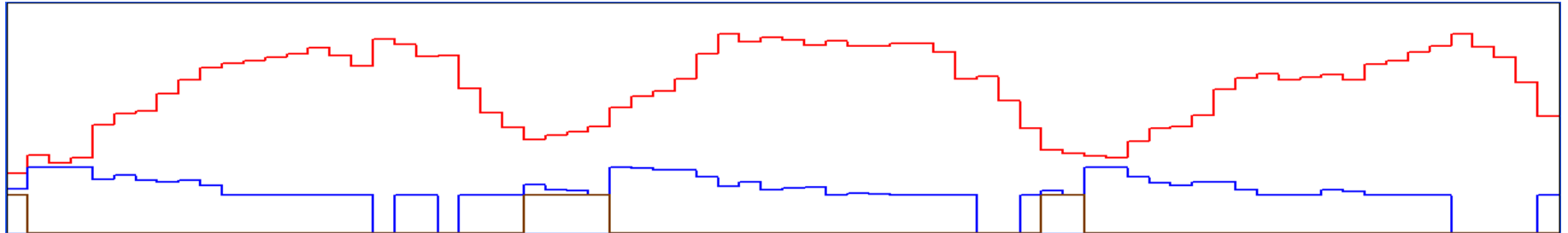
- Plan for failure



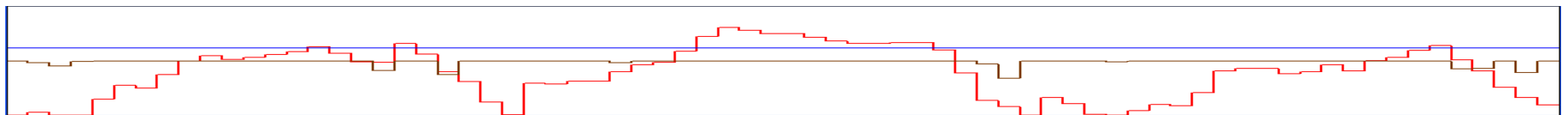
(Note: Need for scenario-reduction methods)

Need for Caution / Robust Operating Policies

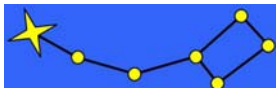
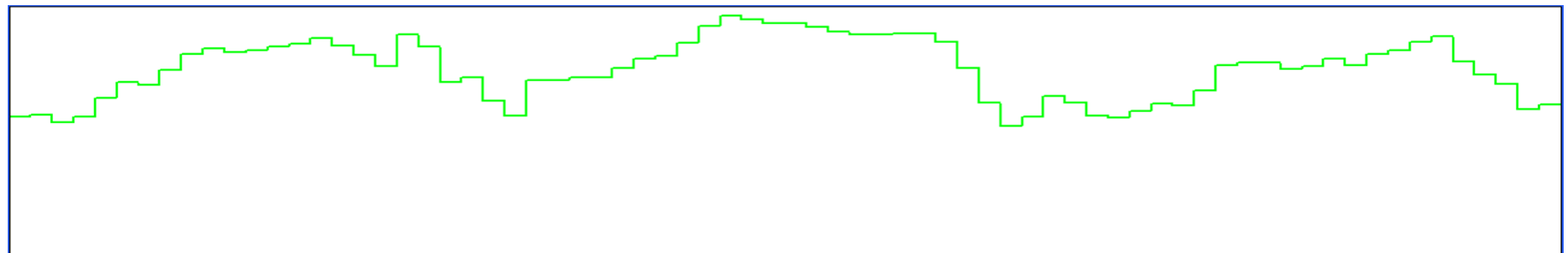
- Need to prepare for extreme highs



- and extreme lows

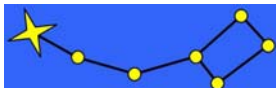


- to meet requirements



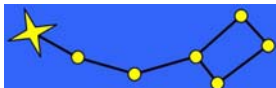
Implicit vs. Explicit: The Need For Transparency

- Markets and utilities need transparent rules, particularly when procuring and paying for ancillary services from others
- Probabilistic and stochastic methods can be difficult to interpret and communicate
 - Similar to challenges with UC and LMP
- May need to convert probabilistic results to deterministic policies and rules for operations and market clearing
 - Dynamic reserve procurement
 - New reserve definitions that match system needs for flexibility
 - Adaptive processes that respond to changing system configuration and composition



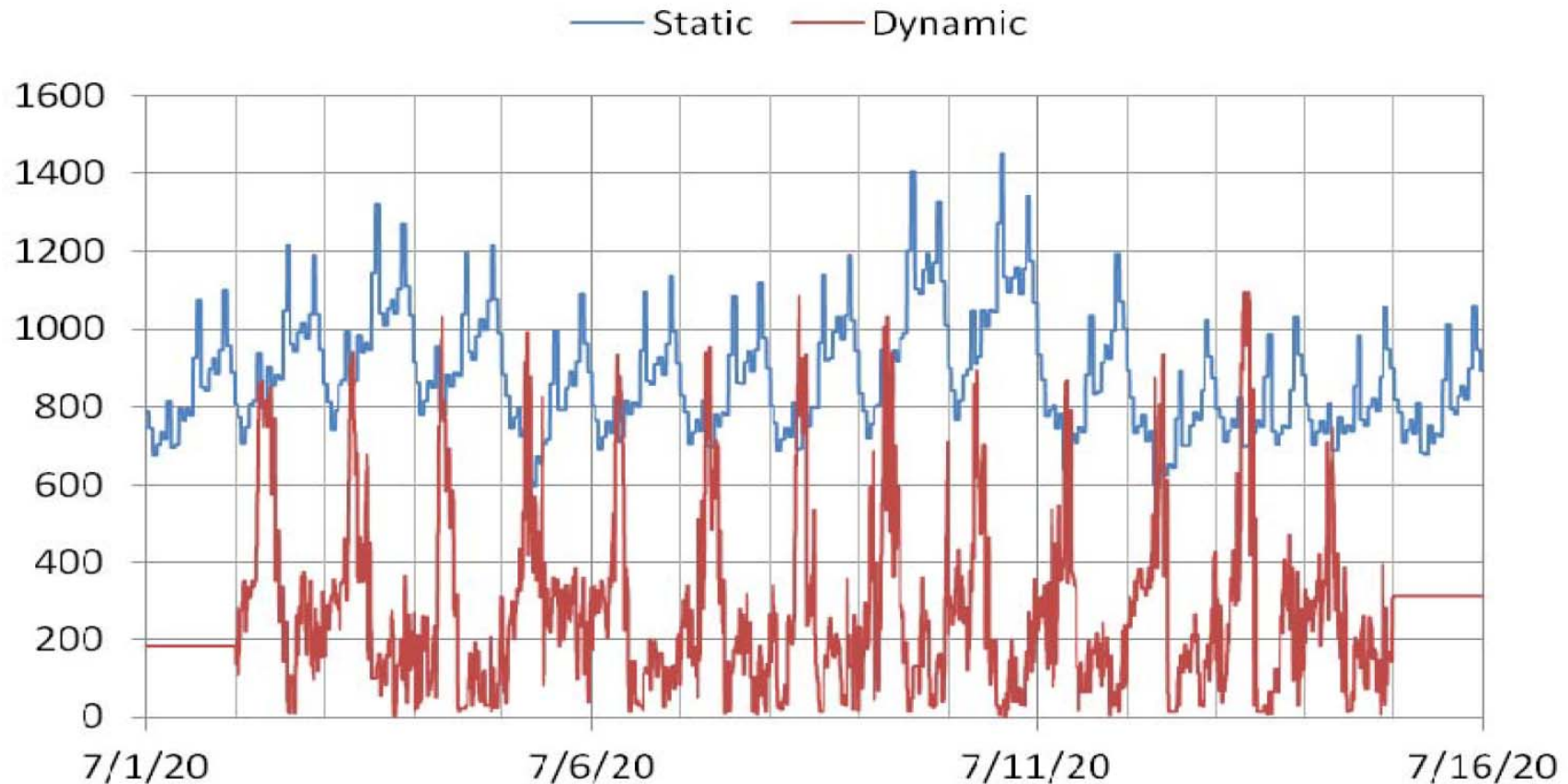
Probabilistic Operating Reserve Procurement

- Need methods to allow adoption of probabilistic methods
 - Similar to today's approach but much more frequent and closer to real time
 - Greater locational granularity in procurement and pricing
- Deterministic policies require explicit definition of services
 - These impose constraints on the operation of the system, potentially reducing social welfare
 - Direct application of stochastic methods can be more efficient: services procured implicitly without being bound by specific definitions of services.
- Policies driven by requirements of utility and stake-holders.
 - Where transparency is less important (such as for internal reliability processes), stochastic methods may have direct application to operations.
 - Where requirements dictate use of deterministic policies, probabilistic methods can be significant contributors to identifying efficient policies.
 - However the above distinction is not set in stone. The industry will learn to speak stochastic language.

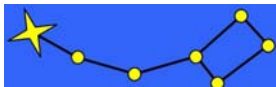


Example: Dynamic Procurement Using Stochastic Reserve Constraints

Comparison of Load Following Up Procurements



T. Yong, C. R. Philbrick, R. Entriken, A. Tuohy, "Multi-Settlement Simulation of Reserve Procurement using Stochastic Optimal Power Flow," *Proc. 2012 IEEE Power and Energy Society General Meeting*, San Diego, CA, Jul 2012



In conclusion...

- Lack of “good” probabilistic tools inhibit the development of advanced market models and business practices. But outdated market structures and business practices do not encourage development of advanced tools
- Breaking this vicious circle takes a lot of work. Need to demonstrate that:
 - the way things done today are not perfect,
 - the new tools are feasible
 - the improvements are worth the effort of both developing new tools and changing business practices
- A comprehensive implementation of stochastic modeling in power industry will
 - improve system reliability,
 - provide important investment and deployment signal with needed granularity,
 - Contribute to significant increase in social welfare



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