Renewable Resource Integration

CEE Symposium with NEDO

October 19, 2016

Tokyo, Japan

J. Charles Smith
Executive Director
UVIG

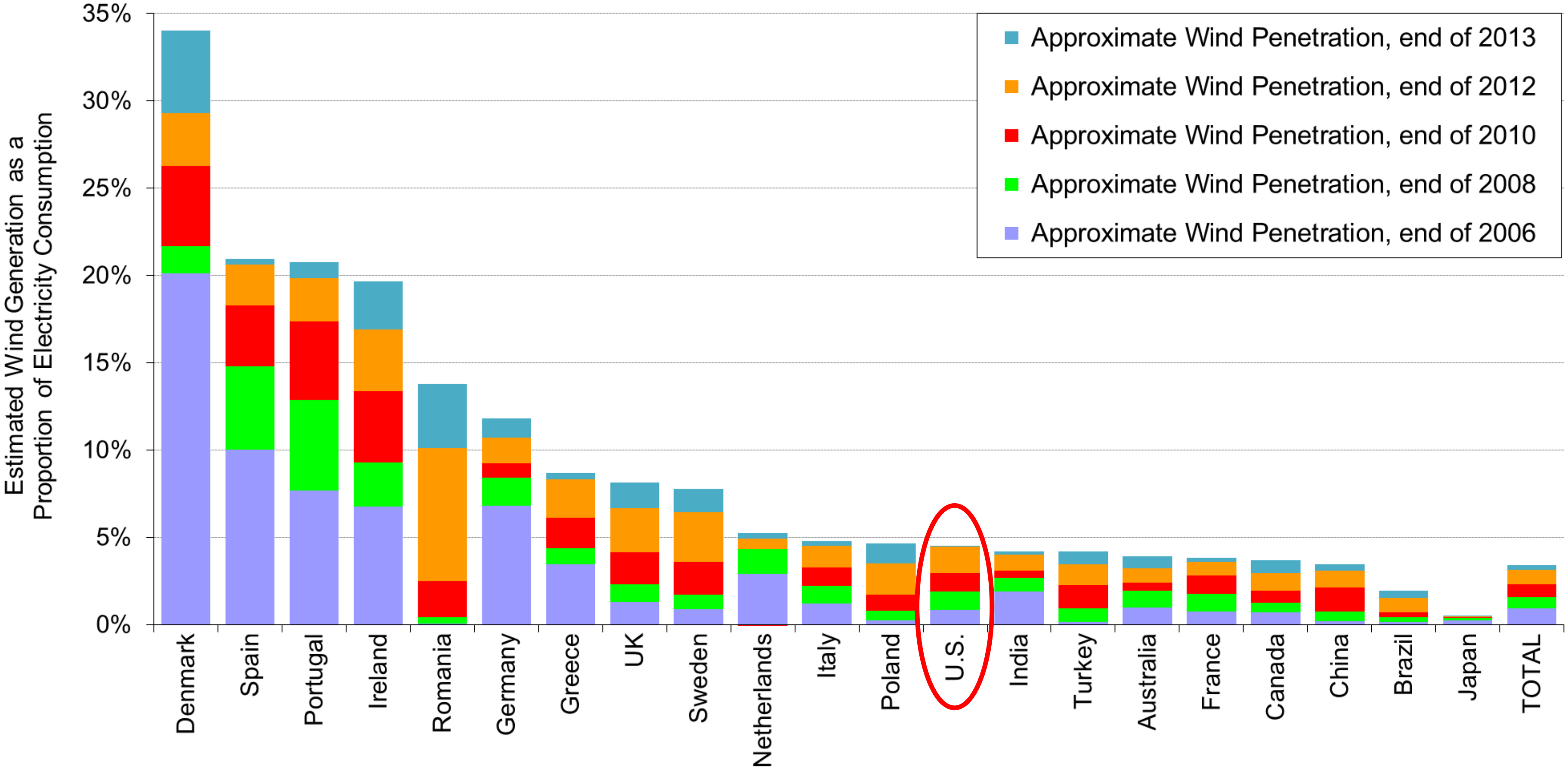
What is UVIG?

- Non-profit corporation established by 6 utilities in 1989 with support from EPRI and DOE/NREL
- Expanded scope from wind to include solar PV in 2011, now Utility Variable-Generation Integration Group (UVIG)
- Over 180 members, including ISOs, utilities, developers, manufacturers, consultants, government organizations
- Focus on technical issues
- Mission: To accelerate the development and application of good engineering and operational practices supporting the appropriate integration of solar and wind power into the electric system

Outline of Topics

- Overview and Recent Trends
- Flexibility
- Forecasting
- Capacity Adequacy
- Market Design
- Grid Codes and Ancillary Services
- Transmission Adequacy
- Summary

Relative Position of Major Wind-Producing Countries



Note: Figure only includes the countries with the most installed wind power capacity at the end of 2013

An Industry Maturing

- US wind capacity end of 2015 > 75 GW
- US solar PV capacity end of 2015 > 27 GW
- US VG installations in 2015
  - Wind 9 GW
  - PV 7 GW
- Ballpark estimates for 2016 US VG installations
  - Wind 9 GW
  - PV 16 GW
- Globally at the end of 2015
  - Wind about 433 GW
  - Solar about 256 GW
  - Each currently growing about 60 GW per year

A PV Industry Maturing - Japan

- Japan wind capacity end of 2015 > 3 GW
- Japan solar PV capacity end of 2015 > 34 GW
- Japan VG installations in 2015
  - Wind 0.25 GW
  - PV 12. GW
- Ballpark estimates for 2016 Japan VG installations
  - Wind 0.25 GW ??
  - PV 14. GW ??

US Renewable Energy is Very Competitive

- Lazard reports on lowest unsubsidized energy costs for:
  - Rooftop residential solar: $180/MWh
  - Simple Cycle GT $165/MWh
  - Nuclear $97/MWh
  - Coal $65/MWh
  - Combined Cycle GT: $52/MWh
  - Utility scale solar: $50/MWh
  - Wind energy: $32/MWh
- Other reports from industry pubs on recent PPA prices:
  - Utility scale solar $37-$50/MWh
  - Wind energy $18-$30/MWh

Recent Industry Trends

- NERC Essential Reliability Services Task Force (ERSTF) highlights growing interdependence between gas and electricity, concern over coal plant retirements and maintaining future system reliability
- EPA Clean Power Plan (CPP) final rule required 32% CO_2 reductions below 2005 levels from power sector by 2030; stay issued by Supreme Court in Feb 2016
- New carbon emission rules and coal retirements continue to drive concern for capacity adequacy
- Capacity flexibility issue gaining attention

NERC
Essential Reliability Services Task Force

- Emerging concern in some circles for availability of essential reliability services in the future:
  - Retiring coal units due to MATS and EPA 111d
  - Increasing penetration of gas units
  - Increasing penetration of wind and solar
  - Increasing reliance on demand response, DG, and new sources of energy storage
- Essential reliability services must be identified, measured and monitored in the future

NERC
Essential Reliability Services Task Force

- Will examine supply and metrics for measuring:
  - Inertial response
  - Frequency response
  - Ramping capability
  - Active power control
  - Disturbance ride-through tolerance
  - Reactive power and voltage control
- Will examine future system reliability in light of its ability to provide these services with the changing generation mix

NERC Reliability Report

- State of Reliability May 2015, published November 2015
- Report provided pessimistic view on ability of wind and solar plants to provide ancillary services
- This was a common point of view among NERC and industry stakeholders a year ago, based on very early deployments of Type 1 turbine technology
- It has taken a lot of time and energy to bring the industry up to speed on the recent capabilities of renewable energy generators

What a Difference Six Months Makes

- NERC ERSTF Measures Framework Report, published November 2015
- ***In order to maintain an adequate level of reliability through this transition, generation resources need to provide sufficient voltage control, frequency support, and ramping capability—essential components of a reliable BPS.***
- NERC got it right!

It's All About Dealing with Variability and Uncertainty

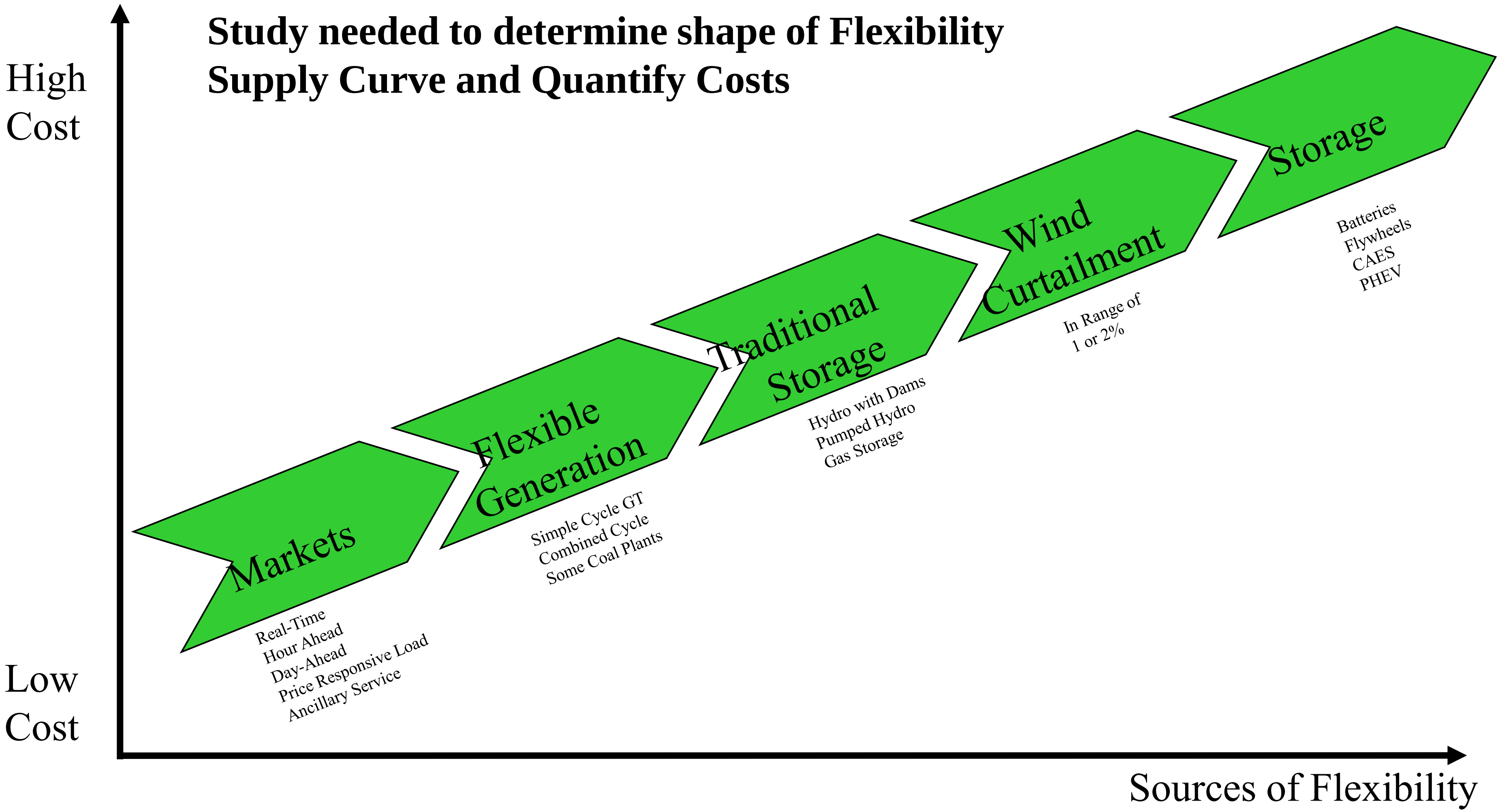
- Variability
  - Load varies by seconds, minutes, hours, by day type, and with weather
  - Supply resources may not be available or limited in capacity due to partial outages
  - Prices for power purchases or sales exhibit fluctuations
  - Address variability with flexibility
- Uncertainty
  - Operational plans are made on basis of best available forecasts of needs; some error is inherent
  - Supply side resource available with some probability (usually high)
  - Address uncertainty with forecasting
- Key questions
  - How do wind and solar generation affect existing variability and uncertainty
  - What are the costs associated with the changes
  - What does the future hold

Flexibility

- Many definitions, but simply put: the ability to adjust rapidly to changing system conditions
- Potential sources:
  - Conventional generation
  - Variable generation
  - Markets
  - Demand response
  - Storage
  - Integrated energy systems

Flexibility Supply Curve

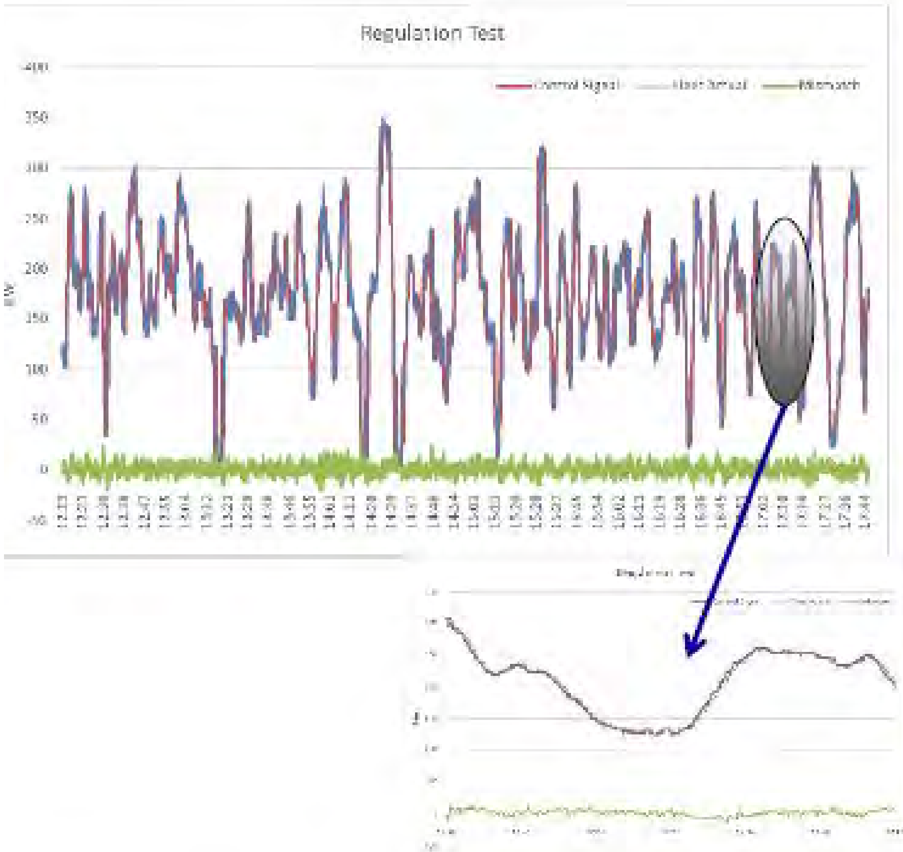
Study needed to determine shape of Flexibility Supply Curve and Quantify Costs



Conventional Generation Sources of Flexibility Adequacy

- Deep stack
  - Limit self-schedule
  - limit must run - must take arrangements
- Reserves Across Multiple Time Scales
  - Frequency responsive reserves
  - Imbalance reserves
  - Slow start reserves
- Unit characteristics
  - Fast start units with high ramping rate
  - Low minimum load and short minimum down time
  - Daily start-up and shut-down cycles

Flexible DR Can Provide Services Very Well- Regulating Reserve Example



- PJM signal (RegD) for 48 hours *tracks signal closely*
  - *Delay, accuracy and precision*
  - *Constant availability if signal skewed*
- Mismatches within tolerances
- Average Performance Score = 93% (Natural Gas ~70%)
- Load to AGC signal root-mean-square error value of + / - 3.8%
- Very little impact on water temperature/comfort
- Need to investigate with HI specific signals
- Show DR can provide AGC services and other reliability services

Focus on 10 minute interval

Taken from E. Rehberg, ACEEE Hot Water Forum 2015 | GIWH Pilot Demonstration, Feb, 2015

Aidan Tuohy, UVIG, 2015

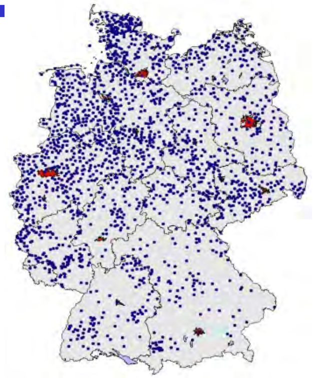
Wind Power Forecasting – Why Is it Important

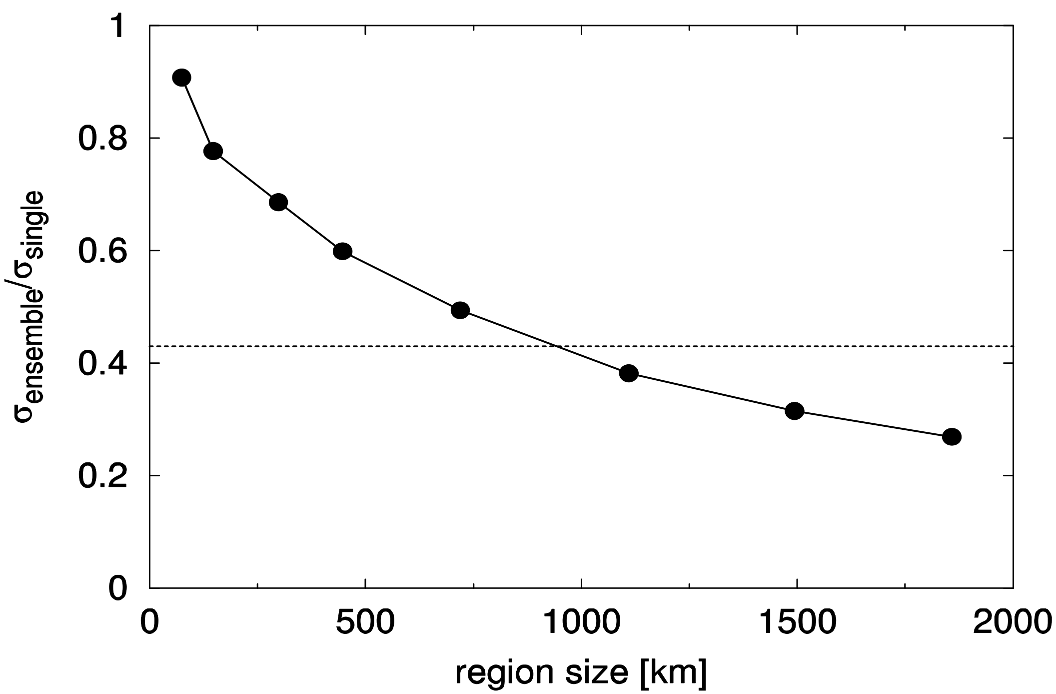
- Economics
  - Better forecasts mean lower operating reserves
  - Lower operating reserves mean lower operating costs
  - Avoid penalties for bad forecasts
- Reliability
  - Situational awareness for operators
  - System positioning for ramping events
  - Preparation for extreme events
- Market Operation
  - Understand need for and provide incentives for the right market products with high VG penetration
  - Align market rules with forecasting capabilities

Different Forecasts for Different Time Periods

- Situational awareness forecast: used for severe weather events (real-time)
- Hour ahead forecast: uses rapid update cycle to produce 5-10 min forecasts 4-6 hours ahead, updated at least every hour, sometimes more frequently
- Day ahead forecast: Hourly forecasts 2-7 days ahead, updated every 12 hours, uses national weather service models
- Nodal forecast: hourly forecast of transmission system nodal injections for managing transmission congestion
- Different performance metrics for different forecasts

Error Decreases with Region Size

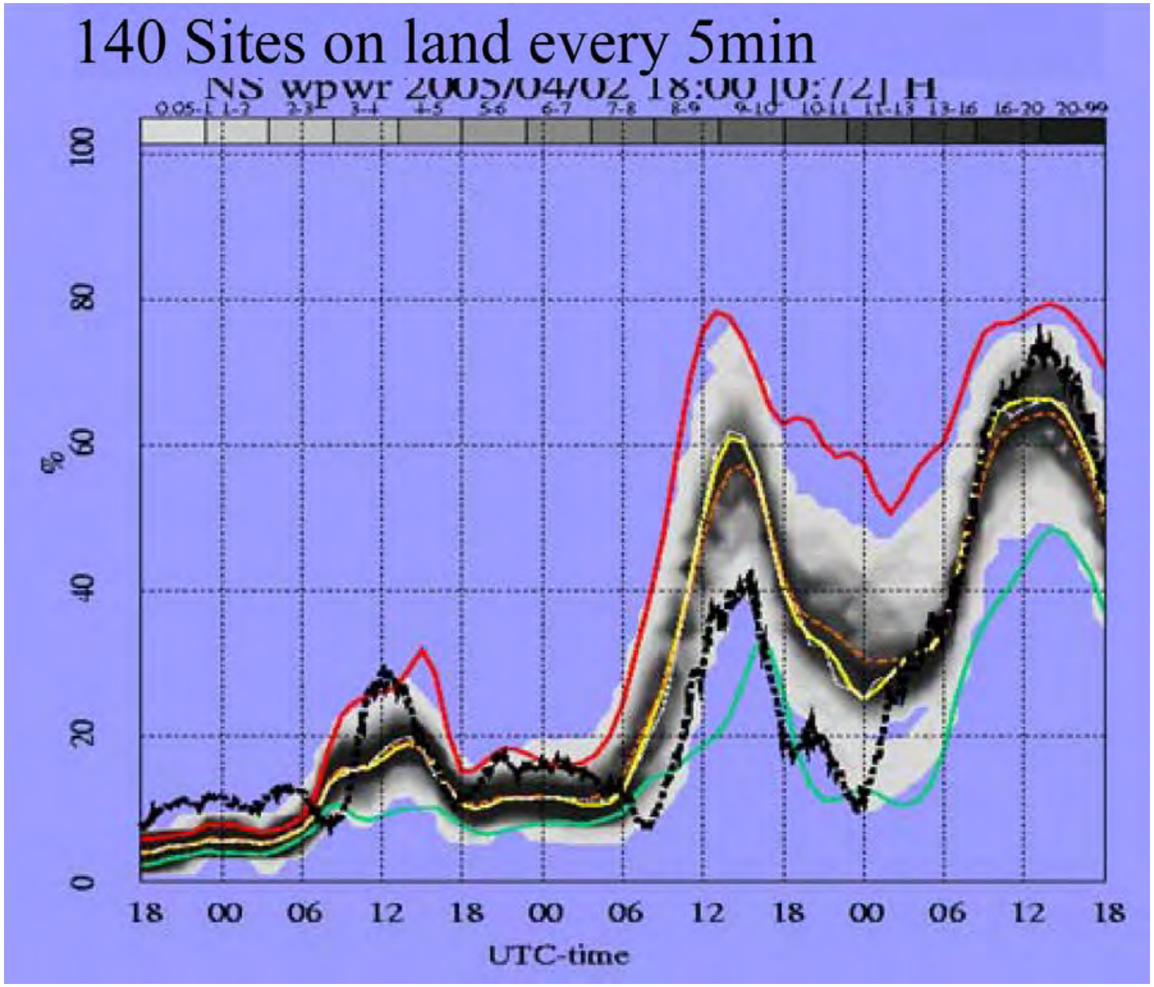




- Error decreases with increase of region size
- Regional smoothing depends only on region's size, not on number of sites
- Error is reduced in Germany to 42 % compared to single forecast

Source: Energy and Meteo Systems

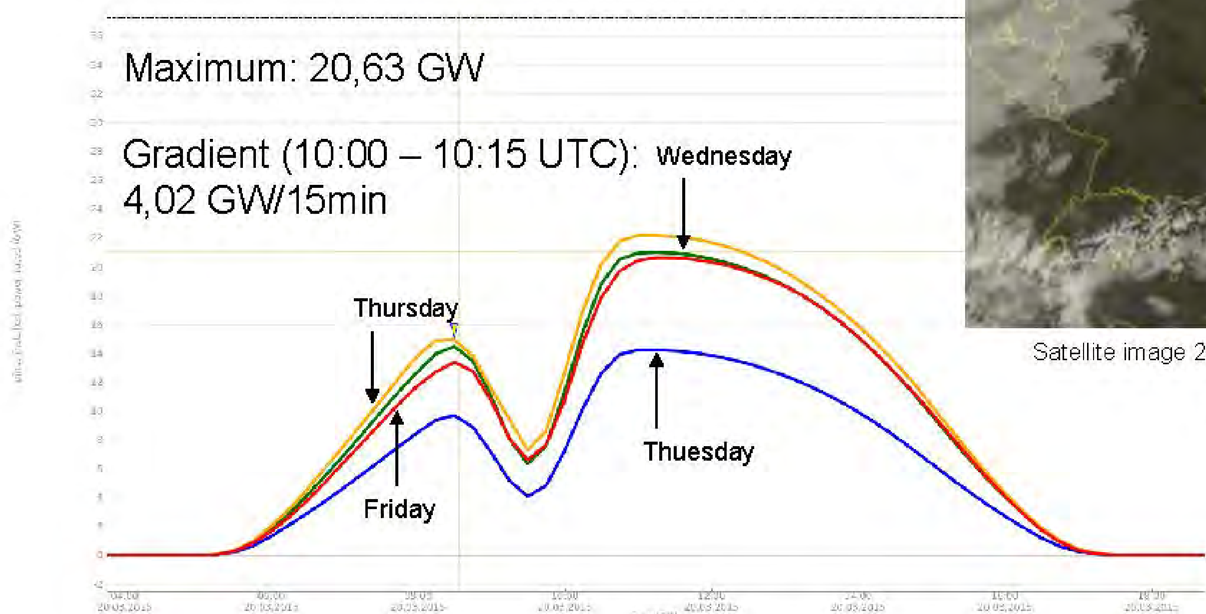
Forecasting and Balancing Markets Reduce Impacts



March 20, 2015 European Solar Eclipse in Germany

weather forecast for Friday

- Forecast Germany of Friday, 2015-03-20, for Friday, 2015-03-20



Satellite image 20.03.15, 9:00

Source:
Woksat.info

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energy & meteo systems

How Good is the Forecast?

- Wind plant output can be forecast within some margin of error, and forecasts are getting better

	Forecast Error	
	Single Plant	Large Region
Hour Ahead Capacity (% rated)	4-6%	3-5%
Day Ahead Hourly Capacity (% Rated)	8-12%	6-8%

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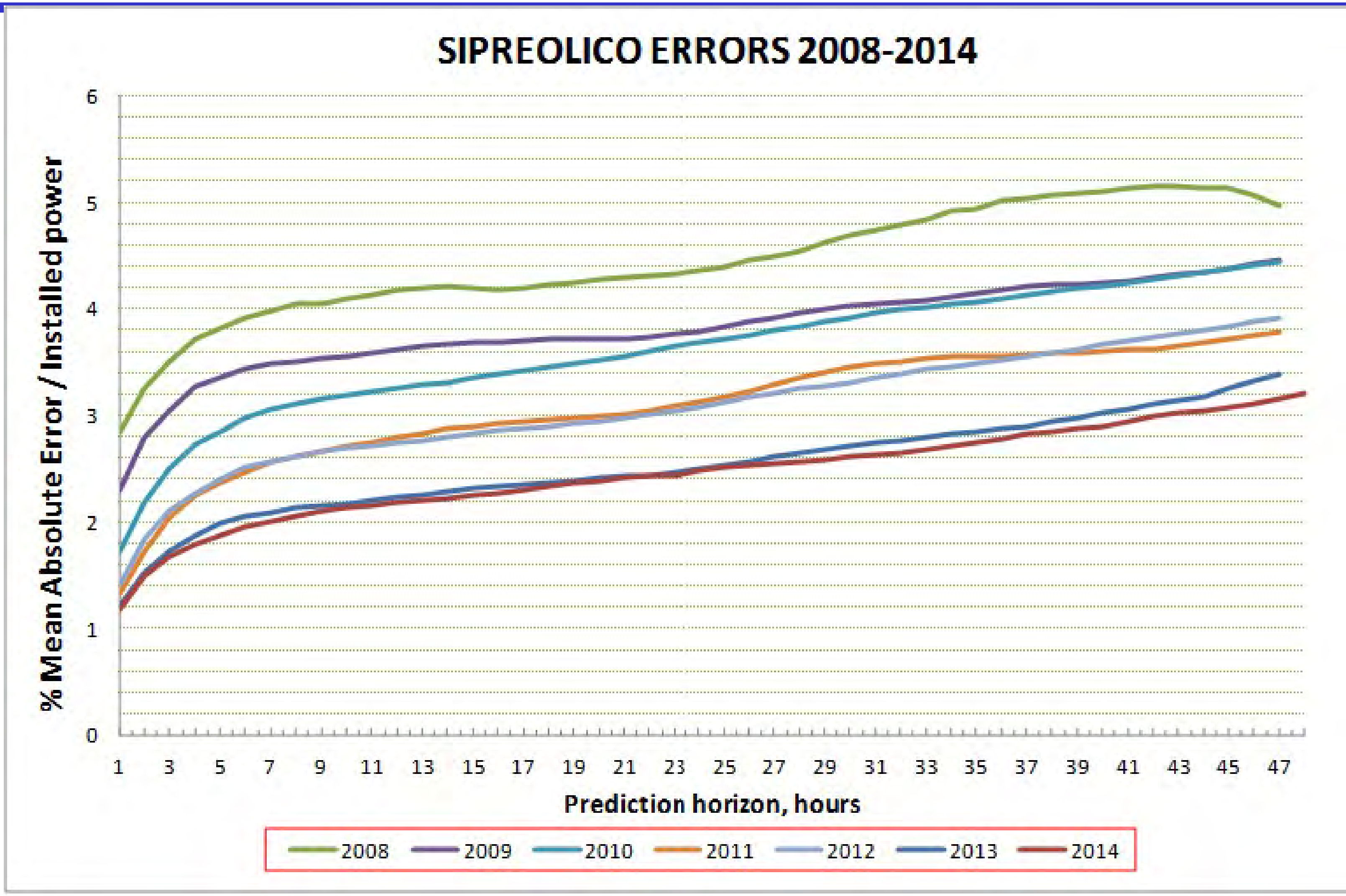
How Low Can You Go?



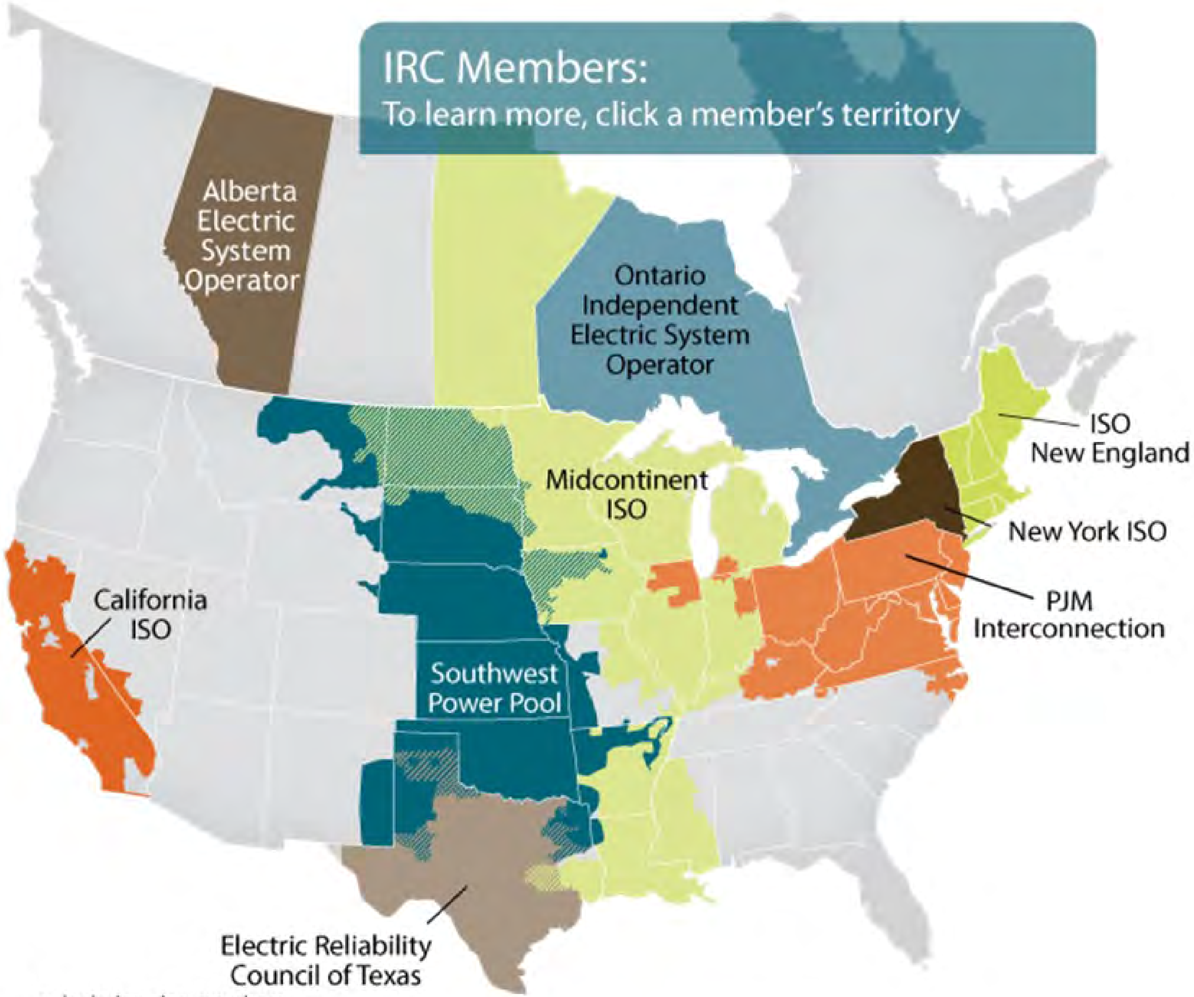
Ana Rodriguez, REE

Market Design

- Today's markets not designed with VG in mind
  - *Energy markets*
  - Capacity markets
  - Ancillary service markets
  - Price responsive load markets
- Market shortcomings must be identified and corrected
  - Energy market price volatility
  - *Capacity adequacy concerns*
  - Ramping products for flexibility
  - Slow reserve products

Capacity Adequacy and Market Design

- The organized markets are similar in their energy and ancillary service market designs, but vary widely in approaches for resource adequacy
- The two primary market alternatives are
  - energy-only market with capacity costs recovered in the energy and ancillary service market (e.g. ERCOT)
  - energy market with a parallel capacity market to recover some portion of the capacity cost (e.g. PJM, NYISO, ISO-NE)
- Either alternative may also have additional regulatory capacity planning margin requirements that require load serving entities to contract for capacity (e.g. CAISO and parts of MISO).



- Includes nine members
- Serves two-thirds of electricity consumers in the U.S. and more than half in Canada
- Created April 24, 2003
- Hashmarks represent areas in which transmission lines or utility service areas overlap adjoining ISO/RTO regions.

US Market Design and Operation with Variable Resources

- ERCOT and PJM are examples of very different market designs
- ERCOT operates an energy-only market and is close to its reserve margin target of 13.75%
  - Wholesale prices in the real-time energy market increase automatically as available operating reserves decrease
  - When operating reserves drop to 2,000 MW or less, the Operating Reserve Demand Curve (ORDC) will automatically adjust energy prices to the established Value Of Lost Load (VOLL), which is set at $9,000 per megawatt-hour (MWh).
- PJM operates a capacity market with three-year forward procurement using a sloped demand curve that recognizes the value of capacity beyond the installed/planning reserve margin target. PJM is projected to be above its reserve margin target of 15.6% through 2018

Another Option

- A third option is bi-lateral markets
  - stand-alone balancing areas
  - tend to saturate with renewables sooner
  - stand-alone provider tends to have a smaller pool of dispatchable resources available to manage the renewable integration
  - often limited by hourly scheduling protocols
  - may not make full use of load response to provide ancillary services
  - increasing efforts to develop wind integration charges which are allocated to the renewable provider

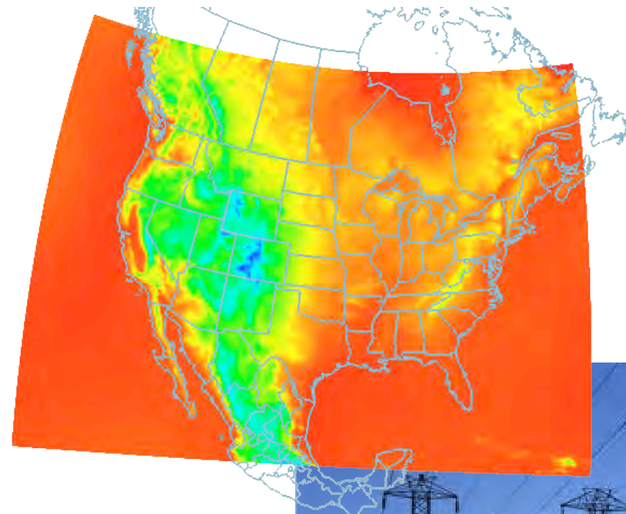
All Generators
Impose Operating Constraints

- Every resource has operating constraints that reflect characteristics of fuel and technology
- Conventional limitations
  - Start-up times & costs
  - Minimum run times
  - Minimum generation
  - Operating ranges
  - Ramp rate limitations
  - Forced outages & contingencies
- Fuel supply characteristics matter… for gas, nuclear, wind, solar, etc.
- The challenge of Variable Energy Resources (VER) is a bit different, but not unique

Mark Ahlstrom, UVIG, 2015

Unit Commitment and Dispatch

- Unit commitment and dispatch is a rolling optimization process
- “Dispatchable” does <u>not</u> mean being able to provide any desired amount of power at any specified time



Dispatch is not arbitrarily telling a generator what to produce…
It is knowing what is available for the dispatch period and optimizing the system as a whole

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Most Wind in North America is Dispatched Today

Most ISO/RTO systems now include wind in Day Ahead Unit Commitment and Security Constrained Economic Dispatch (SCED)

- Wind dispatch done with a 10-minute-ahead forecast or faster
  - Using the current telemetered value ("persistence" forecast)
    - NYISO, ERCOT, SPP
  - Using a rolling five-minute forecast ("persistence + model" forecast)
    - MISO, PJM, IESO
- Not a markets issue (markets may help, but this works anywhere)
  - Forecast wind into day ahead unit commitment
  - Dispatch the entire system (including wind) every five minutes using a very short term wind forecast or the current telemetered output value

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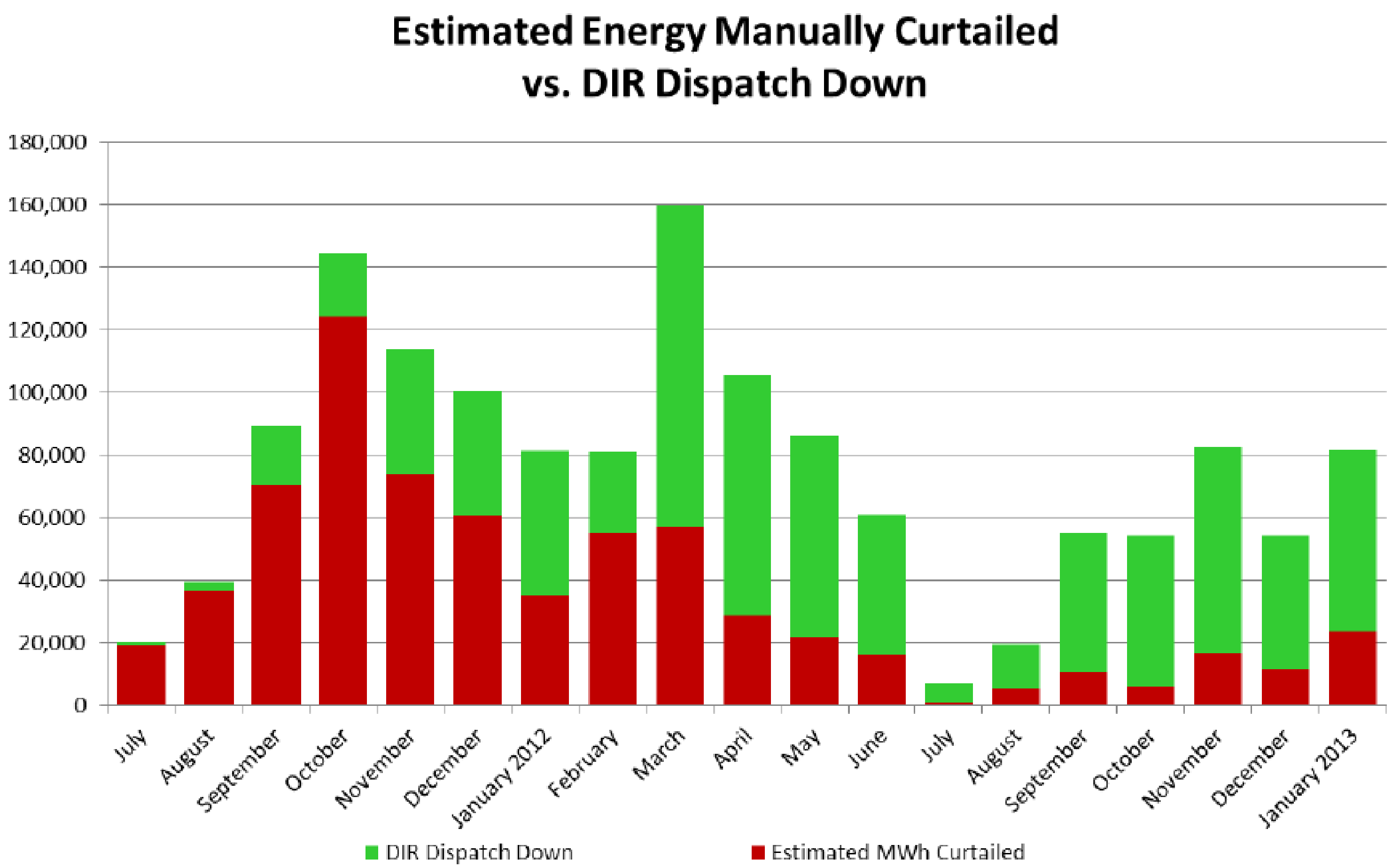
Impact of the DIR in MISO



Dispatching Wind Changes the Perception of the Problem

"Variability" is the change or error within the dispatch period

Uses a small amount of regulation

"Uncertainty" is mostly the error from the day-ahead forecast

Largely handled through the real time dispatch stack

May use some non-spin reserve for extreme situations

Is there a ramping or flexibility problem?

With a deep and robust real time dispatch… not really

- Wind ramping up - you have dispatch control of wind if needed
- Wind ramping down - units backed down & have room to move up

The concept of "net load" becomes irrelevant when wind and solar are dispatched… dispatched renewables become flexible generation rather than net load

Mark Ahlstrom, UVIG, 2015

Wind and Solar Plants are Power Plants

- **Dispatchable**
  - Easy if done right, high errors if "fuel characteristics" are ignored
- **Ride through disturbances**
  - Wind ride-through requirements exceed those of conventional generators per FERC Order 661A and exceed NERC Standard PRC-024 requirements
- **Provide frequency response and voltage control**
  - Implemented for wind in ERCOT and other regions
- **Impressive ramping and active power control**
  - Very fast and accurate response over entire capability range

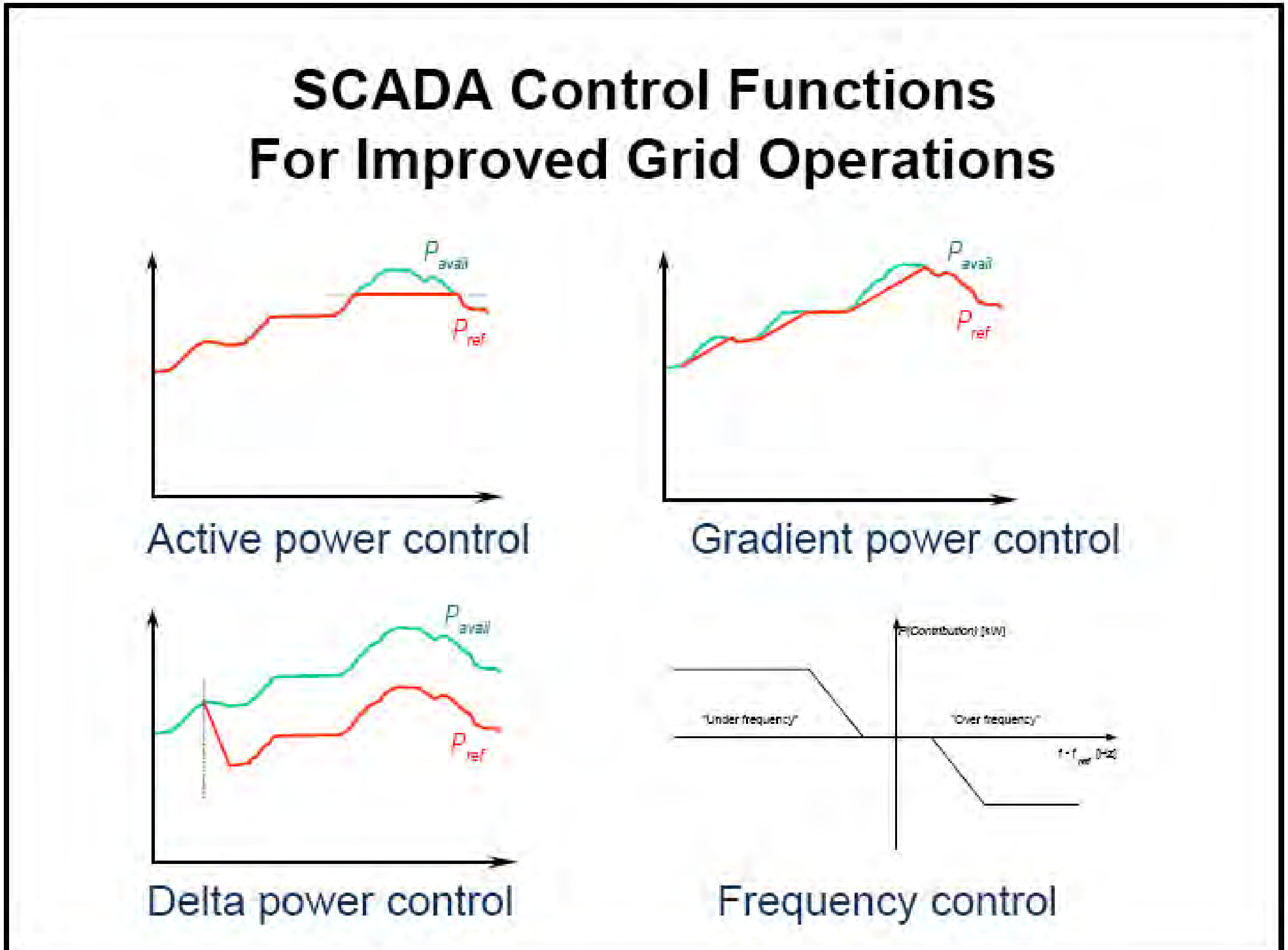
Utility-scale solar plants can support similar capabilities

Mark Ahlstrom, UVIG, 2015

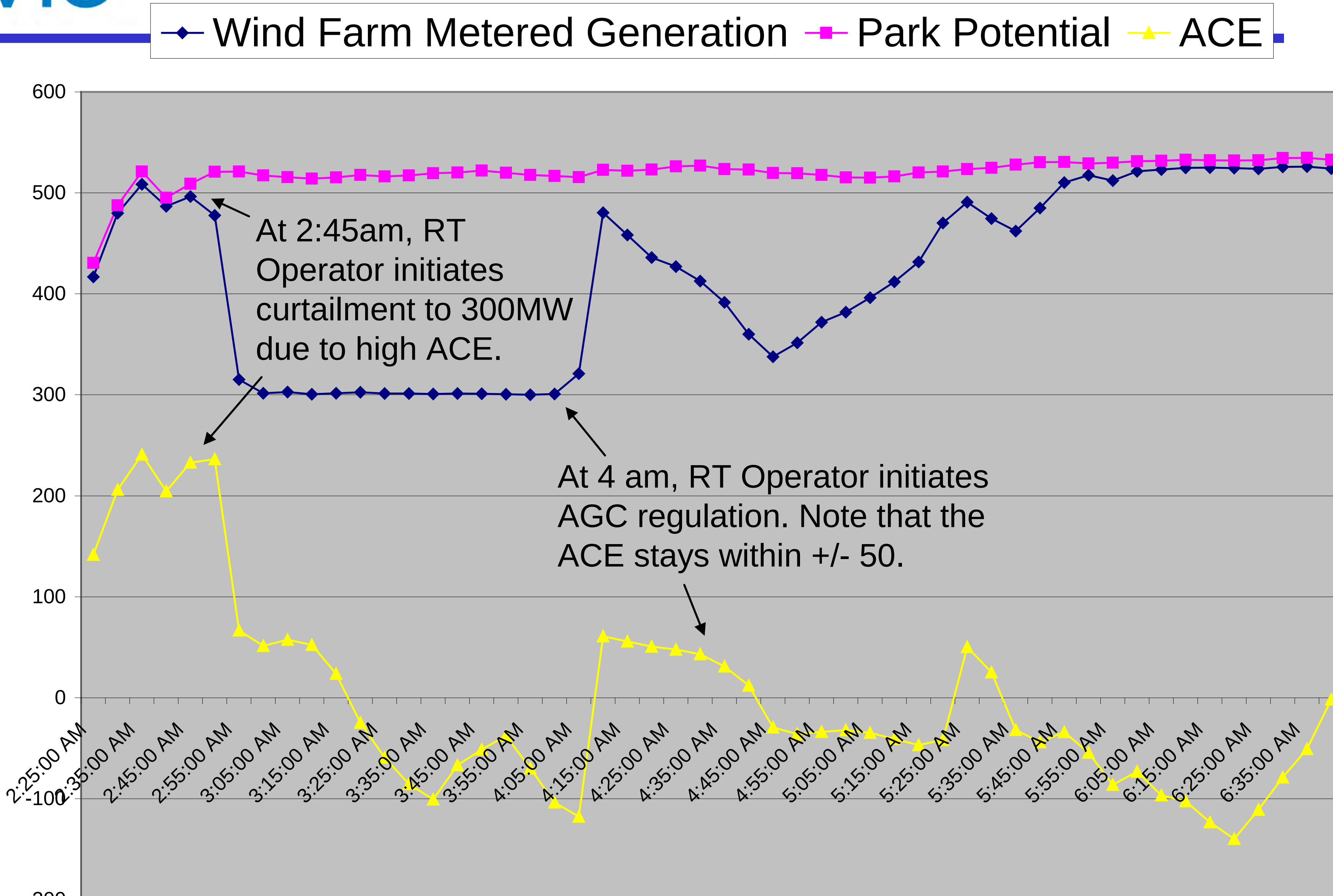
Grid Codes and Models

- Strong grid code is in the best interest of both the manufacturer/developer and the utility
  - Wind and solar power plants are very capable machines
  - VG plants must support system reliability requirements
- Grid code should identify the following requirements
  - Real power
  - Reactive power
  - Voltage and frequency ride through
  - Frequency and inertial response
  - Provision of ancillary services
  - Detailed dynamic models for facility interconnection study
  - Communications between plant and grid operator

Turbine Technology Advances Reduce Operating Impacts



Xcel Wind Plant on AGC

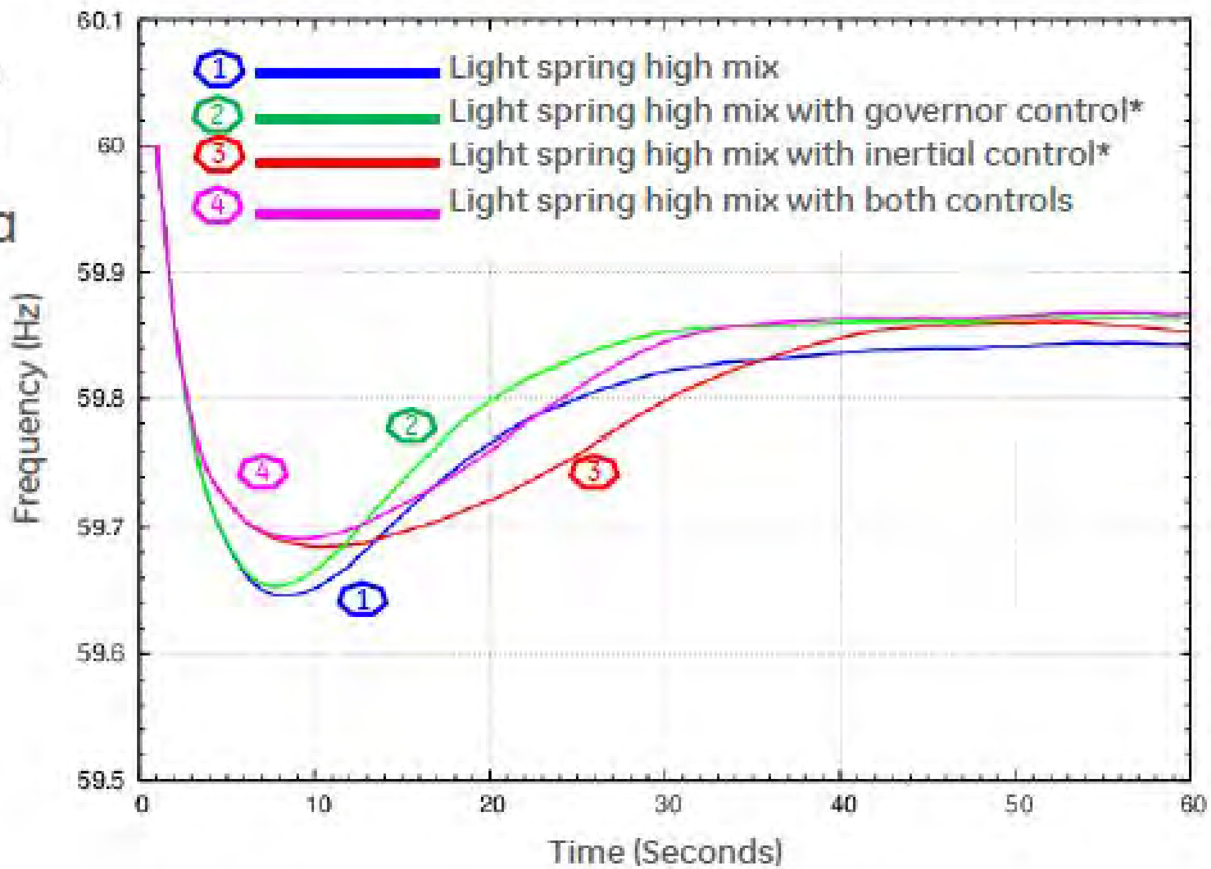


Conclusions from a Recent GE Case Study

- WECC 20% Electricity from Wind Scenario
  - Systems with high wind penetration can exhibit superior frequency performance
  - Presently available wind plant controls can contribute positively to system frequency performance
  - "It is *possible* for systems with wind generation to experience degraded frequency performance"
  - "Statements that wind generation *necessarily* results in degraded frequency performance are *incorrect*"

Frequency Control on Wind Plants – WWSIS Phase 3 Results

40% of wind plants (i.e., new ones) had these controls, for a total of 300 MW initial curtailment out of 27GW production



Disturbance: Trip 2 Palo Verde units (~2,750MW)

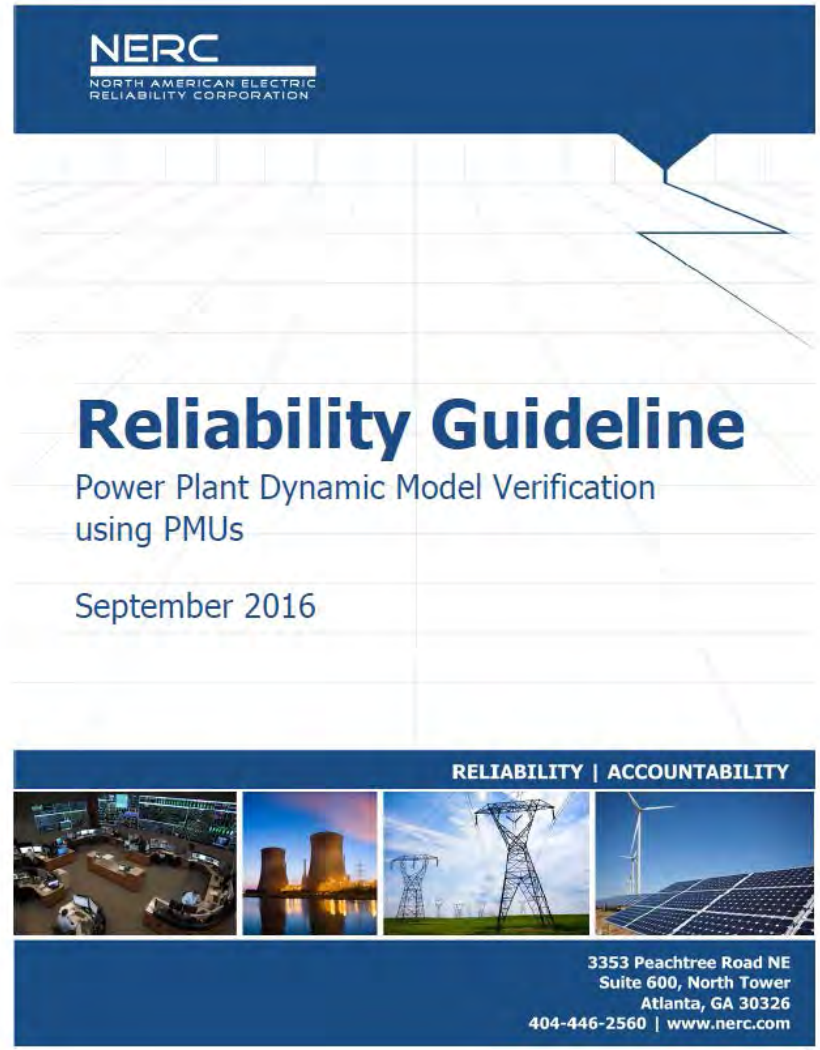
Nick Miller, UVIG, 2015

A Few Comments on …

- Governor control - this feature has been available on wind turbines and wind plants for at least 10 years, and is now available on solar plants
- Synthetic inertial response – this feature has been available on wind turbines and plants for at least 8 years; similar fast frequency control capability can be obtained from curtailed utility solar PV plants
- Voltage control - This feature has been available on wind turbines and wind power plants for over 10 years, and is now available on solar plants. It is difficult to purchase a plant without it.

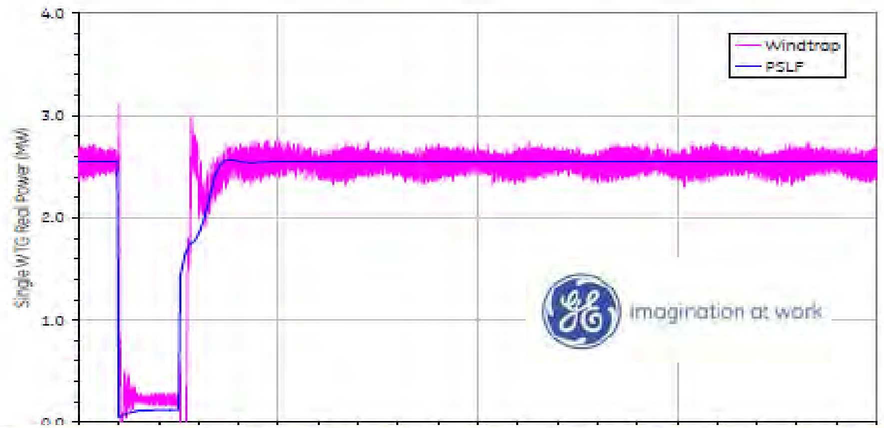
Reliability Guideline: Power Plant Dynamic Model Validation using PMUs

- Guideline approved by NERC Planning Committee Sept 2016
- Overview of mechanics and considerations for performing disturbance-based verification
- Appendix of available playback model and tools
- First step in supporting industry with model verification

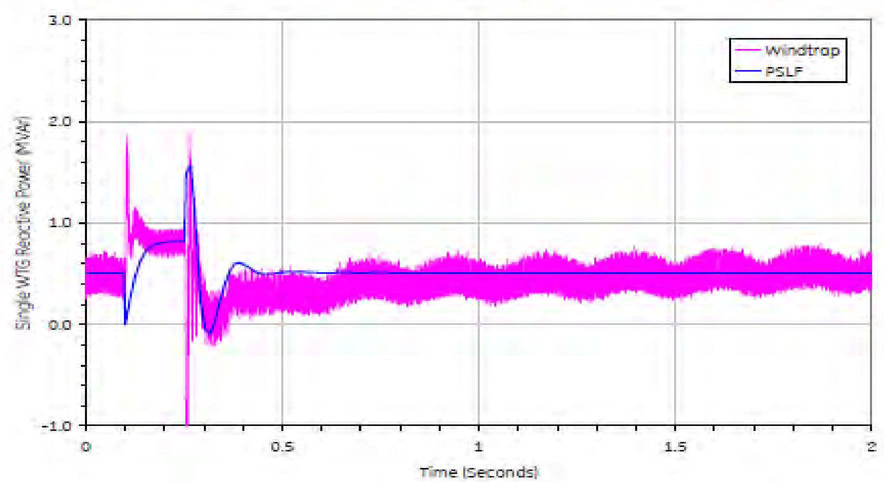


Analytical Validation Example – GE 2.5 MW Type IV

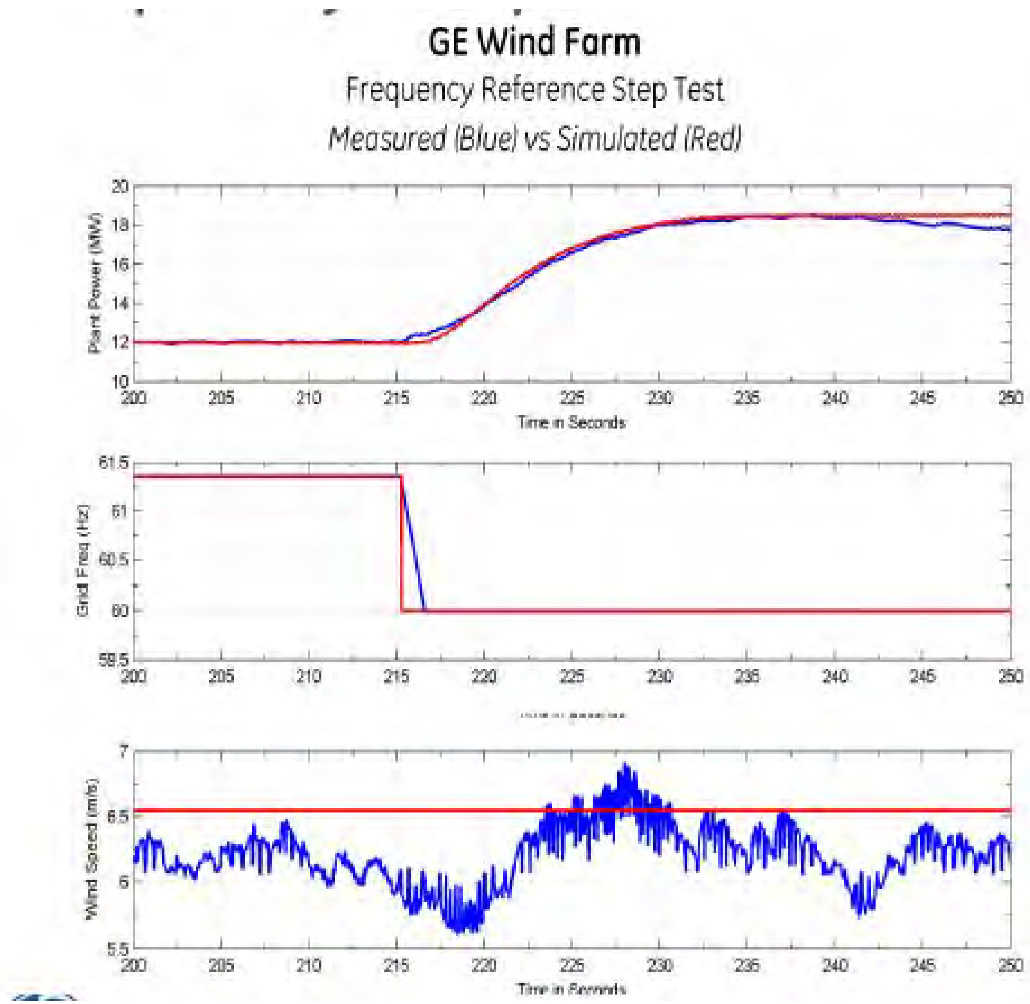
2.5 MW Full Converter PSLF and Windtrap Real Power Response



2.5 MW Full Converter PSLF and WindTrap Reactive Power Response



Field Test and Model of GE Wind Plant Frequency Response



- 83 MW plant in Alberta
- Test is *release* of high frequency input
- Std GE WTG model (wndtge); parameters tuned for this plant

McDowell, Miller, UVIG, 2015

Some Recent FERC Activity

- Notice of Inquiry (NOI) in Docket No. R16-6-0003 on primary frequency response
- FERC Order 827 on Reactive Power Requirements for Non-Synchronous Generation
- FERC Order 828 on Requirements for Frequency and Voltage Ride Through Capability of Small Generating Facilities

General Recommendations

- Install reliability services capabilities in new wind & solar plants
  - All power plants should contribute to maintaining system reliability in ways that make economic sense given their fuel and technology characteristics
  - All power plants should ride through disturbances
  - Not every plant needs to provide every reliability service at all times
- Support performance-based, technology-neutral standards
  - Focus on operating performance outcomes
    - » Discretion on how to achieve performance requirements
- We will learn and adapt as the generation mix changes
  - These are good engineering problems

Mark Ahlstrom, UVIG, 2015

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Transmission Adequacy

- Transmission planning for energy sources
  - Planning driven by LMP differences
  - Look at 8760 hours instead of peak load hour
  - New contingencies likely around times of minimum load and minimum conventional generation
  - Need wind integration study to determine ancillary service requirements
  - LOLE and ELCC calculations likely to modify planning reserve margins
- HVDC system design, use and justification across synchronous zones for aggregation, diversity and control benefits

Transmission Adequacy Recommendations

- Develop adequate transmission capacity – can't meet renewable energy goals without it
- Comprehensive regional planning processes, i.e. FERC Order 1000 is a good start
- Inter-regional cost allocation for high voltage lines
- More certainty of transmission cost recovery
- Develop and maintain strong grid codes
- More robust and flexible "smart" grid to enable participation of load and PHEV

Benefits of Broad Geographical Markets

- More reliable and less expensive to operate a system that aggregates diverse resources across broad geographic regions
- Coordination and trading in regions with wholesale power markets can:
  - Integrate higher levels of wind and solar
  - Result in better use of existing assets
  - Help keep costs low as coal plants retire and air gets cleaner

When is VG Integration Difficult?

- Inefficient VG dispatch
  - » Using hour- or day-ahead forecasts
  - » Lack of visibility and control
- Limited export and interchange capabilities
- Minority of generators dispatched or offering flexibility
  - » Generation is self-scheduled or viewed as "can't touch"
  - » Incentives discourage using/building flexibility
  - » "Inflexible floor" pushes other generation out of dispatch and creates a min-gen situation when VG output is high

System-wide constraints may make it difficult to commit flexibility and maintain a robust dispatch stack, creating "ramp scarcity"

Mark Ahlstrom, UVIG, 2015

Alternative Market Design

- New market paradigm?
  - Less revenue from energy
  - More revenue from capacity/flexibility and ancillary services

Energy versus Services & Capacity?

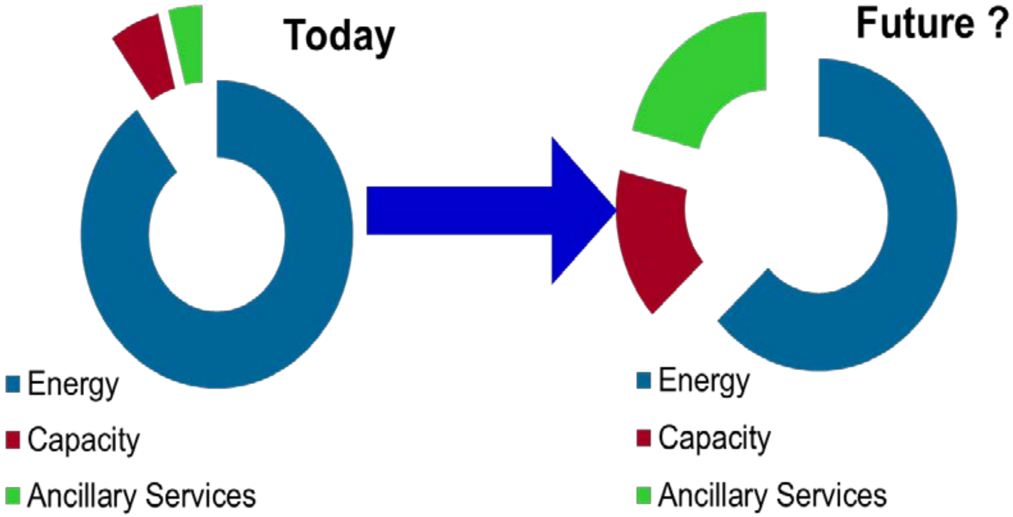

Figure courtesy of EPRI

Revenue mix will change, but paths and values are uncertain

- Capacity markets vs. long-term contracts vs. rate-based plants…
- Ample supplies of services may lead to low values
- New sources of services and flexibility are likely

Outlook for Wind and Solar

- In spite of the stay issued by the Supreme Court in the implementation of the CPP …
- Corporate America is on board with renewable energy
- The expectation is that there is no turning back the clock
- Low cost renewables and customer demand are driving increasing interest in carbon-free electricity
- A lot of experimentation is going on in markets to understand the value of flexibility and A/S from DR, storage and other new sources. VG should be included.
- Markets provide an opportunity to let all resources compete on a level playing field and help market participants understand the value of new services

and the conclusion is…

- There are no fundamental technical barriers to the integration of 30% to 40% or more wind and solar energy into the electrical system, but…
- It will not be accomplished with a business as usual scenario
- There needs to be a continuing evolution of transmission planning, system operating policy, market development and cross-border cooperation for this to be achieved

For More Information

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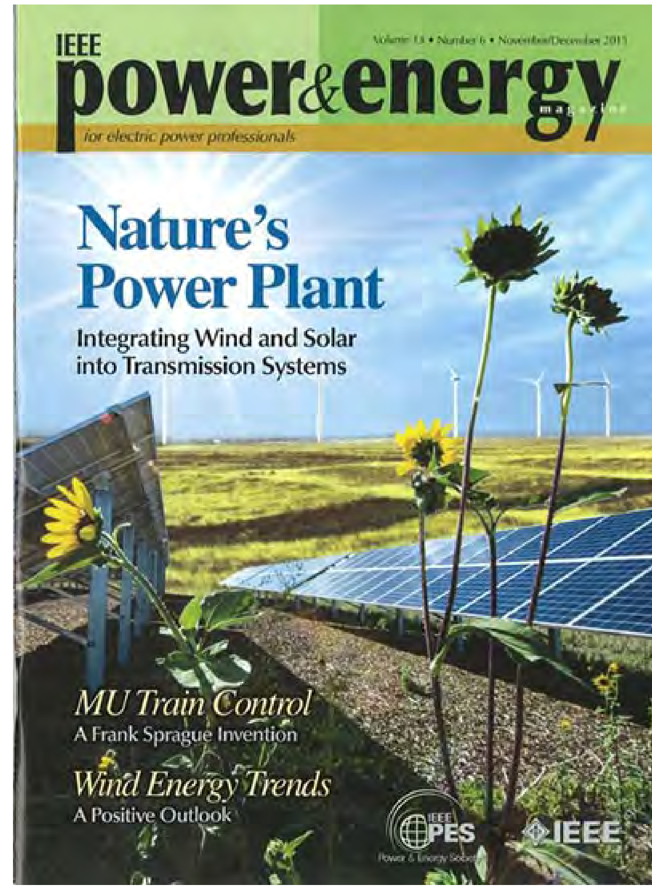
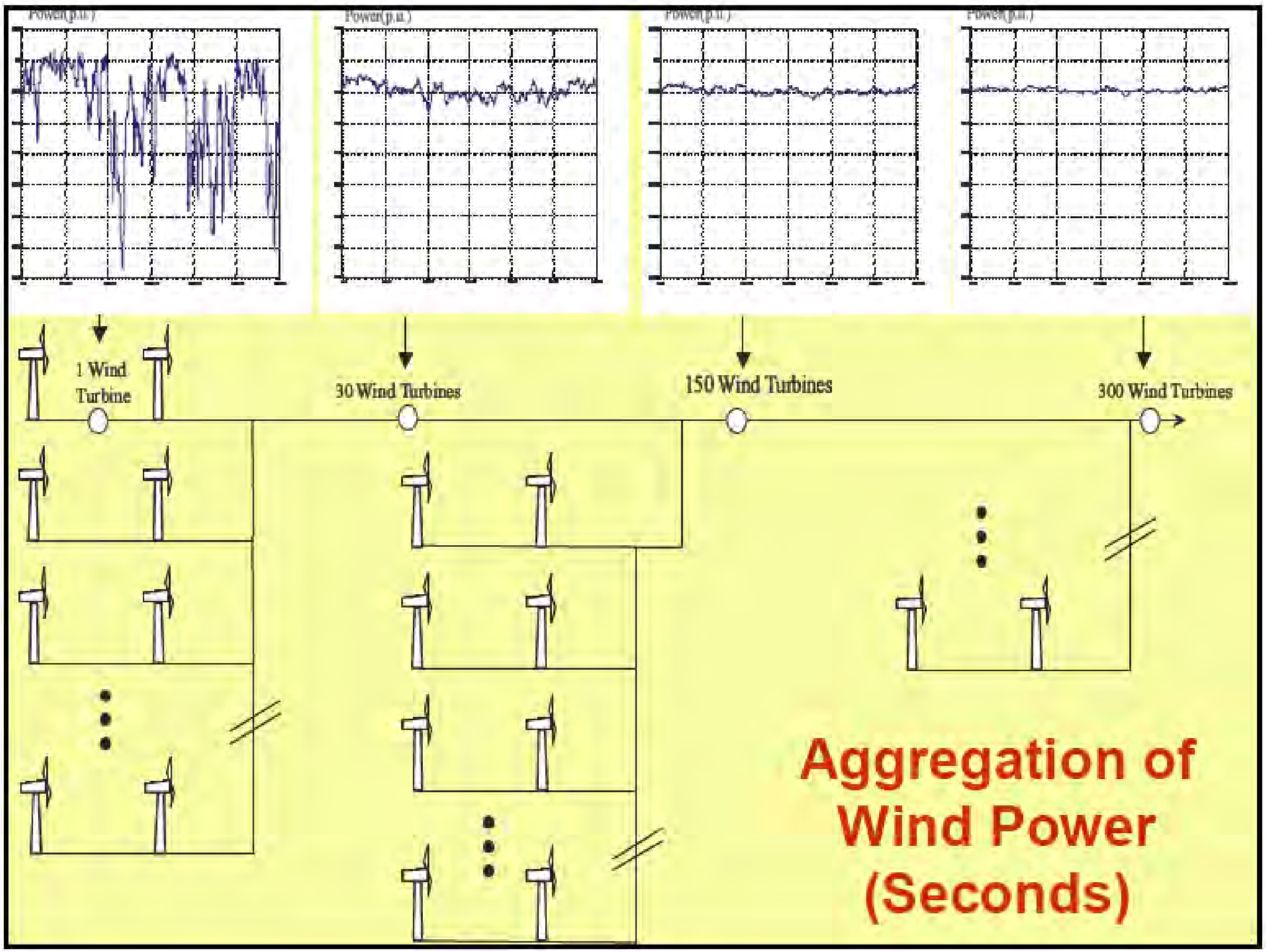


Additional Slides

What If the Wind Stops Blowing Everywhere at the Same Time?

- Meso-scale wind forecasting techniques provide the answer
- Significant benefit to geographical dispersion
  - Dispersion provides smoothing in the long term
  - Aggregation provides smoothing in the short term
- Extensive modeling studies have shown no credible single contingency leading to simultaneous loss of capacity in a broad geographical region

The Power of Aggregation

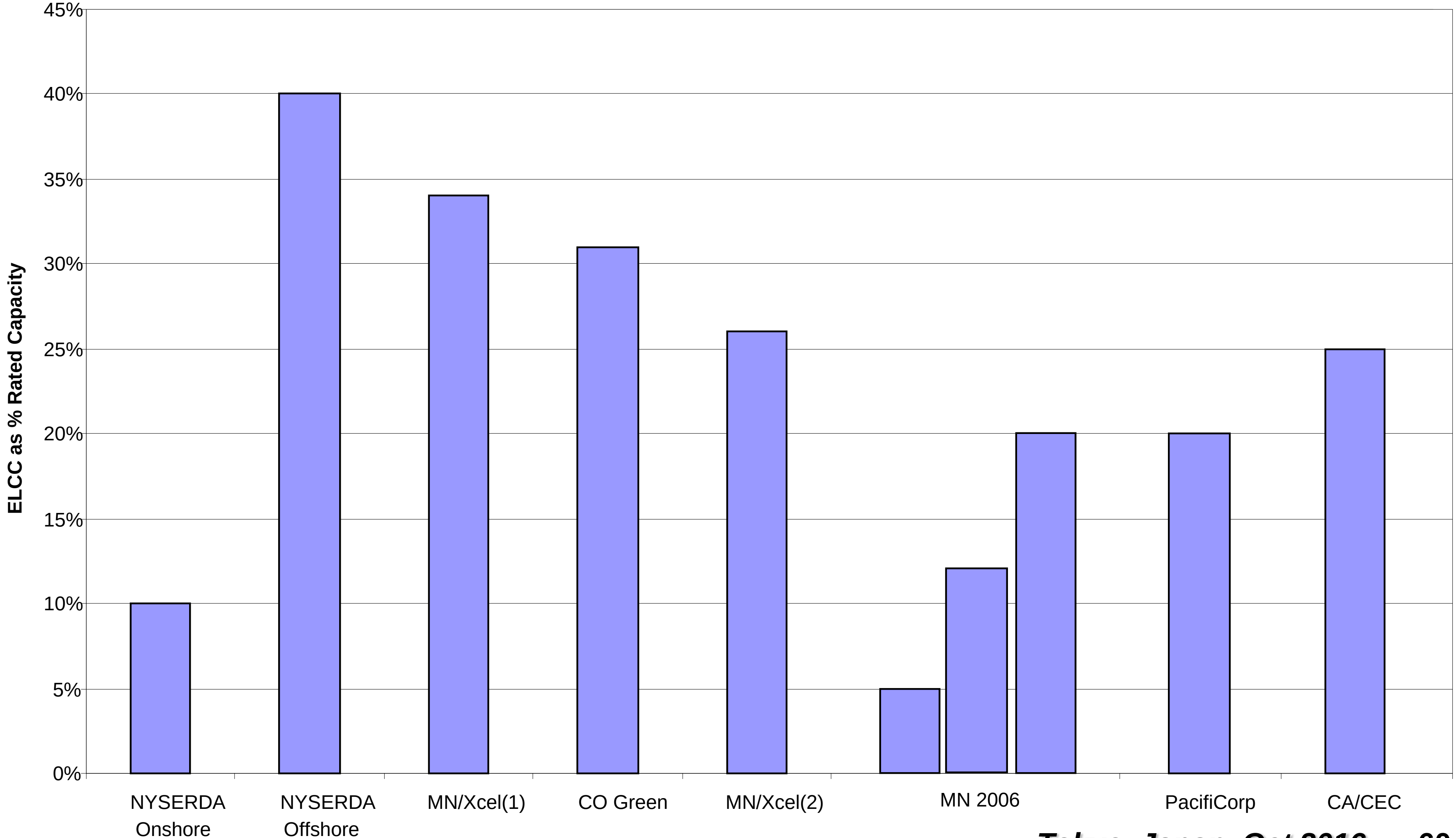


Source: Thomas Ackermann, Energynautics

What To Do When the Wind Doesn't Blow

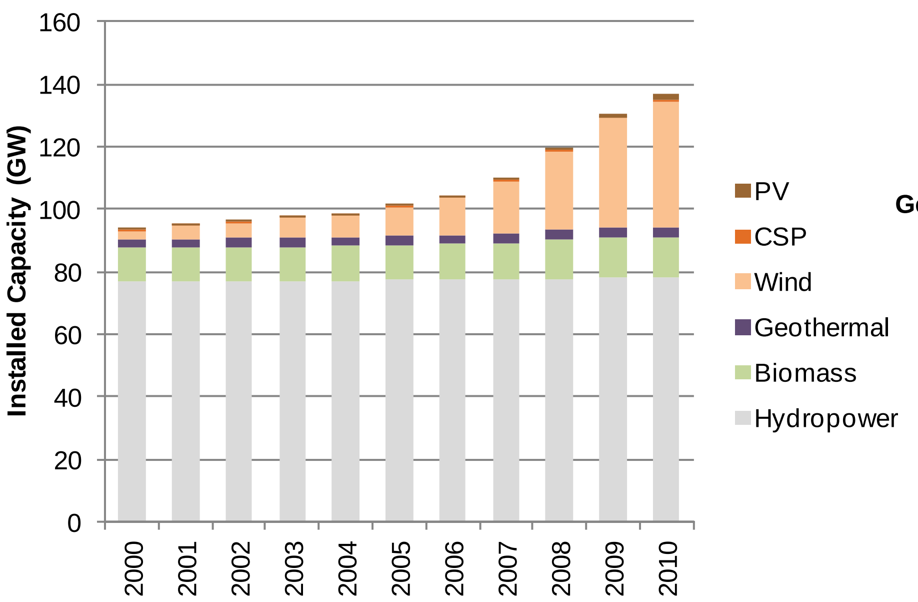
- Good question!
- Must deal with energy resource in a capacity world
- Dealt with through probabilistic reliability methods used to calculate Effective Load Carrying Capability (ELCC)
- Contribution may be large (40%) or small (<5%)
- Once the ELCC is determined, get on with the job of designing a reliable system
- And that means adding more flexible capacity in the future!

An Energy Resource in a Capacity World



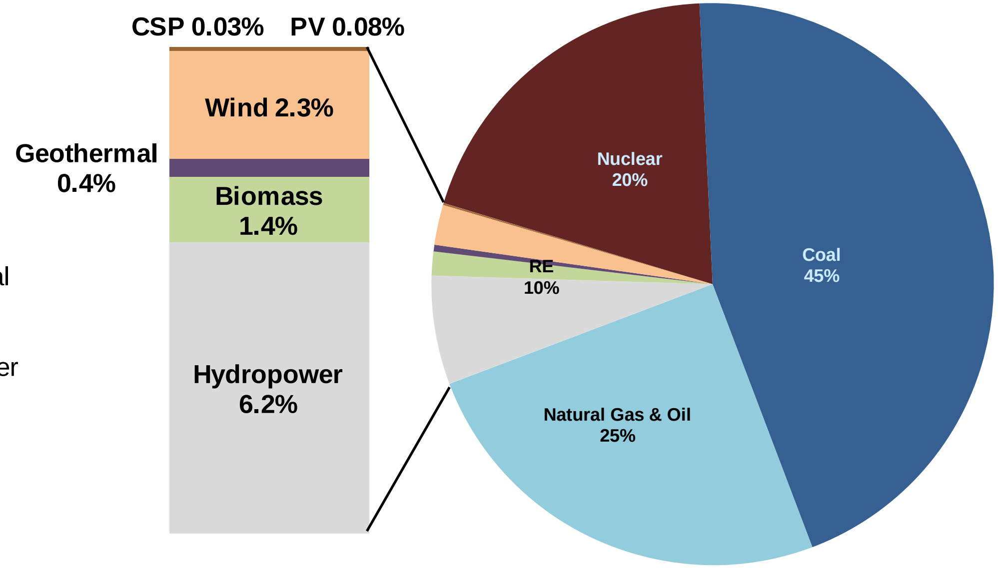
Renewable Electricity Futures (REF) Study Motivation

RE Capacity Growth 2000-2010



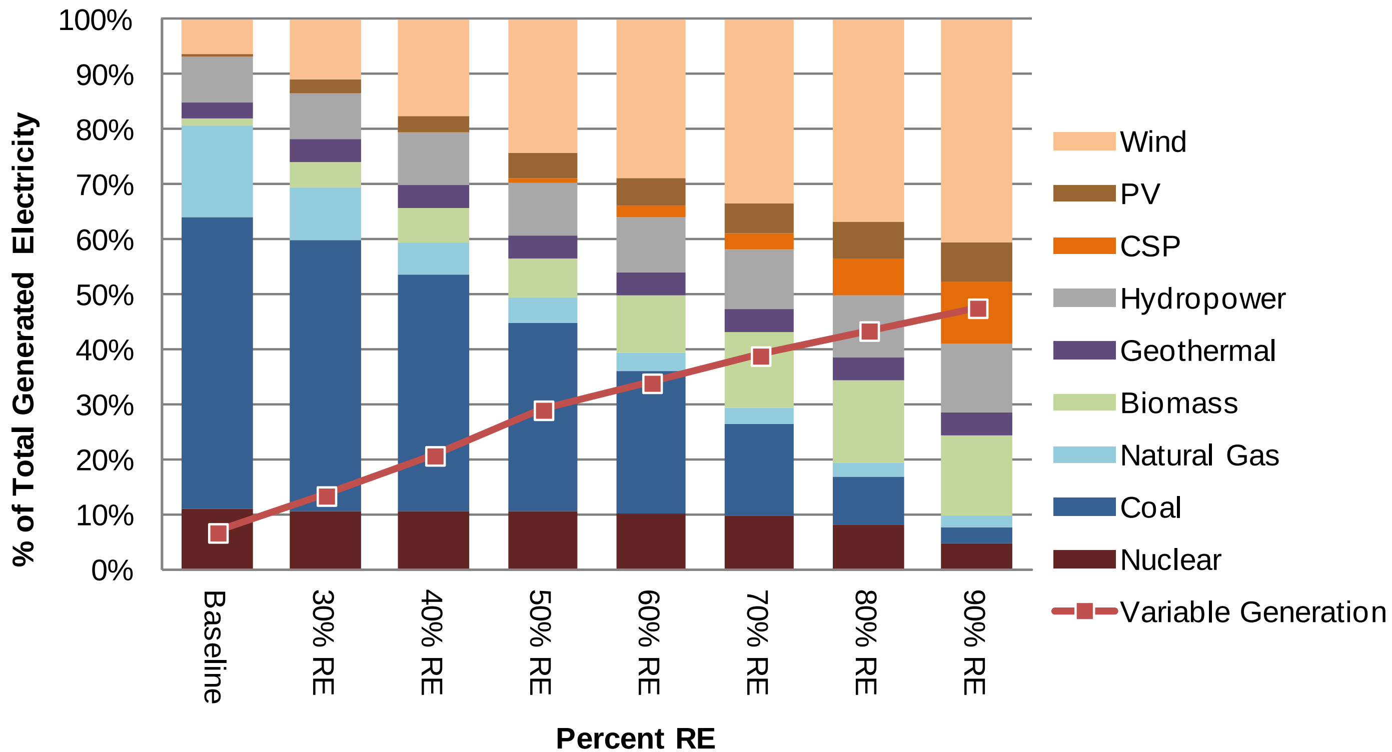
Source: RE Data Book (DOE 2011)

2010 Electricity Generation Mix



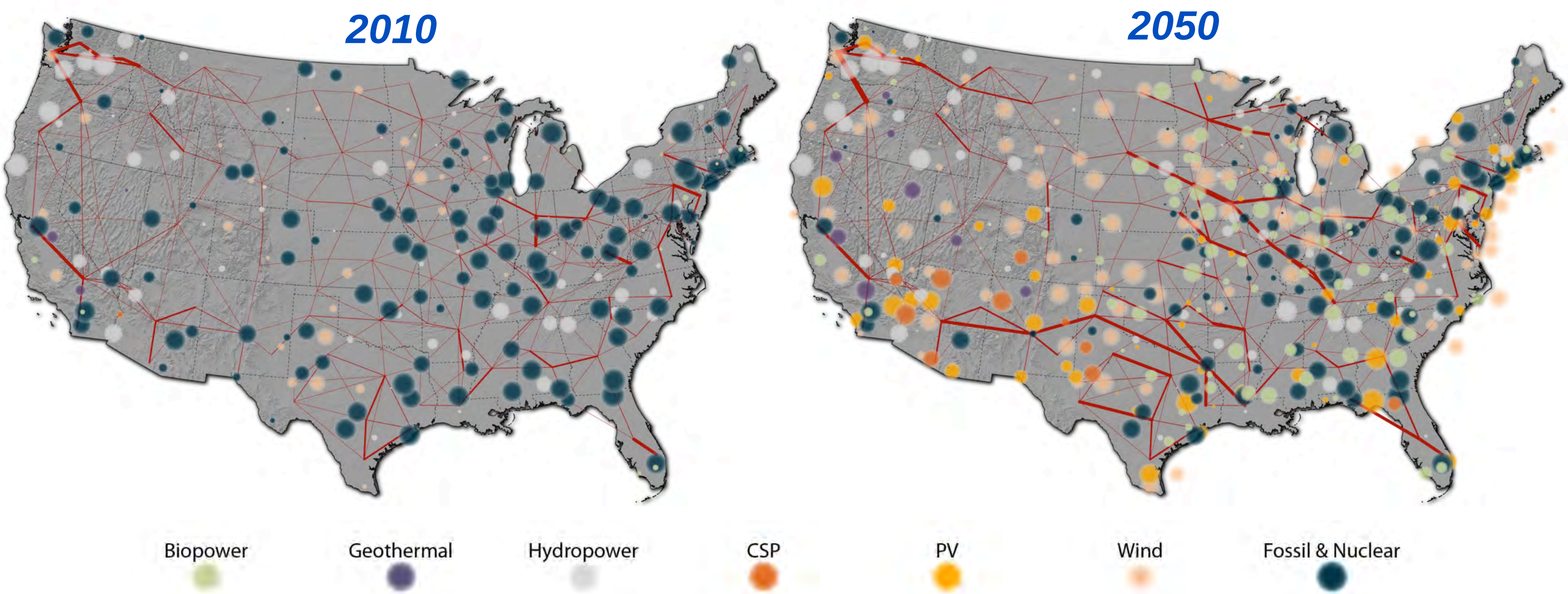
- RE is a low carbon, low air pollutant, low fuel use, low water use, domestic, sustainable electricity source.
- To what extent can renewable energy technologies commercially available today meet the U.S. electricity demand over the next several decades?

RE Resources Supply from 30% - 90% Electricity



Additional variability challenges system operations, but can be addressed through increased use of supply and demand-side flexibility options and new transmission.

A Transformation of the U.S. Electricity System



RE generation from technologies that are commercially available today, in combination with a more flexible electric system, is more than adequate to supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country

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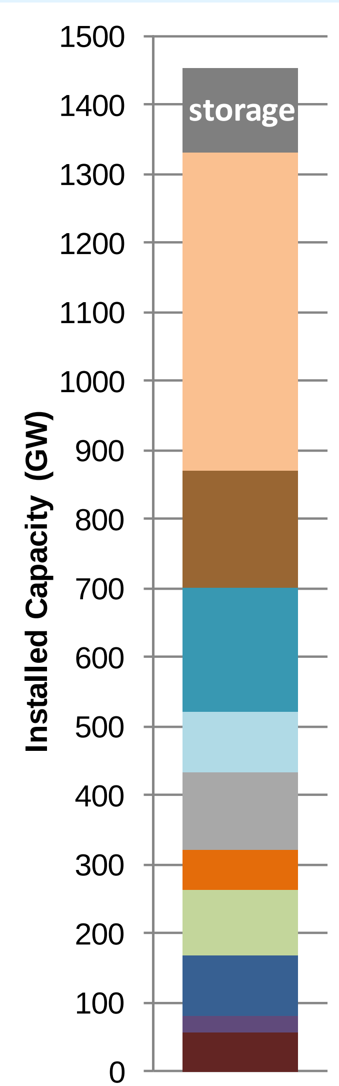
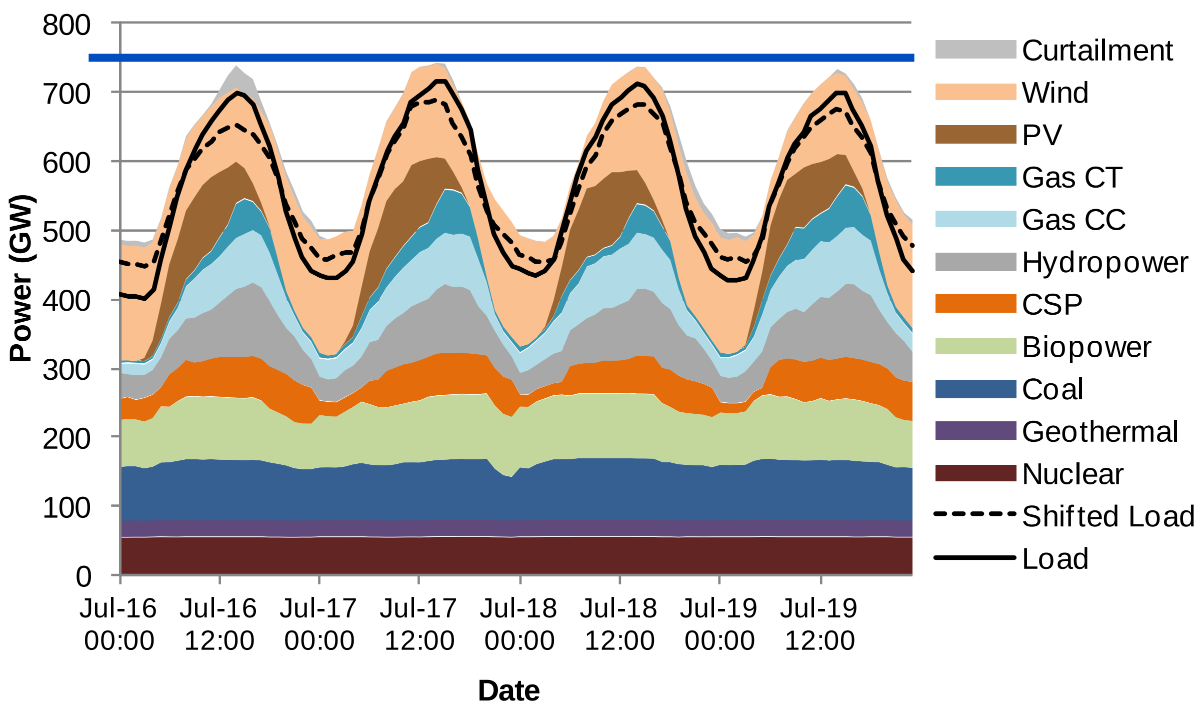
Supply and Demand Balanced Every Hour of the Year



Installed capacity is sufficient to meet summer afternoon peak demand from diverse reserves including:

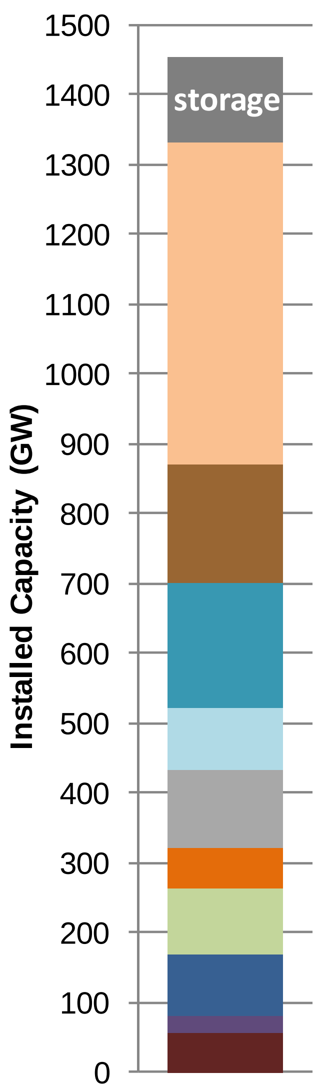
- Biopower
- Geothermal
- Hydropower
- CSP with storage
- Gas
- Coal
- Nuclear
- Utility-scale storage

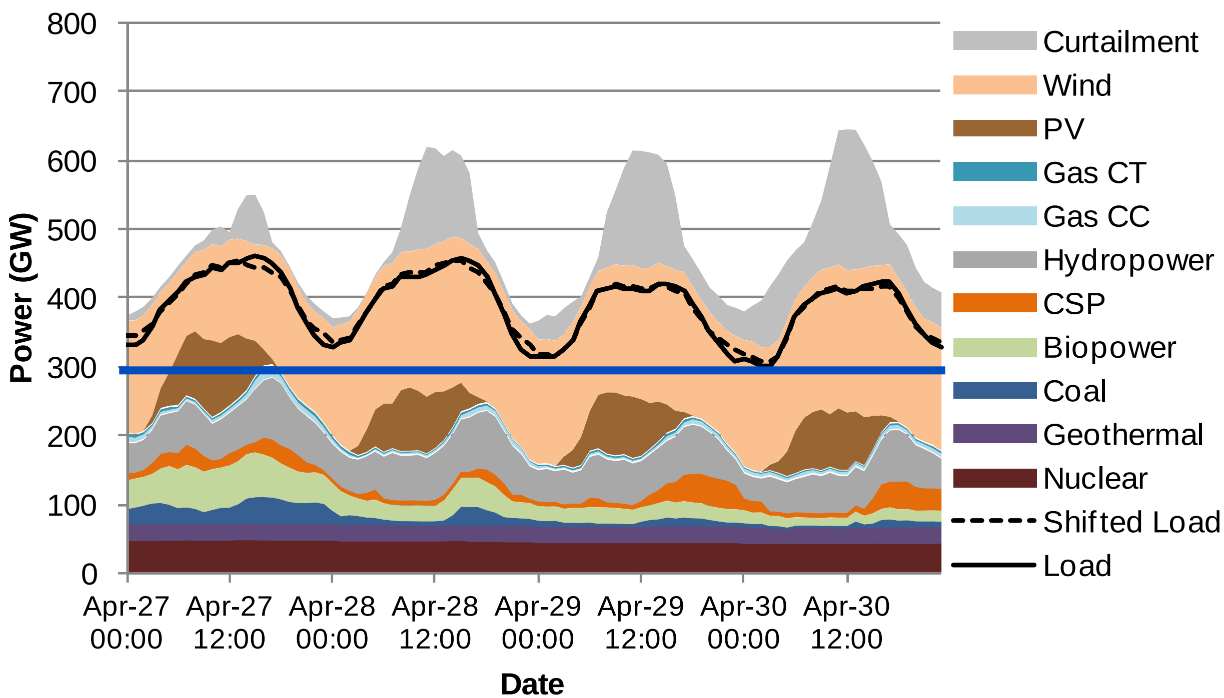


Flexible Electricity System Manages Variability

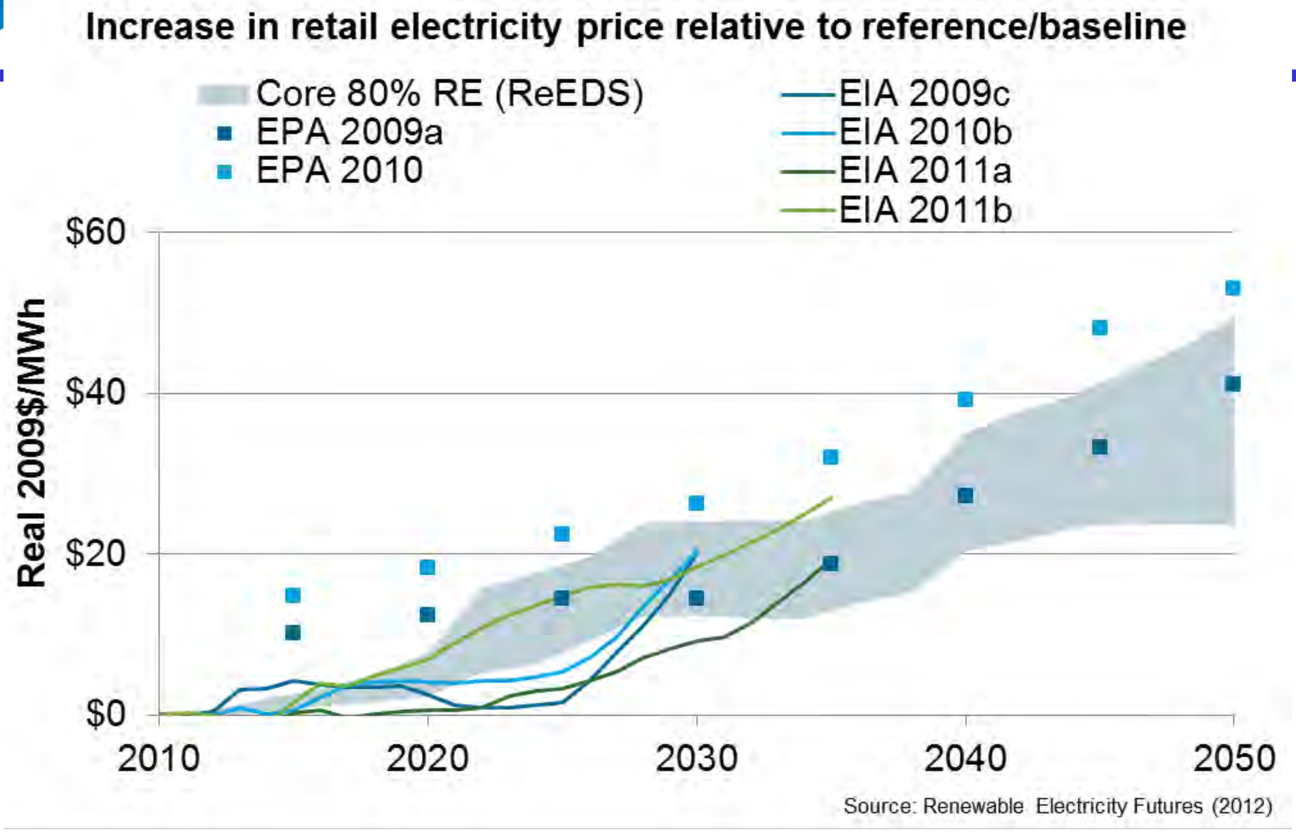
Especially during low-demand periods in the spring months a broad portfolio of supply and demand-side flexibility options are used, including:

- Ramping and cycling fossil and some RE plants
- Reserve sharing over larger geographic areas
- New Transmission
- Utility-scale storage
- Demand response





Renewable Futures Cost Comparison



- The estimated incremental cost of high RE scenarios is comparable to published cost estimates of other clean energy scenarios.
- Improvement in the cost and performance of renewable technologies is the most impactful lever for reducing this incremental cost.