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Integrating High Levels of Variable Renewable Energy Sources

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Troy, NY
May 6, 2016

EPRI Grid Operations & Planning R&D Area at a Glance

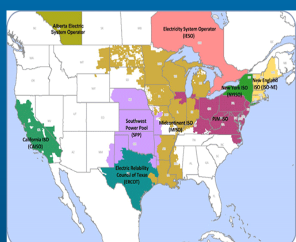
Grid Operations

- Operator Visualization
- Synchrophasor Applications
- Operating Limit Assessment
- Reactive Power & Voltage Management & Control
- System Restoration Support

Grid Planning

- Modeling & Validation
- System Protection
- Risk-Based Planning
- Contingency Screening
- Special Planning Studies (GMD, TOV, etc.)

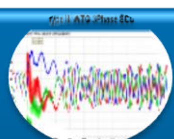
Market Operations



- Technical Market Design
- Market Software Implementation
- Price Formation
- Energy, Ancillary Services, FTRs, Capacity

Bulk Renewables Integration

- Modeling & Protection
- Flexibility Planning
- Operator Tools for Variability & Uncertainty
- Voltage & Frequency
- DER Impacts on Bulk System

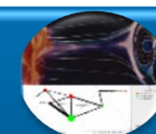


Model Development & Validation

Reliability Analysis Methods/Tools

Economic Analysis Methods/Tools

Decision Support Methods/Tools



Operator/Planner Reference Guides

Common approach to all programs

Agenda

- What are the characteristics of Variable Energy Resources?
- Impacts of VER on system planning
- Impacts of VER on bulk power system operations
- Impacts of VER on electricity market design and market operation
- Research projects and needs

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Why Does VER Present Operating Challenges

Key VER Characteristics that May Result in Power System Reliability and Economic Impacts

1. **Variability**
   - Available power from VG changes at different timescales
   - Ramp needs of other resources, frequency control
2. **Uncertainty**
   - Available power from VG not known with perfect accuracy
   - Reserve needs, commitment error, economic and reliability impacts
3. **Inverter-based, non-synchronous**
   - Does not respond autonomously to events, creates weaker portions of the grid
   - disturbance voltage and frequency performance
4. **Location of connection**
   - Bulk system VER – Far from loads, needs transmission
   - Distribution system VER – Limited controllability and observability
5. **Cost distribution**
   - High capital, low or zero operating
   - Negative prices, revenue sufficiency, scheduling and market impacts

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Planning, operations and markets

SYSTEM PLANNING

Build and modify the technologies that are needed to meet predicted future needs.

How much to build?

Where to build?

What to build?

Hand off a system that wi
the operators use it ef

SYSTEM OPERATIONS

Operate the existing system by making decisions at different timeframes that will ensure reliability and efficiency

Who, how much, where to turn on?

how much, where to dispatch P&Q E&R?

t, where to prepare for and correct
during events and emergencies?

iability, if the independent
s do as directed.

MARKET OPERATIONS

Incentivize the resources that are assisting in meeting planning and operations objectives, so that they have reason to do so.

Incentivize how much, what, where to build

Incentivize how much, what, where to provide energy and services?

How to ensure fair, efficient, transparent provision while limiting market power potential

As long as the decisions are right, ensure that independent entities will have reason to follow those decisions.

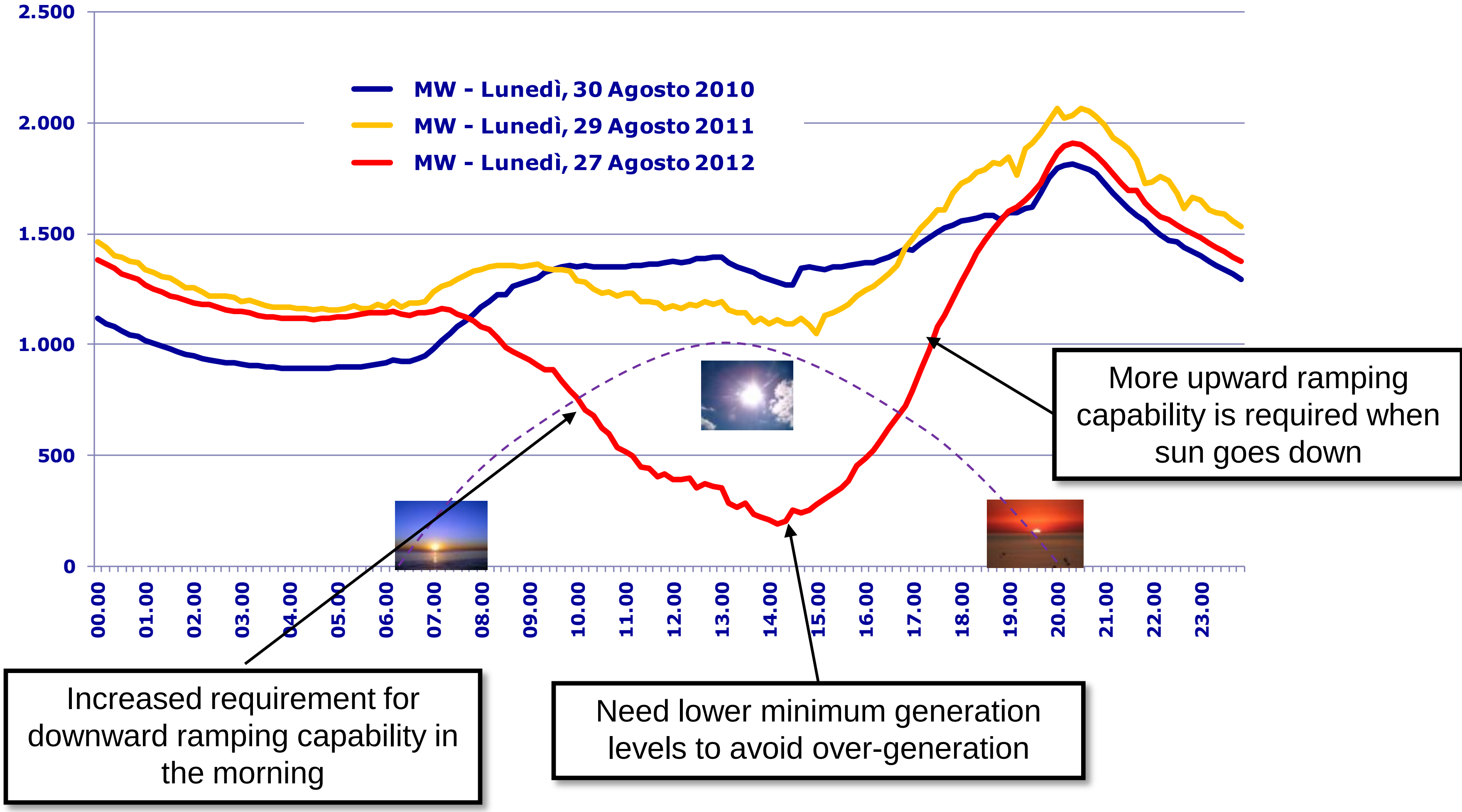
Impact of VER on Planning

Challenges

- Determining the capacity value of VER
- Understanding the multitude of scenarios needing to be studied with high VER systems
- Does the future installed capacity require more than just MW

The "Duck" Curve

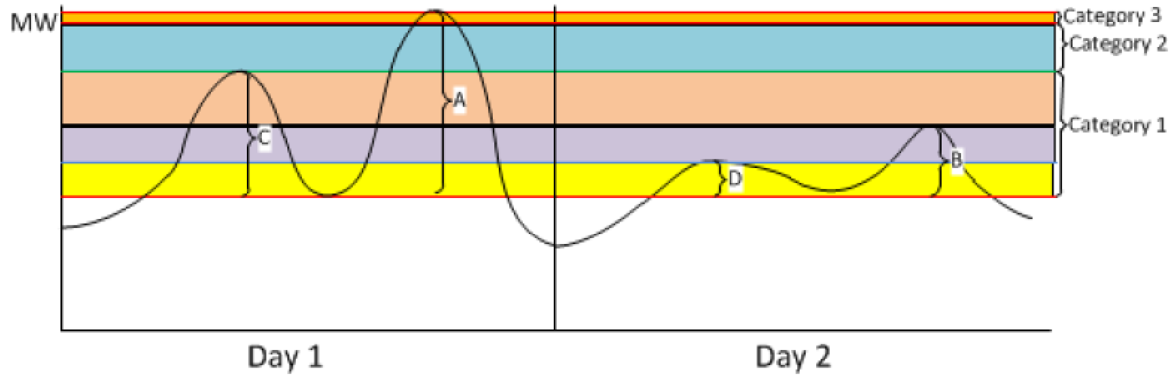
Not Just Resource Adequacy but the Adequacy of Resource of the Right Type

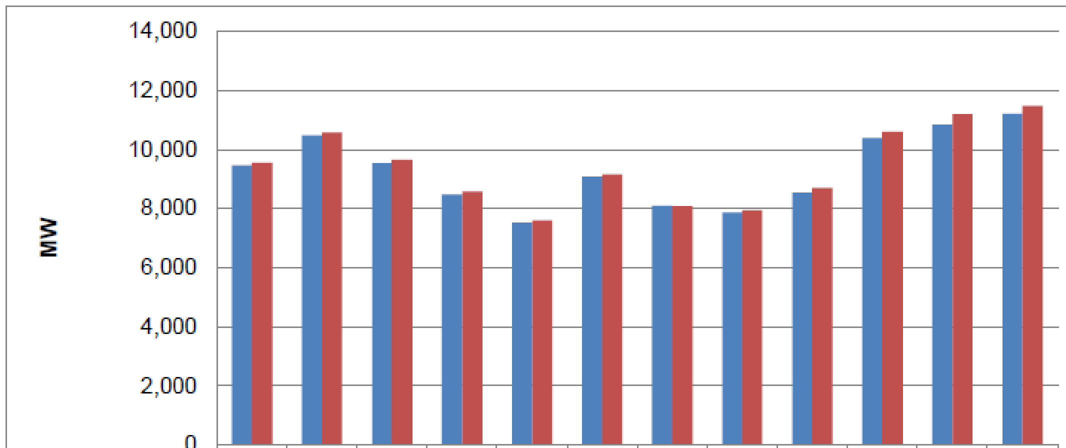


Source: *ENEL – Measured Data from Southern Italy*

California Flexible Capacity Procurement

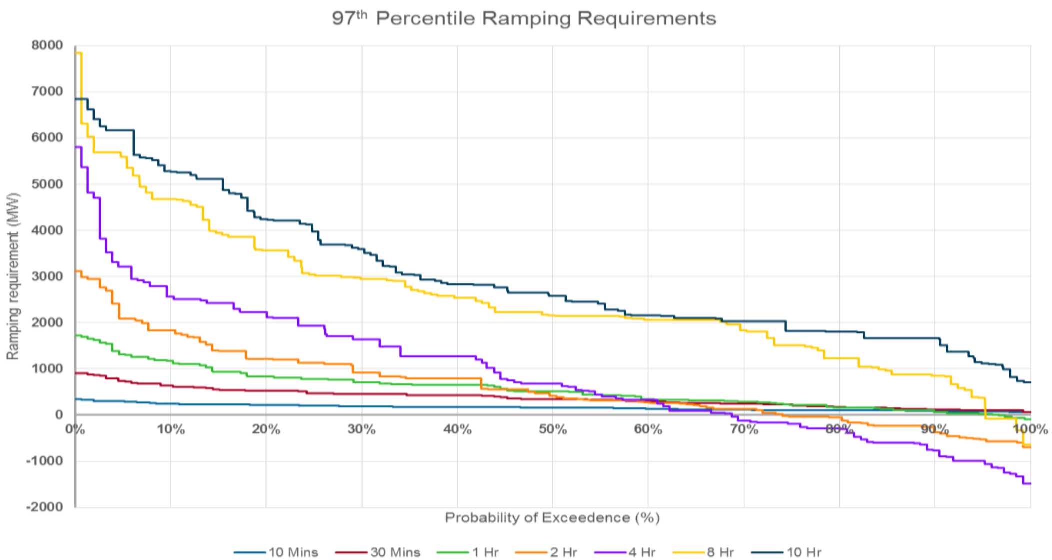
- Flexible ramp need: Max 3-hour ramp rate per month + Contingency reserve
- Three types:
  - Base flexibility
  - Peak flexibility
  - Super-peak flexibility
- Allocation to system flexibility capacity needs allocated to LSEs based on contribution to 3-hour net load ramp





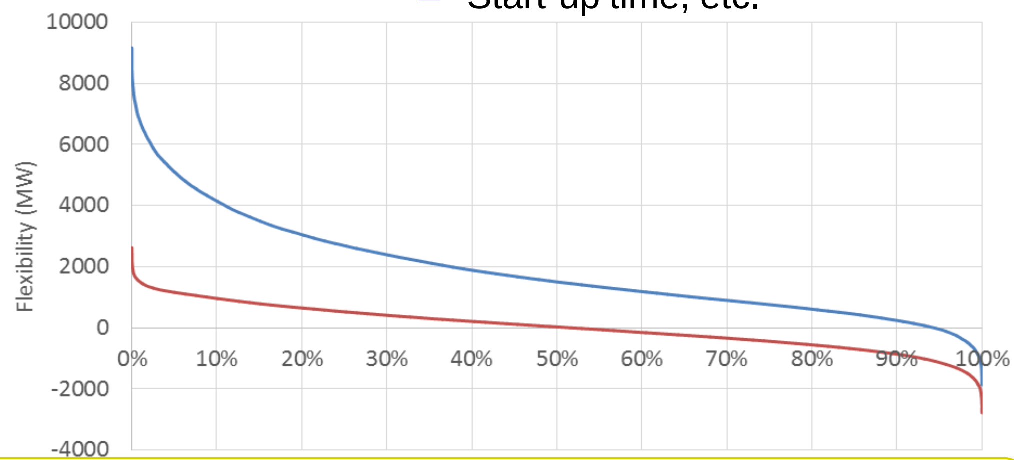
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flex_Req_2015	9,459	10,465	9,543	8,468	7,520	9,078	8,083	7,861	8,523	10,381	10,848	11,212
Flex_Req_2016	9,550	10,589	9,656	8,560	7,596	9,166	8,072	7,934	8,706	10,610	11,209	11,477

Flexibility Metrics



- What horizon are flexibility needs most constraining?
- How do you measure flexibility needs?
- What attributes are most crucial?
  - Ramp rate
  - Min gen
  - Start-up time, etc.

- Can renewable curtailment be relied upon for flexibility needs
- What about locational flexibility needs?
- Do these metrics lead to installed flexibility needs?



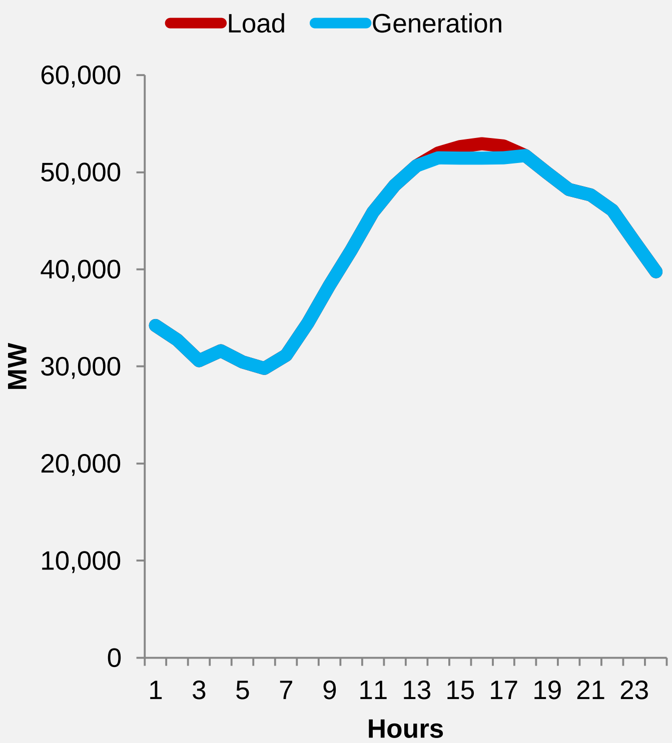
Tools and methods are required to provide planners with flexibility assessment information

Definitions of Existing and New Reliability Metrics

Traditional "Generic Capacity" Metrics

LOLE$_{\text{GENERIC-CAPACITY}}$

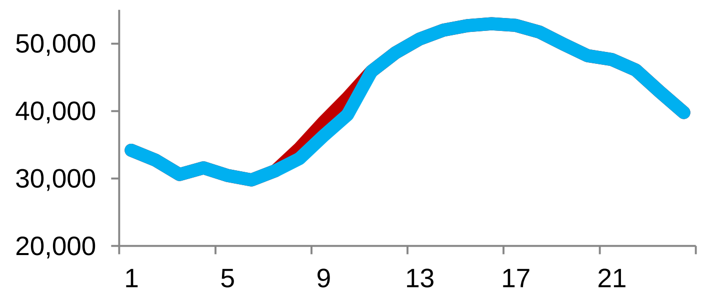
Traditional metric to capture events that occur due to capacity shortfalls in peak conditions



New "Flexible Capacity" Metrics

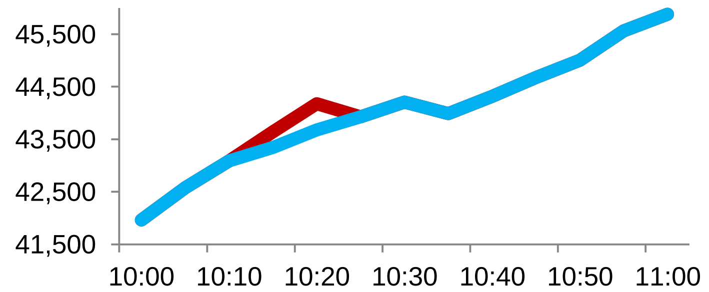
LOLE$_{\text{MULTI-HOUR}}$

New metric to capture events due to system ramping deficiencies of longer than one hour in duration



LOLE$_{\text{INTRA-HOUR}}$

New metric to capture events due to system ramping deficiencies inside a single hour



CPUC Workshop – Draft

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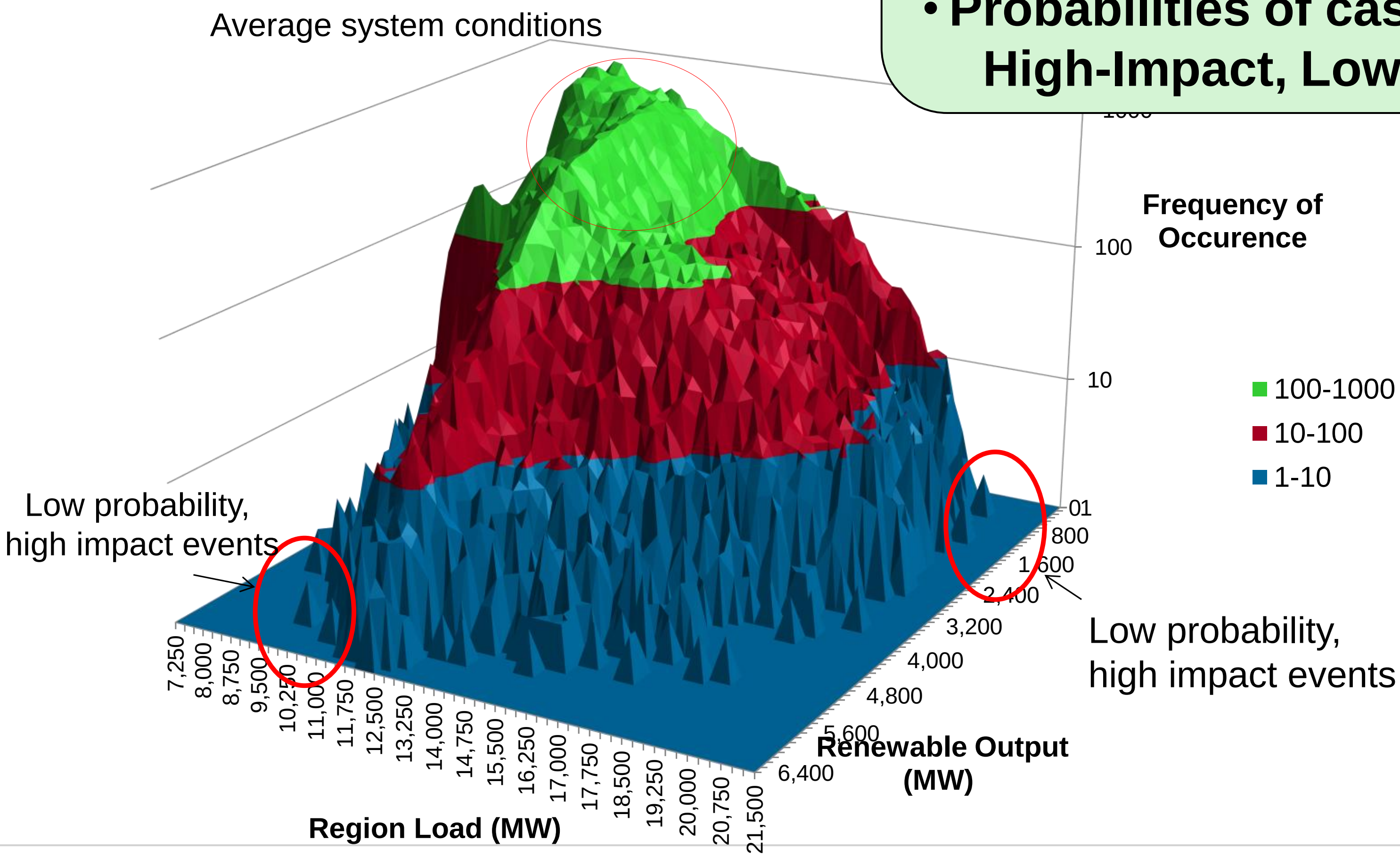
Addressing Uncertainty in Realized Load and Generation

- **Determine dispatch scenarios across many varying factors**
  - Load, Renewables, Hydro, DR

- **Probabilities of cases including High-Impact, Low Frequency**



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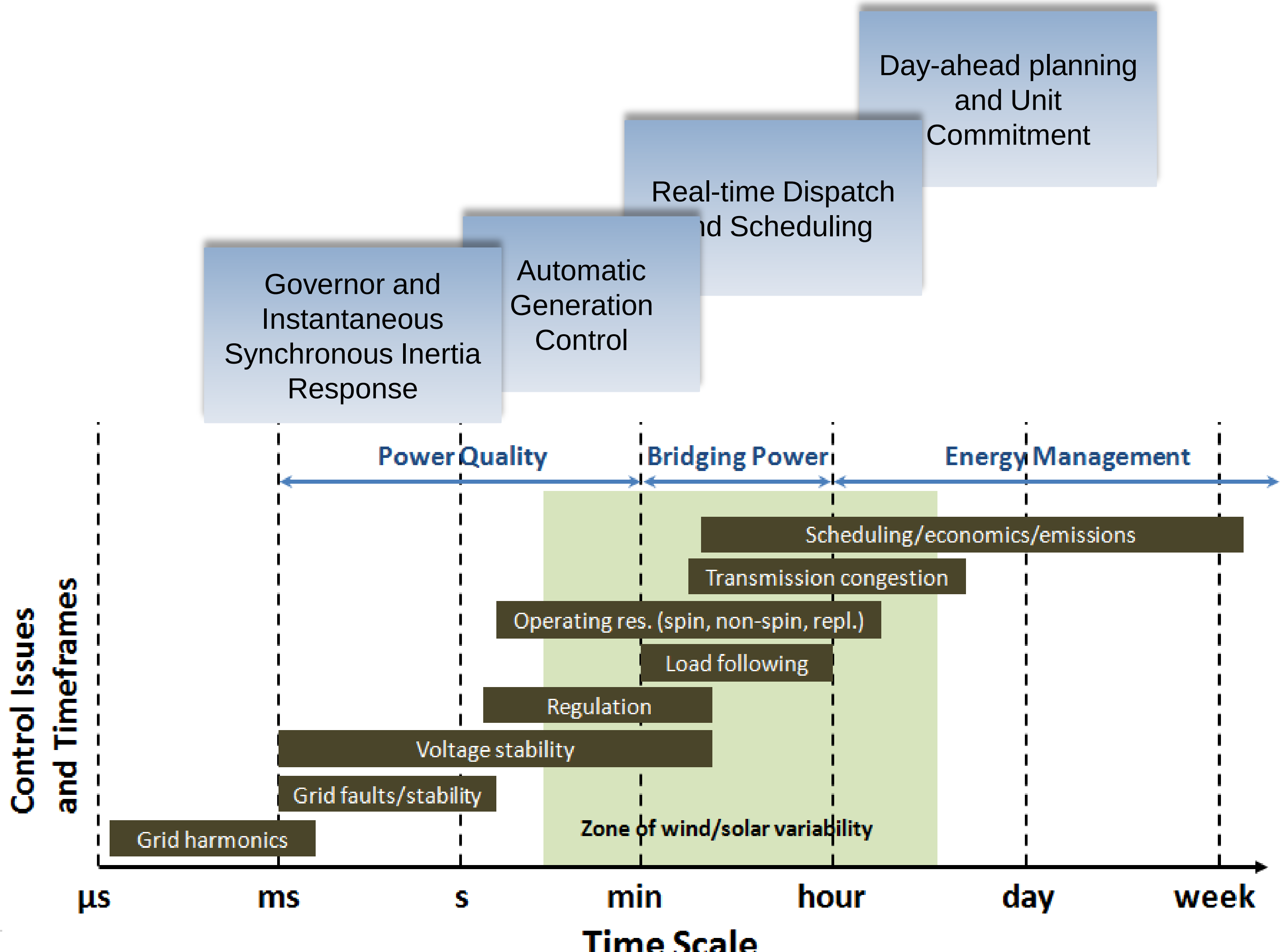
Impact of VER on BPS Operations

<u>Challenges</u>

- Can we predict VER output for better system operations?
- What essential reliability services are needed to maintain reliability?
- How are operating reserve needs evolving?
- Is the system able to maintain system frequency, thermal, voltage, stability, and contingency constraints with increased VER?

Bulk Power System Operations

- Divided among timescales



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Variable Resource Forecasting

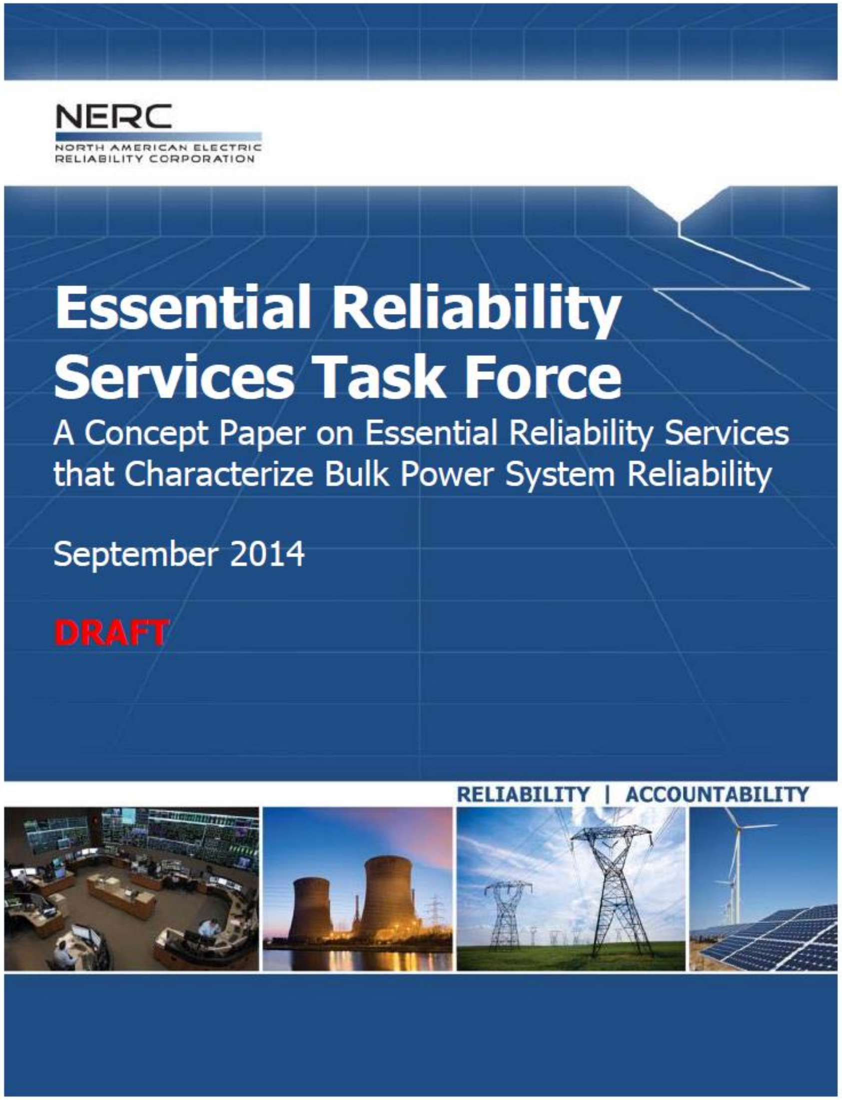
- VG prediction accuracy varies at different horizons
- Utilized in operations in different ways
  - Ramp, RUC, market
- Solar forecasting (incl. dist. PV)
- Probabilistic vs. Deterministic
- Cost savings and reliability benefits

	Peak Load	Wind Generation	Annual Operating Cost Savings: SOA Forecast vs. No Forecast	Annual Operating Cost Savings: Perfect Forecast vs. SOA Forecast
California	64 GW	7.5 GW	$ 68M	$ 19M
	64 GW	12.5 GW	$ 160M	$ 38M
New York	33 GW	3.3 GW	$ 95M	$ 25M
Texas	65 GW	5.0 GW	$ 20M	$ 20M
	65 GW	10.0 GW	$ 180M	$ 60M
	65 GW	15.0 GW	$ 510M	$ 10M

Source: GE Energy

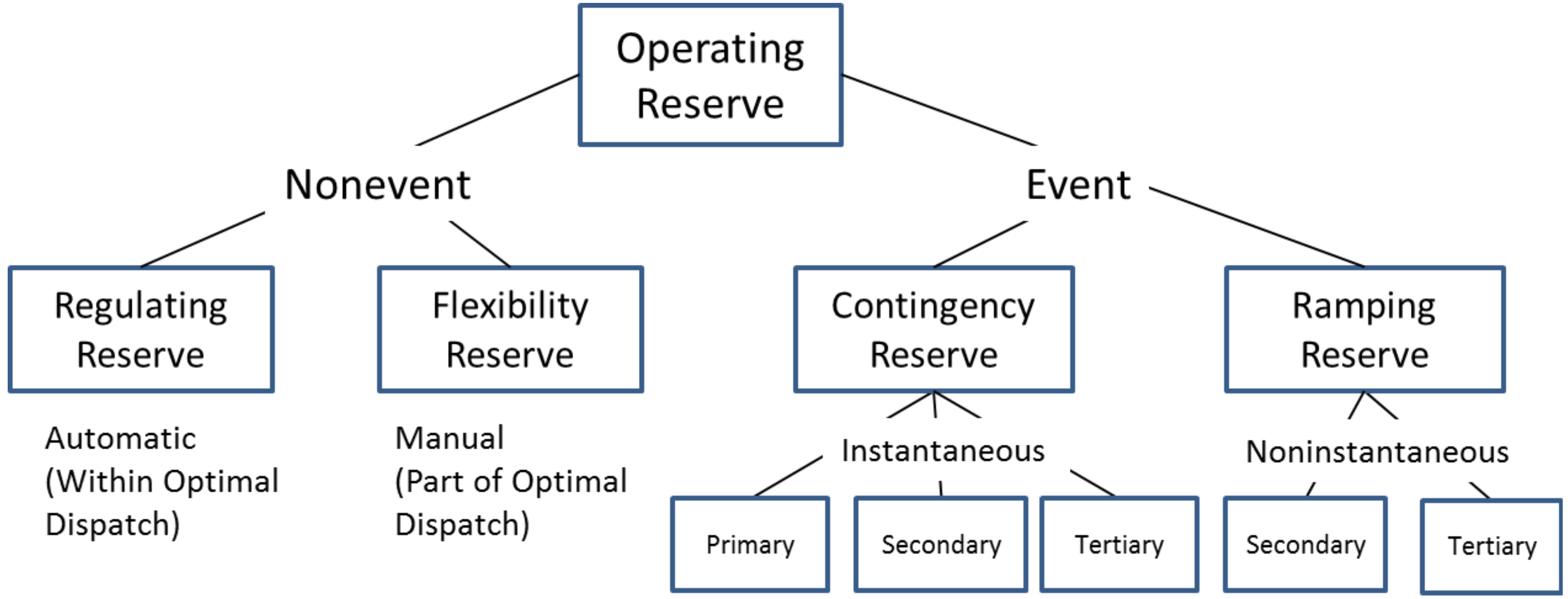
Essential Reliability Services

- Reactive power/voltage control
- Frequency Control
  - Voltage & frequency ride through
  - Inertia, primary frequency control
- Load & Resource Balancing
  - Operating reserve
  - Regulation
  - Ramping
- Impacts on changing system
  - Retirements, replacement resources
- Development of measures
  - Using system data across N. America



Operating Reserve

- Operating reserve: capacity above or below the energy schedule that can be used to correct active power imbalance
- Static requirements to dynamic requirements
- Variability and uncertainty
- Tradeoff between reliability and costs
  - *Reserve may now be used for efficiency reasons rather than strictly reliability purposes.*



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Industry Relevance

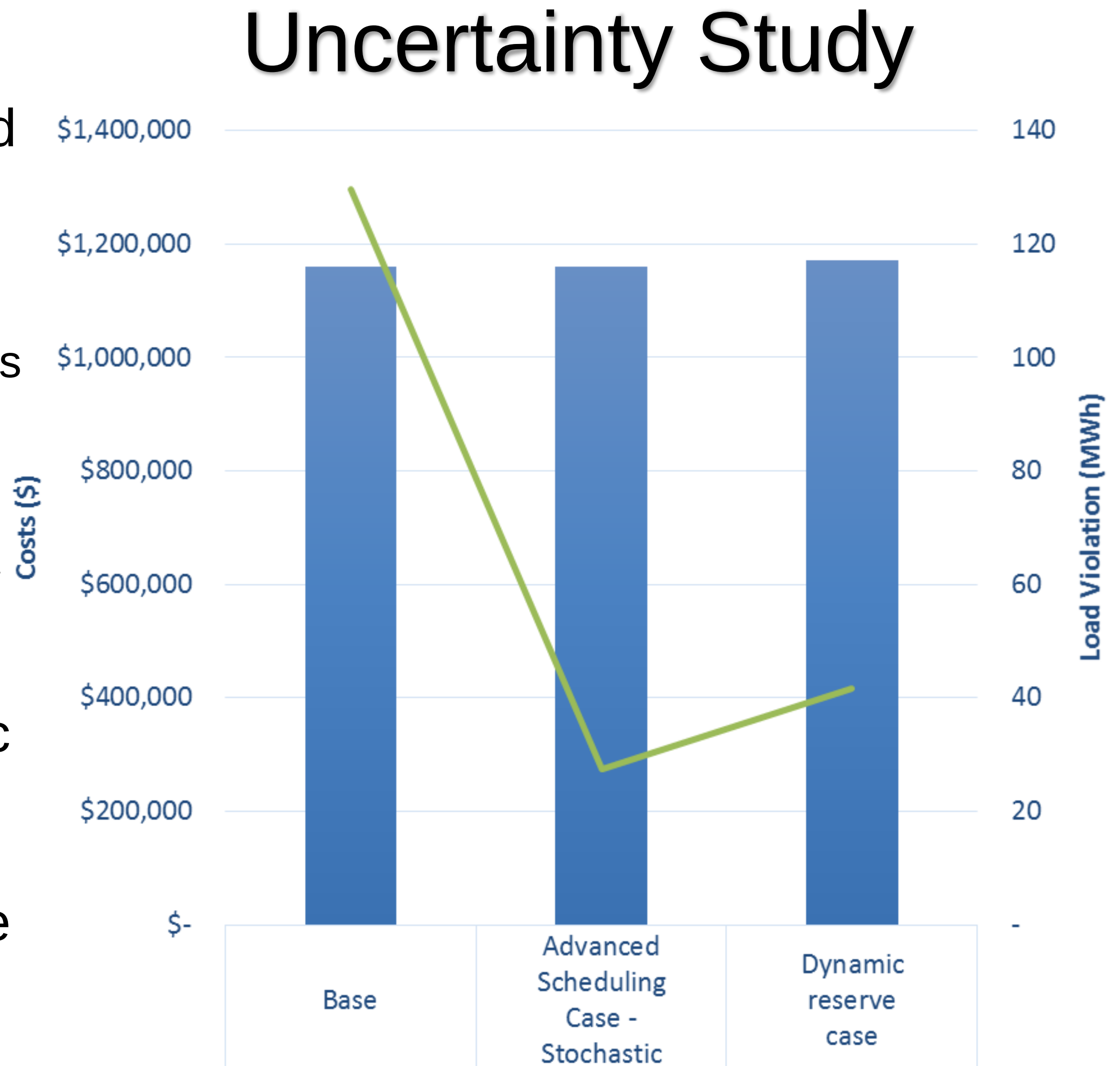
- California ISO Shaping a Renewed Future **FlexiRamp**
  - Reserving flexible capacity for use in real time
  - Reduce price spikes
- MISO **Ramp Product & Look Ahead Dispatch**
  - Capability to ramp 10-minutes ahead
  - Further look-ahead for ramping needs assessment
-
- Xcel Energy® **Flex Reserve**
  - Reserve for long-term wind ramps that are not regulation or contingency
- ERCOT **Ancillary Service Redesign**
  - Wide scale reorganization of ancillary service products
  - Primary frequency response, fast frequency response, inertia service
  - Regulation requirements based on forecast error characteristics
- Performance-based regulation service (*FERC Order 755*)

Meeting Operating Reserve Needs Implicitly Through Advanced Scheduling Applications

Three Central Needs for Reserve	Explicit Reserve Requirement	Implicitly Scheduled Flexibility
1. Variability occurring within the interval	Reserve Requirements (e.g., regulation reserve)	Shorter scheduling intervals
2. Variability anticipated beyond the interval	Reserve Requirements (e.g., flexible ramping reserve)	Time-coupled multi-period dispatch w/ longer look-ahead horizons
3. Uncertainty of future conditions	Reserve Requirements (e.g., contingency reserve)	Stochastic or robust unit commitment and dispatch meeting multiple scenarios

Case Study Results

- In all three studies, advanced scheduling tends to perform the best
  – Sometimes not by large margin and not both categories
- Hard to compare reliability and costs simultaneously
  – Assuming a "loss of load" cost has challenges
- Stochastic case takes at least 5X longer than dynamic reserve case to solve
- Further improvement can be made to the dynamic reserve requirement
  – Locational requirements
  – Deployment costs



	Base	Advanced Scheduling Case - Stochastic	Dynamic reserve case
Operating Costs	$1,158,623.84	$1,159,343.98	$1,170,118.82
Change from Base	0%	0%	1%
Load Violation	129.58	27.50	41.67

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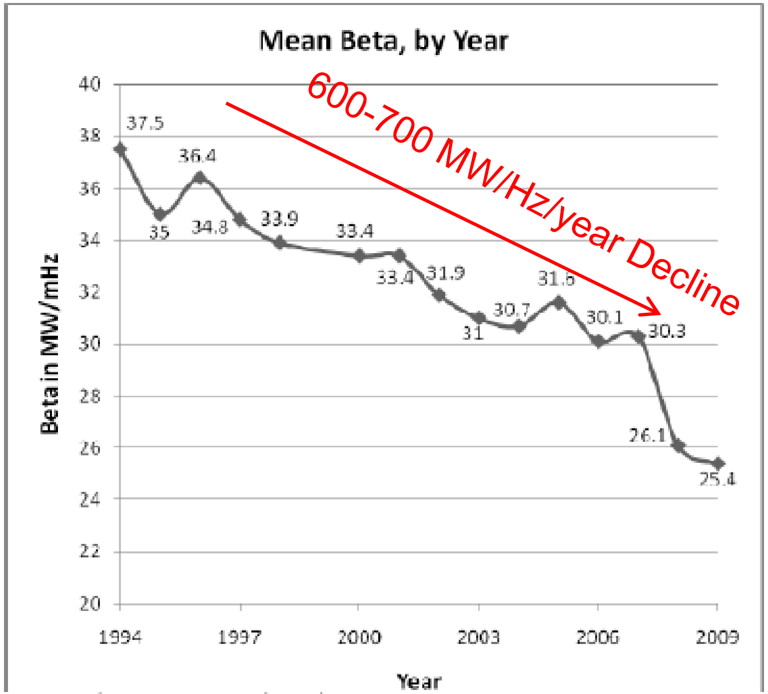
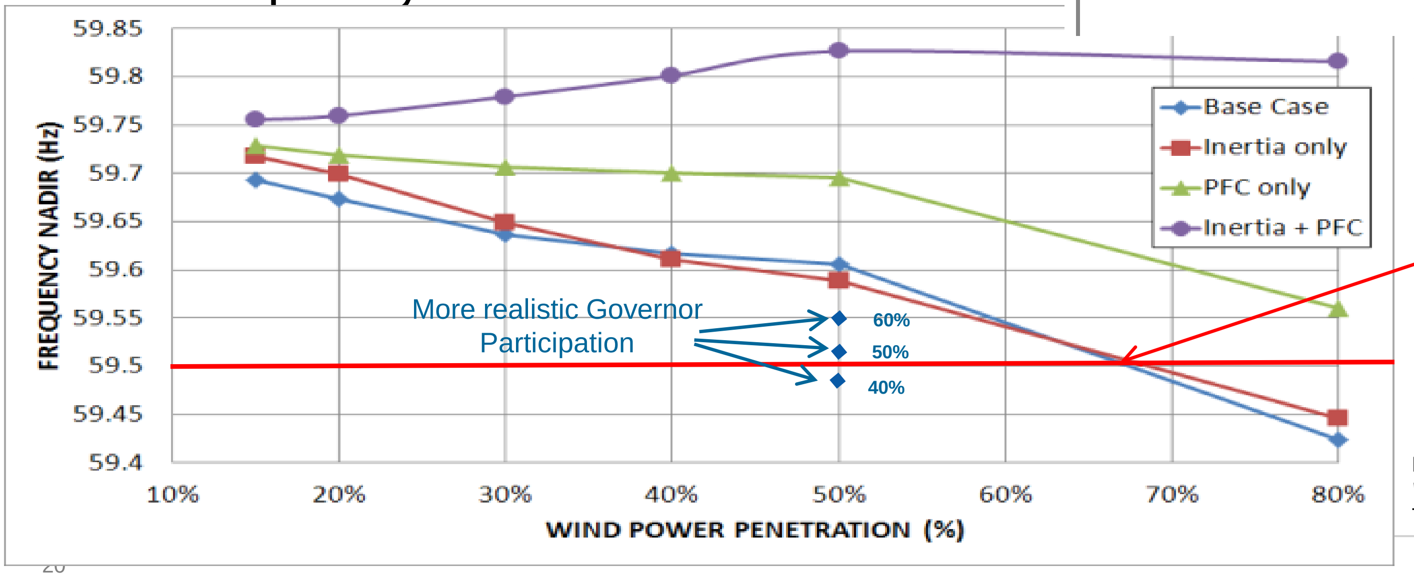
Frequency Control

- Current issues exist
  - Governor dead bands
  - Blocked governors
  - Operational modes (e.g., sliding pressure)
- Variable renewables (wind and PV) are non synchronous resources and do not inherently provide inertia or frequency control

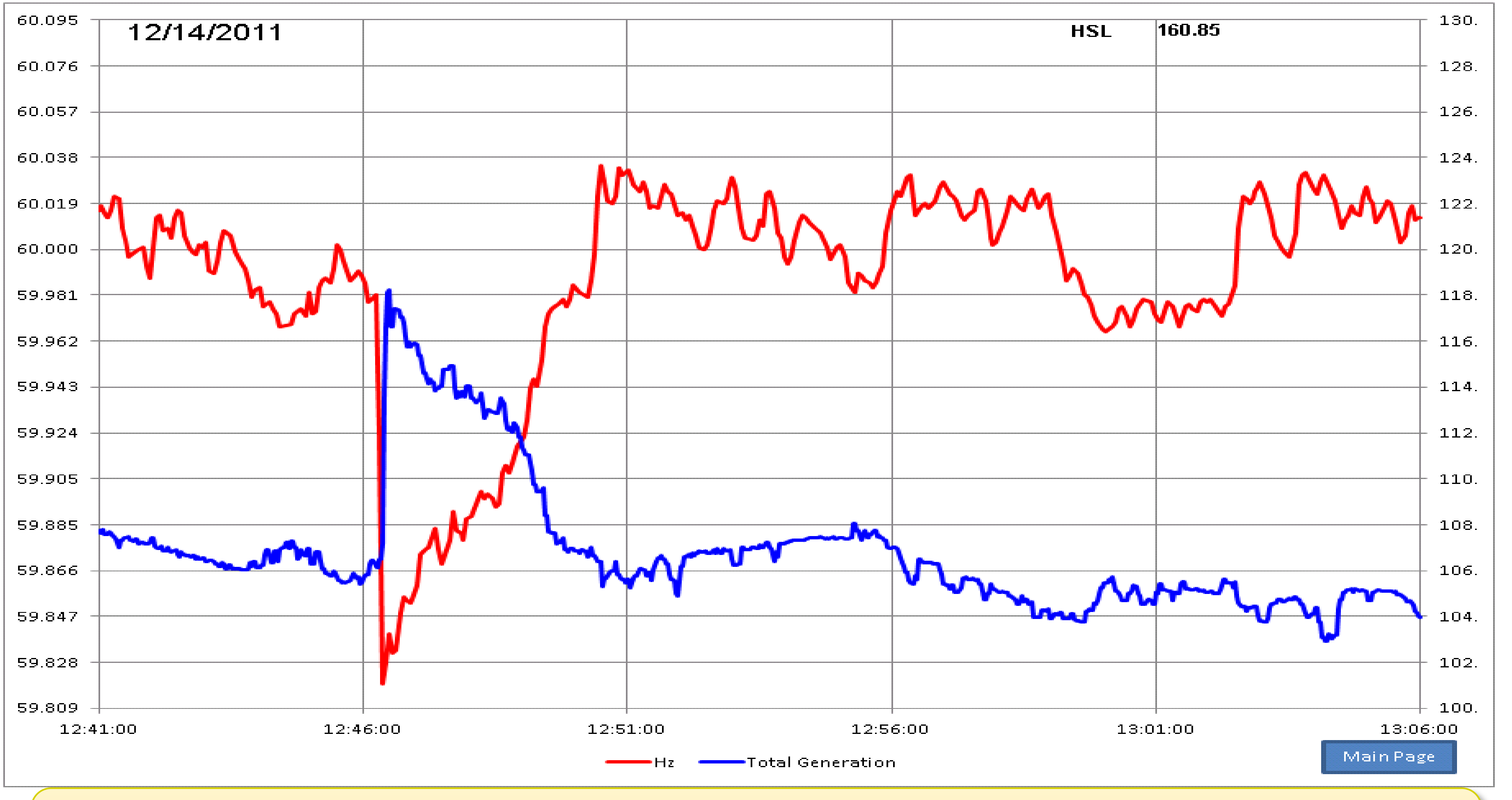


J. Ingleson and E. Allen, "Tracking the Eastern Interconnection Frequency Governing Characteristic," IEEE Power and Energy Society General Meeting 2010.



E, Ela et al., *Active Power Control from Wind Power: Bridging the Gaps,* NREL Technical Report, December 2013.

VG can be a solution



Wind (and solar) can provide many of the services they displace– need to enable controls and compensation/requirements

SOURCE: Sandip Sharma, ERCOT, "Frequency control requirements and performance in ERCOT ISO," presented at EPRI/NREL/PJM Inverter Generation Interconnection Workshop, Apr 11-12, 2012.

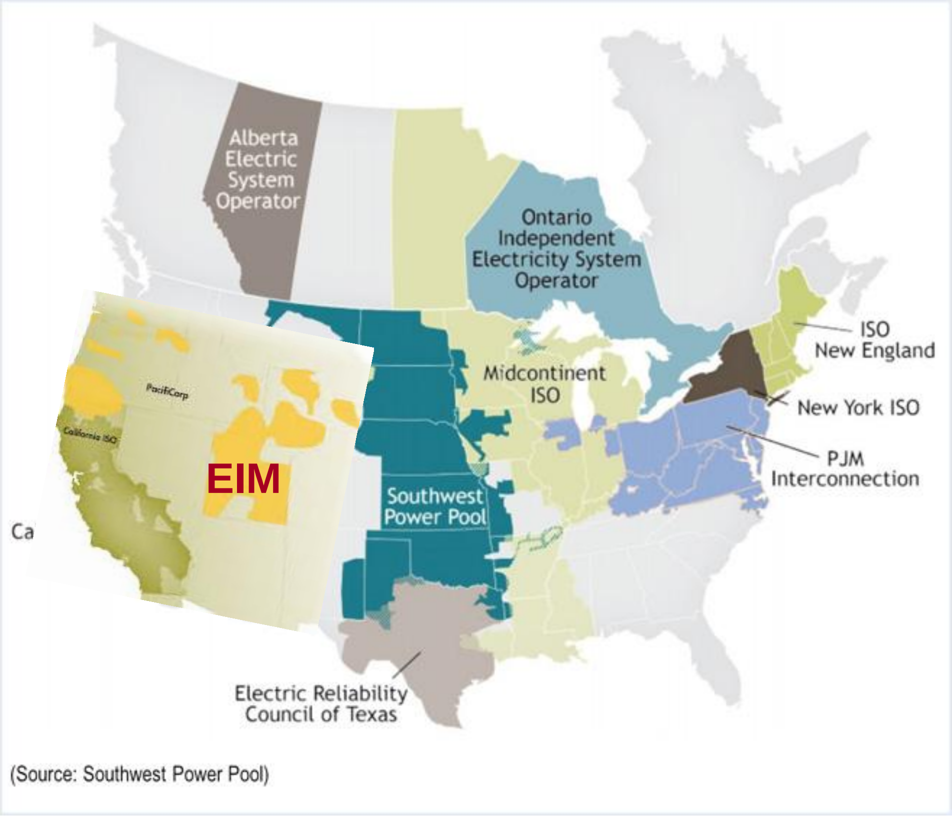
Impacts of Variable Generation on Wholesale Electricity Markets

Challenges

- Are incentives still present for new and existing needed capacity?
- Are incentives present for ramping, flexibility, and essential reliability services?
- Are markets able to capture unique characteristics of emerging resources?
- Are we setting the price efficiently?

Market Evolution

- Increasing Scope
  - MISO South, SPP-WAPA, EIM
- Increasing technology diversity
  - VER, DER, ESS, DSM
- Market complexity
  - Market design following the computational power

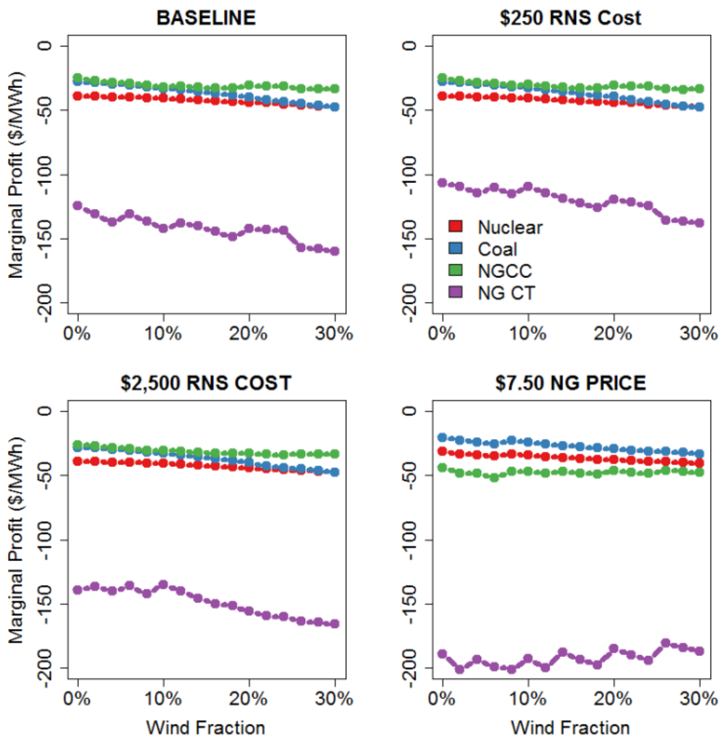


North American Electricity Market Initiatives

- Large Design Changes
  - Ancillary service redesign (ERCOT)
  - Market Renewal (IESO)
- Energy Markets
  - Coordinated Transaction Scheduling (ISO-NE, NYISO, PJM, MISO, CAISO)
  - Virtual Spread products, UTC, PTP (NYISO, MISO, CAISO)
  - Combined Cycle Modeling (NYISO, PJM, SPP)
  - Energy Storage Design (ISO-NE, NYISO, SPP)
- Ancillary Service Markets
  - Primary frequency response (ERCOT, MISO, CAISO)
  - Ramp product (MISO, CAISO, SPP)
  - Evolution to regulation mileage and fast regulation benefits (ISO-NE, PJM, MISO, SPP, CAISO)
- Financial Transmission Rights Markets
  - Long-term FTR Market (ISO-NE, NYISO, MISO, CAISO)
  - FTR Revenue Adequacy Changes (PJM, MISO, CAISO)
  - Outage Modeling improvements (PJM, SPP, CAISO)
- Capacity Markets
  - Performance products (PJM, ISO-NE)
  - Improvements to locational incentives (ISO-NE, NYISO, MISO)
  - Flexible capacity procurement (CAISO)

Impact of VER on Electricity Markets

- **Impacts on Energy Markets**
- Low variable cost of wind and solar can reduce the average energy prices
  - It can increase the amount of occurrences of zero or negative prices
- The variability of VER can also cause increased variability in energy prices
  - Variability and uncertainty can also increase the amount of price spikes due to insufficient capacity or ramp
- It can cause greater disparity between prices of forward markets (DA) and real-time markets due to the uncertainty of VER output
- It can cause greater need for flexible resources, which may or may not be incentivized to provide that flexibility in the energy market



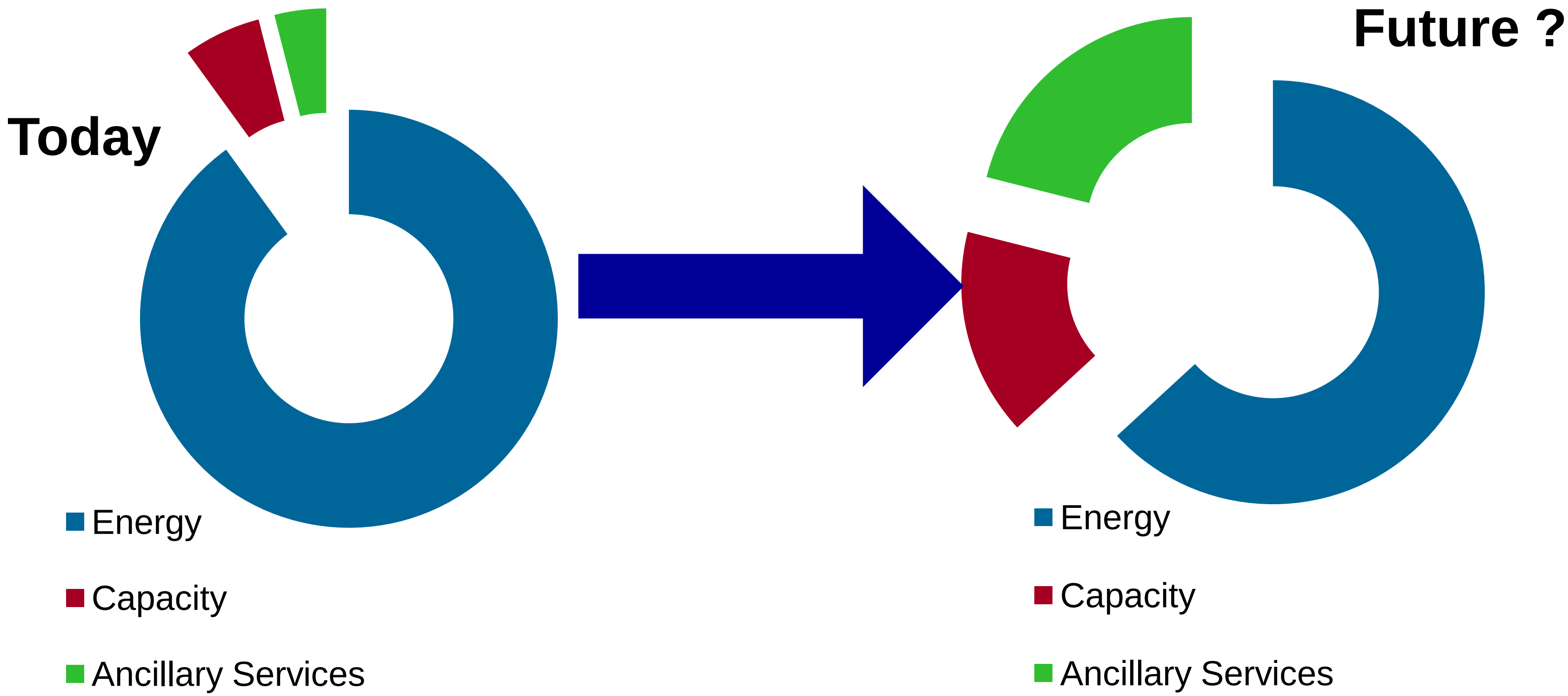
Impact of VER on Electricity Markets

- **Impacts on Ancillary Service Markets**
- VER can increase the amount of normal balancing operating reserve (e.g., regulation) required therefore increasing the demand and prices of ancillary services
- Since VER is non-synchronous, it can cause a need for action to incentivize frequency response capabilities
  - Incentives could also cause VER to provide frequency response
- Uncertainty can make the requirements change day to day, hour to hour, and forward to real-time
- The variability and uncertainty can cause uncertain power flows affecting financial transmission rights markets
- It can cause greater need for flexible resources, which may or may not be incentivized to provide that flexibility in the ancillary services market

Impact of VER on Electricity Markets

- **Impacts on Capacity Markets**
- The reduction in LMP can cause the need for other mechanisms for capital-intensive plants needed for long-term reliability to recover fixed costs
- The increased variability and uncertainty of VER can cause long-term needs of different types of resources to be built, specified not only by their capacity levels
  - The current capacity markets want more MW capacity alone, but MW/min, start-up times, etc., maybe more important characteristics of those resources being built.
  - If it cost more capital to build a flexible plant, why would one invest?
  - Similarly, would there be incentives for existing plants to make retrofits to make their plant more flexible if that flexibility is needed?

Value of Capacity and Services



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What is EPRI doing?

- Optimal Operating Reserve Determination and Enhanced Scheduling Applications
  - Stochastic programming techniques compared with enhanced dynamic reserve requirement methodologies
  - Western Interconnection, HECO, TVA, others
- Flexibility Assessments
  - InFLEXion tool
  - Quantification of flexibility
  - Deliverable Flexibility Methods
- Methods for Incentivizing Flexibility, Ramping, and frequency response
- Frequency and Voltage Impacts on Systems with High Penetrations of Inverter-based Resources
- Dynamic VER and Storage Models including DER Aggregation Models
- Enhanced Risk-based Planning Methods
- Linking of Capacity Expansion Tools with Reliability Assessment Tools
- Mitigation Strategies to Extreme Cold Weather Events

Together…Shaping the Future of Electricity

Questions?

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