New Phenomena in Bulk Power System Control

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KTH Presentation

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- Our Laboratory
  - provides the facilities, unique scientific equipment, and world-renowned scientists/engineers to strengthen U.S. scientific foundations for fundamental research and innovation
  - prevents and counters acts of terrorism through applied research in information analysis, cyber security, and the non-proliferation of weapons of mass destruction
  - increases U.S. energy capacity and reduces dependence on imported oil through research of hydrogen and biomass-based fuels
  - reduces the effects of energy generation and use on the environment.
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- Battelle Memorial Institute has operated PNNL since 1965.

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  - Improving grid reliability and productivity
  - Increasing the efficiency of powering vehicles and buildings
  - Enabling economically and environmentally sustainable conversion of domestic hydrocarbons to gases, liquid fuels, electricity, and chemicals
  - Accelerating safe and economic expansion of nuclear power

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- 66 staff members:
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  - 27: PhD’s
  - 21: MS
  - 5: BS
- Visiting Researchers:
  - USA
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  - Italy
  - Australia
  - Japan
  - Russia
  - Canada
  - New Zealand

Research Agenda

- System Transparency – *Seeing and operating the grid as a national system in real-time*
- Analytic Innovations - *Leveraging High-Performance Computing and new algorithms to provide real-time situational awareness and models for prediction and response*
- End-Use Efficiency and Demand Response – *Making demand an active tool in managing grid efficiency and reliability.*
- Renewable Integration – *Addressing variability and intermittence of large-scale wind generation and the complexities of distributed generation and net metering*
- Energy Storage – *Defining the location, technical performance, and required cost of storage; synthesizing nanofunctional materials and system fabrication to meet requirements*
- Cyber Security for Energy Delivery Systems – *Defining requirements for and developing technology to enhance secure control systems*

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PNNL's Integrated Energy Operations Center

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Focus of This Presentation

- With the increasing penetration of renewable variable generation resources, <u>many new system impacts</u> have been observed, many previously known impacts require different treatment

- Power system control tasks require significant rethinking and revisions, <u>new control tasks</u> appear

- <u>Proactive integration</u> of variable resources requires a new look on system operational principles and controls

- This short presentation attempts to review some of these phenomena and discuss their possible solutions.

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Talking Points: Issues

- Topics discussed in this presentation:
  - Increasing balancing needs require more traditional and non-traditional balancing resources and their better flexibility
  - Tail events can create major system transmission impacts and imbalances that are not adequately addressed
  - Impacts on interchanges and congestion on a wide area basis requires a lot of coordination on the use of transmission level in an interconnection
  - Impacts on conventional generators
- Other topics:
  - Over-generation problem is a very major potential issue that require a lot of thinking
  - Frequency response (primary regulation) is deteriorating posing potential threats to system reliability
  - System inertia and dynamic stability issues

Issues: Variability and uncertainty (1)

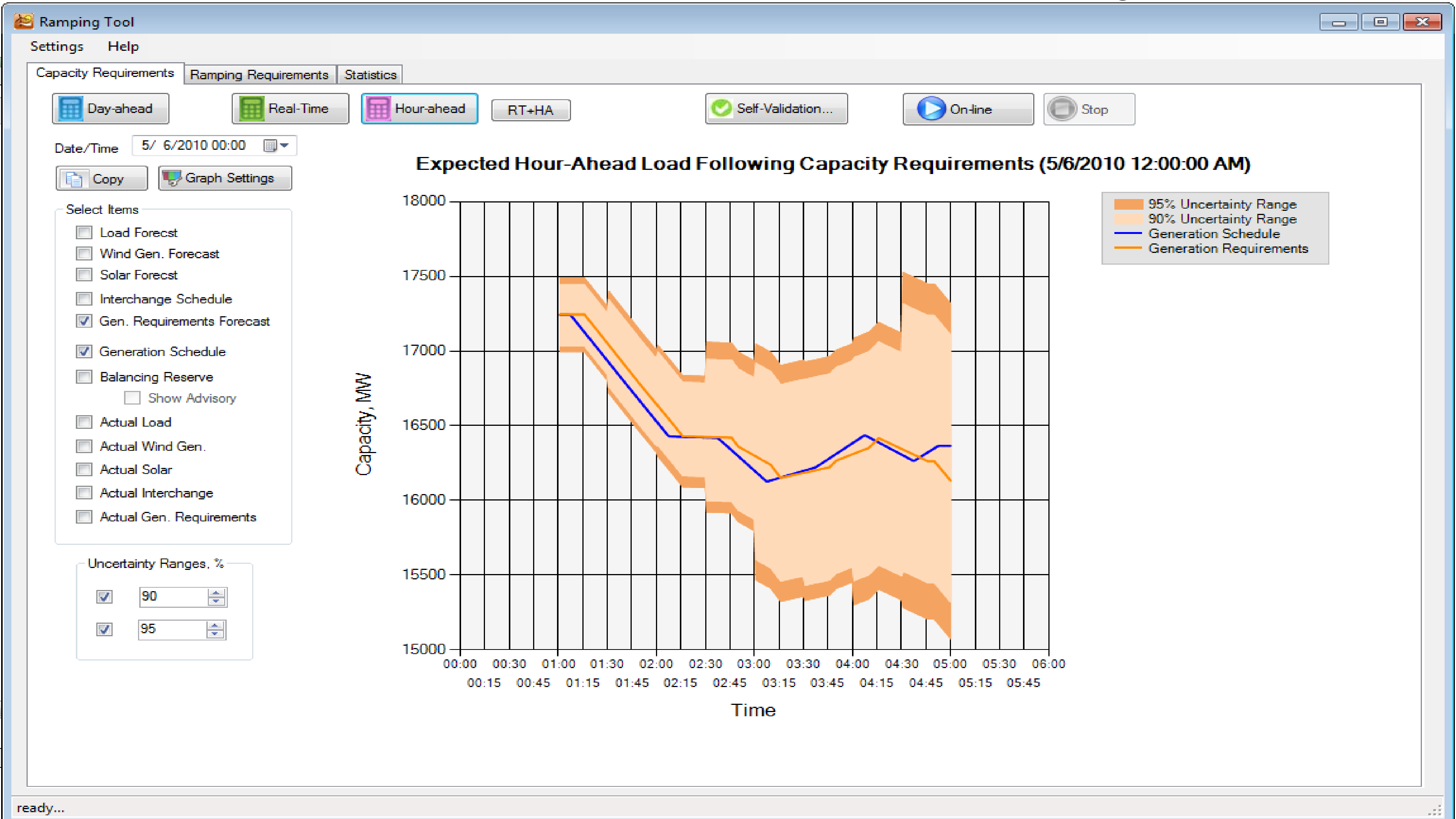
- Sources of variability and uncertainty:
  - Loads and load forecast errors
  - Wind and solar generation and forecast errors
  - Wind and solar ramps
  - Forced generation outages
  - Uninstructed deviations of conventional generators
  - Load drops
  - Transmission events
- Overall uncertainty model includes continuous and discrete factors
- These factors interact forming sometimes non-parametric non-stationary distributions and processes. So, it could be a bad idea:
  - To use normal distribution models, 3 sigma rule, etc.
  - To use stationary models
- These random processed can have weekly, intra-day, and intra-hour patterns

Issues: Variability and uncertainty (2)

- Forecast errors usually have strong autocorrelation (which is good for system balancing functions)
- Cross-correlations are generally weak (which is also good), but sometimes noticeable (e.g., between closely located wind farms)
- Variability and uncertainty decrease with the increasing number of contributing sources and their wider distribution over large geographical areas. So, this could be a bad idea:
  - Address sources of uncertainty one by one rather that their aggregates, e.g., provide balancing services to specific wind farms rather than to their aggregates
  - Operate small control areas independently
  - Deal with sources of uncertainty concentrated in a few small regions
- Uncertainty distributions have heavy tails that must not be ignored as potential causes of extreme events (major system imbalances)
- Uncertainty increases if we look further into the future

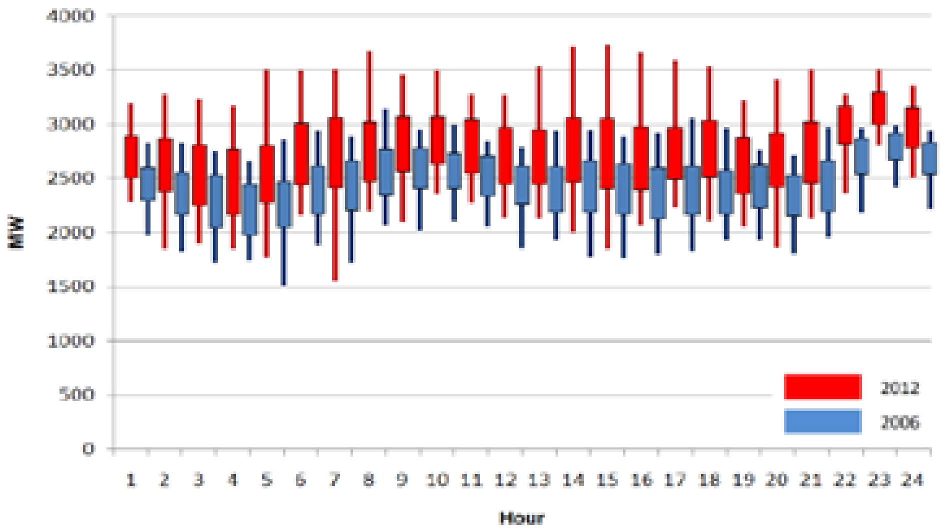
Issues: Variability and uncertainty (3)

- PNNL uncertainty model developed for California ISO
  - Installed at the California ISO Control Center for testing



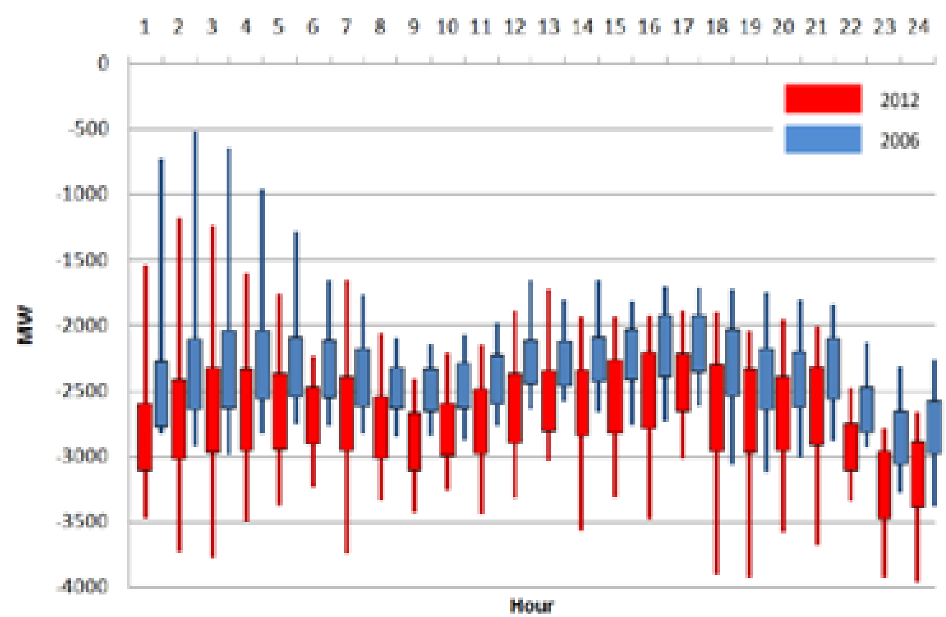
Issues: Increasing balancing needs (1)

- Growing variability and uncertainty affects power system operations, including system balancing requirements and reserves



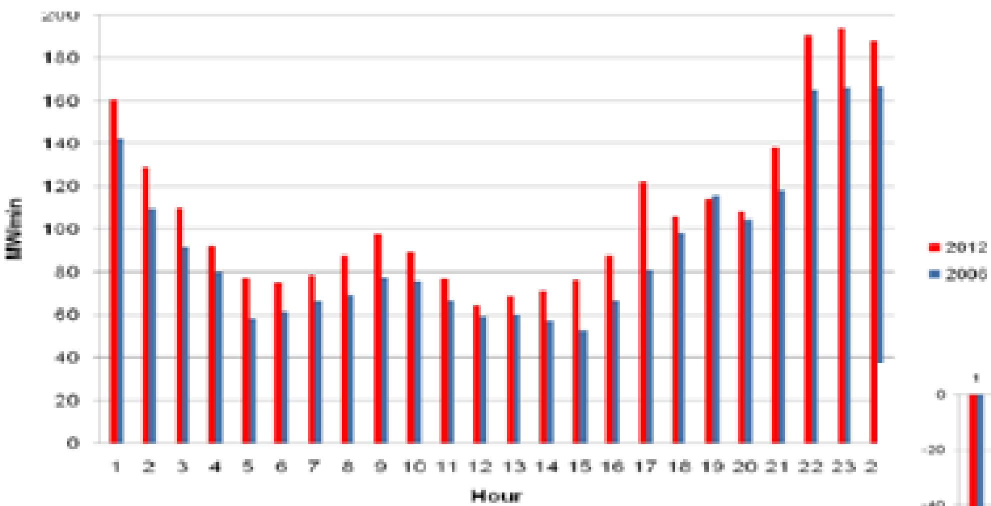
(a) Impact of 20% renewables on the California ISO operational requirements (intra-hour upward balancing)

(a) Impact of 20% renewables on the California ISO operational requirements (intra-hour downward balancing)



Issues: Increasing balancing needs (2)

- To balance the system, we need to move our conventional units faster, that is along with the increasing MW requirements, we have increasing MW/min requirements



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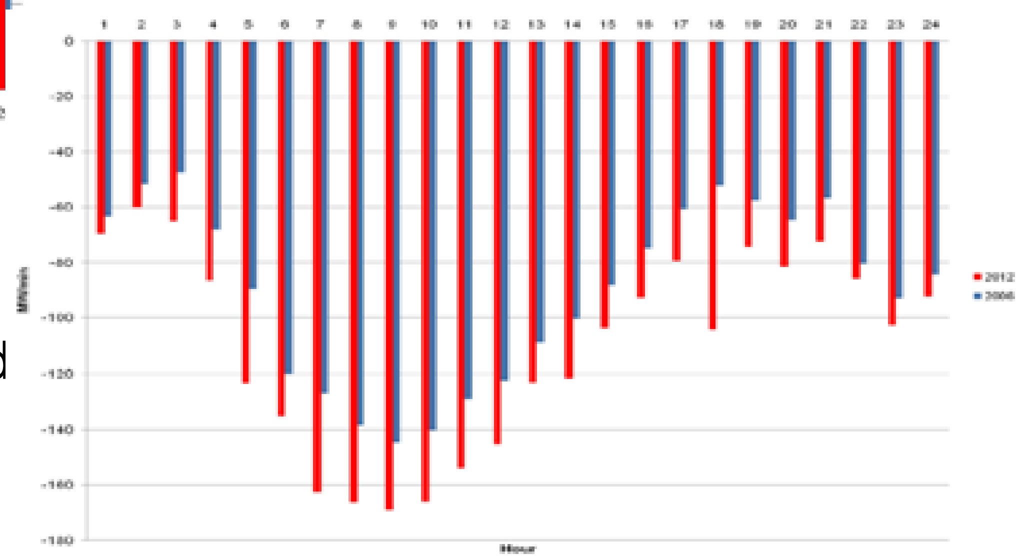


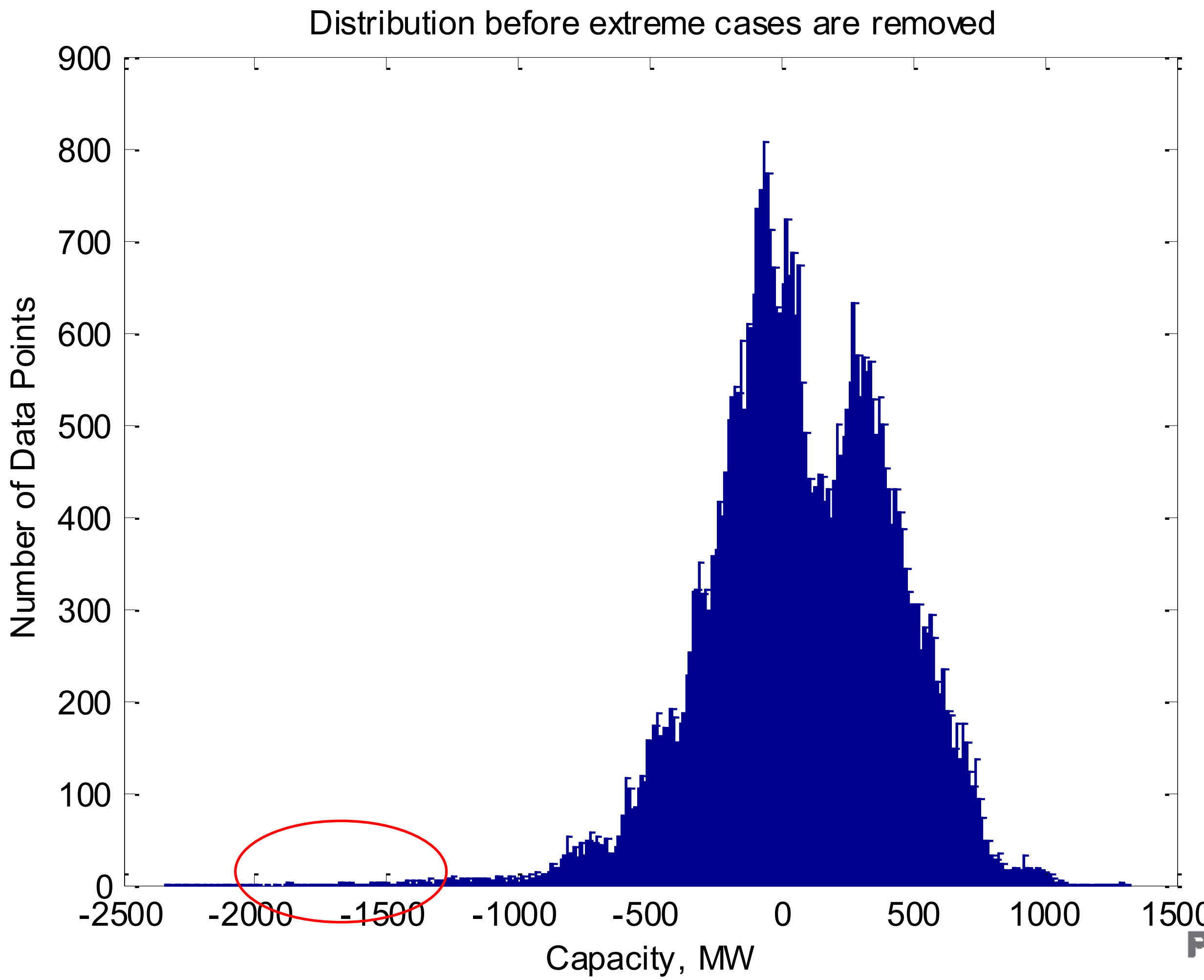
(a) Impact of 20% renewables on the California ISO operational requirements (intra-hour downward balancing)

Issues: Tail events (1)

- Tail events are caused by unfortunate combinations of multiple factors contributing to overall uncertainty
- They are also results of long tails of probability distributions for the elements of uncertainty and variability
- Tail events are not frequent, but can reach several GW in size
- Tail events caused by extreme combinations of forecast errors can hardly be predicted
- There are no special reserves for handling tail events
- Types of tail events:
  - Major system imbalances potentially affecting interconnection frequency
  - Transmission tail events – major power flow variations

Issues: Tail events (2)

- Load following (tertiary reserve) requirements in BPA system in 2010



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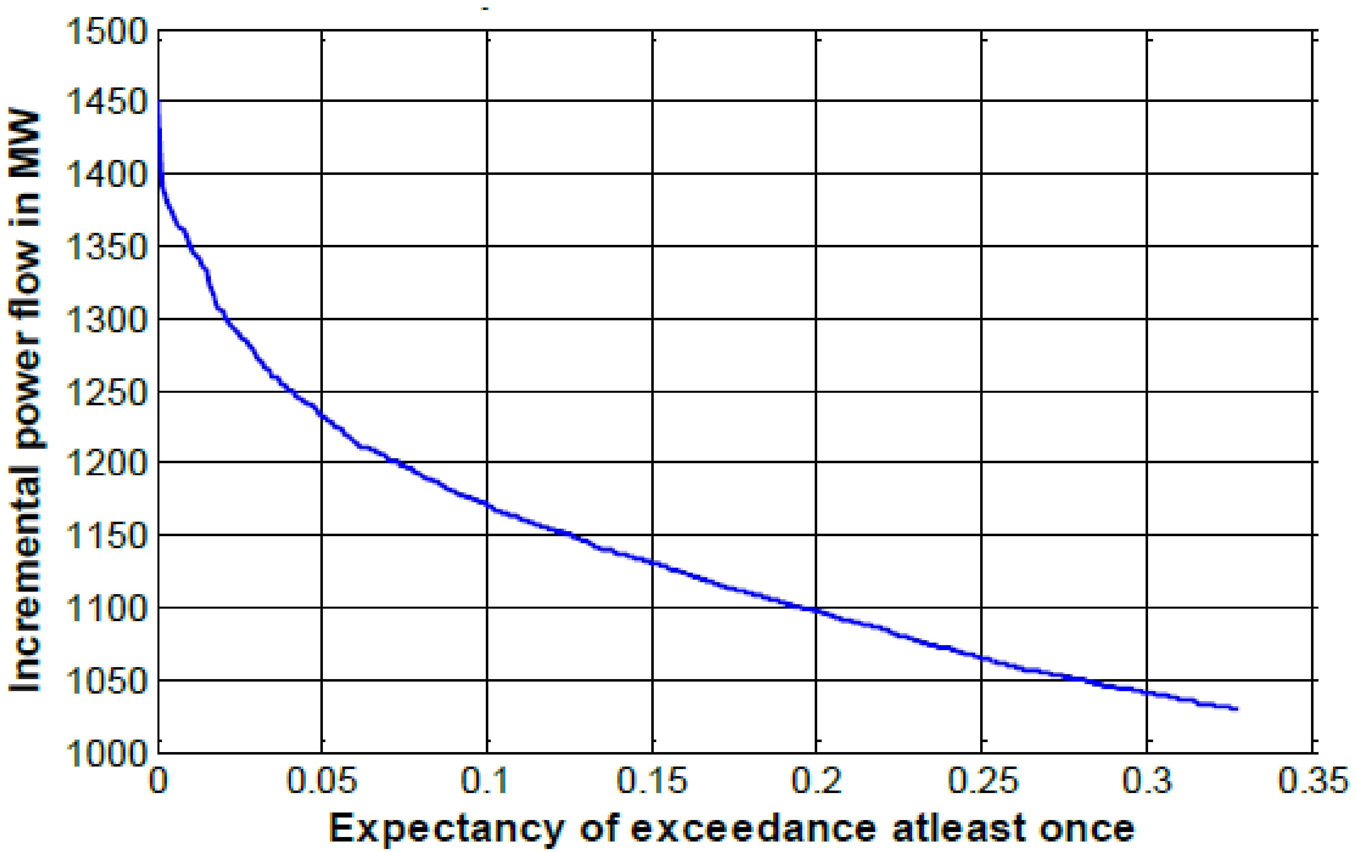
Issues: Tail events (3)

- Tail events on the California-Oregon intertie



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Issues: Impacts on conventional generators

- Economic (displacement) – Leads to potential system controllability and behavioral issues
- Increasing cycling (starts and stops) – Major impact on thermal units, e.g. CC
- Frequent redispatches – Many units are not designed for them
- Decreasing efficiency (deviation from the most efficient operating point)
- Additional wear and tear
- Increasing emissions (fossil fuel plants)
- Fish preservation issues (hydro power plants)
- System control should be redesign to incorporate these factors as constraints or additional objectives.

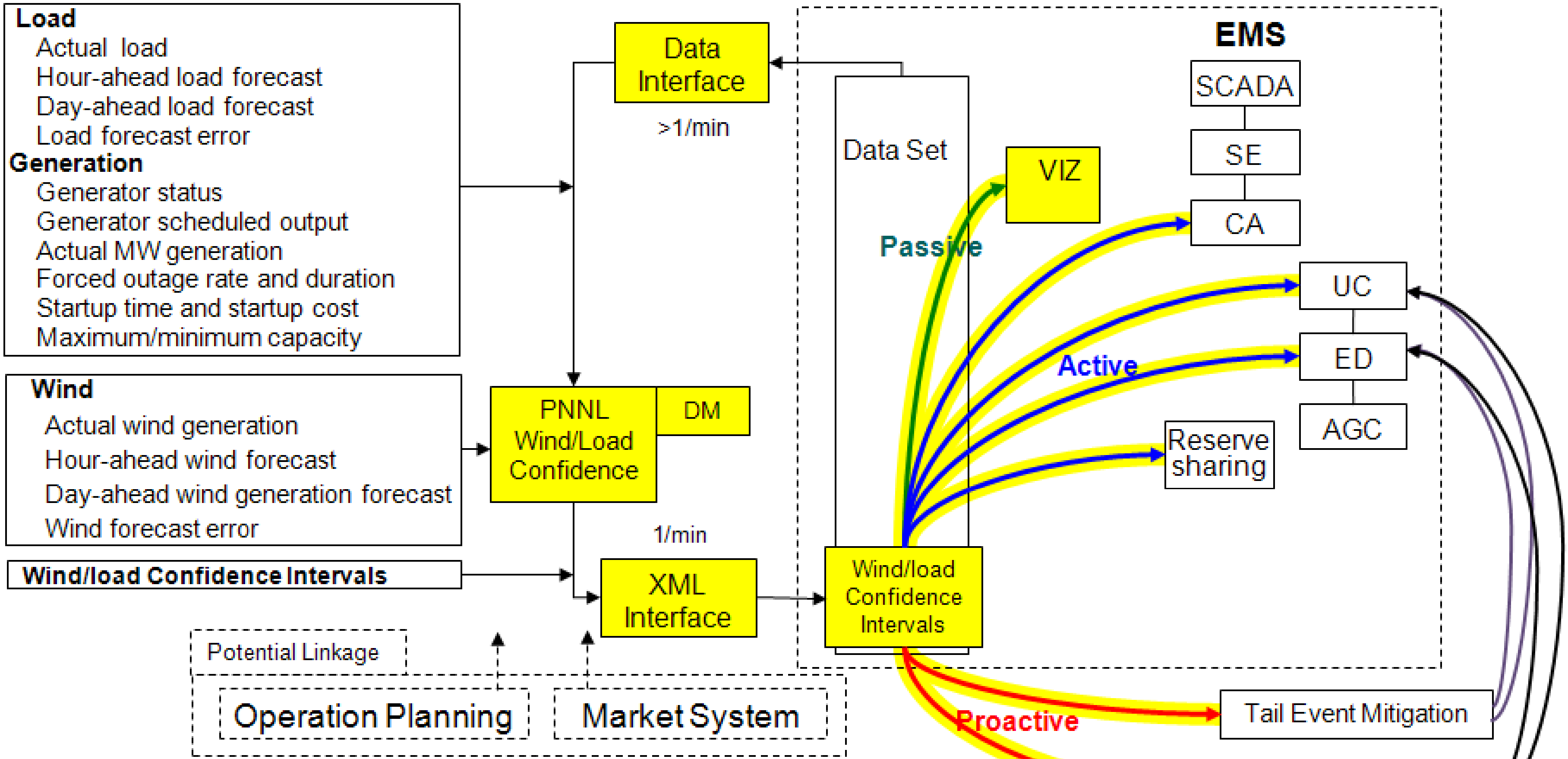
Talking Points: Some Possible Solutions

- Topics discussed in this presentation:
  - Proactive integration of renewables into power operation
  - Incorporation of uncertainty information into system dispatch
  - Performance envelopes
  - Security region concept
  - Consolidation and cooperation among TSOs
- Other topics:
  - Wide area energy management systems
  - Relaxed frequency control (?)
  - Operating reserves
  - Conventional generation flexibility
  - Dispatchability of wind and solar power plants
  - Energy storage, demand control

Solutions: Proactive integration of renewables (1)

- Passive Integration (Level I)
  - Passive integration is the initial step of integration to bring awareness of uncertainties into a control center through visualization and alarming. Displays with look-ahead capacity and ramping requirements are provided to the real-time operators. They help operators assess balancing needs and take preventive actions to mitigate potential balancing energy deficiencies.
- Active Integration (Level II)
  - Active integration uses uncertainty information to re-run existing grid operation functions such as unit commitment (UC) and economic dispatch (ED) processes for the worst-case combination of uncertainties within the specified confidence level. The tool displays warning messages about potential threats to the power system if the UC or ED procedures cannot find solutions for the worst cases. It also provides operators with advisory information regarding the actions that could be taken to avoid potential problems. The active integration does not modify the UC and ED procedures.
- Proactive Integration (Level III)
  - Proactive integration is the most comprehensive level of EMS integration, because it not only interacts with UC, ED and other applications in the EMS system, but also modifies the algorithms. New constraints based on uncertainty range evaluations are incorporated into the UC and ED processes.

Solutions: Proactive integration of renewables (2)

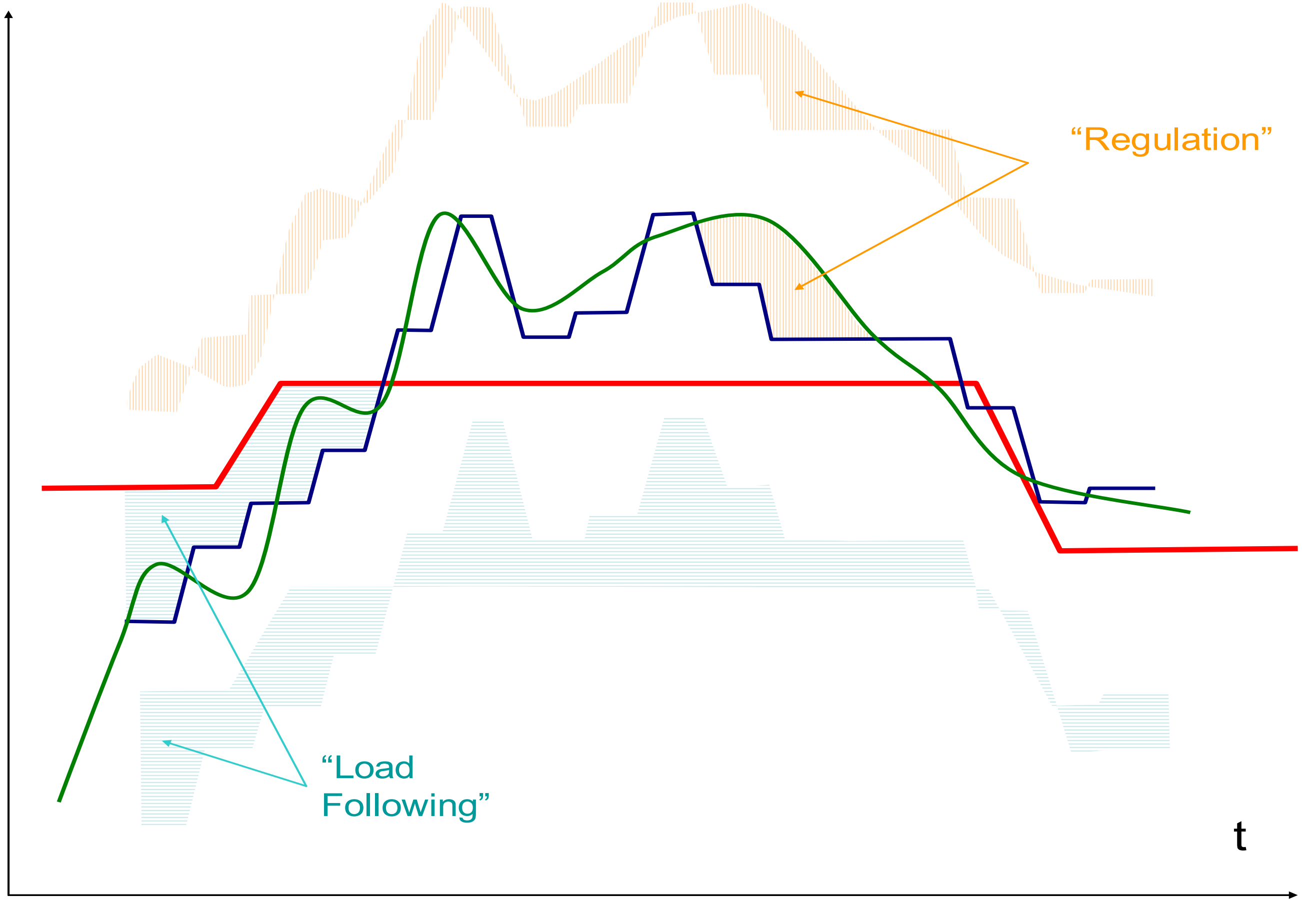


Nomenclatures:

EMS – Energy Management System
UC – Unit Commitment
ED – Economic Dispatch
DM – Data Management
AGC – Automatic Generation Control
CA – Contingency Analysis
VIZ – Visualization

Solutions: Performance Envelopes (1)

- Scheduling, load following (tertiary regulation) and regulation (secondary regulation) processes



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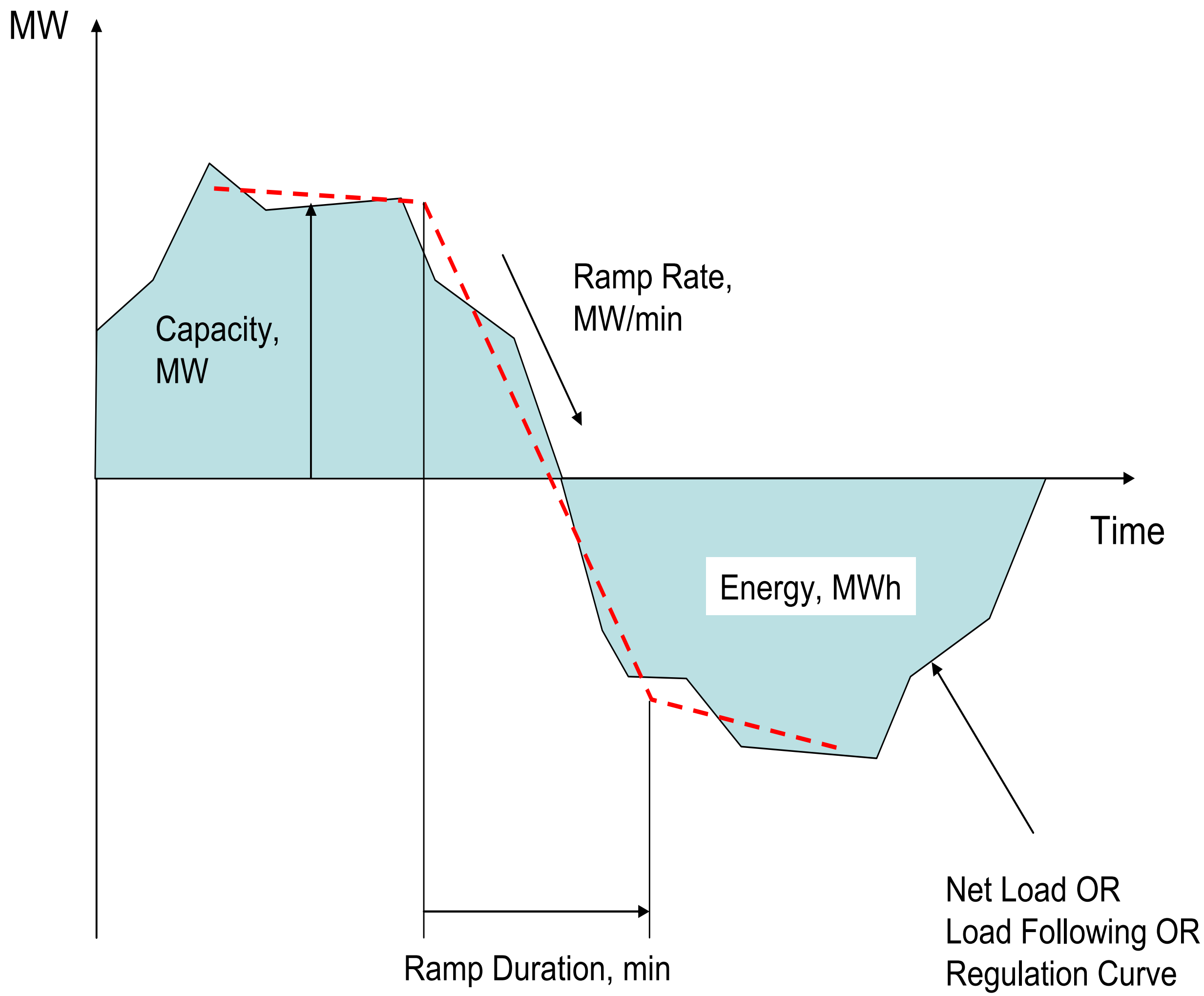
Solutions: Performance Envelopes (2)

- Aspects of balancing processes



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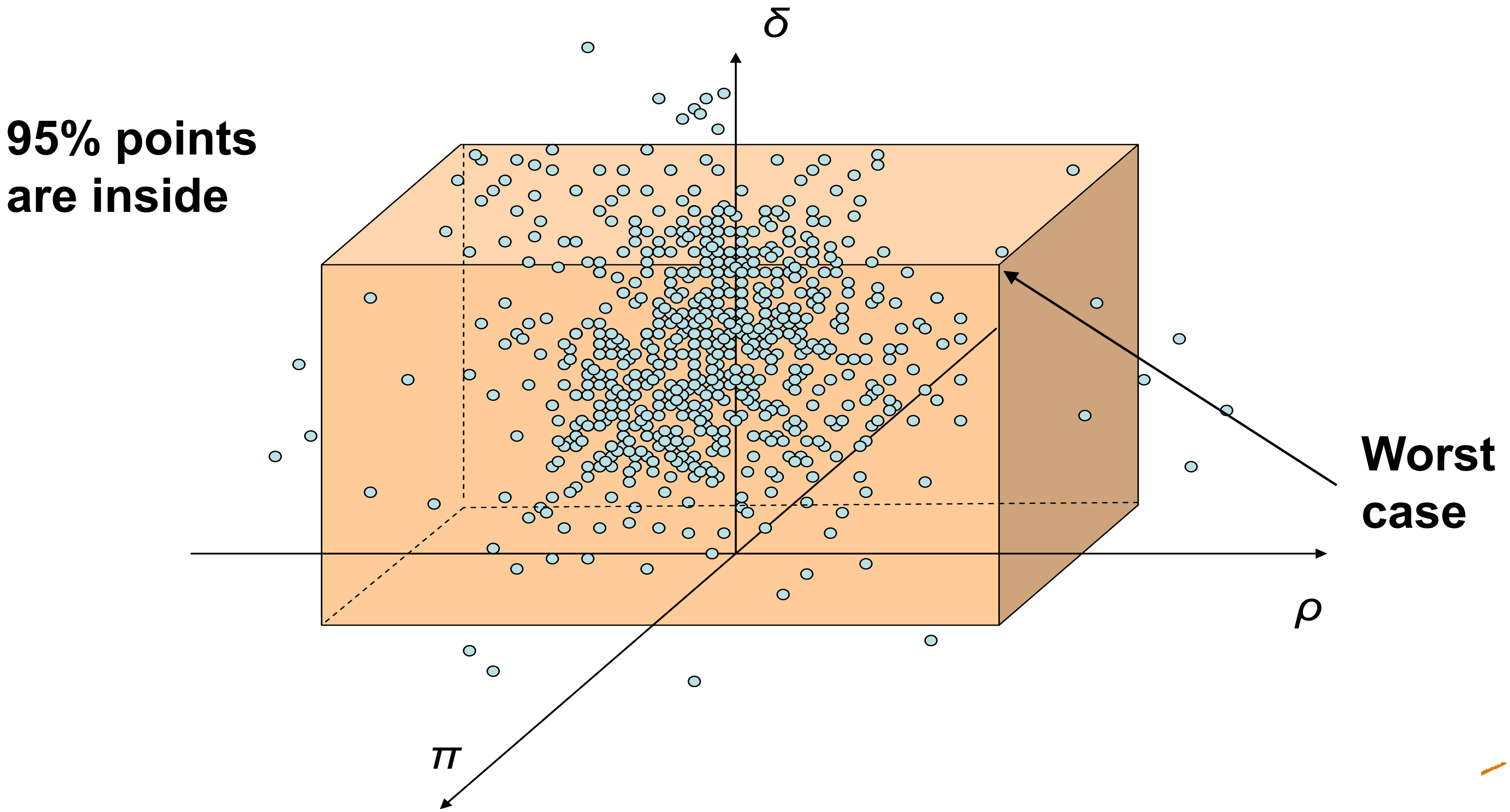
Solutions: Performance Envelopes (3)

- Aspects of balancing processes:
  - *Capacity* (π, MW): Minute-to-minute amount of generation or change in generation output, either up or down, to meet variations.
  - *Ramp rate* (ρ, MW/min): Needed ramping capability of on-line generating units to meet the net load/load following/regulation requirements.
  - *Ramp duration* (δ, min): How long the generators need to change their output at a specific ramp rate.
  - *Energy* (Є, MWh): is the integration of capacity over time and can be calculated as the area between the analyzed curve and the time axis.

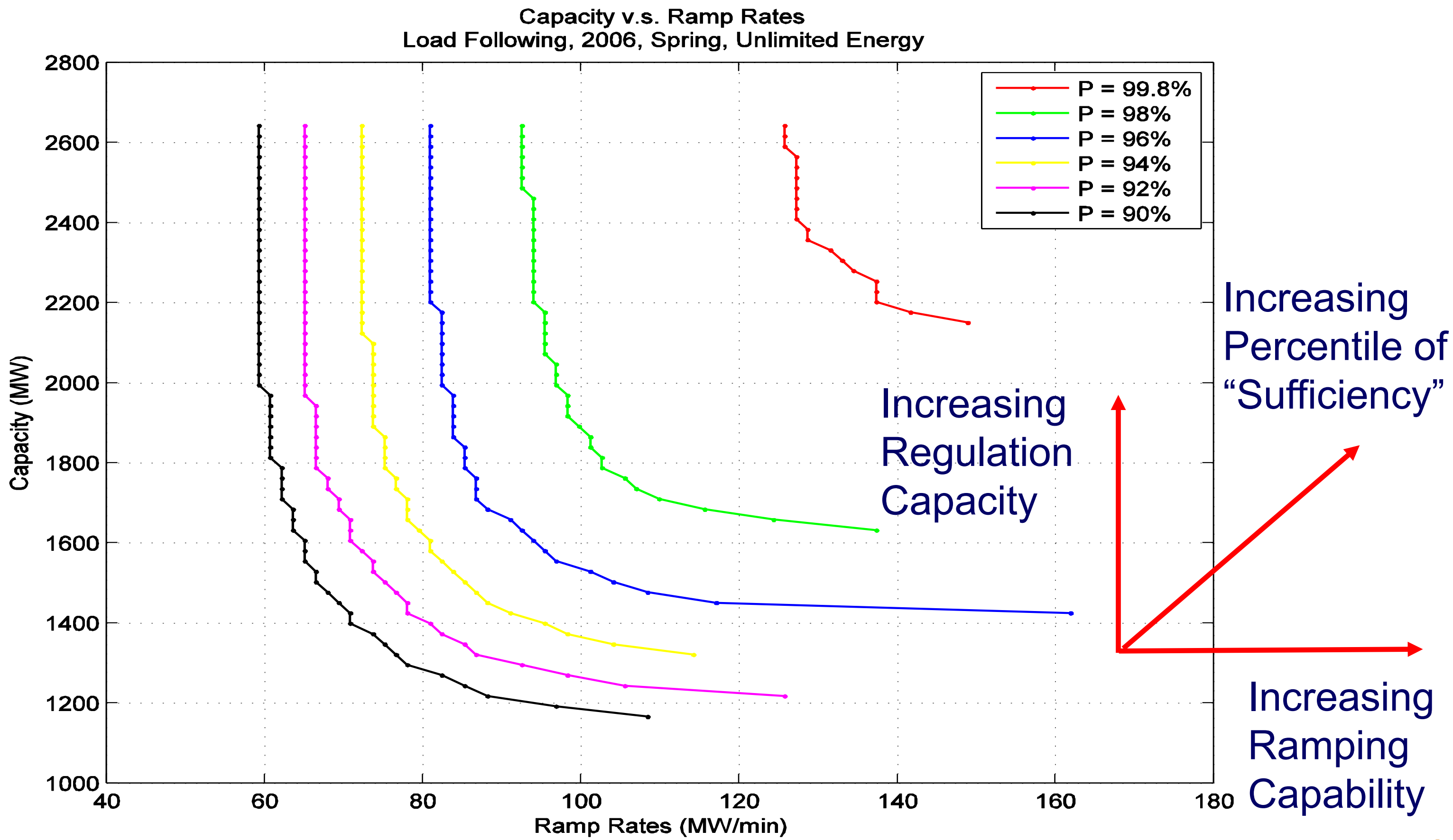
Solutions: Performance Envelopes (4)

- Performance envelopes: Interdependence between the balancing capacity, ramping capability and ramp duration



Solutions: Performance Envelopes (5)

- Performance envelopes: Example of use: Value of fast regulation analysis



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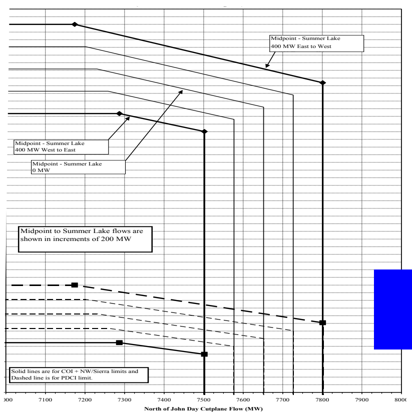
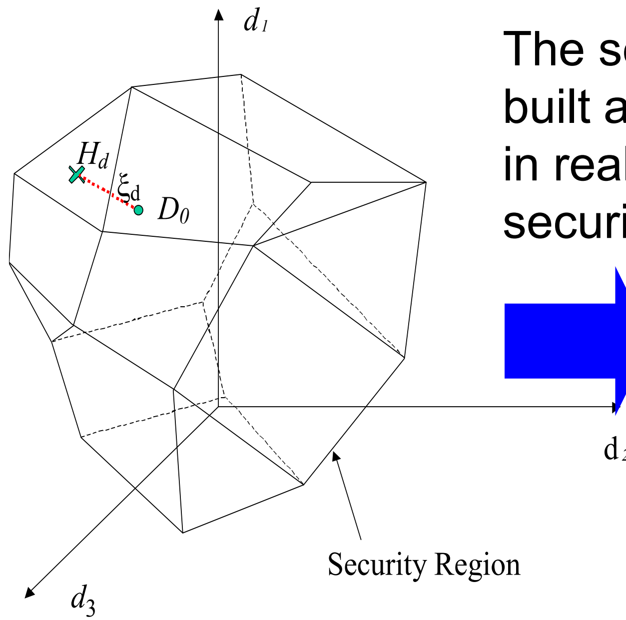
Solutions: Security region concept (1)

- Project objectives:
  - Develop a tool for analyzing security conditions of a power system, based on wide-area multidimensional nomograms (WAMN) or, which is the same, the security region concept
  - Incorporate all types of security and other constraints:
    - Thermal constraints
    - Voltage stability constraints
    - Transient stability constraints
    - Phasor constraints
  - Provide an open platform for new methods of calculating the security boundary
  - Based on SCADA and PMU data, the tool will:
    - Quickly evaluate available security margin ("distance to insecurity")
    - Identify constraining factors (e.g., flow limits)
    - Suggest controls to increase the security margin.

Solutions: Security region concept (2)

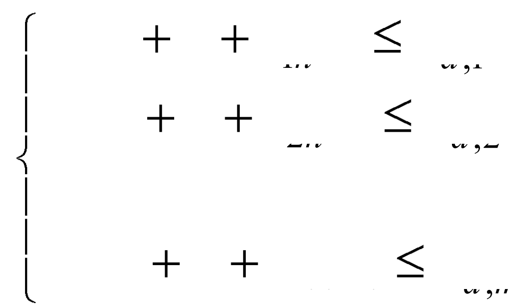


2-D



n-D

The security region (polyhedron), is built and updated offline, and used in real time to evaluate the security margin and controls.



The nomogram limits are also simple linear inequalities!

Each inequality is associated with a combination of constrained parameters d_i (e.g., flows in critical paths). It reflects interactions and dependence between the parameters (in large extent, missing in 2-D plots).

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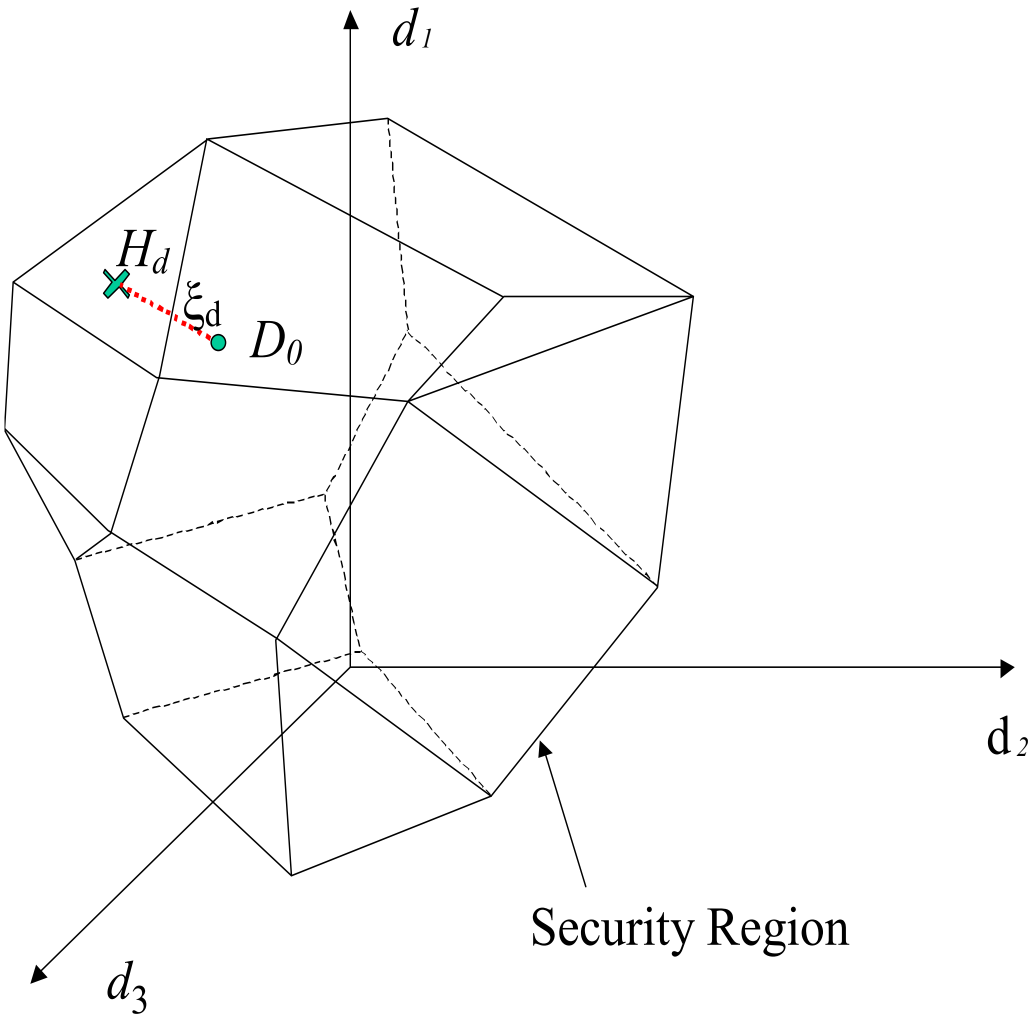
Solutions: Security region concept (3)

- Security Margin and Control Direction

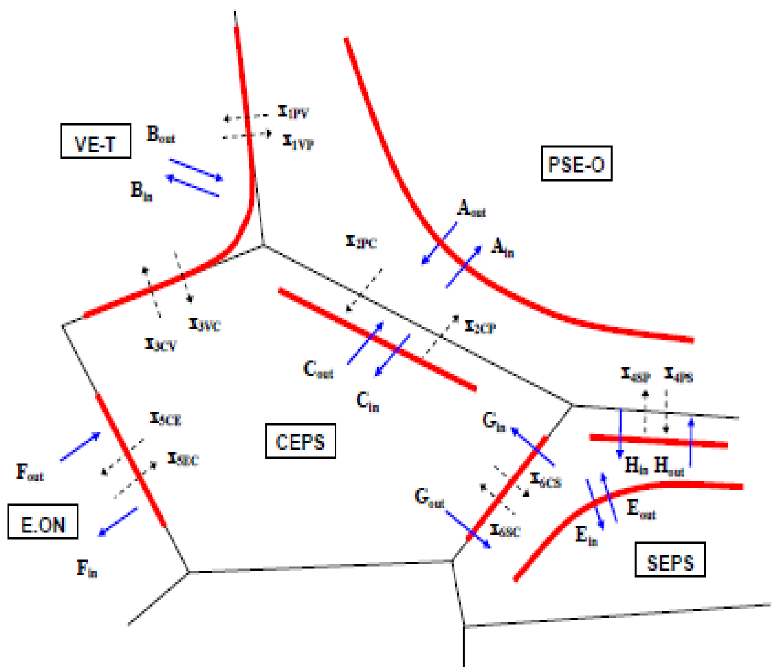


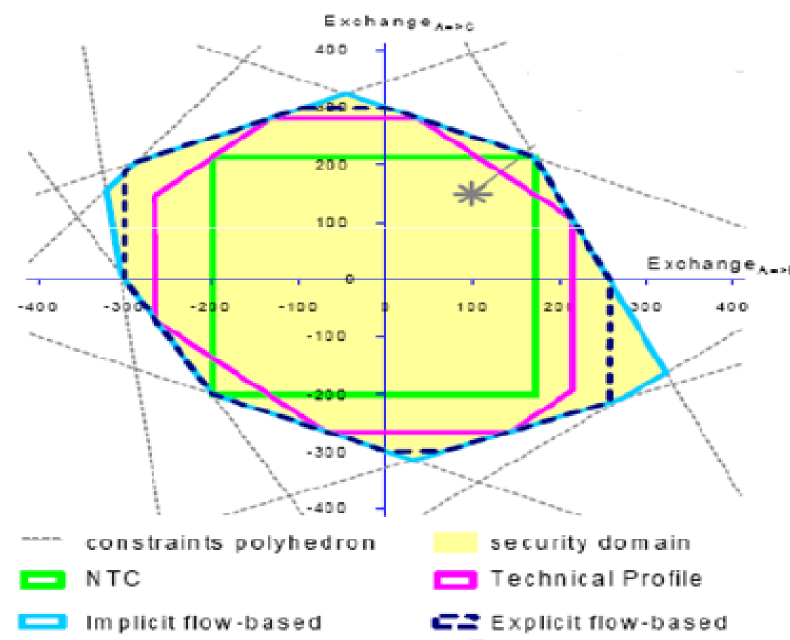
- Security margin ‖ξd‖ provides situation awareness
- Control vector ξd provides actionable information
- Constraints applied to control parameters and their priorities can be incorporated.

Solutions: Security region concept (4)

Is tis methodology realistic?

- Similar methodology has been implemented in Europe* between several TSOs last Summer to manage congestion problem (Central Allocation Office GmbN) and is currently successfully used**.





- Source: David Myska, "Allocation Algorithm Review," 2nd Workshop for Market Participants, Central Allocation Office, Munich, August 12, 2009.

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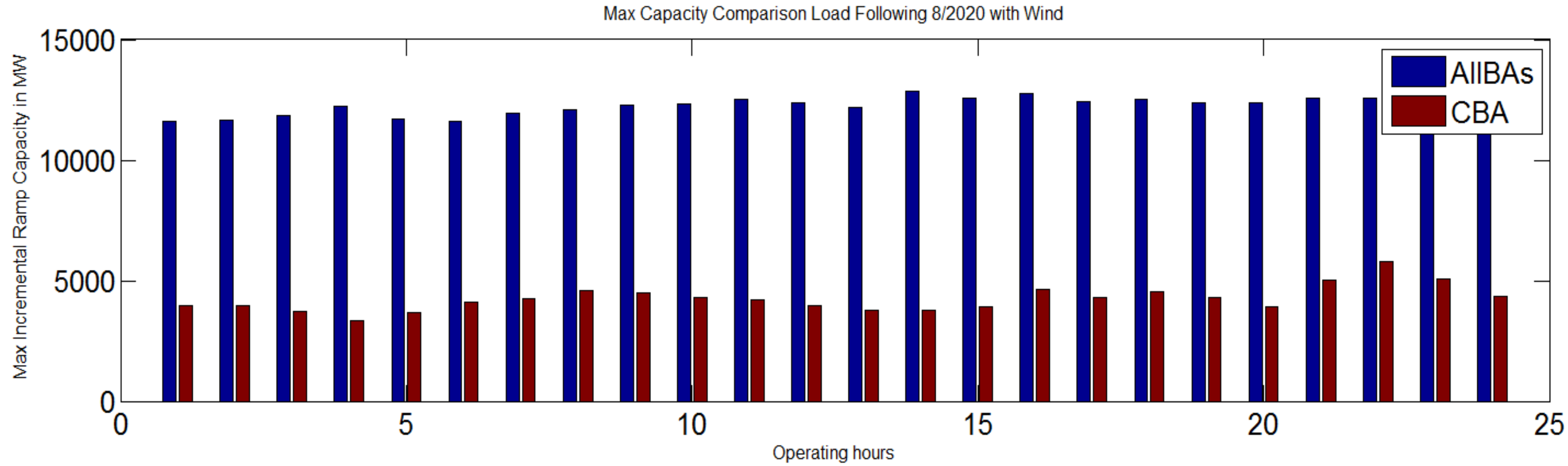
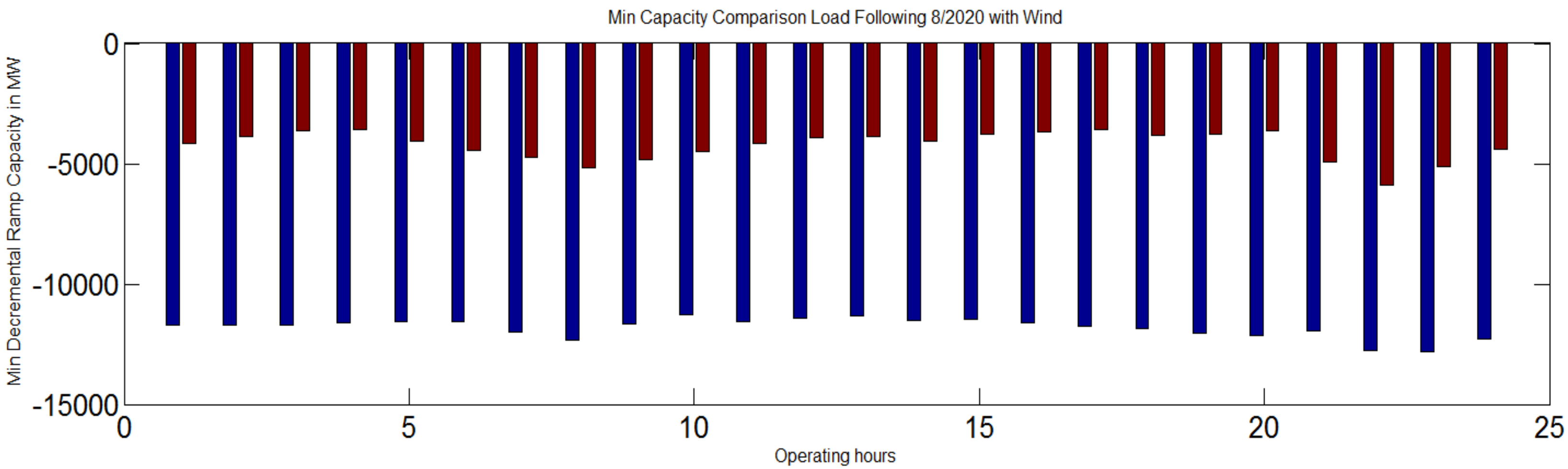
Solutions: Cooperation & consolidation among TSOs

- PNNL study for the Western Interconnection





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Questions? Thank you!

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