
System Flexibility and Clean Energy Integration

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Topics

❖ **Context**

- Increasing Variable Energy Resources, Flexibility Issues

❖ **Power Systems**

- Time Scales for Operations and Planning, Reserves

❖ **Integration of Variable Energy Resources**

- Study Results & Operational Experience

❖ **Key Issues**

- Stability/Balancing/Adequacy, Variability/Uncertainty, Net Load

❖ **Flexibility**

- Overview, Assessment, Sources

❖ **FERC Dockets**

❖ **Wind Integration in MISO**

- Dispatchable Intermittent Resources
- Development of Ramp Capability for Load Following

❖ **Summary**

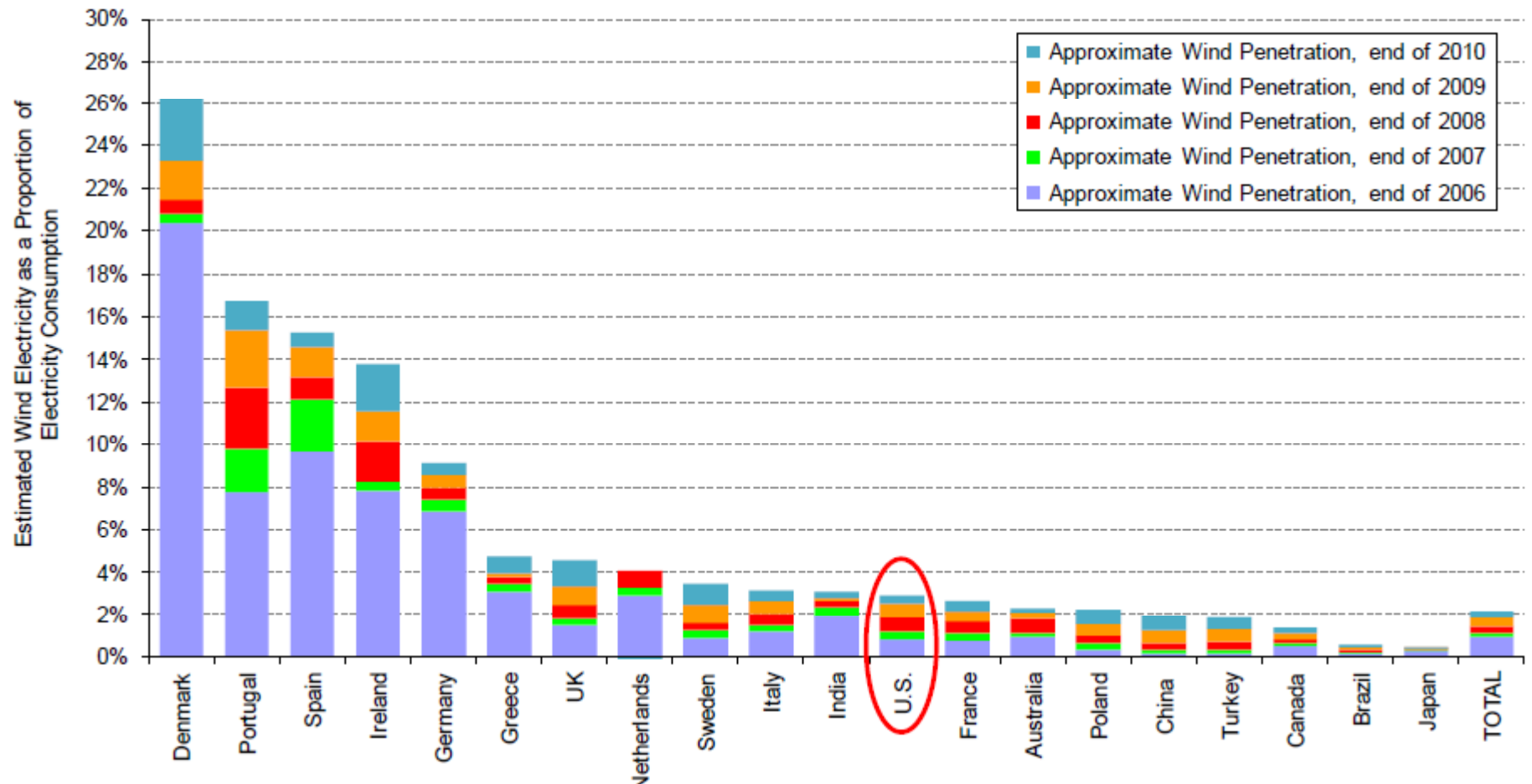
Overview

- ❖ Physical power systems and competitive wholesale markets were designed around the operation of traditional forms of generation (fossil, nuclear, hydro)
- ❖ Variability and uncertainty have always been common characteristics of all power systems and are managed by grid operators with reserves
- ❖ Use of Variable Energy Resources is rapidly increasing; resulting in additional variability and uncertainty for the power system over seconds, minutes, and hours
- ❖ VER integration impacts are substantially reduced with large, liquid, fast markets, large balancing areas with a strong grid that capture diversity and enable access to the physical flexibility that exists in the regional power system
- ❖ Forecasting VERs significantly reduces uncertainty and costs
- ❖ Numerous peer reviewed studies have shown that integrating large amounts of VER is effectively a balancing challenge (tens of minutes to hours)

Overview

- ❖ Power systems have much greater ability to handle variable renewable energy than commonly understood
- ❖ Sources of flexibility include dispatchable plants, demand side resources, grid / interconnections, and storage
- ❖ The extent to which existing flexible resources are actually available and used varies widely
- ❖ Key power system characteristics which affect whether technical flexibility is available include: grid strength, market size, scheduling / dispatch speed, use of forecasting, and value of flexibility in the market
- ❖ Market rules are evolving to improve system flexibility including improved system scheduling / dispatch, improved procurement / payment of ancillary services, incentives for load following / ramp management; Additionally, markets will increasingly incorporate dispatch of VERs

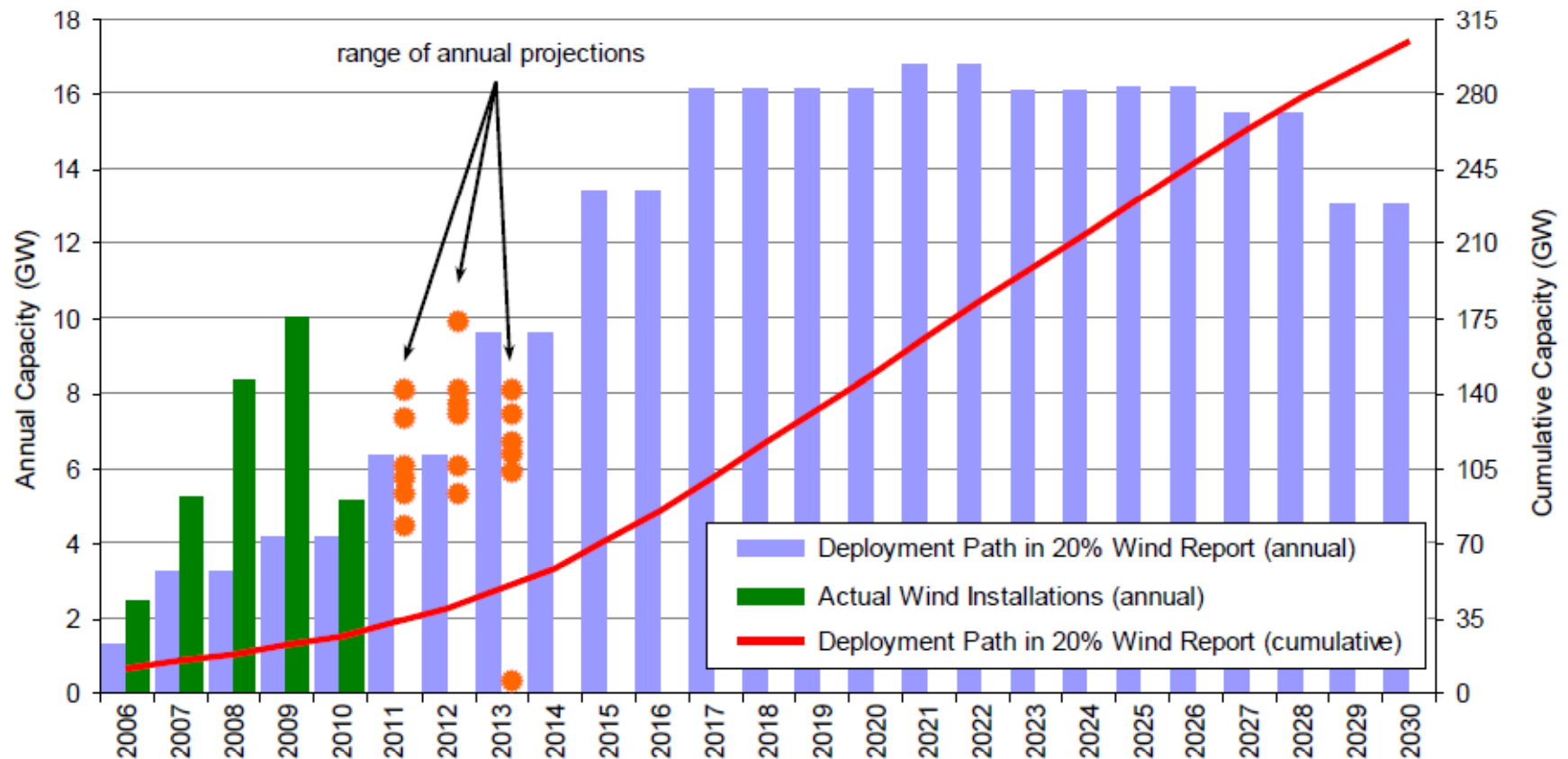
Variable Energy Resources are a Growing Percentage of Electricity Consumption



Source: 2010 Wind Technologies Market Report, Ryan Wiser & Mark Bolinger, LBNL, June 2011

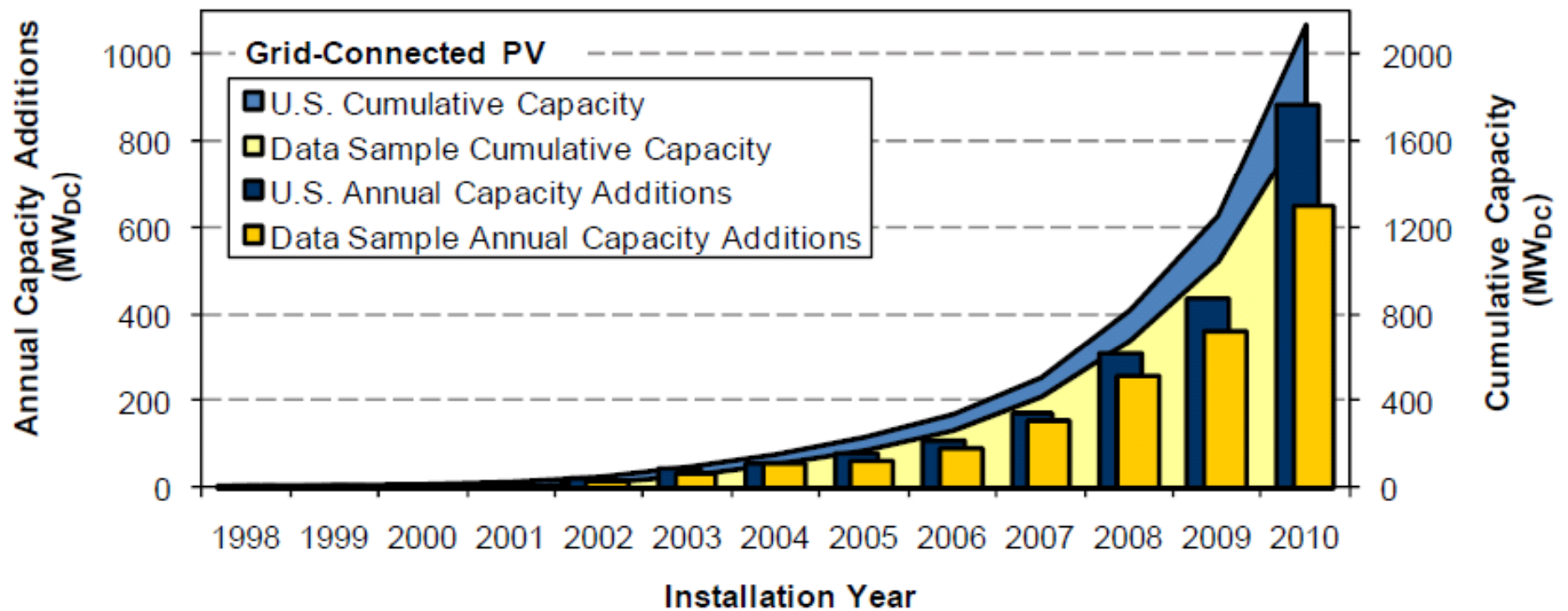
U.S. Is on a Trajectory that May Lead to 20% of Electricity Coming from Wind

But ramping up further to ~16 GW/year and maintaining that pace for a decade is an enormous challenge, and is far from pre-determined



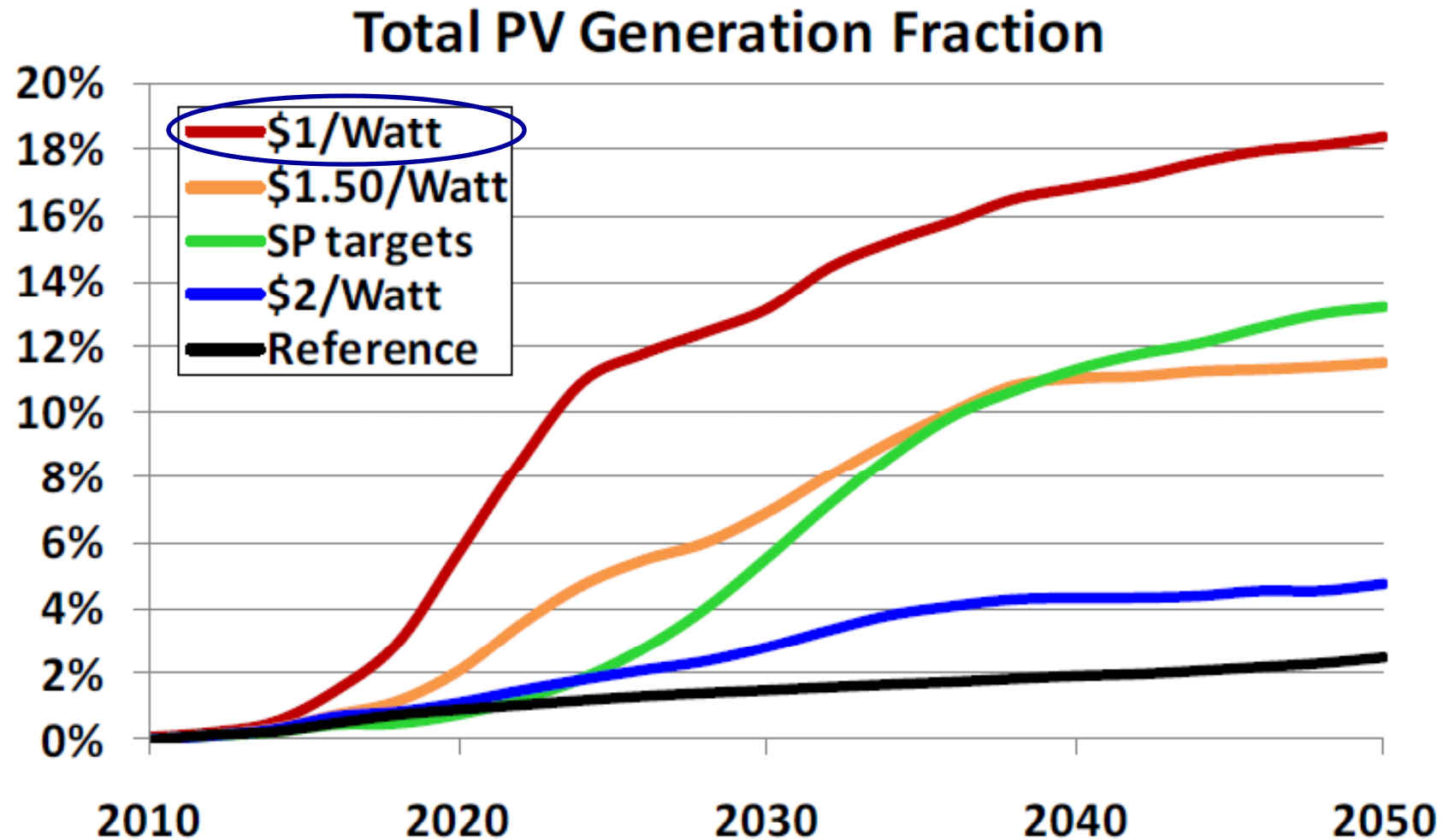
Source: 2010 Wind Technologies Market Report, Ryan Wiser & Mark Bolinger, LBNL, June 2011

U.S. Grid-Connected PV



Source: *Tracking the Sun IV*. LBNL, Sept 2011

U.S. DOE SunShot Goals for PV



Source: U.S. DOE SunShot, October 2011; Goodrich, Margolis, et al, NREL.

Variable Energy Resource Integration Challenge

- ❖ Reliable power system operation requires balance between load and generation *within acceptable statistical limits*
- ❖ Output of Variable Energy Resources resources cannot be controlled and scheduled with high degree of accuracy
- ❖ VER levels are becoming large enough to have measurable impact on system operating characteristics and cost
- ❖ Capacity value of power plants depends on their contribution to system reliability

Variability and Uncertainty

❖ Variability

- Load varies by seconds, minutes, hours, by day type, and with weather
- Regional imports / exports vary with system needs & power prices
- VERs vary with fuel availability (wind, solar)
- Supply resources may not be available (or limited in capacity) due to partial outages

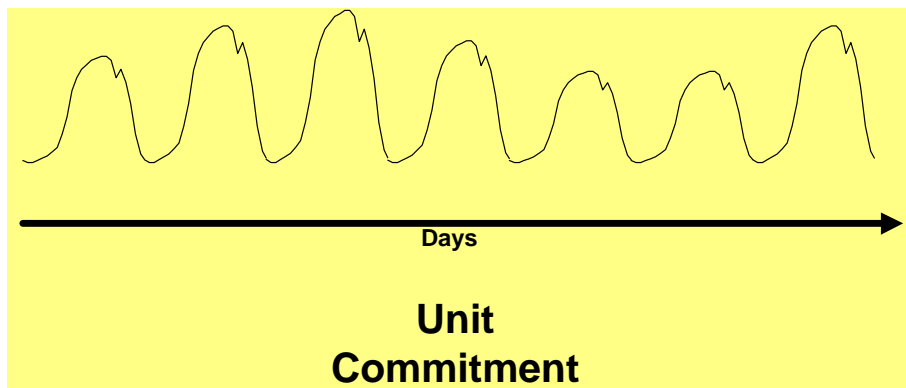
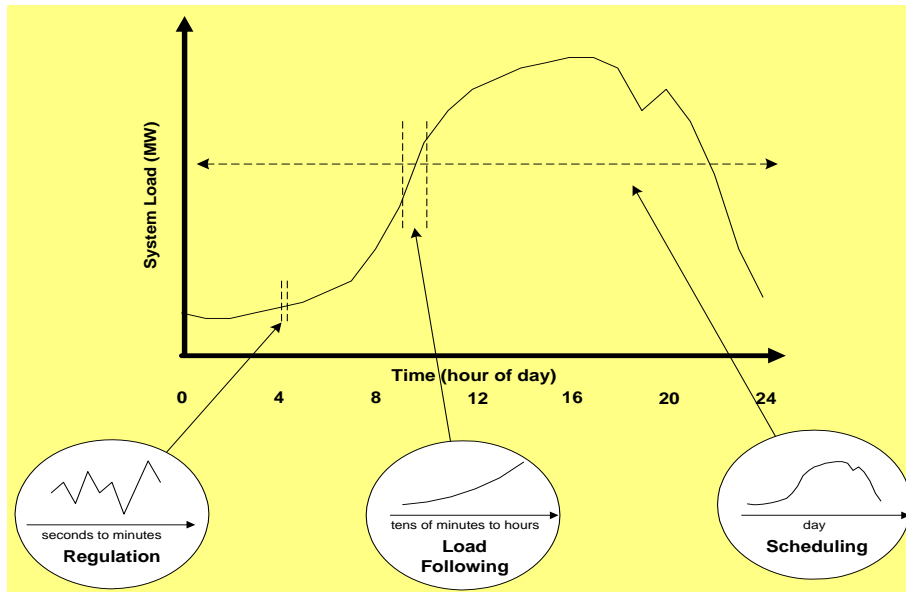
❖ Uncertainty

- Operational plans are made on basis of best available forecasts (load, VERs, imports/exports); some error is inherent
- Supply side resources may deviate from dispatch instructions
- Regional imports / exports

❖ Key questions

- How do VERs affect existing variability & uncertainty
- What are the impacts on reliability?
- What are the costs?

Power System Time Frames



- ❖ Regulation – seconds to a few minutes – similar to variations in customer demand
- ❖ Load-following – tens of minutes to a few hours – demand follows predictable patterns, wind & solar less so
- ❖ Scheduling and commitment of generating units – hours to several days – wind & load forecasting capability
- ❖ Planning – months to years – capacity value based on reliability metric (Loss of Load Expectation / Effective Load Carrying Capability)

Time Scales for System Planning and Operation Processes

Slower (Years)
Time Frame
Faster (seconds)

Planning and Operation Process

Resource and Capacity Planning
(Reliability)

Unit Commitment and Day-Ahead Scheduling

Load Following
(5 Minute Dispatch)

Frequency and Tie-Line Regulation
(AGC)

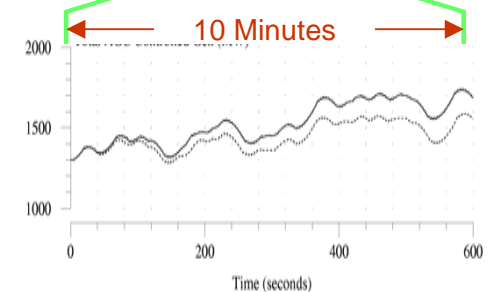
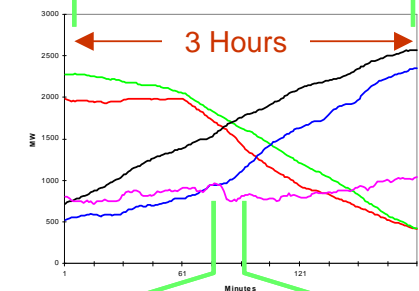
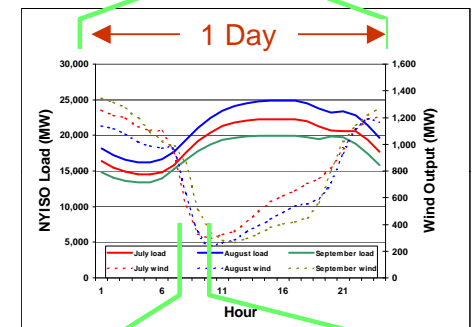
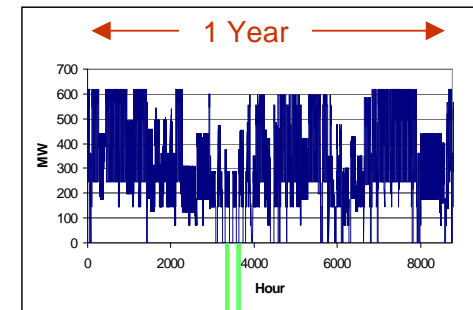
Technology Issues

Capacity Valuation
(UCAP, ICAP) and Long-Term Load Growth Forecasting

Day-ahead and Multi-Day Forecasting

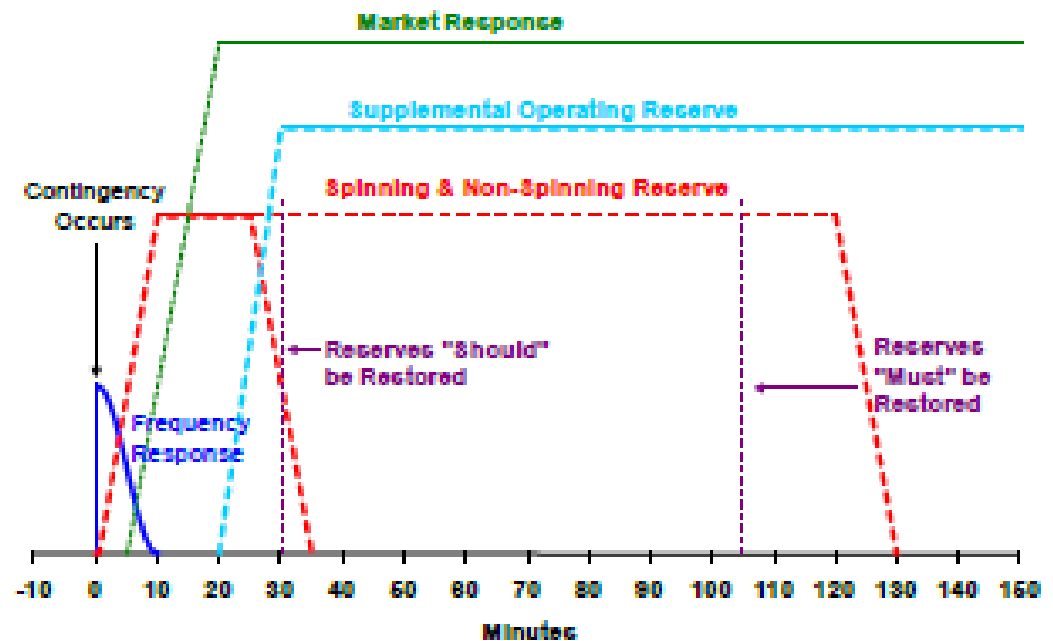
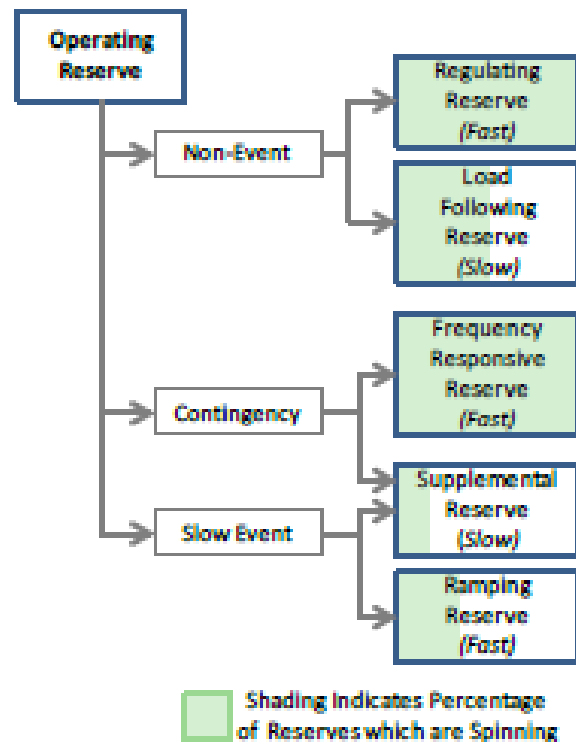
Hour-Ahead Forecasting and Plant Active Power Maneuvering and Management

Real-Time and Autonomous Protection and Control Functions
(AGC, LVRT, PSS, Governor, V-Reg, etc.)



Operating Reserves

That capability above firm system demand required to provide for regulation, load forecast error, equipment forced and scheduled outages, and local protection. It consists of spinning and non-spinning reserves [NERC]



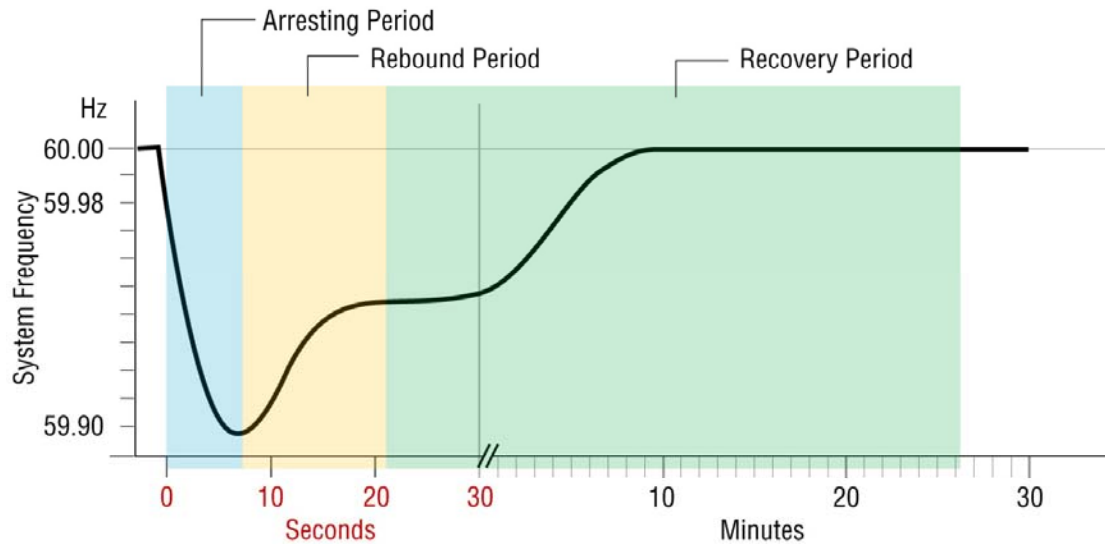
Source: *Operating Reserves and Wind Power Integration: An International Comparison*. IEA/NREL. 2010.

Reserve Functions

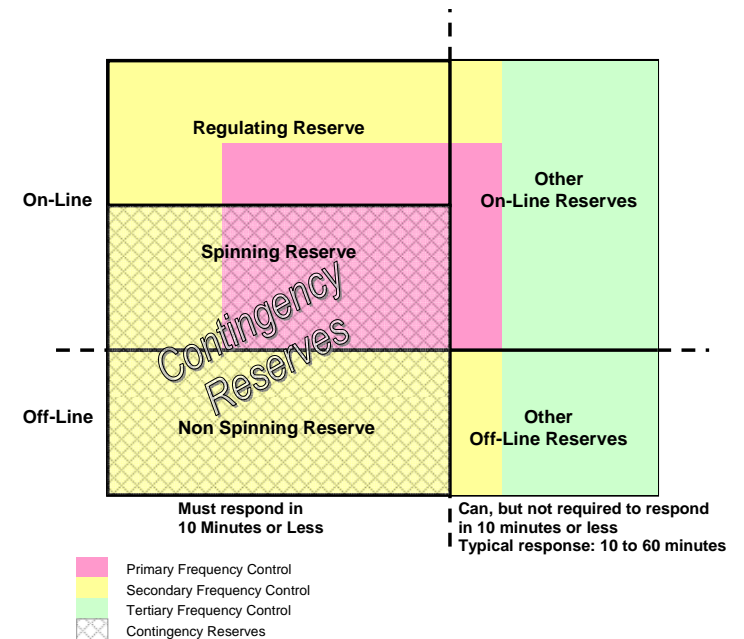
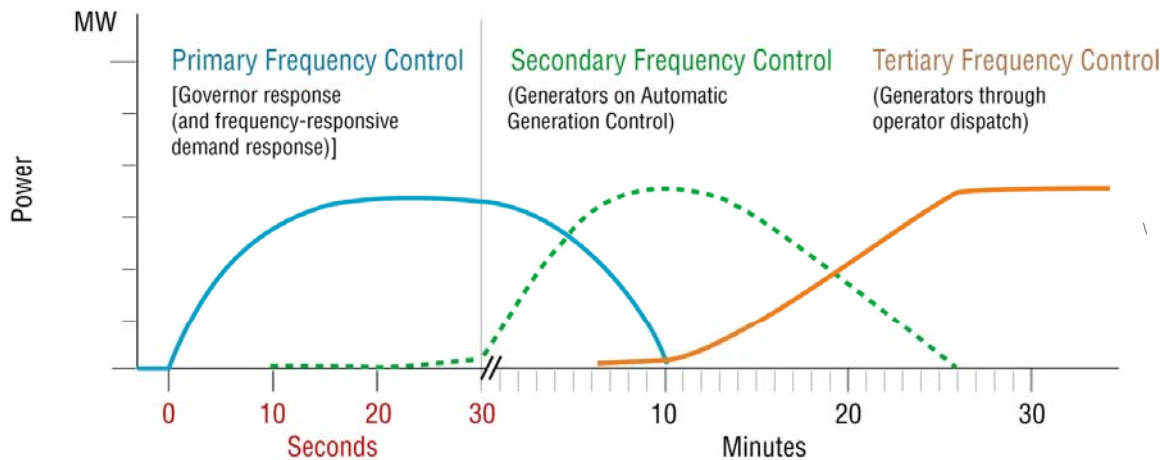
Differentiated by the type of event they are used for (non-event, contingency event, etc), the timescale of the response (seconds, minutes, hours) and the response direction (up/down)

- Frequency Response Reserves
 - Provide initial frequency response to major disturbance
- Regulating Reserve
 - Maintain area control error due to random movements in a time frame faster than energy markets clear (seconds)
 - Responsive to Automatic Generation Control (AGC)
- Ramping Reserve
 - Respond to failures and events that occur over long time frames (minutes-hours)
- Load Following Reserve
 - Maintain area control error and frequency (minutes)
- Supplemental Reserve
 - Replace faster reserve to restore pre-event level (minutes-hours)

Frequency Response



- ❖ The sequential actions of primary, secondary, and tertiary frequency control restore system frequency following the sudden loss of generation

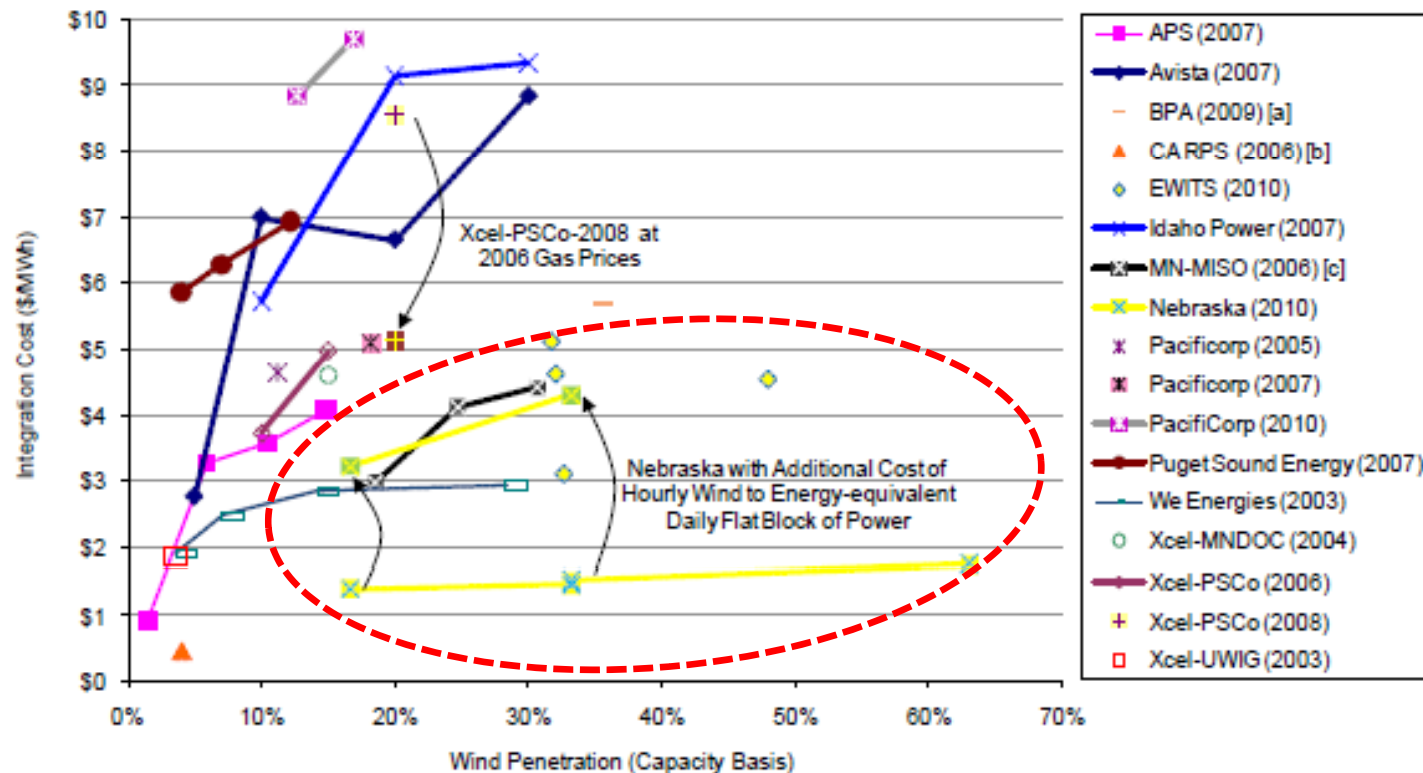


Frequency Response

- ❖ Frequency Response in the Eastern Interconnection is declining and has been for many years
 - Drivers have included markets, disaggregation of vertically integrated utilities, increase in independently produced power
- ❖ *Use of Frequency Response Metrics* Report (LBNL) recommendations include:
 - **Accelerate efforts to better understand interconnection and balancing authority specific requirements for frequency control** (especially in the Eastern Interconnection)
 - **Interconnections must schedule adequate primary and secondary frequency control reserves** to both manage variations in net system load and withstand the sudden loss of generation
 - **The frequency control capabilities of the interconnections should be expanded** including expanded use of the existing generation fleet, expanded use of demand response, expanded use of variable renewable generation frequency control capabilities, and expanded use of advanced technologies (e.g. energy storage and electric vehicles)
 - Develop comprehensive planning and enhanced operating procedures

Wind Integration Costs

Cost of Reserves to Balance Variability and Uncertainty



- [a] Costs in \$/MWh assume 31% capacity factor.
 [b] Costs represent 3-year average.
 [c] Highest over 3-year evaluation period.

Fast Markets (scheduling < 15 minutes)

VER Integration Summary

- ❖ Variable Energy Resources add variability & uncertainty to the power system over seconds, minutes, and hours
 - There are significant benefits from diversity (geographic, resource, load)
 - Regulation impacts are small
 - **Load following / ramp management can be an issue at higher levels of VERs**
 - Unit commitment and scheduling impacts can dominate without forecasting
 - No credible single contingency leading to simultaneous loss of regional wind generation
- ❖ Forecasting wind & solar significantly reduces uncertainty and costs
- ❖ Key mitigation measures included:
 - Larger balancing areas and stronger interconnections
 - Large, liquid, fast markets (energy, ancillary services, demand response)
- ❖ **Requires a robust and flexible power system**
 - Improved flexibility in generation and load
 - Transmission expansion is needed to capture diversity (geographic, load, generation)
- ❖ Market rules for wind generation are evolving
 - Dispatch / Economic Curtailment
 - Load following / Ramp management
- ❖ **Large interconnected power systems can reliably and economically accommodate 20+% wind & solar generation if we get the infrastructure and the market rules right!**

NERC Integration of Variable Generation Task Force

- ❖ Formed by NERC's Planning & Operating Committee in December 2007
- ❖ 29 official “members”, 67 participants
 - Utilities, ISO / RTOs, wind and solar industry, government , international representation
- ❖ Focus on reliability

NERC Summary Report: Accommodating High-Levels of Variable Generation

Three key requirements:

Forecasting

- Forecasts of variable generation output inform the operators and reduce the *uncertainty*

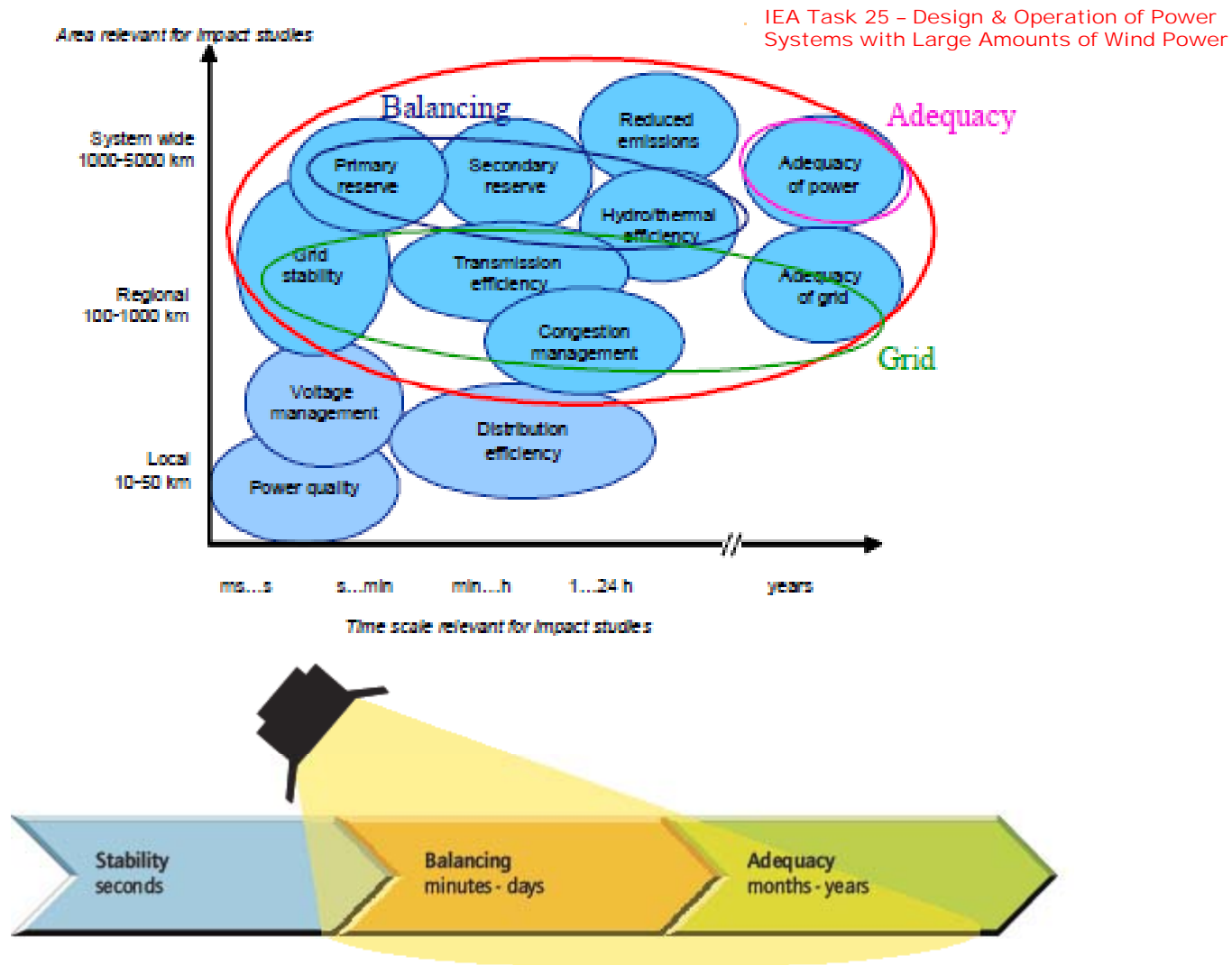
Transmission

- Interconnect remote variable resources
- Smooth variable generation across a broad geographical region and resource portfolio
- Deliver ramping capability and ancillary services from inside and outside a Balancing Area to equalize supply and demand

Flexibility

- Greater access to larger pools of generation and demand can facilitate the large-scale integration of variable resources
- Additional flexible resources such as demand response, plug-in hybrid electric vehicles, and energy storage can help balance steep “ramps”

Stability, Balancing, Adequacy

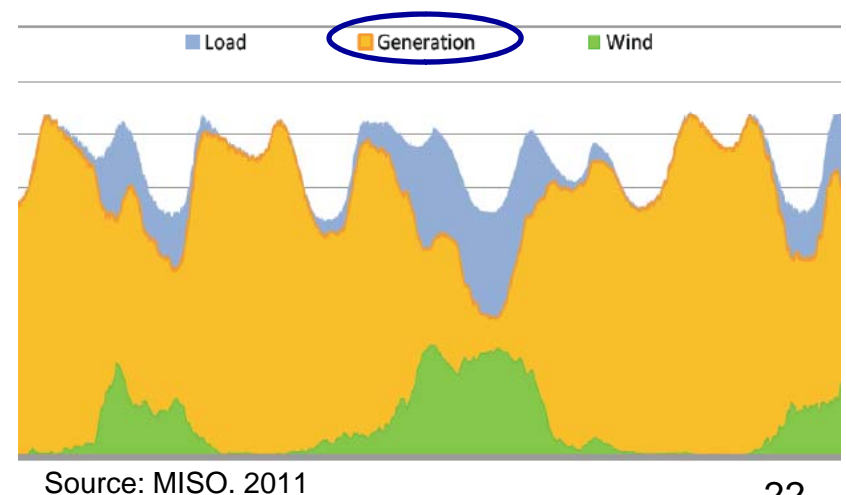
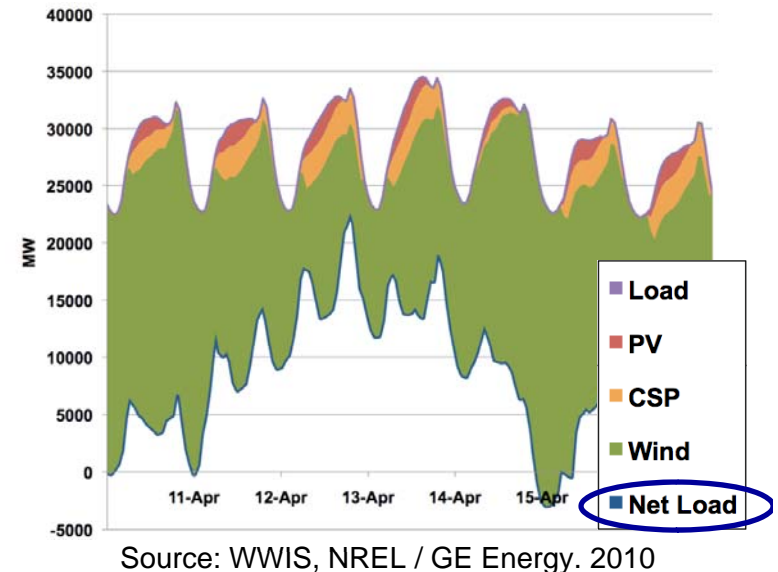


Sources: IEA Wind R&D Task 25. 2008
 Harnessing Variable Renewables. IEA. 2011.

The Load Following Challenge

Net Load Variability and Uncertainty

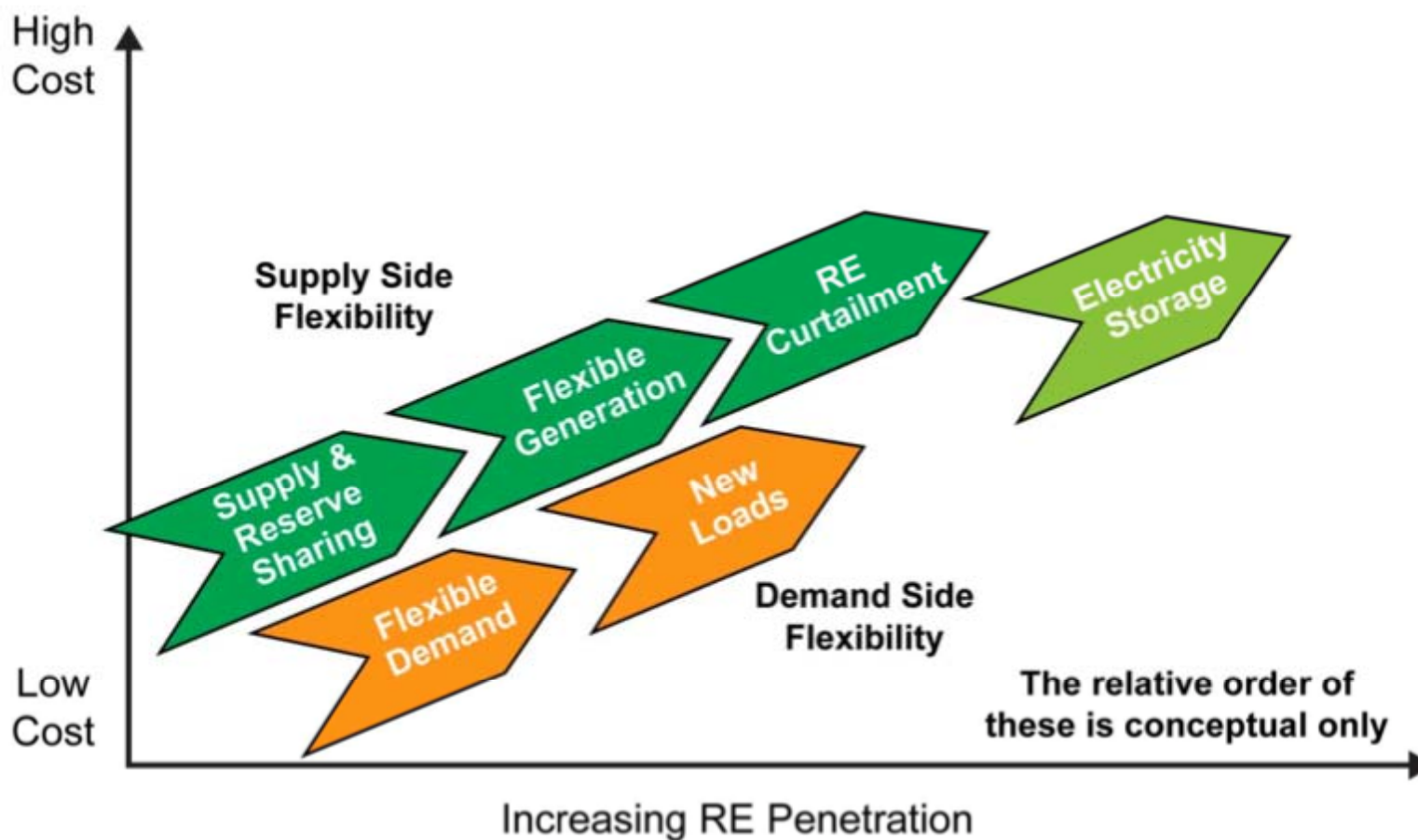
- ❖ Power system operators are constantly faced with variability and uncertainty
 - Load and regional imports/exports vary by seconds, minutes, hours, by day and with weather; may not be what it was forecast to be
 - In real time operations, the system must respond to the net load including both expected and unexpected variations
 - VERs add to the net load variability and uncertainty
- ❖ Increasing net load variability & uncertainty is driving the rising need for more flexible resources



Power System Flexibility

- ❖ The ability to increase / decrease supply or demand
 - In response to fluctuations in either supply or demand (expected or otherwise)
 - By a large amount, rapidly, and frequently
 - Measured in MW available to ramp up or down over time
 - Capability of the power system to maintain reliable supply through rapid and large imbalances
- ❖ Institutional flexibility
 - Fast energy markets
 - Sub-hourly scheduling protocols with neighboring balancing areas
- ❖ Additional sources of flexibility may be needed at higher penetration rates of renewables

Flexibility Supply Curve



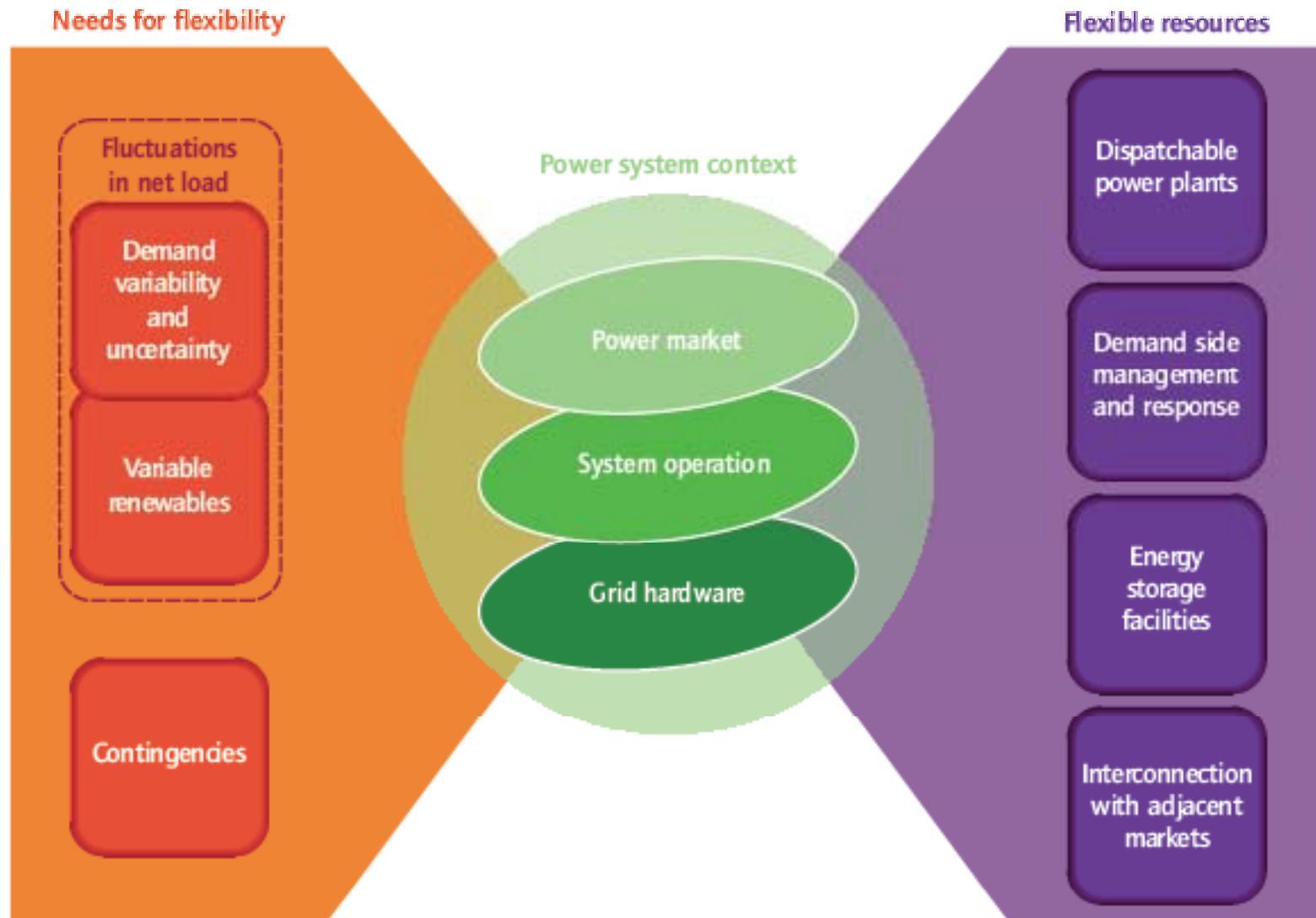
Demand Response & Smart Grids

- ❖ Demand Response has significant potential to help mitigate VER integration impacts; Will require changes to market rules and regulatory policies
- ❖ Smart grids support greater deployment of variable energy resources by providing operators with real-time system information and mechanisms to actively control distributed resources
 - Demand Response
 - Electric Vehicle (charging and discharging)
 - Distributed Generation
 - Storage

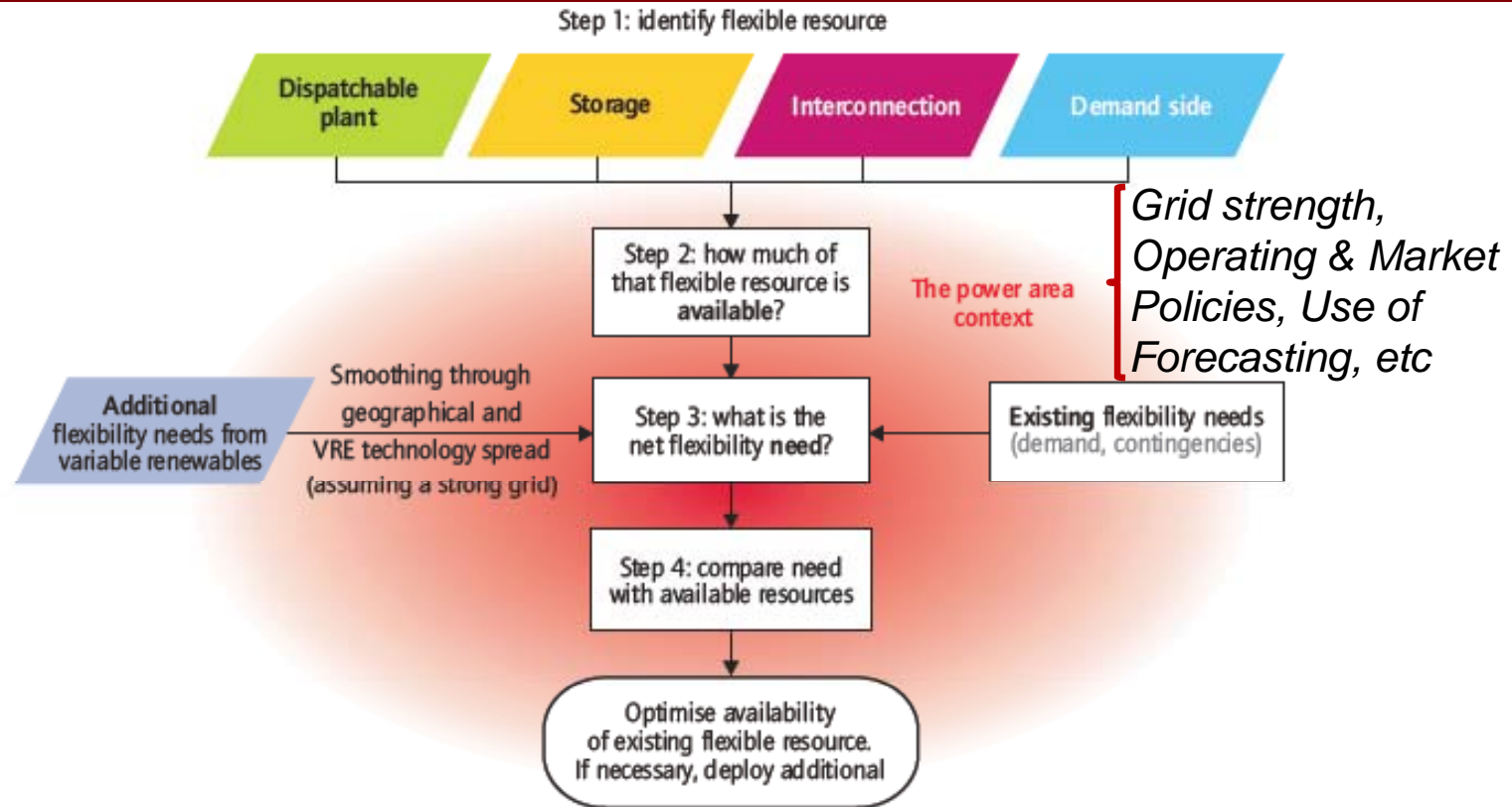
Storage

- ❖ Detailed simulations of power system operation have found no *requirement* for storage up to 30% wind energy penetration
- ❖ *Cost-effective* storage can be a valuable *system* resource
- ❖ Assessment of the value of storage needs to include the revenue streams from multiple, co-optimized services. Services can include:
 - Energy arbitrage
 - Ancillary Services
 - Capacity Value
 - Transmission & distribution support

The Balancing Challenge - IEA








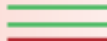







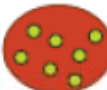









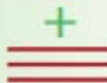






























Flexibility Assessment Tool - IEA



- ❖ Designed to capture key aspects of power systems for a quantitative / qualitative analysis of power system flexibility
- ❖ Generic tool, designed to be applicable to any type / size of power system

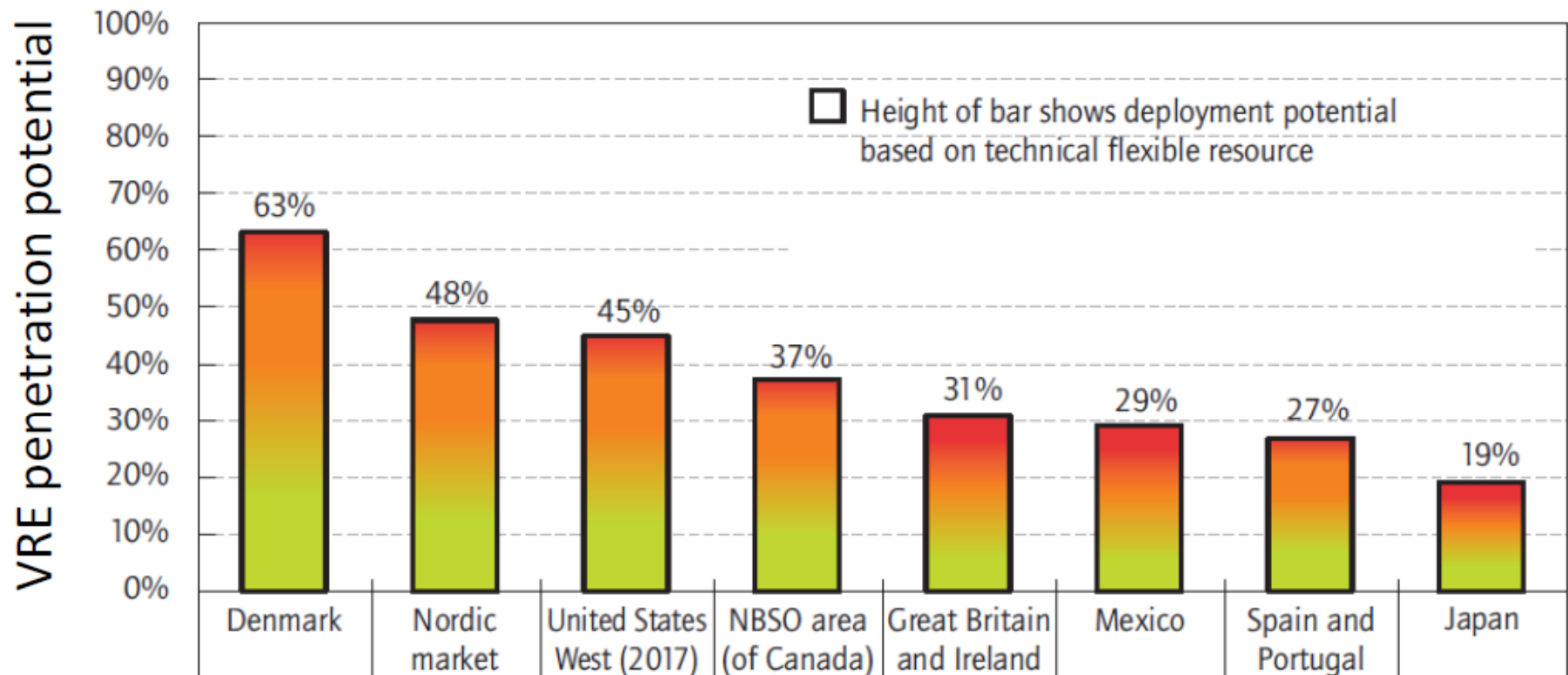
Attributes of Power Systems - IEA

	Area size (peak demand)	Interconnection (actual and potential)	N°. of power markets	Geographical spread of VRE resources	Flexibility of dispatchable generation	Grid strength
British Isles (GB and IR)						
Mexico						
Iberian Peninsula (ES and PT)						
Nordic Power Market						
Denmark						
NBSO area (of Canada Maritimes)						
Japan						
US West (2017)						
Island (generic)						

Sources: Aidan Touhy, EPRI; *Harnessing Variable Renewables*. IEA. 2011. 29

Flexibility Assessment Tool - IEA

Snapshot of present penetration potentials



Integration of Variable Energy Resources

FERC Docket RM10-11 (November 2010)

❖ Notice of Proposed Rule Making to remove barriers to the integration of variable energy resources

❖ Key proposals:

- Transmission providers would need to provide intra-hourly transmission scheduling
- Variable generators would need to provide meteorological and operational data to transmission operators for improving forecasts
- Transmission providers would establish a rate to recover capacity costs incurred by the transmission operator to provide balancing between scheduling periods to a generator in a transmission providers balancing area (i.e. generator regulation service)

Frequency Regulation Compensation NOPR

FERC Dockets RM11-7 / AD10-11 (February 2011)

- ❖ Notice of Proposed Rulemaking to remedy undue discrimination in the procurement of regulation service in RTO/ISO markets
- ❖ Key proposals:
 - Require that each regulating resource is paid a uniform capacity payment
 - Require that all resources be paid for performance (price per MW, up or down; reflect accurate response to the system operator's dispatch signal)
 - Commission seeks comment on appropriateness current net energy payment given the proposed two part payment

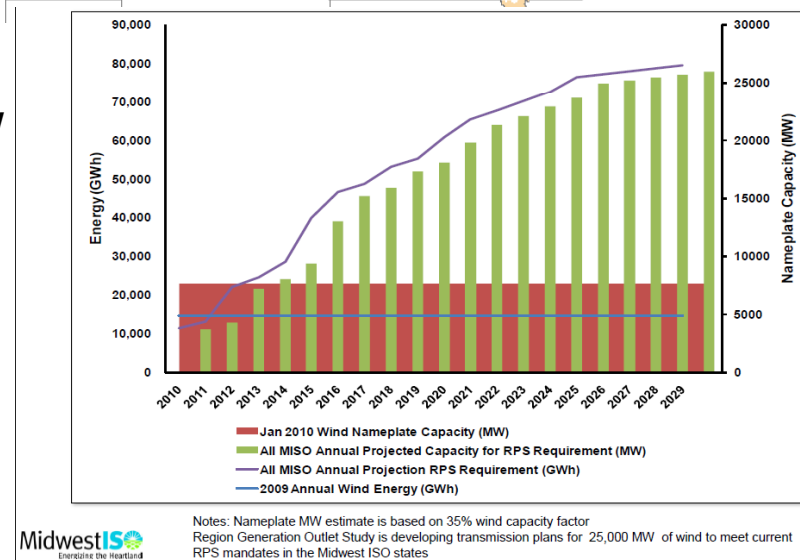
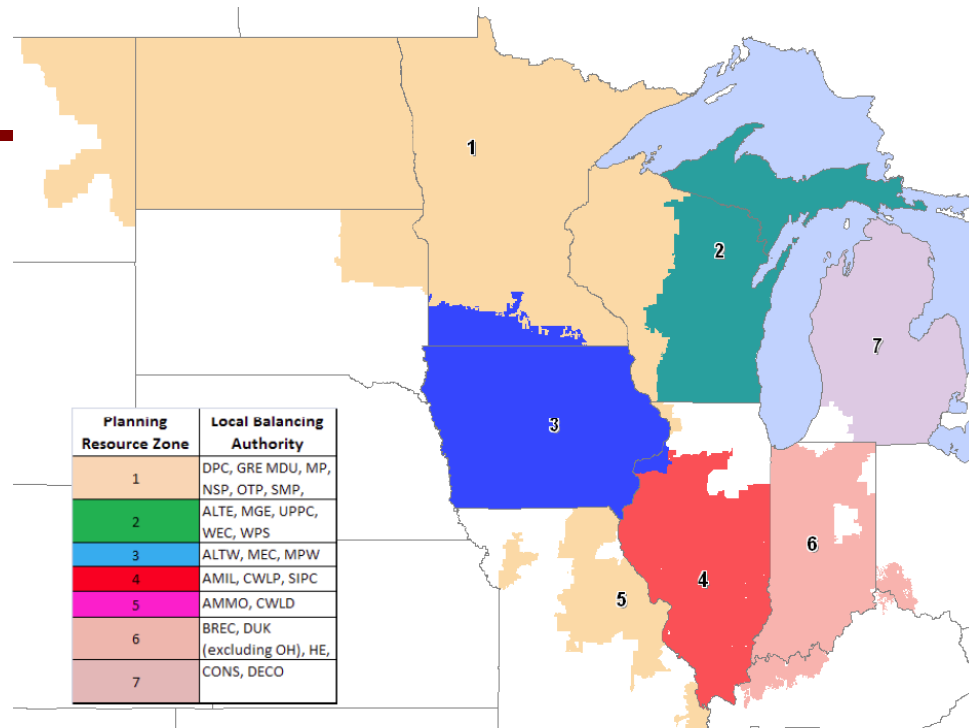
Third Party Provision of Ancillary Services NOI

FERC Dockets RM11-24 / AD10-13 (June 2011)

- ❖ Notice of Inquiry seeking comments on:
 - Ways to facilitate development of robust competitive markets for provision of ancillary services from all resource types (market power, threshold, alternative rates, advancing regulation service NOPR)
 - Issues unique to electric storage and the role they can play in providing multiple services including ancillary services (accounting, reporting)

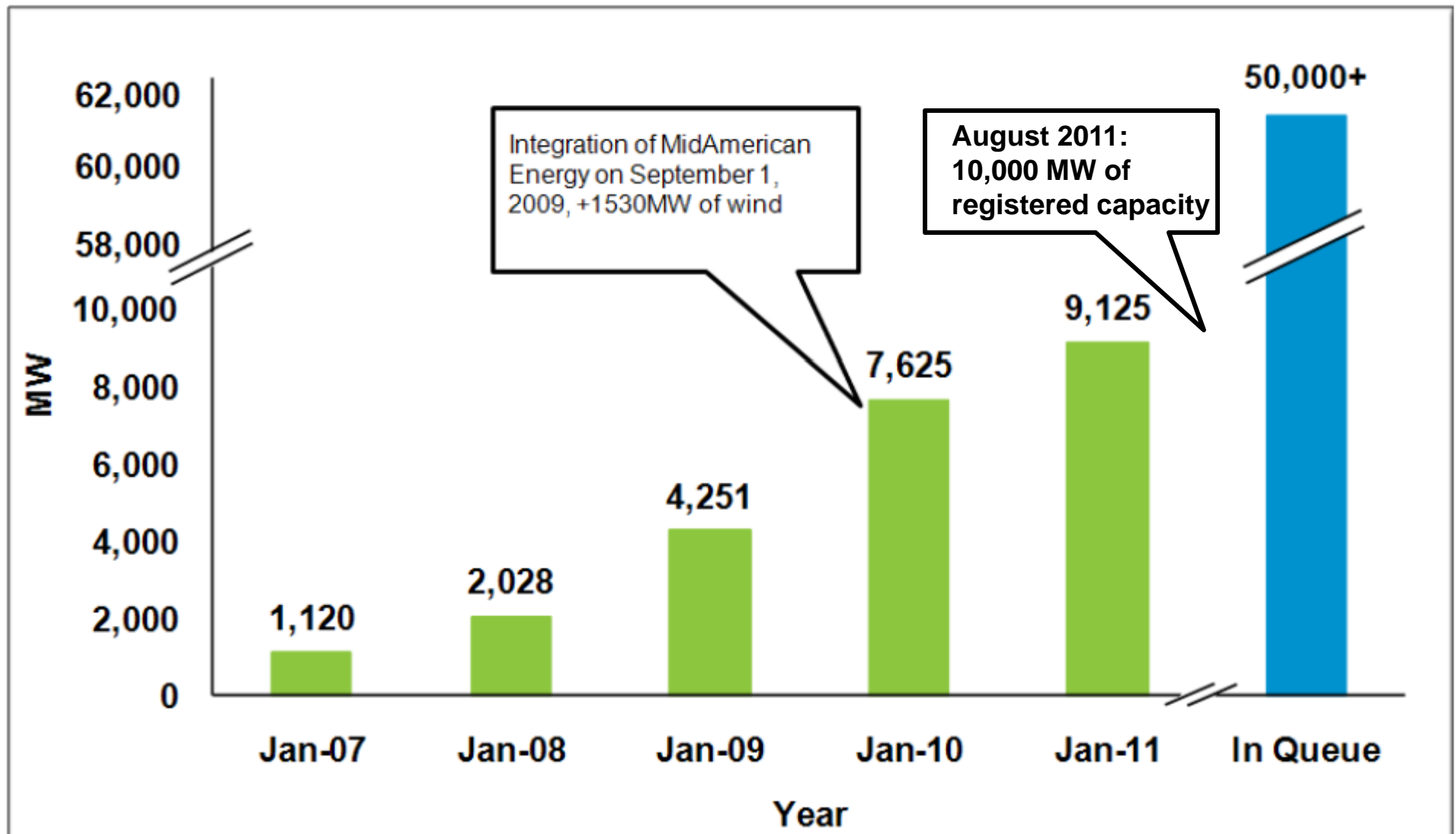
Midwest ISO

- ❖ **Peak load: 109,000 MW** (2010)
- ❖ **Resources: 144,000 MW** (2010)
 - *By capacity:* 53% coal, 28% gas, 7% nuclear, 3% hydro, 6% wind
 - *By energy:* 75% coal, 14% nuclear, 6% natural gas, 4% wind, 1% hydro
 - Time on the margin: coal ~80%, natural gas ~20% (2010)
- ❖ **Wind generation**
 - **Installed: 10,000 MW** (August 2011)
 - **Active Queue: ~50,000 MW** (~75% of queue)
 - Projected (RPS Reqrmts in 2030): ~25,000 MW
- ❖ **Markets:**
 - Day-ahead and real-time energy markets
 - Ancillary services markets (regulation & contingency reserves)
 - Co-optimized between energy & ASM
 - Financial Transmission Rights market
 - Voluntary Capacity Auction



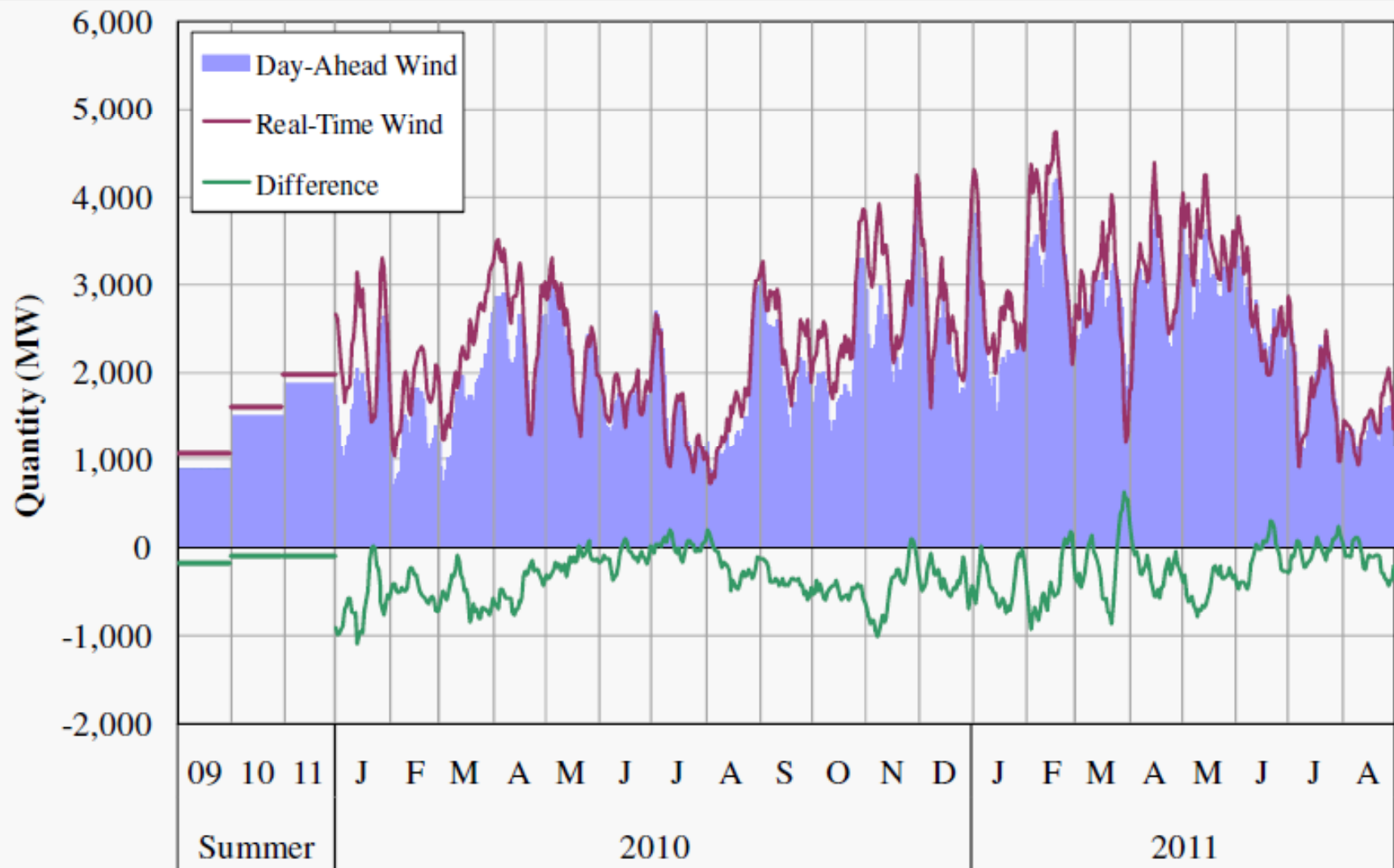
Sources: 2010 State of the Market Report for the Midwest ISO, IMM, June 2011
 2010 Summer Assessment Report, Midwest ISO October 2010
 Wind Integration Work Plan, Midwest SO, Dec 2010

Wind Generating Capacity in MISO



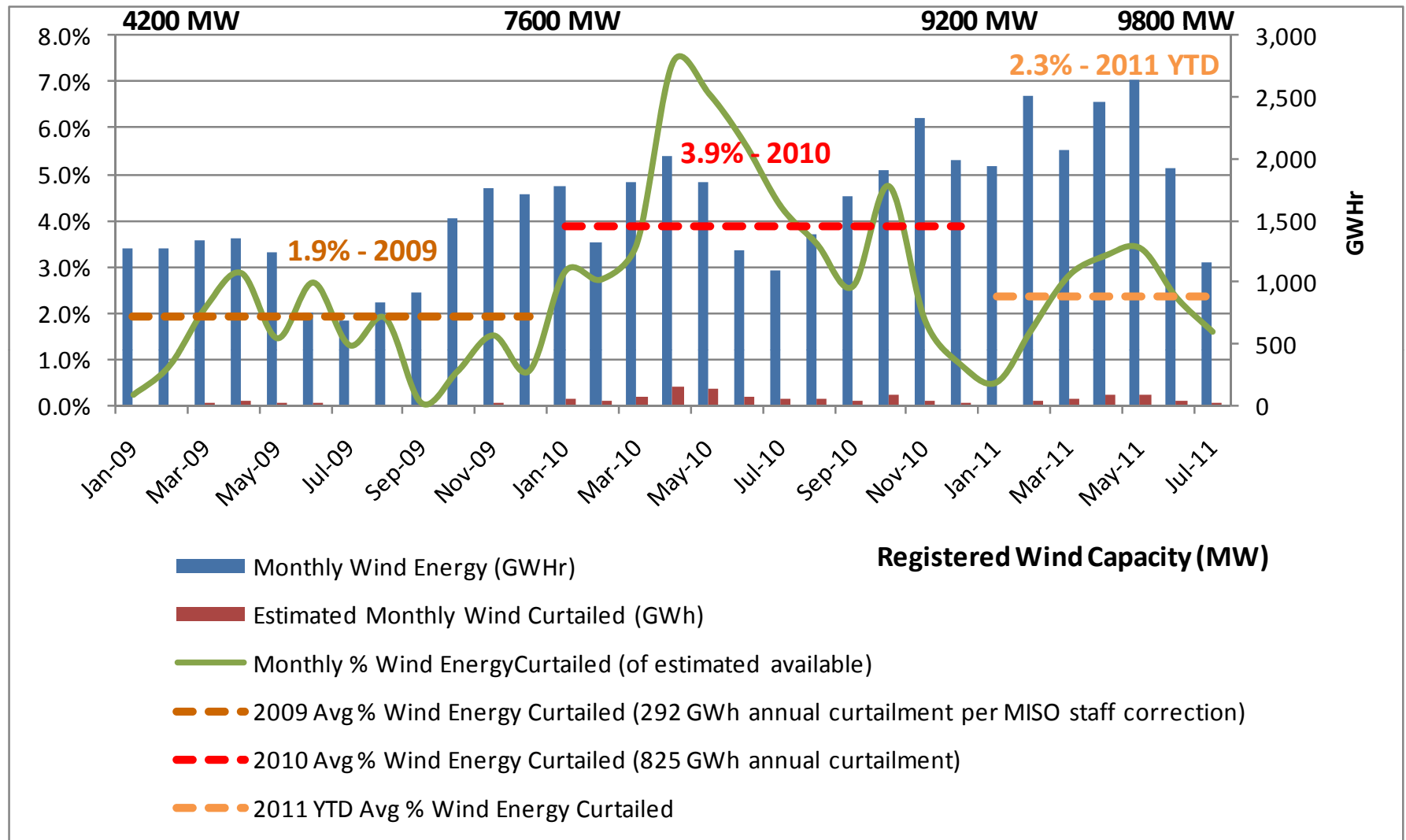
Source: MISO, Wind Operations Planning, Markets Committee of the BOD, 2/23/11; MISO Info Forum

Wind Output in Real-Time and Day-Ahead Markets 7-Day Moving Average, 2009–2011



Source: IMM Quarterly Report Summer 2011, BOD System Planning Committee

Wind Curtailments - MISO



Sources: Midwest ISO, Aug 2011 RSC & monthly Informational Forum presentations

Dispatchable Intermittent Resources - MISO

Key points of the MISO DIR designation include:

- Allow real-time optimization to determine an economic dispatch of wind generation, with consideration for congestion (along with other resources)
- Wind can be included in the day-ahead and real-time co-optimization, is able to set price, is eligible for make whole payments
- Decrease manual curtailments, increase market efficiency & transparency
- Day-ahead and real-time wind generation offer structures are like those for Generation Resources except:
 - In real-time, no economic maximum offer; wind generators provide a CP-node level forecast (5 minute) that is used for the Max Limit
 - In day-ahead, no operating reserve offers; MSC & RSC motions support allowing DIR to supply spinning and regulating reserves
- Intermittent Resources will be required to register as DIRs or purchase 100% long term firm transmission service after a two year transition; waiver for projects >5 yrs old
- All IRs and DIRs will be subject to Revenue Sufficiency Guarantee charges; For DIRs, this will be for positive deviations only (over scheduling Day Ahead) because the Economic Minimum will be zero. Resources with IRs market registration will be subject to RSG for both positive and negative deviations.

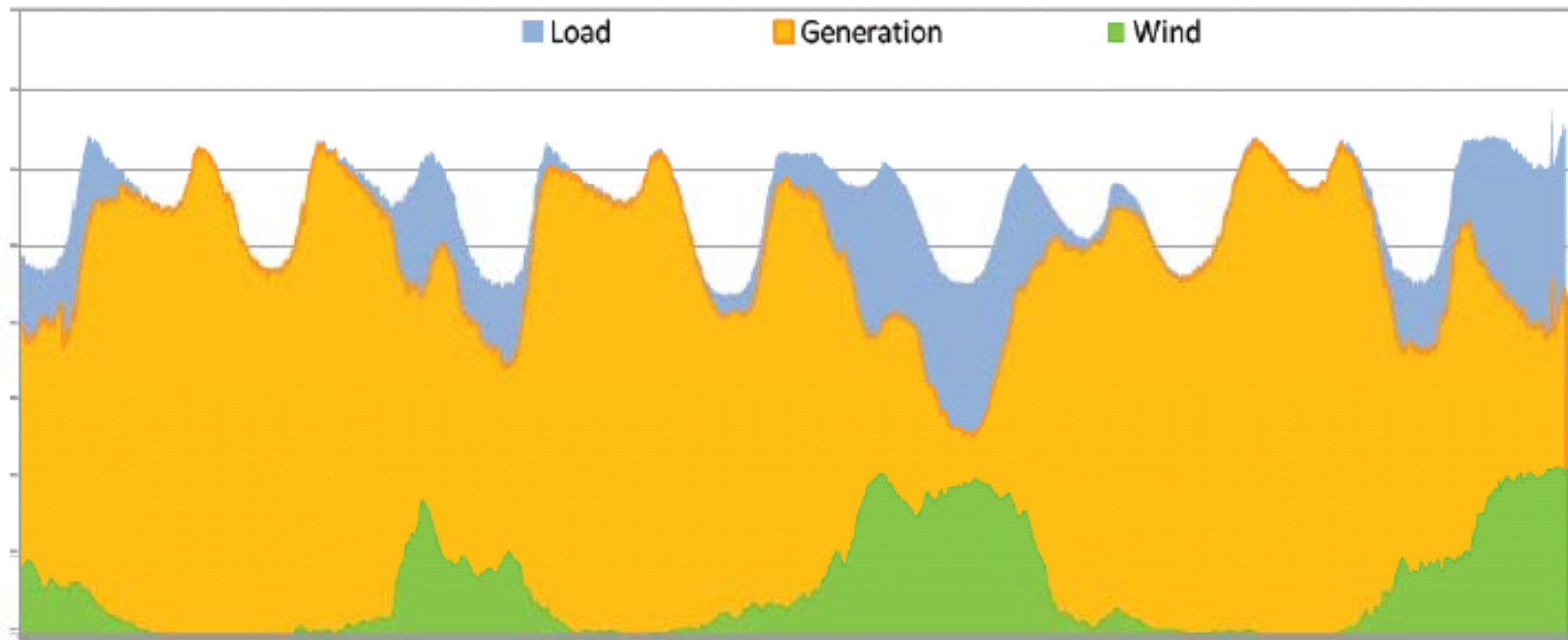
Dispatchable Intermittent Resources - MISO

- ❖ FERC Order issued 3/2/11 Conditionally Approved DIR Proposal
 - Approved DIR for wind generators
 - Resources that register as DIR may not switch back to IR
 - Directed MISO to review applicable generation resources tariff, to analyze (over the coming year) whether the existing 8% tolerance band continues to be appropriate for Excessive/Deficient Energy Deployment charges for DIRs, to address whether DIRs should be eligible to be able provide operating reserves
- ❖ MISO expectation of benefits of DIRs in Real-Time operations
 - Improve market efficiency through economic dispatch and better price signals
 - Improve system reliability through better congestion management by replacing manual curtailments with automated real-time dispatch; some overall reduction in curtailment
 - Enable wind generation to fully participate in the real-time market
- ❖ DIR launched on June 1st 2011
 - 1,200 MW wind registered as DIR in the June Commercial Model
 - 2,037 MW wind registered as DIR in the Sept Commercial Model
- ❖ Key issues / concerns include:
 - Forecasting, Ability to follow dispatch, Coordination with MISO

MISO Load Following Challenge

- ❖ Operational flexibility from controllable resources is limited within a fleet of resources
 - Flexibility from online resources is inexpensive compared to committing offline resources
 - Existing resources (supply or demand side) should be incentivized to provide required flexibility
- ❖ Ramping capability is a non-trivial issue in MISO with predominantly coal fired generation resources
 - Other RTOs or utilities with high renewable penetration have more flexible generation resources (e.g. natural gas, hydro) in their fleet

What is Happening?



- Traditional view of Power System Operation is evolving
 - Variability of net load is increasing
 - Uncertainty is increasing
 - Needs for more flexible resources are in rise

Ramp Management / Load Following - MISO

❖ Key drivers

- Net load variability (load, wind, & Net Scheduled Interchange) and forecast uncertainties (forecast errors and generator deviations)

❖ Objectives

- Ensure required flexibility in all market layers (Day Ahead to Real Time)
- Maximize the usage of current approaches
- Explore new products and services

❖ Approach

- Aid reliable operations by keeping sufficient ramp capability available for use in Real Time dispatch to address variations in ramp requirements
- Reduce price volatility by reducing instances of transitory shortages arising from ramp shortages
- Acquire ramp capability through a market mechanism so a price signal can be sent to the market

MISO Load Following Challenge

- ❖ Need to economically schedule controllable resources to match known Net Load variability plus its uncertainty at any given time
 - Net Load is the load seen by controllable resources
 - **Net Load = Load – Non-controllable generation + Net Scheduled Interchange (imports/exports)**
 - Requires a good understanding of the Net Load variability & uncertainty and of the flexibility of the controllable resources
- ❖ Sources of variability
 - Load, NSI, Wind
- ❖ Sources of uncertainty
 - Load forecast error, NSI forecast error, Wind forecast error, Generators setpoint deviations (not following dispatch)

High Level Impacts of Ramp Capability Products

By withholding Ramp Capabilities for Up Ramp and Down Ramp

1) The dispatch results would be altered:

- Selected units were not fully dispatched for energy and other Ancillary Service products making room for ramp capability products
- Due to the energy and Ancillary Services changes of the selected units, the energy and Ancillary Services dispatch for the rest of the units is changed
- Real-time Ramp shortage is mitigated

2) The cleared prices would be altered:

- Units providing Ramp Capability products are subject to loss of opportunity cost if their dispatch is changed
- Reduce system price volatility by reducing instances of transitory shortages arising from ramp shortages
- Acquire ramp capability through a market mechanism so a price signal can be sent to the market
- Under normal situations with no price spikes, load payments are increased to compensate for opportunity costs, however, including the price spikes, load payments are decreased

MISO Ramp Capability Proposal

❖ Key Issues / Questions include:

- Does the proposed approach (adapt existing market practices rather than develop new ancillary service) actually provide incentives for existing and new flexible resources or does it simply subsidize existing inflexible resources?
- Who will pay for flexibility incentives (spread across all load as with current ancillary services or assigned to “cost causers”)?

❖ Schedule

- Workshops held 5/2/11, 6/16/11, 9/1/11; next workshop 12/13/11
- Implementation ramp management enhancements likely to be 2012
- Postings:
<https://www.midwestiso.org/WhatWeDo/StrategicInitiatives/Pages/RampManagement.aspx>

Flexibility Summary

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 - Variability and uncertainty have always been common characteristics of all power systems and are managed by grid operators with reserves
- ❖ Use of Variable Energy Resources is increasing rapidly in many countries
 - Variable Energy Resources (wind, solar) add variability and uncertainty to the power system over seconds, minutes, and hours
- ❖ VER integration impacts are significantly reduced with:
 - Large, liquid, fast markets (sub-hourly, co-optimized energy and ancillary service markets)
 - Large balancing areas with a strong grid: captures significant benefits to diversity (geographic, resource, load); enables access to the physical flexibility that exists in the regional power system
 - Forecasting VERs significantly reduces uncertainty and costs
- ❖ Numerous peer reviewed studies have shown that integrating large amounts of VER is effectively a balancing challenge (tens of minutes to hours)
 - Regulation impacts are small (geographic diversity, net load); Unit commitment and scheduling impacts are mitigated by forecasting
 - Load following / ramp management can be an issue at higher levels of VERs

Flexibility Summary

- ❖ Power systems have much greater ability to handle variable renewable energy than commonly understood
 - Existing flexibility should be accessed first
- ❖ Sources of flexibility include:
 - Dispatchable plants, demand side resources, grid / interconnections, and storage
- ❖ The extent to which existing flexible resources are actually available and used varies widely
 - Some regions not only have large amounts of flexible resources but are also more likely to make those resources available for balancing
- ❖ Key power system characteristics which affect whether technical flexibility is available include: grid strength, market size, scheduling / dispatch speed, use of forecasting, and value of flexibility in the market
 - After existing flexibility is made available, it may be necessary to increase the flexible resources through removal of barriers and development of incentives
 - Will need to provide incentives to fully engage flexibility from the supply side (both conventional and renewable), the demand side, interconnections / grid, and storage.
- ❖ Market rules are evolving to improve system flexibility including:
 - Improved system scheduling / dispatch
 - Improved procurement / payment of ancillary services
 - Incentives for load following / ramp management
 - Additionally, markets will increasingly incorporate dispatch of VERs

Additional Material

❖ Sources

❖ Biography

❖ Supplemental Information

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Integration of Variable Energy Resources

Notice of Proposed Rulemaking, November 18, 2010

Docket No. RM10-11-000

Frequency Response Metrics to Assess Requirements for Reliable Integration of Variable Renewable Generation

Notice Inviting Comments on LBNL Report, January 20, 2011

Docket No. AD11-8-000

Frequency Regulation Compensation

Notice of Proposed Rulemaking, February 17, 2011

Docket No.s RM11-7-000 and AD10-11-000

Third Party Provision of Ancillary Services; Accounting and Financial Reporting for New Electric Storage Technologies

Notice of Inquiry, June 16, 2011

Docket No.s RM11-24-000 and AD10-13-00

Biography

Matt Schuerger is an independent consultant working on power systems planning and analysis. He has twenty five years of experience in the utility industry, including senior positions in engineering, power plant operations, and business development. Matt has worked extensively with the integration of large amounts of variable renewable energy into power systems including interconnection and delivery, operating impacts, reliability, and market rules. He is a consultant to DOE's National Renewable Energy Laboratory, to Wind on the Wires, and to the Minnesota Office of Energy Security.

Clean energy integration projects include work as a consultant for the National Renewable Energy Laboratory on the 2011 Hawaii Solar Integration Study, the 2011 Maui Smart Grid Demonstration Project, the 2010 Oahu Wind Integration and Transmission Study, and on the 2009 Eastern Wind Integration and Transmission Study, for the Minnesota Office of Energy Security on the 2008 Minnesota Renewable Energy Standard Transmission Studies, and for the Minnesota Public Utilities Commission on the 2006 Minnesota Wind Integration Study.

Matt is a licensed Professional Engineer with a M.S. degree in Electrical Engineering (Power Systems) from the University of Minnesota, a B.S. in Mechanical Engineering from Purdue University, and an MBA from the University of St. Thomas. He is formerly the Executive Vice President of District Energy Saint Paul, Inc, a privately held provider of district heating, district cooling, and cogenerated electricity.

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Energy Systems Consulting Services, LLC is an engineering and management consulting firm focused on planning, development, and analysis for sustainable power systems including applications of renewable energy, demand response and energy efficiency, and distributed generation.

Supplemental Information

“Adequate Level of Reliability”

NERC’s traditional definition of “reliability” consists of two fundamental concepts: Adequacy and Operating Reliability.

The Bulk-Power System will achieve adequate reliability when it possesses the following characteristics:

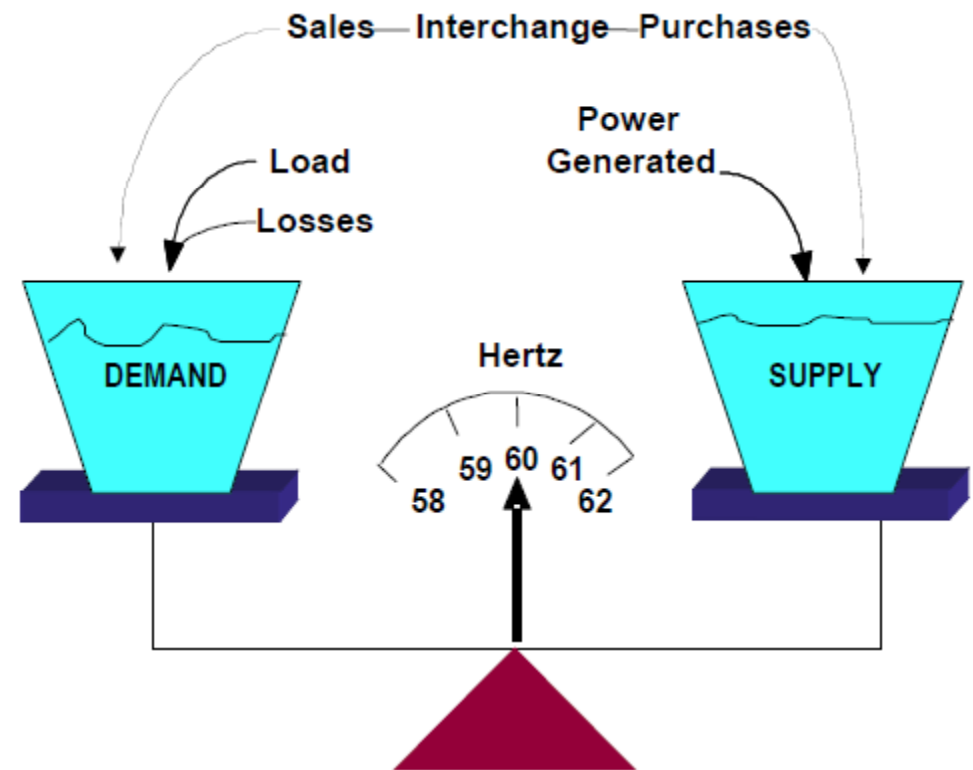
1. The System is **controlled to stay within acceptable limits during normal operation**;
2. The System **performs acceptably after credible Contingencies**;
3. The System **limits the impact and scope of instability and cascading outages when they occur**;
4. The System’s Facilities are protected from unacceptable damage by operating them within Facility Ratings;
5. The System’s integrity can be restored promptly if it is lost; and
6. The System has the **ability to supply the aggregate electric power and energy requirements of the electricity consumers at all times**, taking into account scheduled and reasonably expected unscheduled outages of system components.

Sources: NERC Definition of “Adequate Level of Reliability” Dec 2007.

NERC “2009 Bulk Power System Reliability Performance Metric Recommendations” Sept 2009. 55

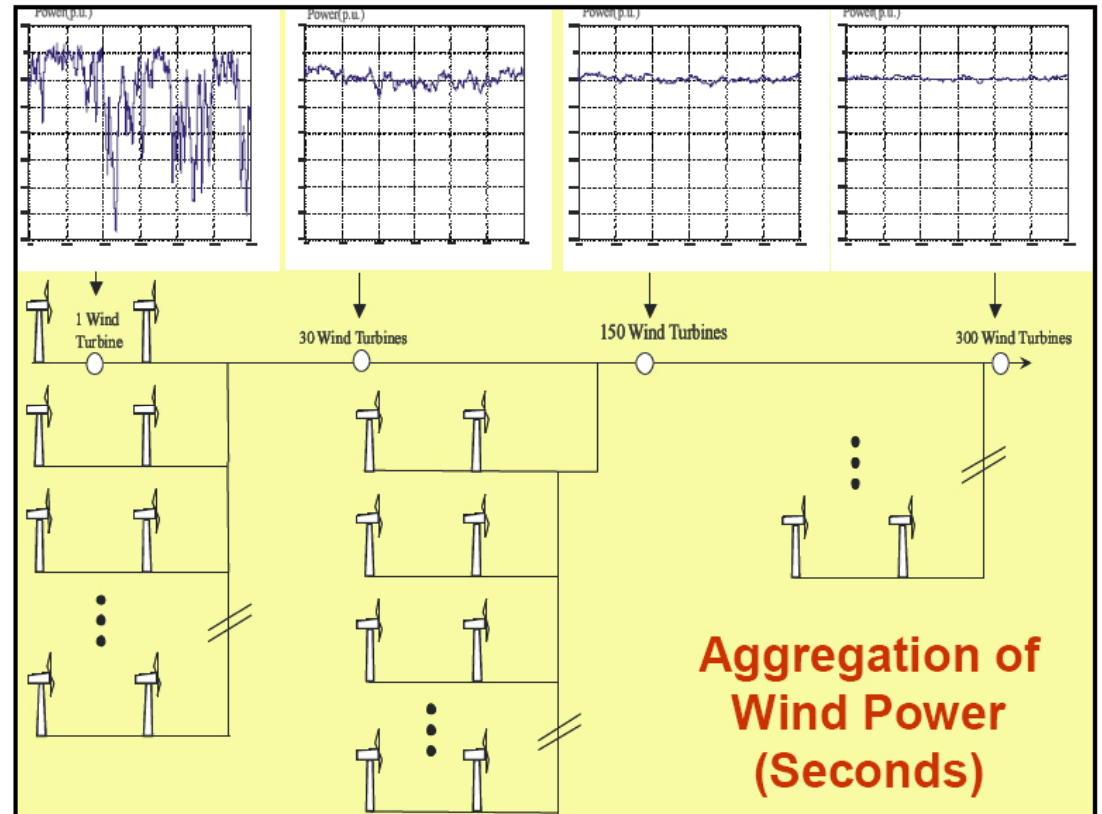
Balancing & Frequency Control

- ❖ Each Interconnection of the power system is a large machine; the speed of Interconnection is frequency (cycles per second or Hertz)
- ❖ If interconnection generation exceeds customer demand, frequency increases beyond the target of 60 Hz until balance is achieved; conversely if there is a temporary generation deficiency
- ❖ Balance is initially restored due to load that varies with frequency (e.g. electric motors)

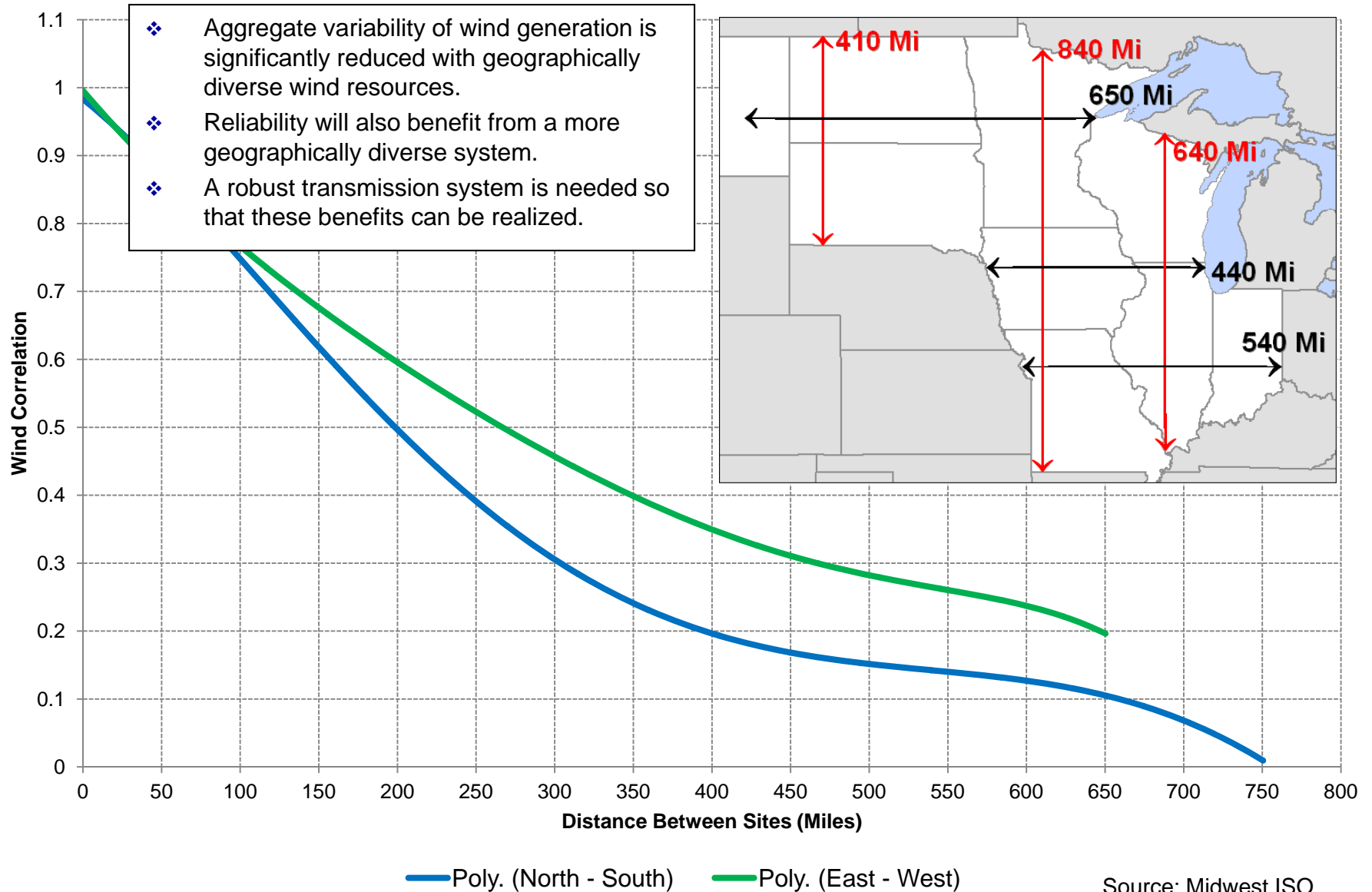


Benefits of Geographic Diversity

- ❖ Both variability and uncertainty of aggregate wind decrease percentage-wise with more wind, more geographic area
- ❖ Transmission is key to capturing this phenomena

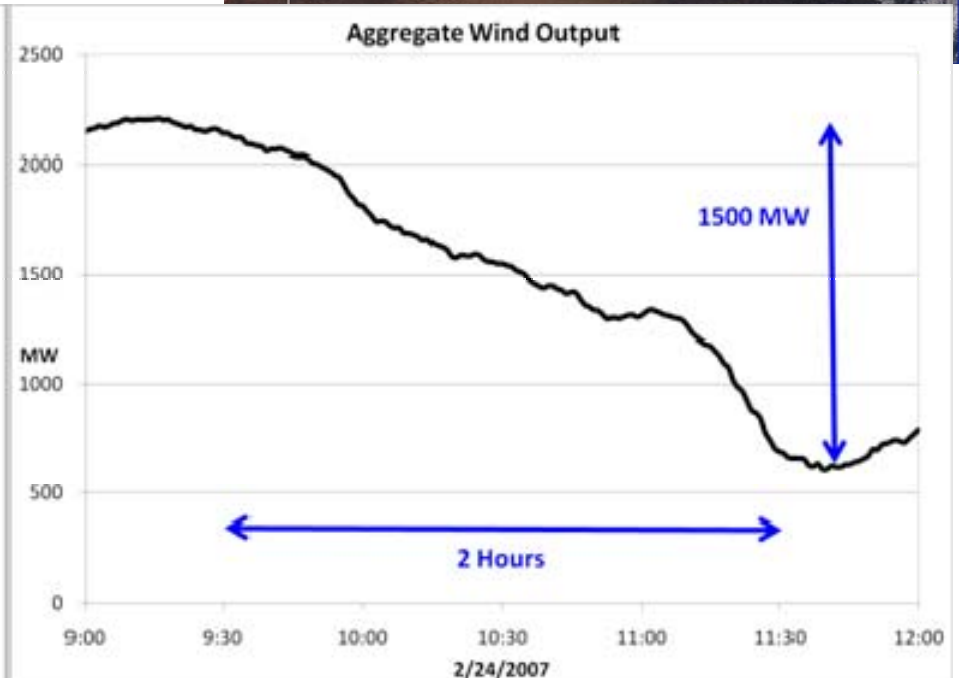
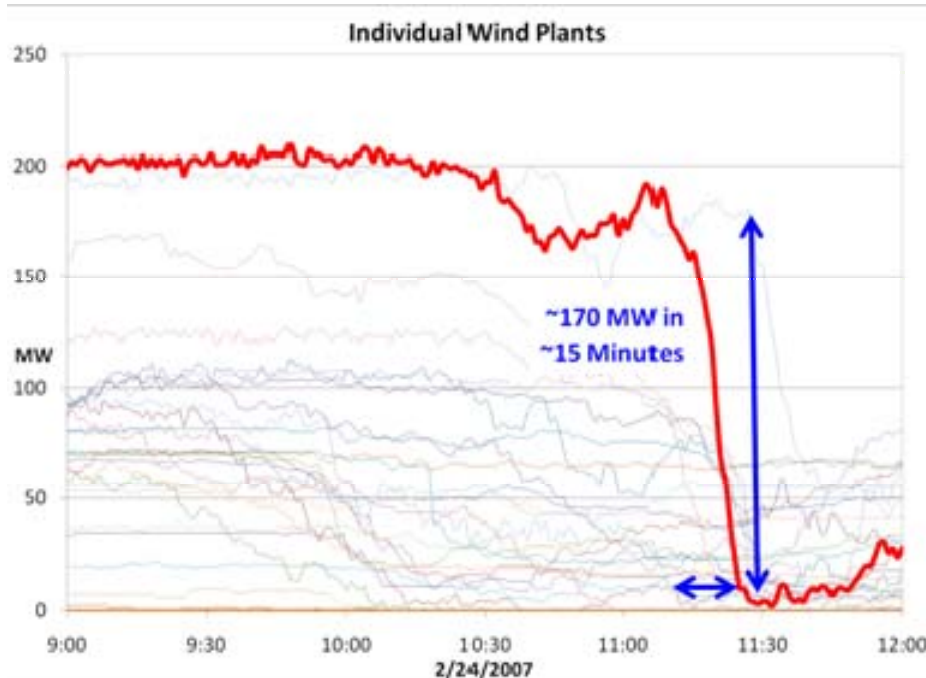
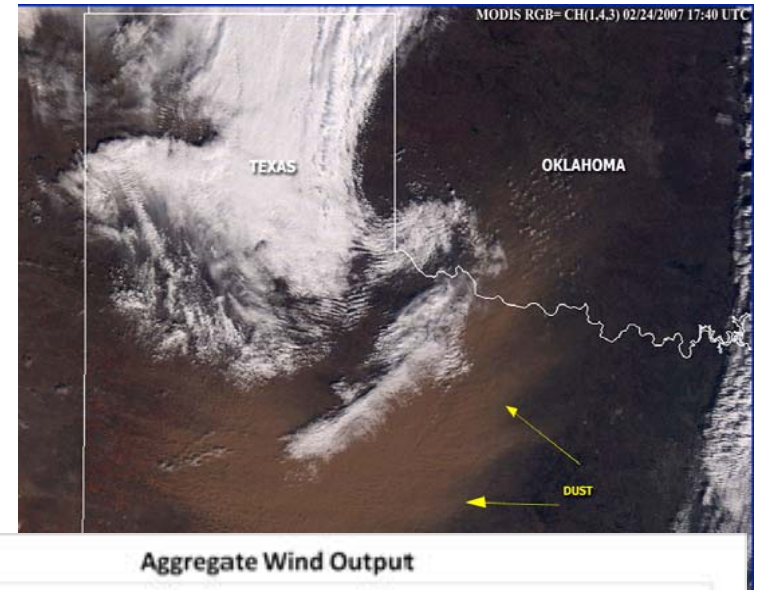


Wind Correlation vs Distance RGOS Study Area



Can wind power start and stop suddenly?

- ❖ Large wind farms have many individual wind turbines
- ❖ The turbines are spread over many miles and do not experience the same wind at the same time
- ❖ ERCOT event Feb 24, 2007: drop of 1,500 MW over 2 hours, similar to behavior of load



Extreme Wind Events Are Typically Not Contingency Events

- ❖ Extreme wind events are ramping events, not contingency events
 - Electrical events are still contingencies (single feeder...)
 - Geography prevents all turbines from seeing *wind* events simultaneously and spreads the response
- ❖ Increasing the amount of wind increases the ramp duration, not the ramp speed

Integration of Conventional Generation

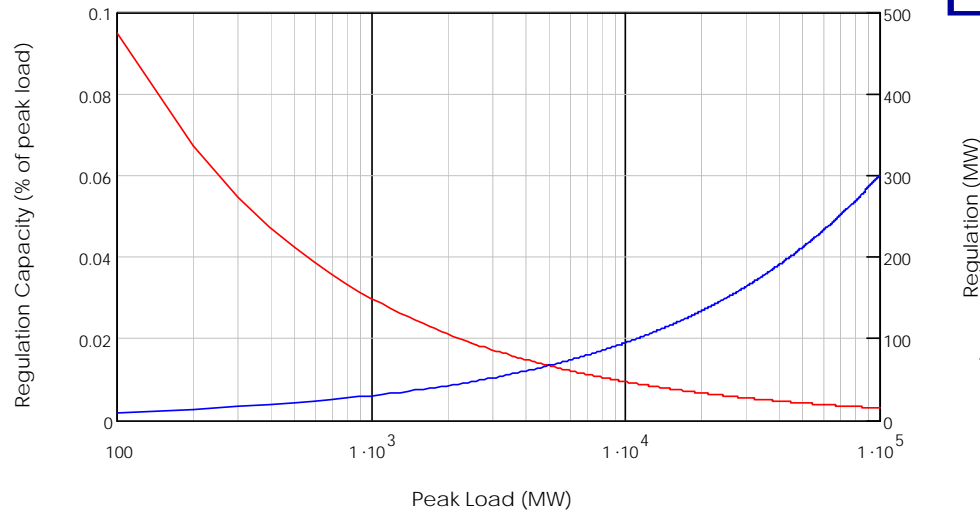
- ❖ Costs for Maintaining Contingency Reserves
 - Contingency reserves are maintained to accommodate the variability and uncertainty of large conventional generators
- ❖ Costs from Integration of Baseload Plants
 - Baseload coal and nuclear plants have limited ability to change their level of output resulting in an additional ramping burden on other generators

VER Integration Study – Approach & Methods

- ❖ **Capture system characteristics** and response through operational simulations and modeling;
- ❖ **Capture VER characteristics**; geographic diversity through synchronized weather simulation;
- ❖ **Examine wind variation in combination with load variations (Net Load)**;
 - Match with actual historic utility load and load forecasts;
 - Use actual large wind plant power statistical data for short-term regulation and ramping;
- ❖ **Utilize VER forecasting best practice** and combine VER forecast errors with load forecast errors;
- ❖ **Examine actual costs** independent of tariff design structure.
- ❖ **Examine impacts of BA consolidation and fast markets.**⁶²

Large Balancing Areas Reduce Reserve Requirements

Approximate regulating requirements for
a BA as a function of peak demand.



Estimated
Regulating
Requirements for
MN BAs - 2020

<i>Balancing Authority</i>	<i>Peak Load</i>	<i>Regulating Requirement (from chart)</i>	<i>Regulating Requirement (% of peak)</i>
GRE	3443 MW	56 MW	1.617%
MP	2564 MW	48 MW	1.874%
NSP	12091 MW	104 MW	0.863%
OTP	2886 MW	51 MW	1.766%
Sum of regulating Capacity		259 MW	
Combined	20984 MW	137 MW	0.655%

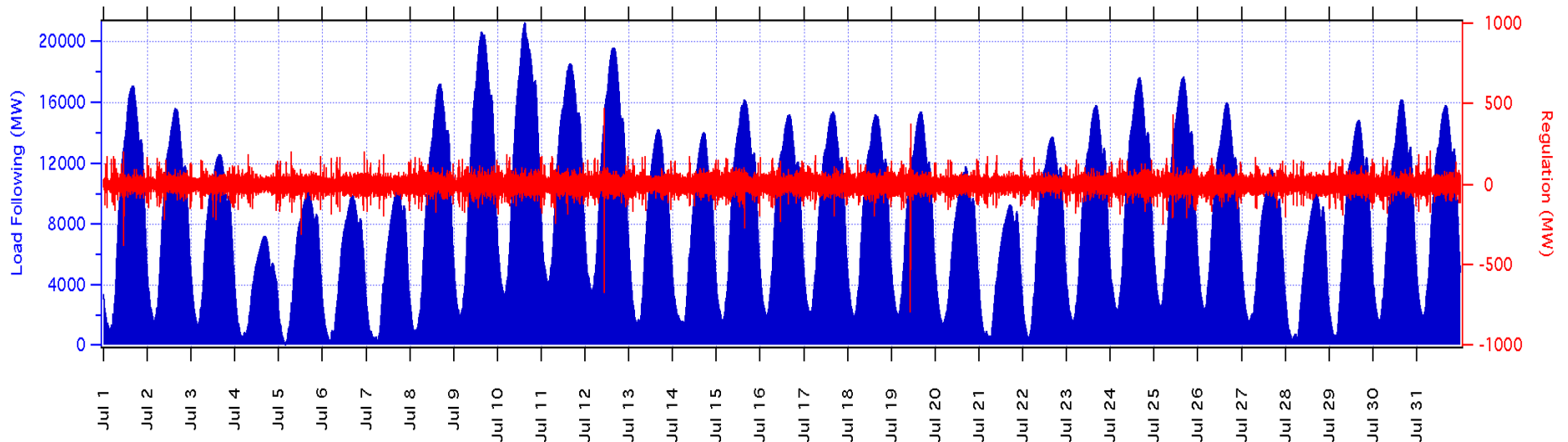
Source: MN DOC

Capacity Value – Wind Generation

- ❖ Measure of relative plant contributions to reliability in the context of overall system reliability
- ❖ Wind is primarily an energy resource, but can make a small contribution to planning reserves
- ❖ Depends on timing of wind energy vs. load characteristics
- ❖ Various uses for capacity value
 - Capacity markets (e.g. PJM)
 - Resource adequacy
 - Resource planning
- ❖ Effective Load Carrying Capability (ELCC)
 - Increase in load that can be supported with a new generator while holding the system reliability constant (fixed LOLE)
 - Data-driven, empirical approach based on hourly load profiles & actual generator unit data
- ❖ From a NERC perspective, capacity is typically calculated at between ~10% & 20% of nameplate

Regulation & Load Following

	<i>REGULATION</i>	<i>LOAD FOLLOWING</i>
<i>Patterns</i>	<i>Random, uncorrelated</i>	<i>Largely correlated</i>
<i>Generator control</i>	<i>Requires AGC</i>	<i>Manual</i>
<i>Maximum swing (MW)</i>	<i>Small</i>	<i>10 – 20 times more</i>
<i>Ramp rate (MW/minute)</i>	<i>5 – 10 times more</i>	<i>Slow</i>
<i>Sign changes</i>	<i>20 – 50 times more</i>	<i>Few</i>



Day and Time

Regulation Findings

- ❖ Increases in regulation requirements due to even large amounts (over 15%) of wind generation are small
- ❖ Large turbine count and geographic diversity contribute to substantial “filtering” of these fast variations in wind generation output
- ❖ Lack of correlation to system load also contributes to modest impact
- ❖ Some types of (much smaller) loads can have much greater influence on regulation requirements
 - Right: System with wind generation and arc furnace load
 - Mill load dominates regulation needs

