National Renewable Energy Laboratory
Innovation for Our Energy Future

Utility operations and variable generation

Utility-scale PV Variability Workshop

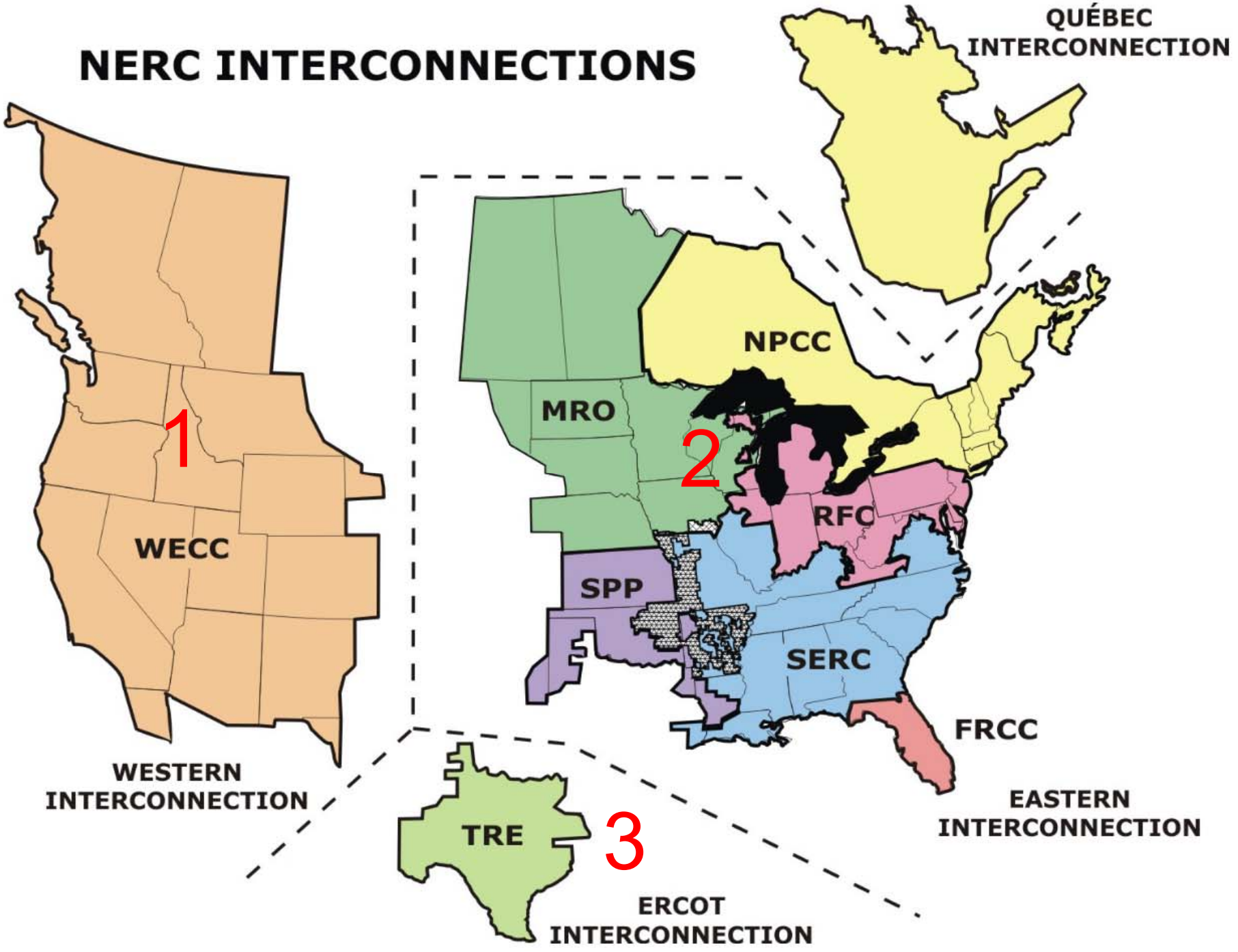
Michael Milligan

Oct 7, 2009

Outline

- Overview of utility operations
  - Interconnections
  - Balancing
  - Time frames for operations
- Possible impacts of PV variability and uncertainty
- Mitigation alternatives

OVERVIEW OF UTILITY OPERATIONS: VG INTEGRATION


NERC INTERCONNECTIONS
QUÉBEC INTERCONNECTION
NPCC
MRO
RFC
SPP
SERC
FRCC
WECC
TRE
1
2
3
WESTERN INTERCONNECTION
EASTERN INTERCONNECTION
ERCOT INTERCONNECTION

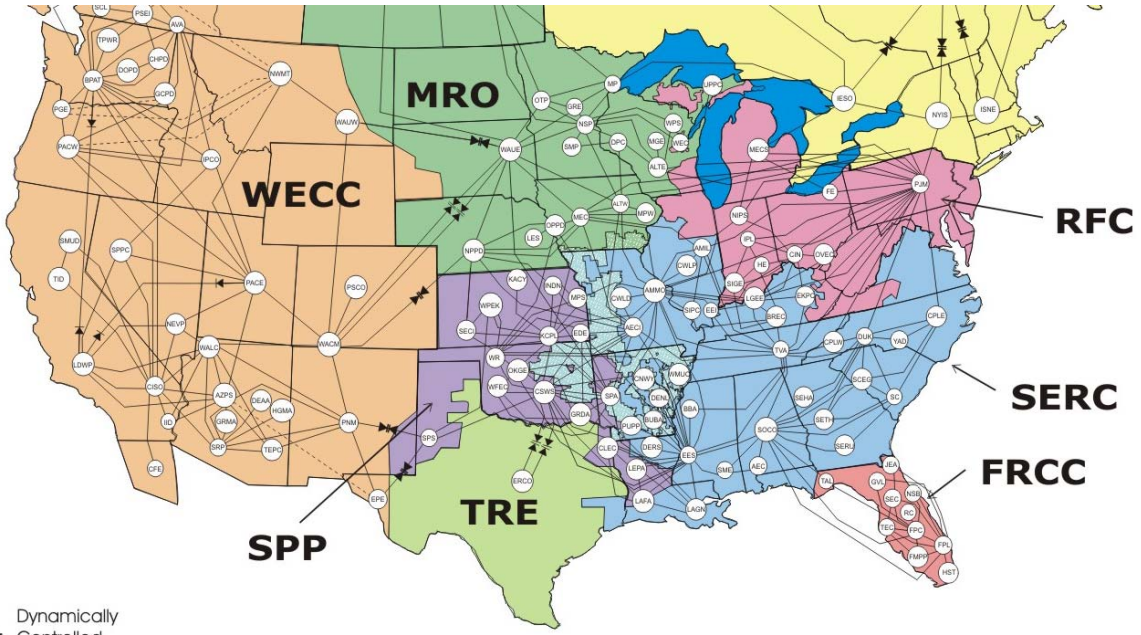
General Operating Requirements

- The interconnection must be balanced

  ∑ loads = ∑ generation *

- Implication for individual balancing areas (BAs)

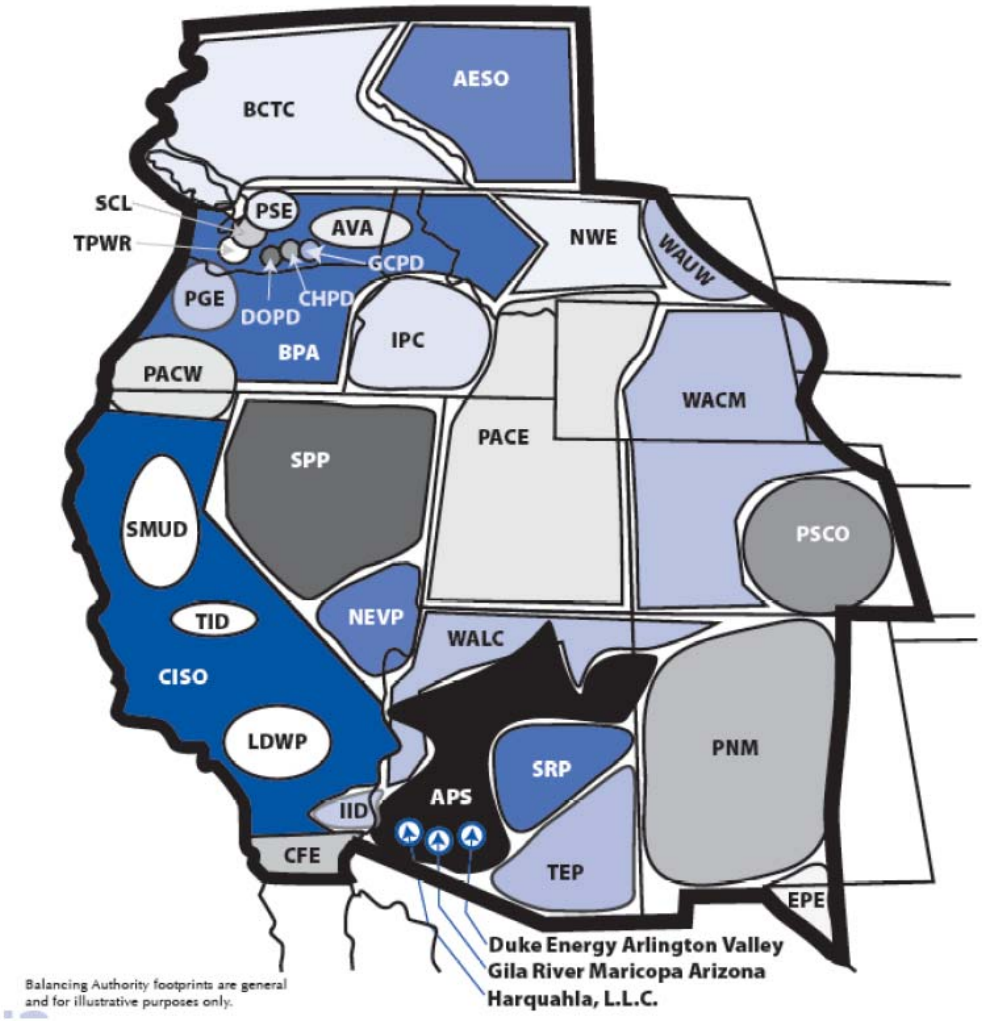
  ∑ loads = ∑ generation + Imports – Exports



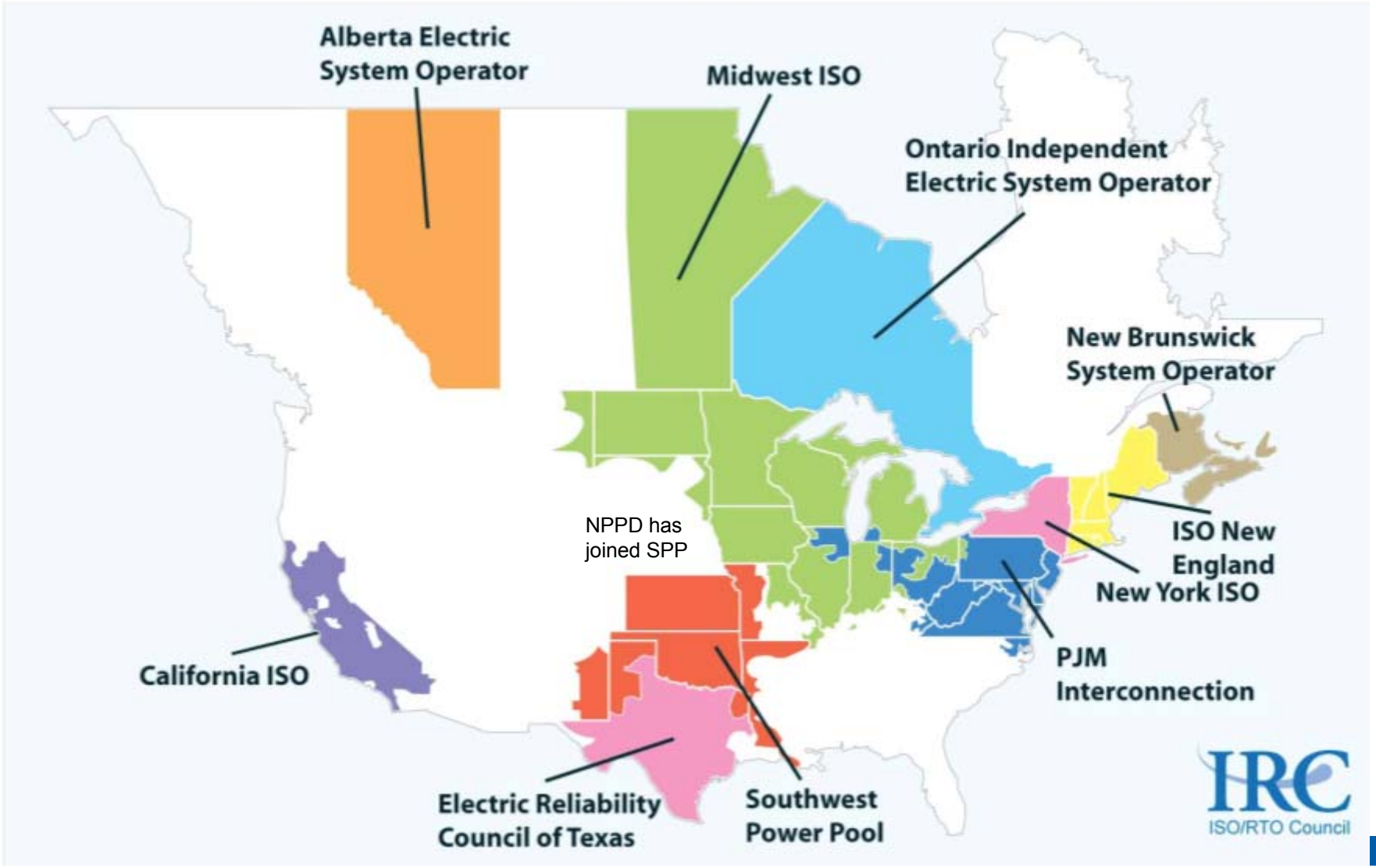
* DC ties can span two interconnections, but these are limited

Dynamically Controlled Generation

Balancing Areas in the West



Markets cover part of the U.S.

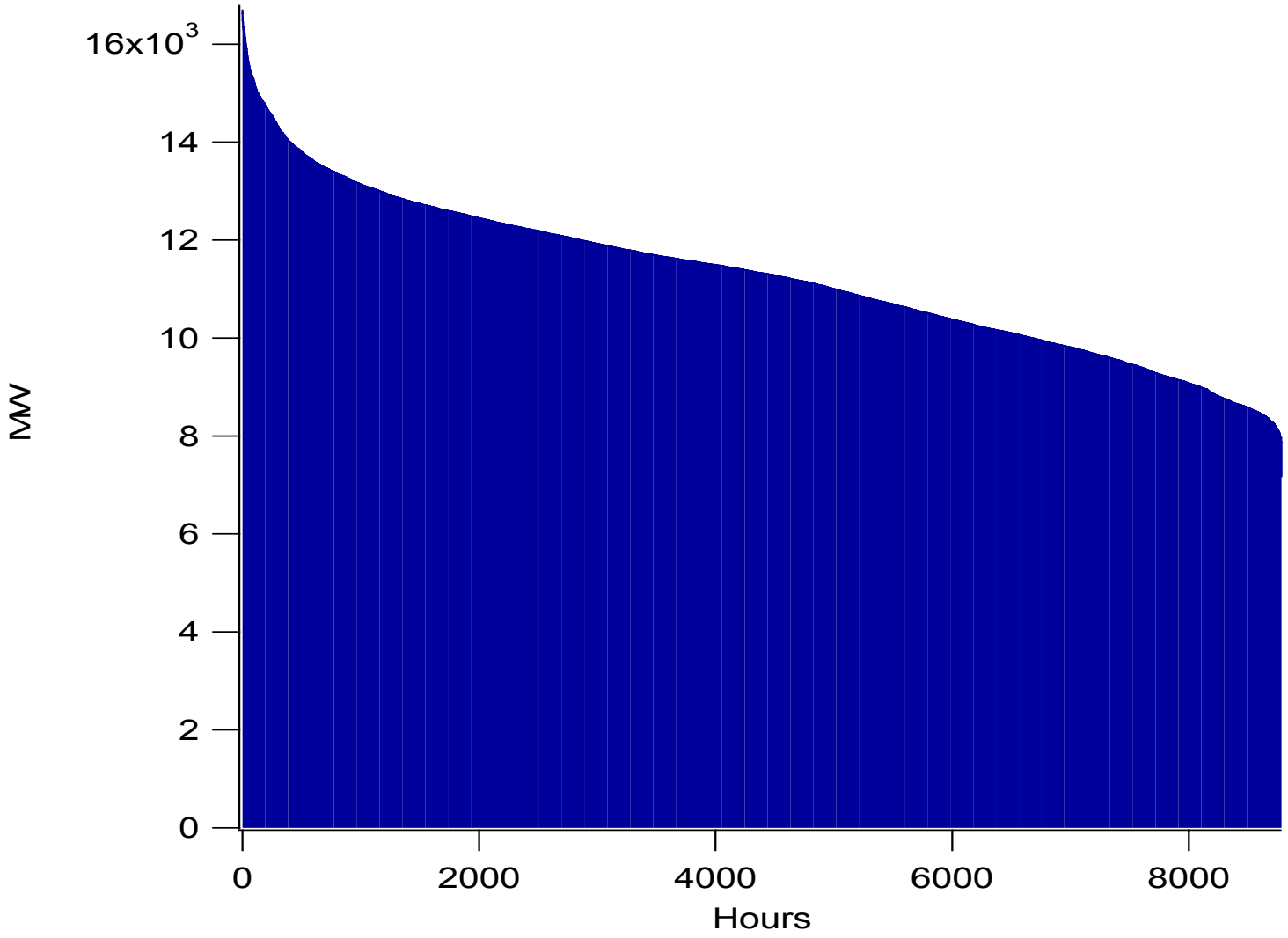


How does the utility schedule resources?

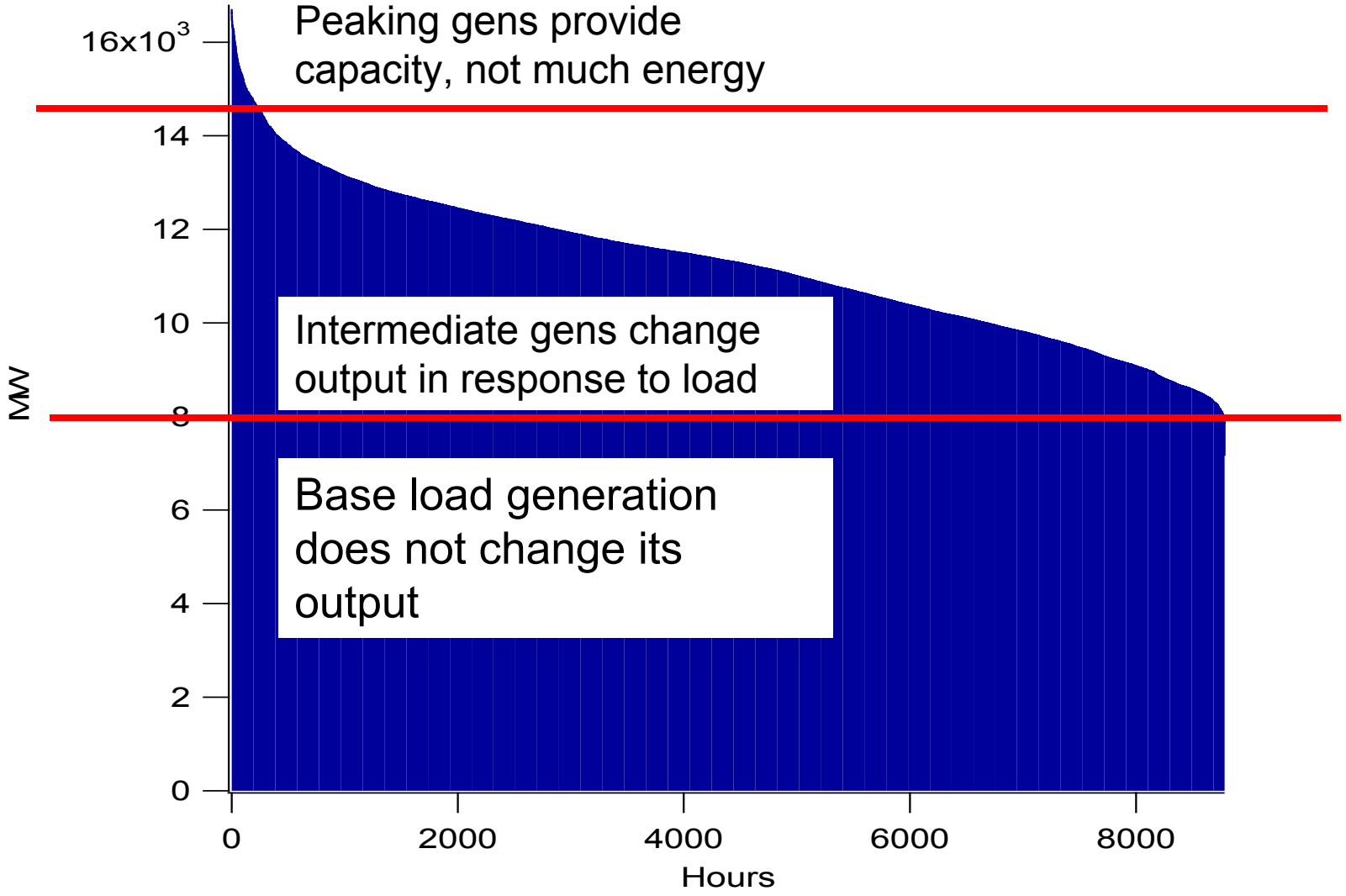
- Non-market areas (regulated by state PUCs)
  - Balancing Authority is responsible for scheduling generation to meet expected loads
  - Individual utilities will often provide schedules to BA, based on economics
- Market areas
  - Similar, except the schedules are induced by the energy market, not single entity

Economic Dispatch

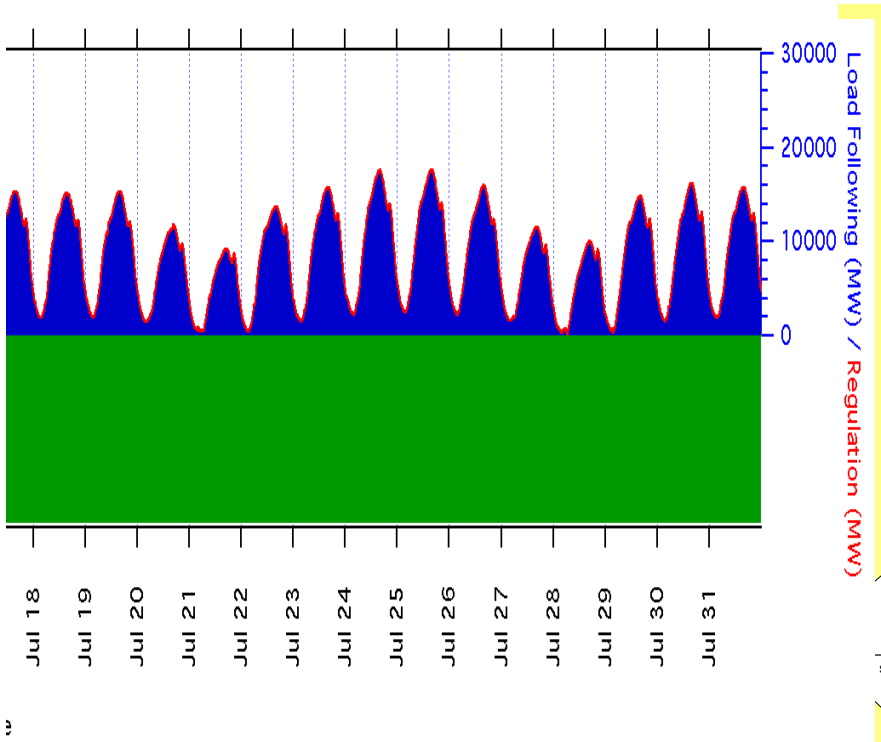
Load Duration Curve

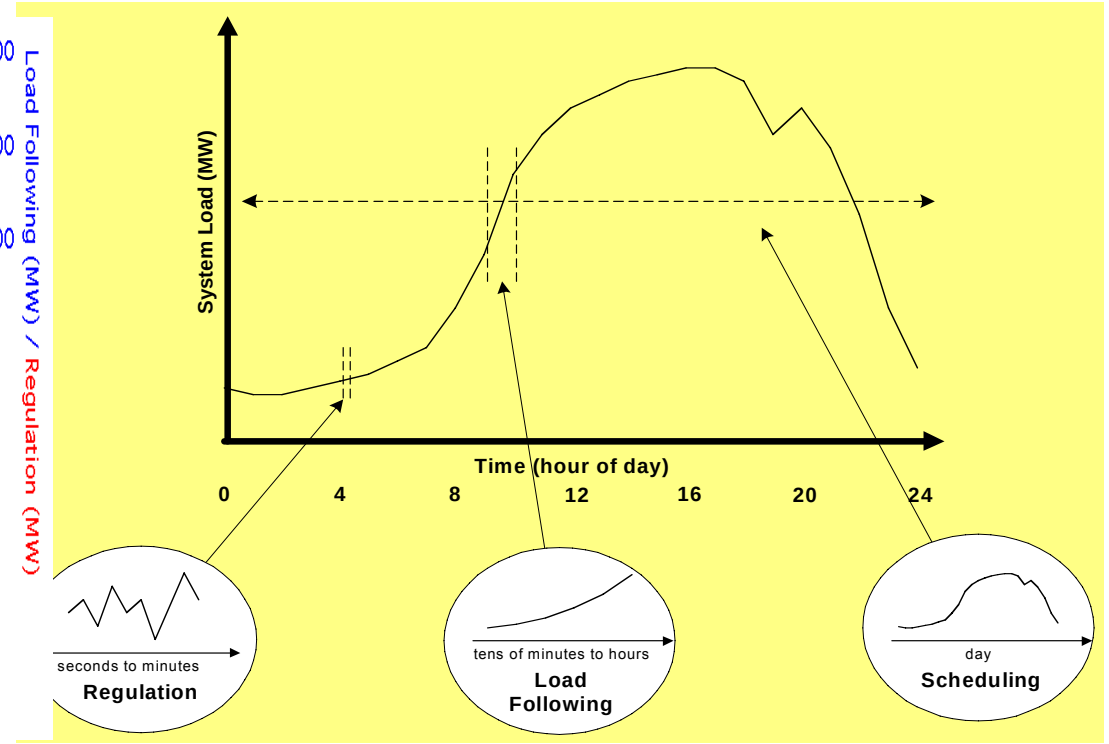


Economic Dispatch



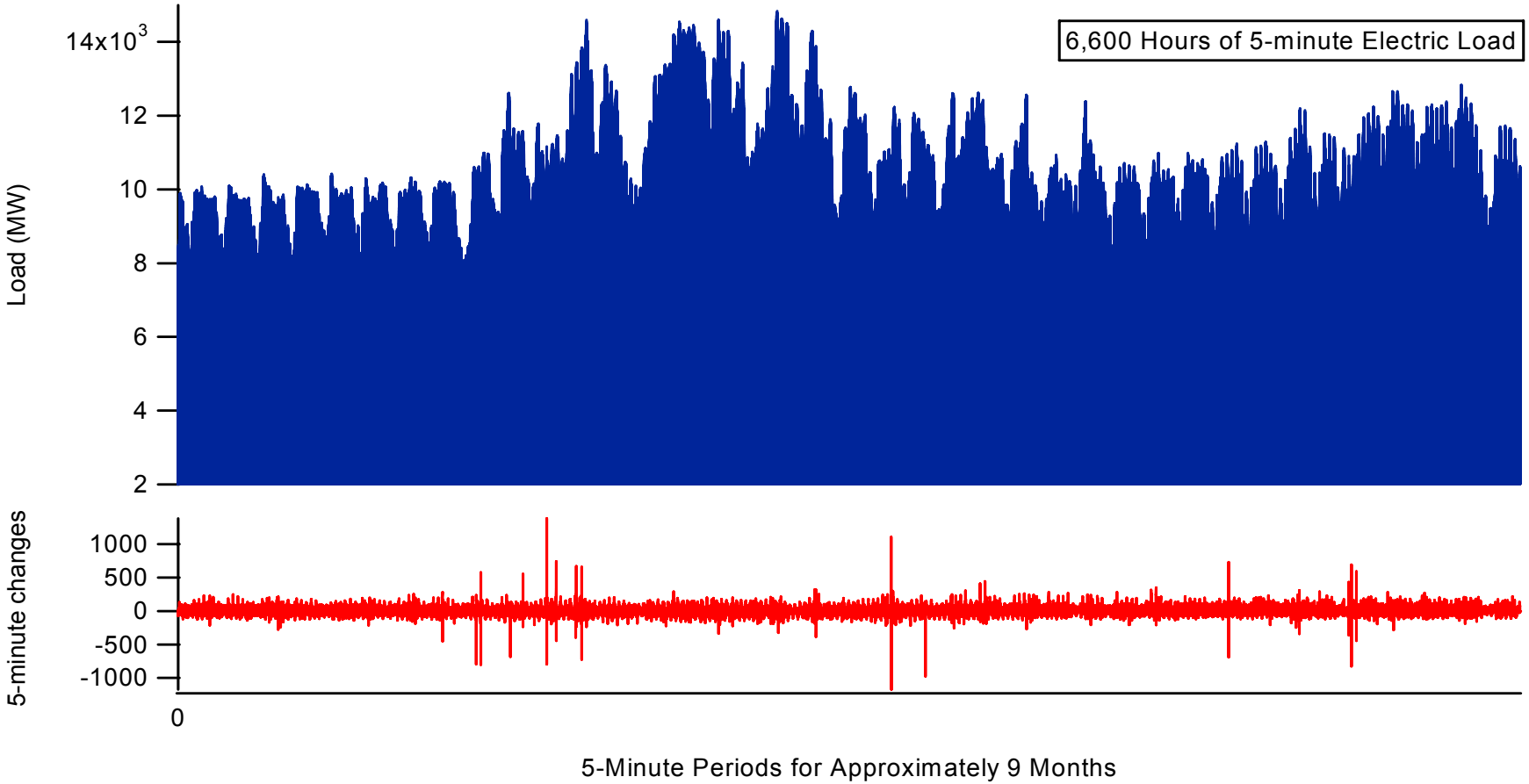
A Chronological View



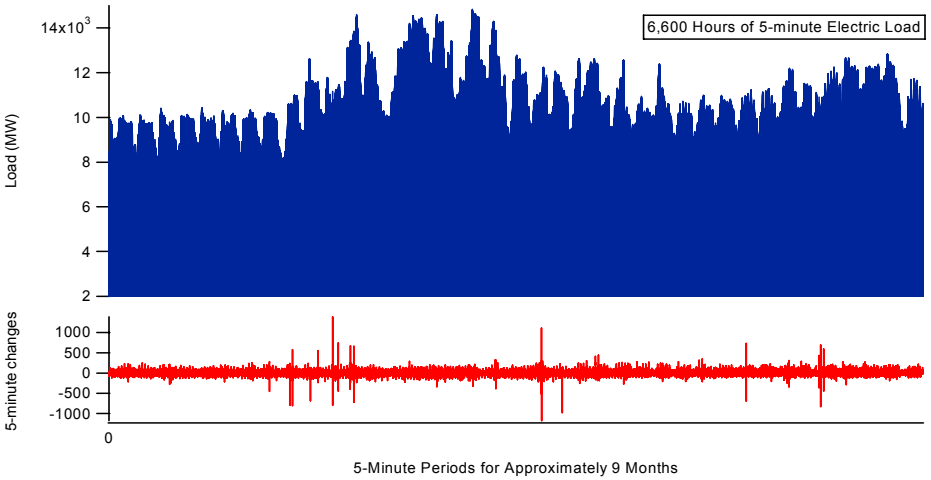


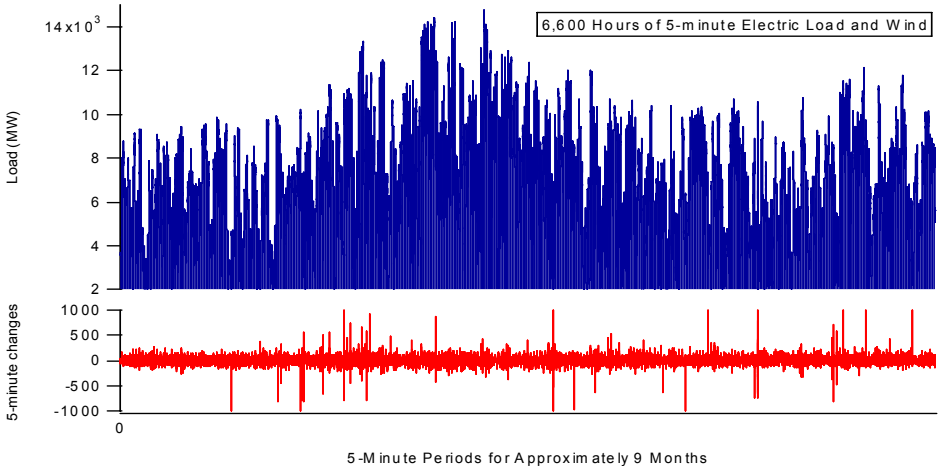
Hours to Day ahead: use load forecast to commit units
10 minutes to few hours: manually adjust generator set points
Seconds to minutes: AGC automatically adjusts generator output

Load is inherently variable



Impact of 25% Wind Energy Penetration: 5-minute data

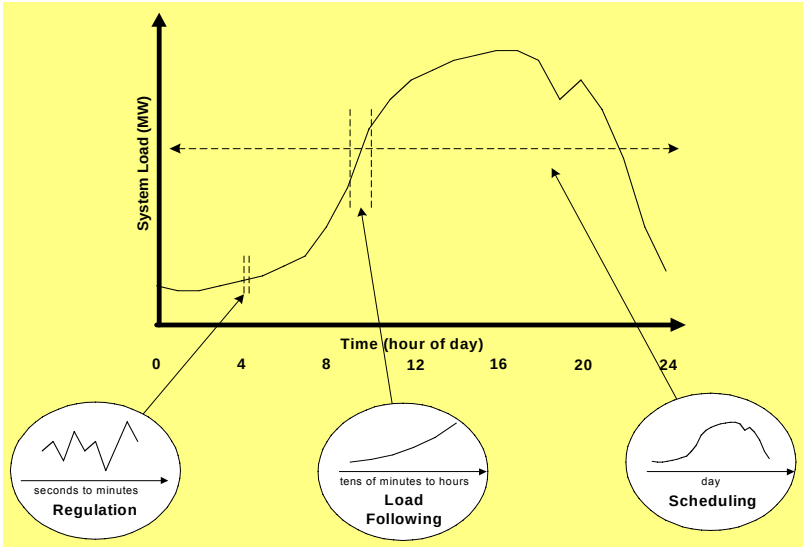




- Wind: Ramp requirements increase with 25% wind energy penetration. The upper panel also shows the importance of being able to achieve lower minimum loads by the conventional generation fleet.
- Solar: Increase in ramping requirements; min-gen not an issue

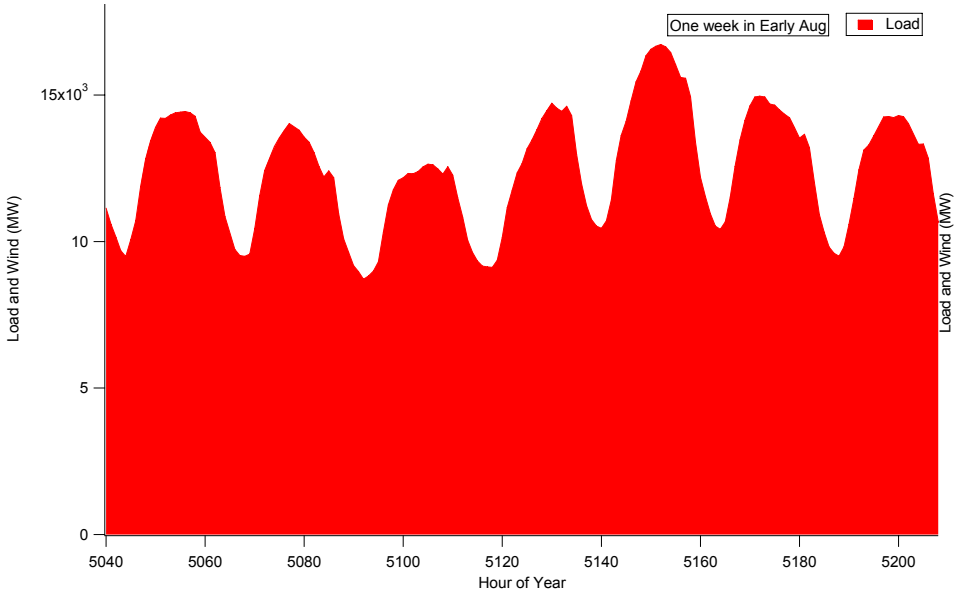
Variable generation increases the variability that must be managed on the grid

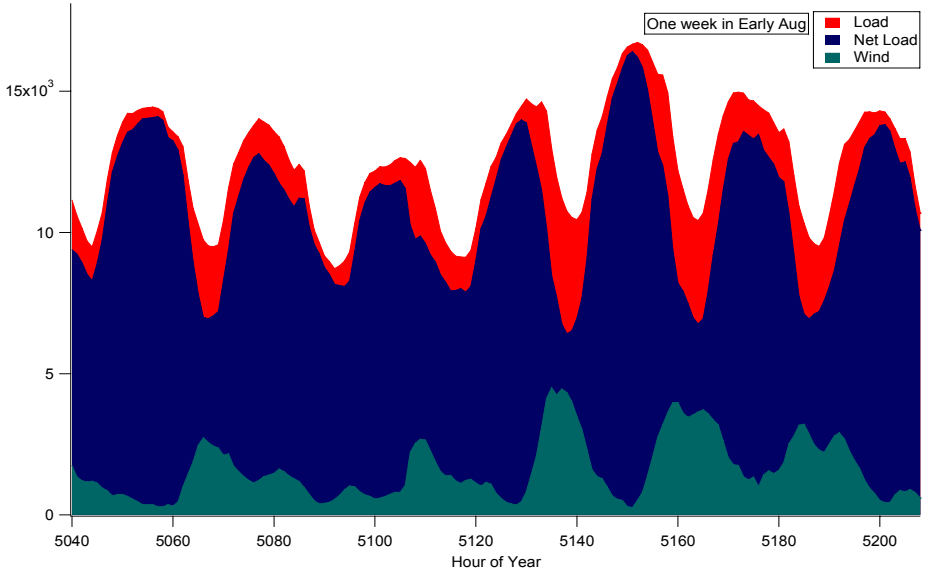
- Wind
  - Some impact on regulation
  - More significant impact on load-following and unit commitment
- PV
  - Potentially large impact on regulation
  - Some impact on load following, likely less significant than on regulation and wind



Unit commitment and uncertainty

- Is there sufficient committed capacity to cover uncertainty of load forecast error, VG forecast error? (spin)
- How much non-spin is available?
- Can I transact with the neighbors on fast time scales?





Advanced unit commitment

- Rolling commitment as new information becomes available ~6-hour time steps
- Stochastic unit commitment can help hedge your bets
- Does unit commitment handle the “sharp edges” or box you in?

Data Requirements for Integration Analysis: VG and Load

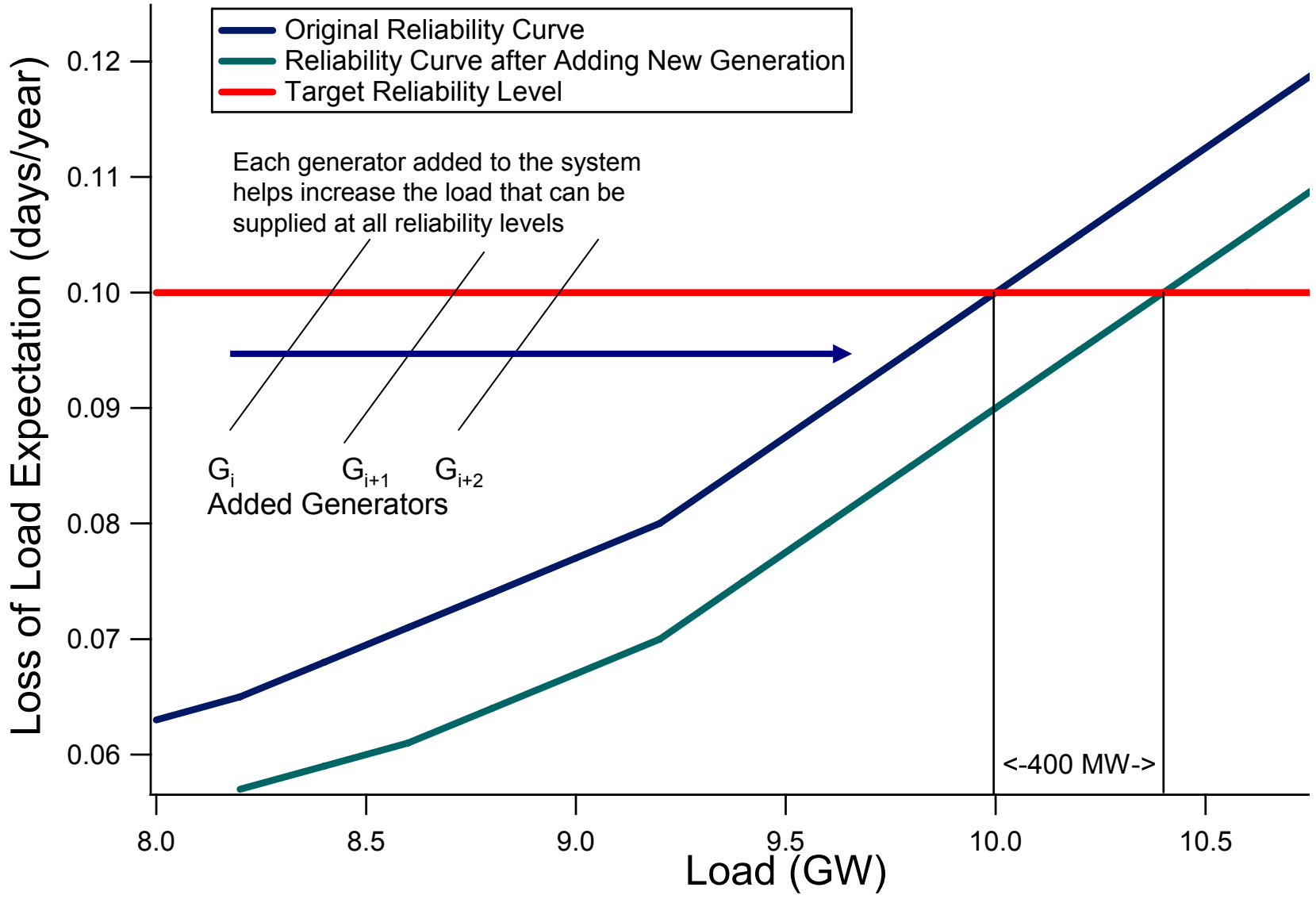
- Weather is common driver
- Hourly VG and load data must be from same year for consistent analysis and plausible results
- Use of meso-scale weather models or actual VG production is state of the art
- Utility Wind Integration and Operating Impact State of the Art, IEEE Transactions, Aug 2007.

CAPACITY VALUE

System Adequacy

- Often measured based on installed capacity, peak load, and a planning reserve
- A fixed planning reserve margin (15%) does not in itself provide a measure of adequacy
- No system can be perfectly adequate
- How adequate is adequate enough?
- Quantify the number of times system will be inadequate – often measured as hours/year; days/year (1d/10y ≈ 99.97%)

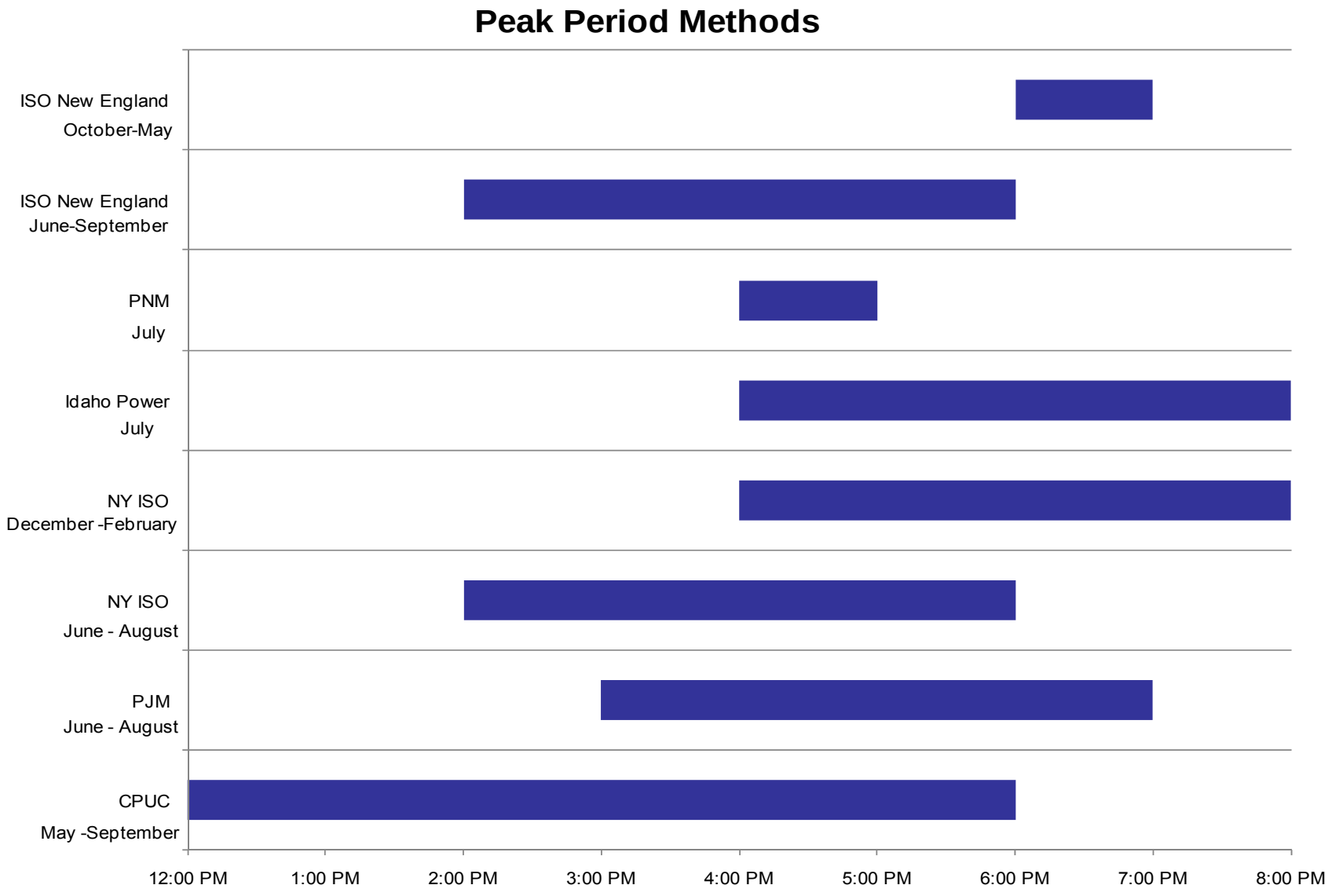
Effective Load Carrying Capability (ELCC)



Pitfalls (things to avoid)

- Using load and VG data from different years
- Applying load forecasts to load shape that changes underlying “weather” assumption
- Sampling VG/resource data from different years (i.e. long term database)
- Assume that one year is enough

Simplified approaches are sometimes applied (full ELCC computation can be expensive)

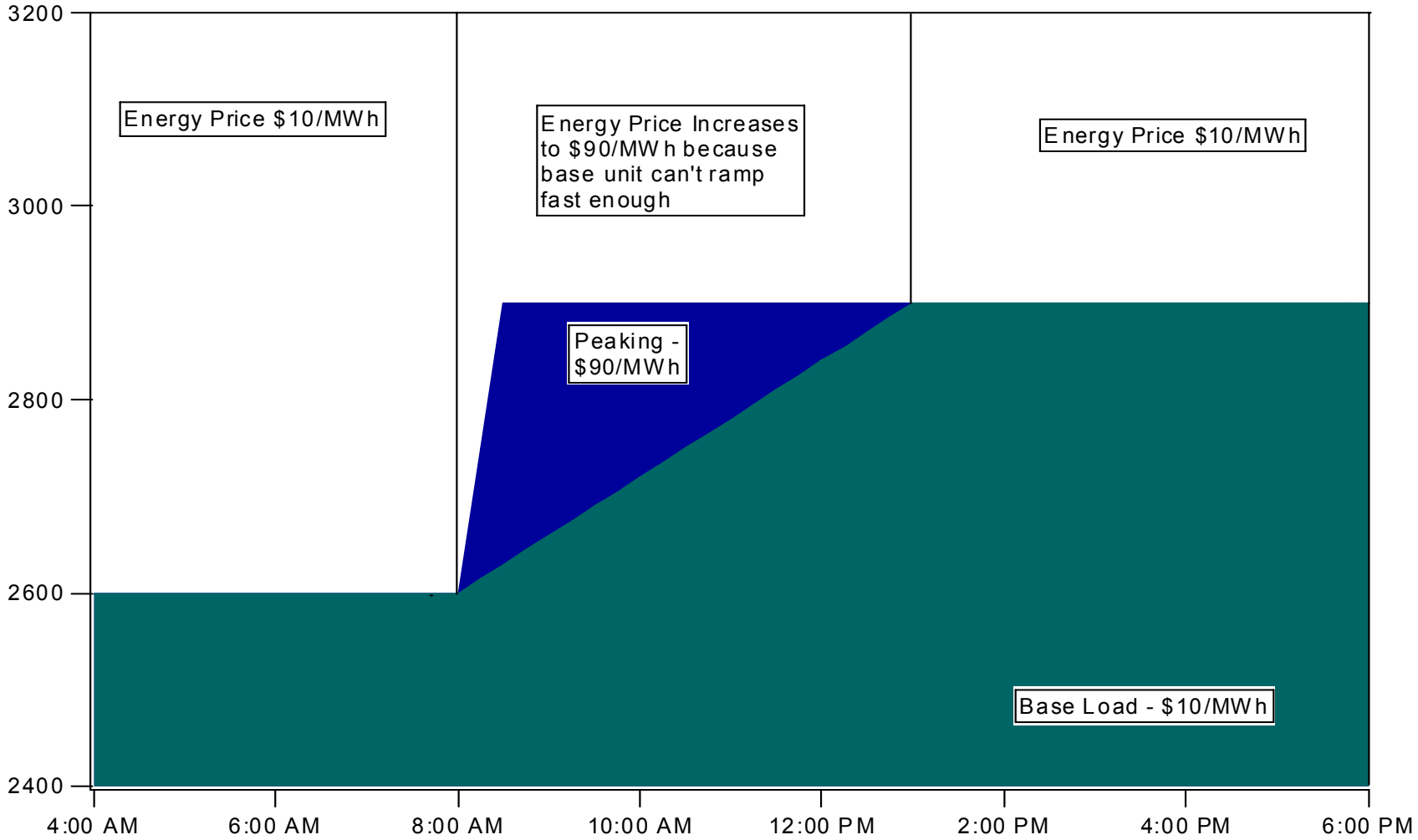


Issues for high VG penetration: what is needed for successful integration?

Key Challenges for VG Integration at High Penetration

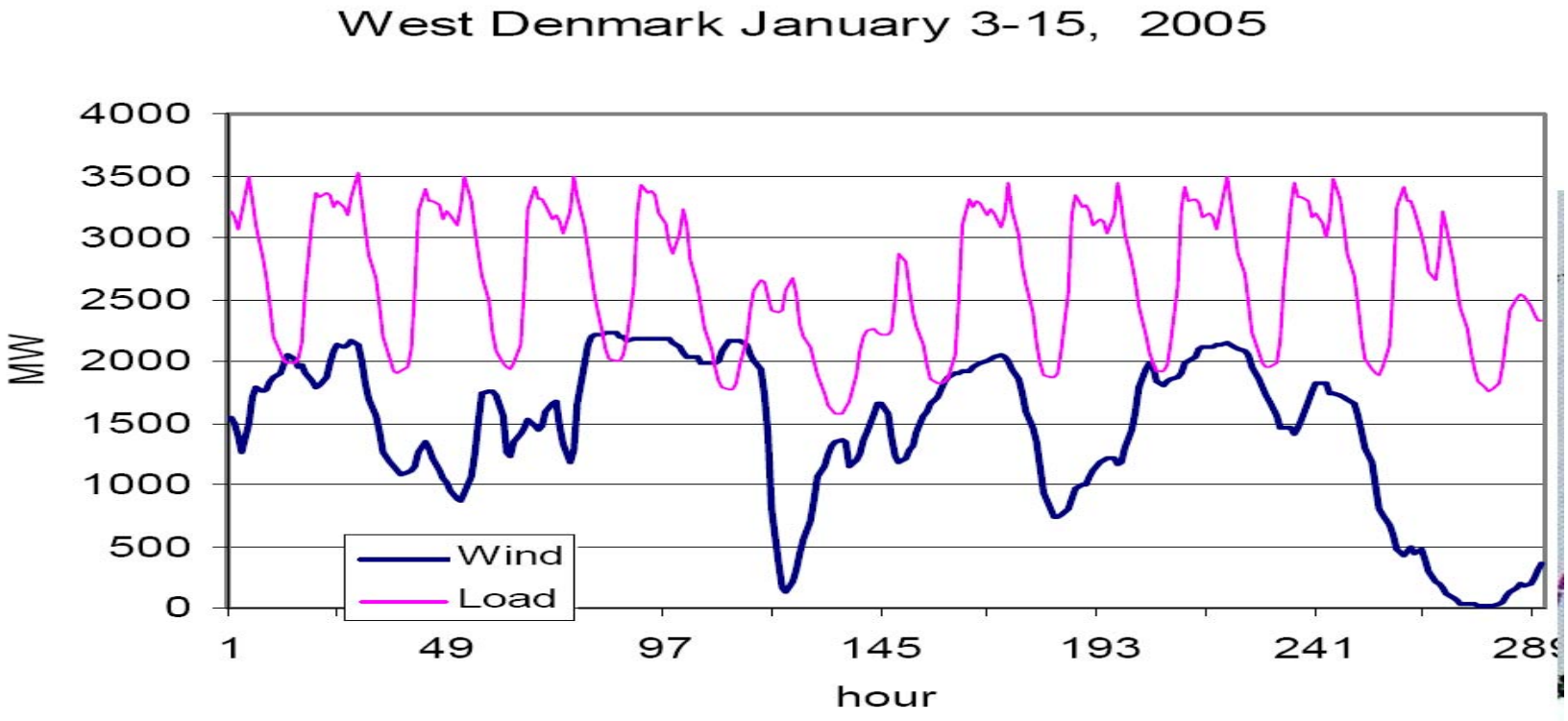
- Can the increased variability be accommodated?
- Can the increased uncertainty be accommodated?
- Is there sufficient turn-down capacity?
- Is there sufficient transmission to ensure deliverability?

Can the non-wind fleet ramp quickly enough?



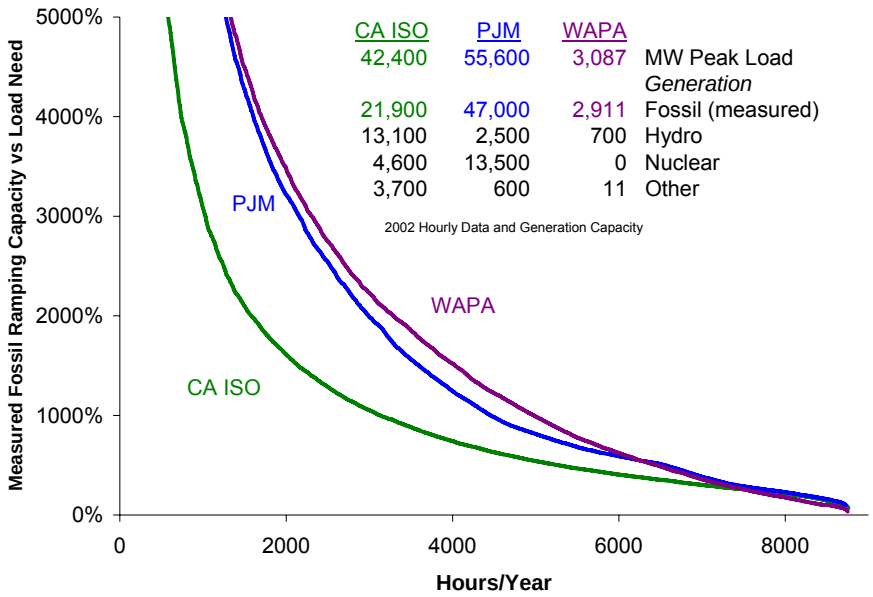
Integrating “large” VG penetrations: what does it take?

- Better use of existing flexibility
- Acquire additional flexibility across BAs
- Acquire additional physical flexibility



Better use of existing flexibility

- Tap into maneuverable generation that may be "behind the wall"[1]
- Provide a mechanism (market, contract, other) that benefits system operator and generator
- Fast energy markets help provide needed flexibility[2] and can often supply load following flexibility at no cost[3]



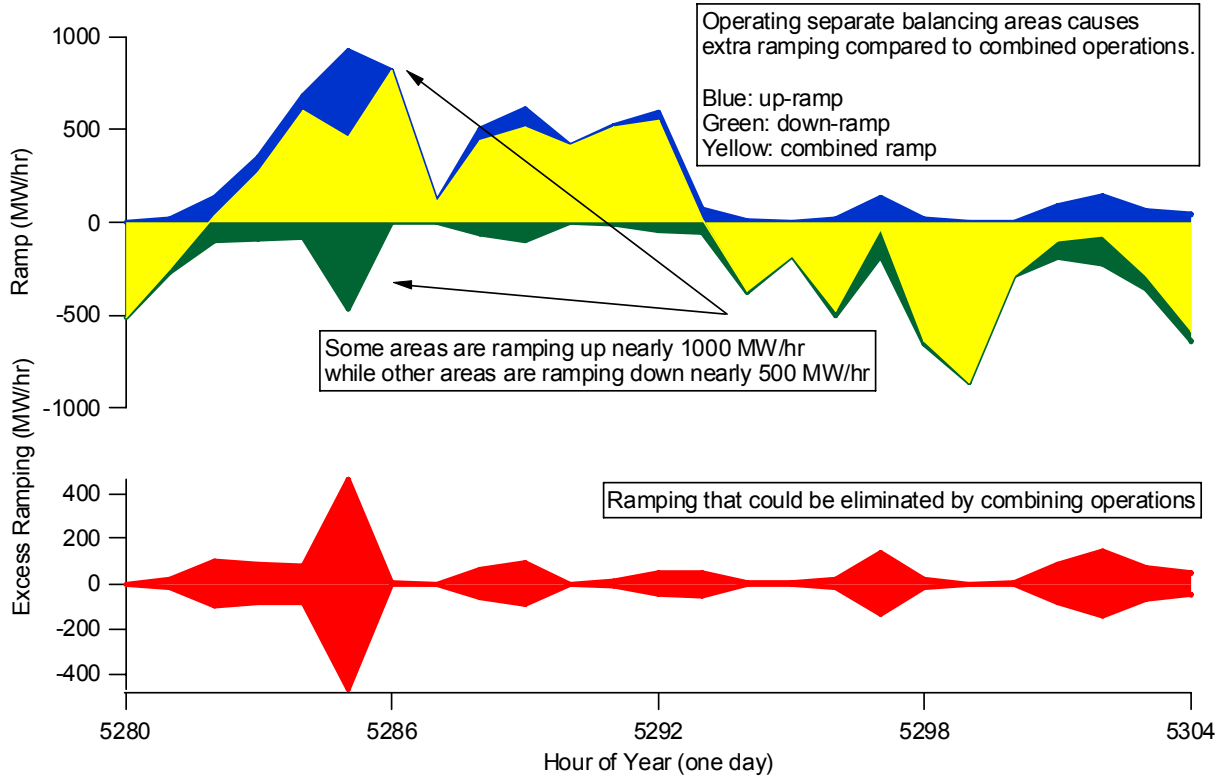
[1]Kirby & Milligan, 2005 Methodology for Examining Control Area Ramping Capabilities with Implications for Wind http://www.nrel.gov/docs/fy05osti/38153.pdf

[2]Kirby & Milligan, 2008 Facilitating Wind Development: The Importance of Electric Industry Structure. http://www.nrel.gov/docs/fy08osti/43251.pdf

[3]Milligan & Kirby 2007, Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration . http://www.nrel.gov/docs/fy07osti/41809.pdf

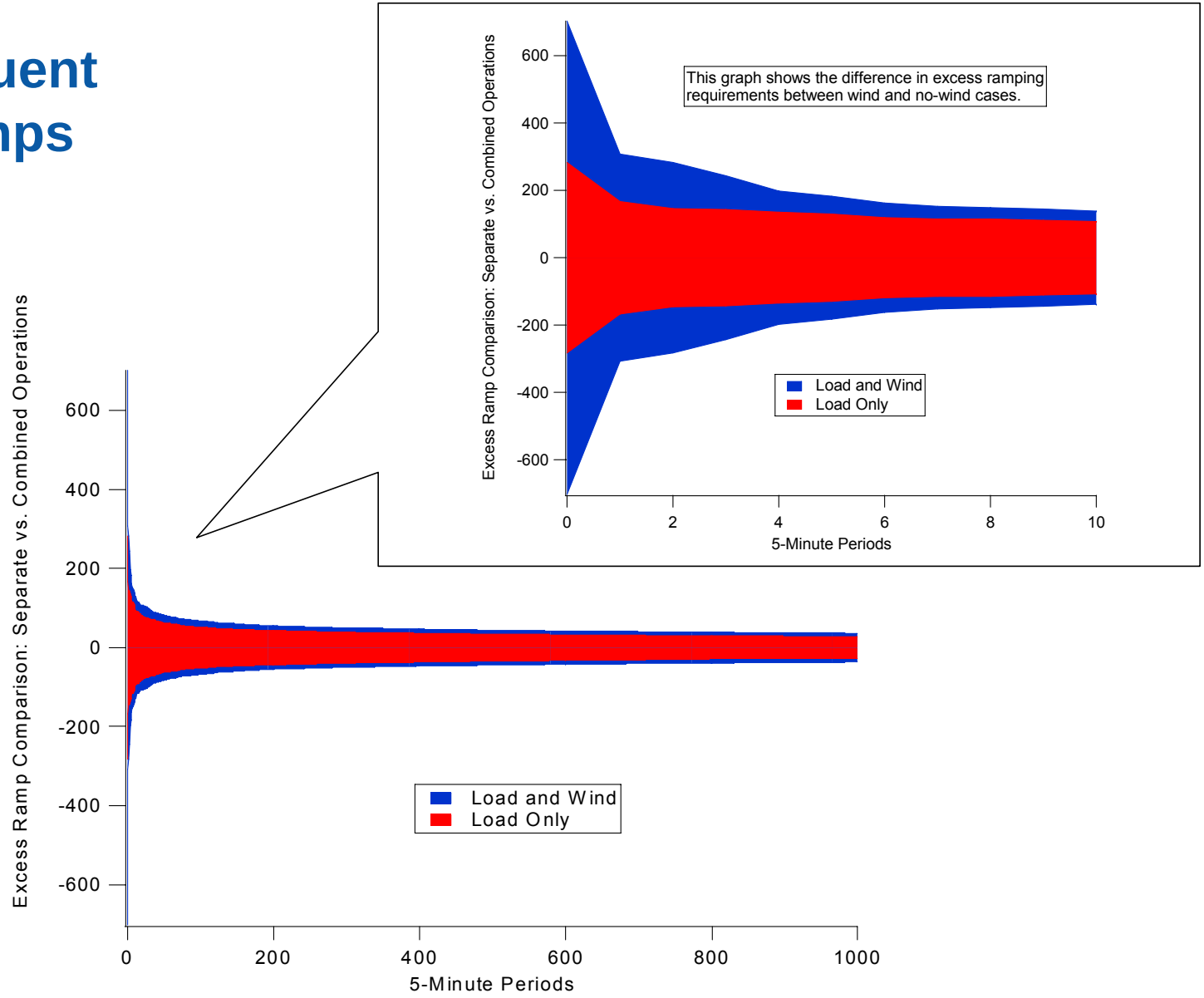
Acquire additional flexibility across BAs

- Reduce the need for ramping by combined BAs (real or virtual)
  - Inter-BA scheduling rules/practices
  - Ramping *capability* adds linearly
  - Ramping *need* adds less than linearly



Milligan & Kirby 2007, Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration . http://www.nrel.gov/docs/fy07osti/41809.pdf

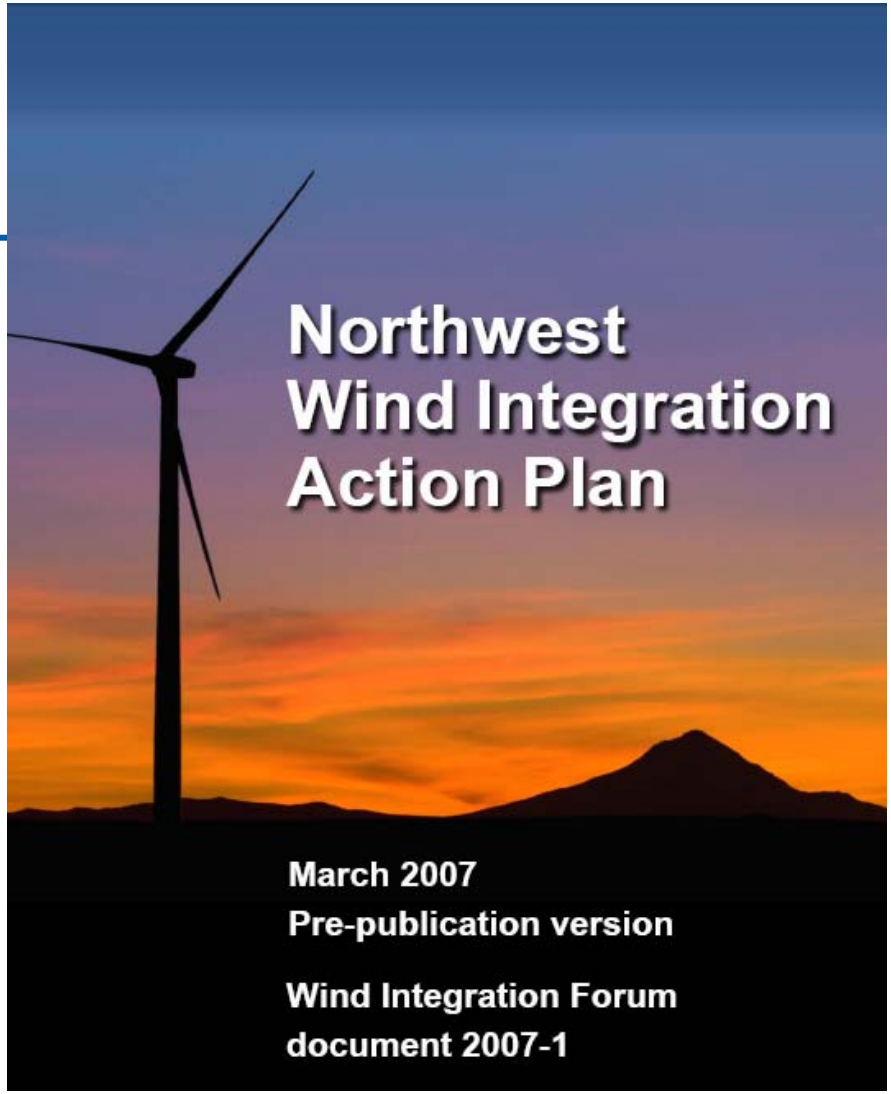
Large, infrequent 5-Minute Ramps can be significantly reduced



Milligan & Kirby 2008, An Analysis of Sub-Hourly Ramping Impacts of Wind Energy and Balancing Area Size:
http://www.nrel.gov/docs/fy08osti/43434.pdf

Recognized Importance of Fast Energy Markets

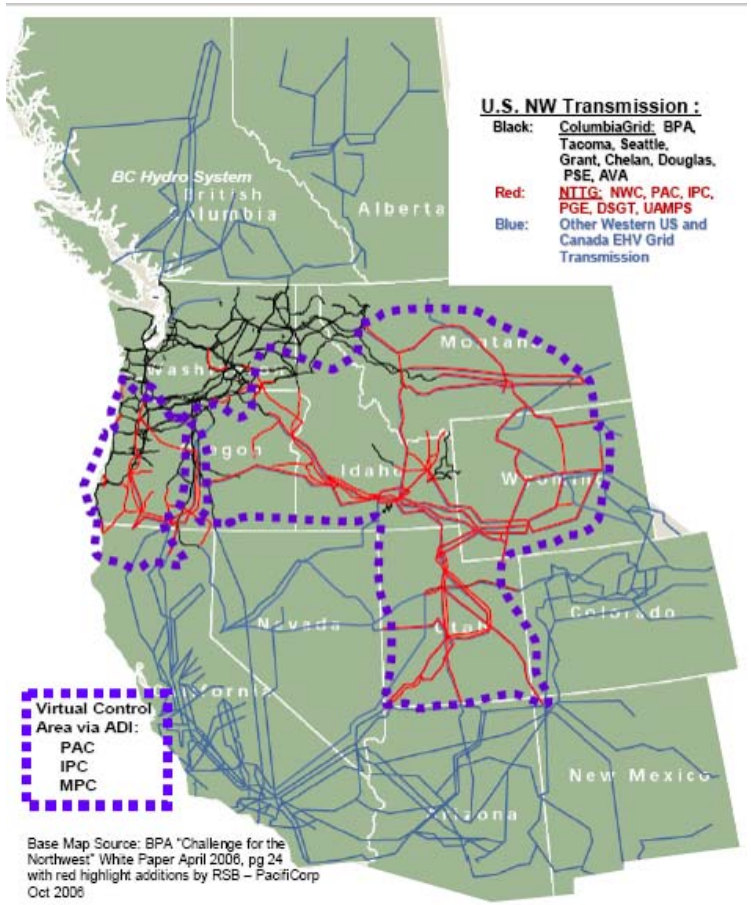
- Fast markets
  - Will improve overall system performance and economics
  - Will correctly separate load following from regulation, increasing flexibility and reducing costs



Milligan & Kirby 2007, Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration . http://www.nrel.gov/docs/fy07osti/41809.pdf found that fast energy markets can often supply the required load following capacity as a by-product of the energy market.

Balancing Area Consolidation: What Other Analyses/Experiments are Underway?

- Virtual consolidation
  - NTTG's ADI
  - Possible expansion to load-following time scale
  - Joint Initiative DSS, ITAP
- NREL's Large-scale studies
  - Western Wind and Solar Integration Study (WWSIS)
  - Eastern Wind and Transmission Study (EWITS) with JCSP
  - Nebraska Power Association



Balancing Area Consolidation: What Other Analyses/Experiments are Underway?

- Activity in the NW includes BPA's 'feed-forward' AGC concept
- Joint NREL-PNNL work
  - Interest in WECC-wide analysis collaboratively with WECC and Variable Generation Subcommittee
  - Northwest analysis

Other Flexibility Options

- Fast-ramping generation with good heat rates, low turn-down, low start-up cost
- Bi-lateral pooling agreements (similar to ADI but longer time frames)
- Innovation in hydro scheduling
- Economic VG curtailment, ramp limitations during critical periods
  - Morning load pickup or evening load drop off
  - Other
- Storage has value, but may not be currently cost-effective

Summary

- Aggregation damps variability (solar, wind, load, and solar+wind+load together)
- Variability can be measured statistically and mapped to current operational practice
  - Load following
  - Regulation
- We care about tail events, and these often have important VG and load influences →time-synchronized data
  - Potential to reduce tail events thru aggregation
- Forecasts help, but must be brought into standard operating practice/tools