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Reliability and the Future of the Electricity Grid:
A North American Bulk Power System Perspective

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Panama City, Panama
October 28, 2016

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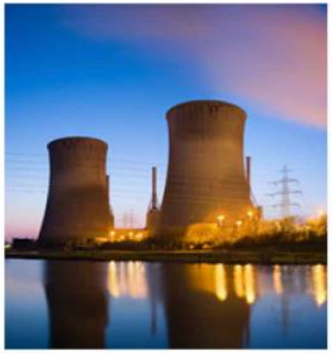


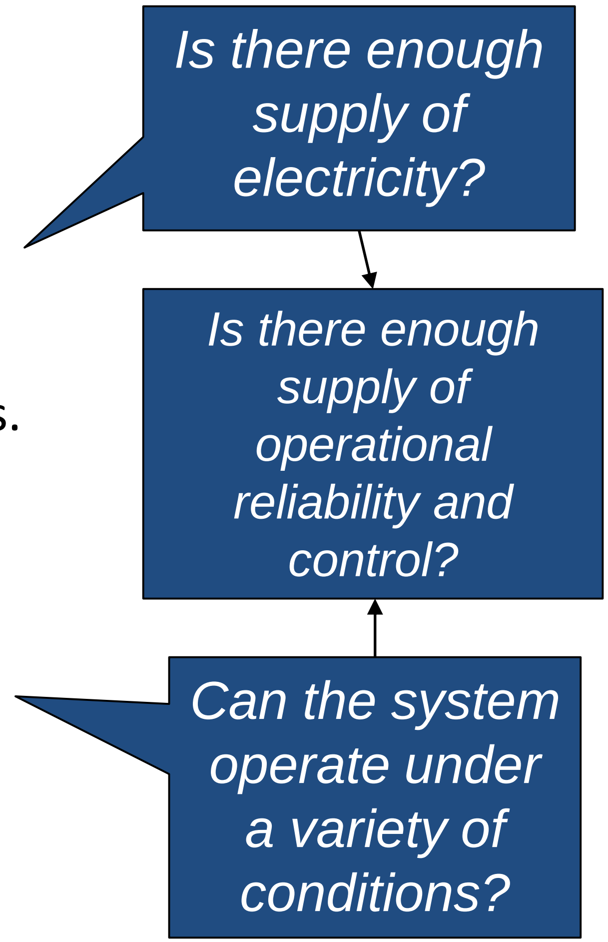
About NERC: Mission

To ensure the reliability of the North American bulk power system

- NERC is an international, non-government Electric Reliability Organization (ERO) for North America
- Accountable to government regulators in North America
- Facilitate active stakeholder coordination and collaboration for reliability:
  - Develop and enforce reliability standards
  - Assess current and future reliability
  - Analyze system events and recommend improved practices

What is Bulk Power System Reliability?

- The ability of the BPS to meet the electricity needs of end-use customers at all times.
  - **Adequacy** — The ability of the bulk power system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.
  - **Operating Reli**ability — The ability of the bulk power system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements from credible contingencies.

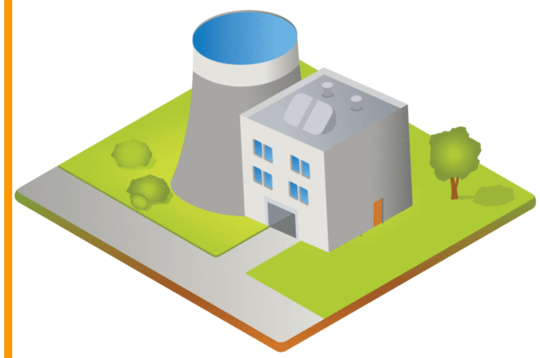


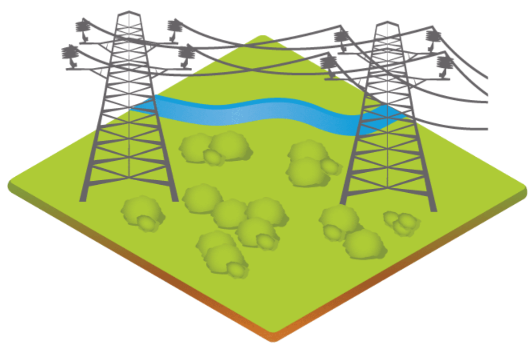
Why an International ERO?

- Complexity:
  - North American grid spans three countries, many regulatory jurisdictions
  - **North American grid is owned and operated by ~2000 diverse entities**:
    - Multiple business and ownership models
    - Multiple market structures
    - Diverse operating conditions
- Reliability requires technical expertise, consistent rules, and coordination
- One electric reliability organization, with a singular focus on reliability



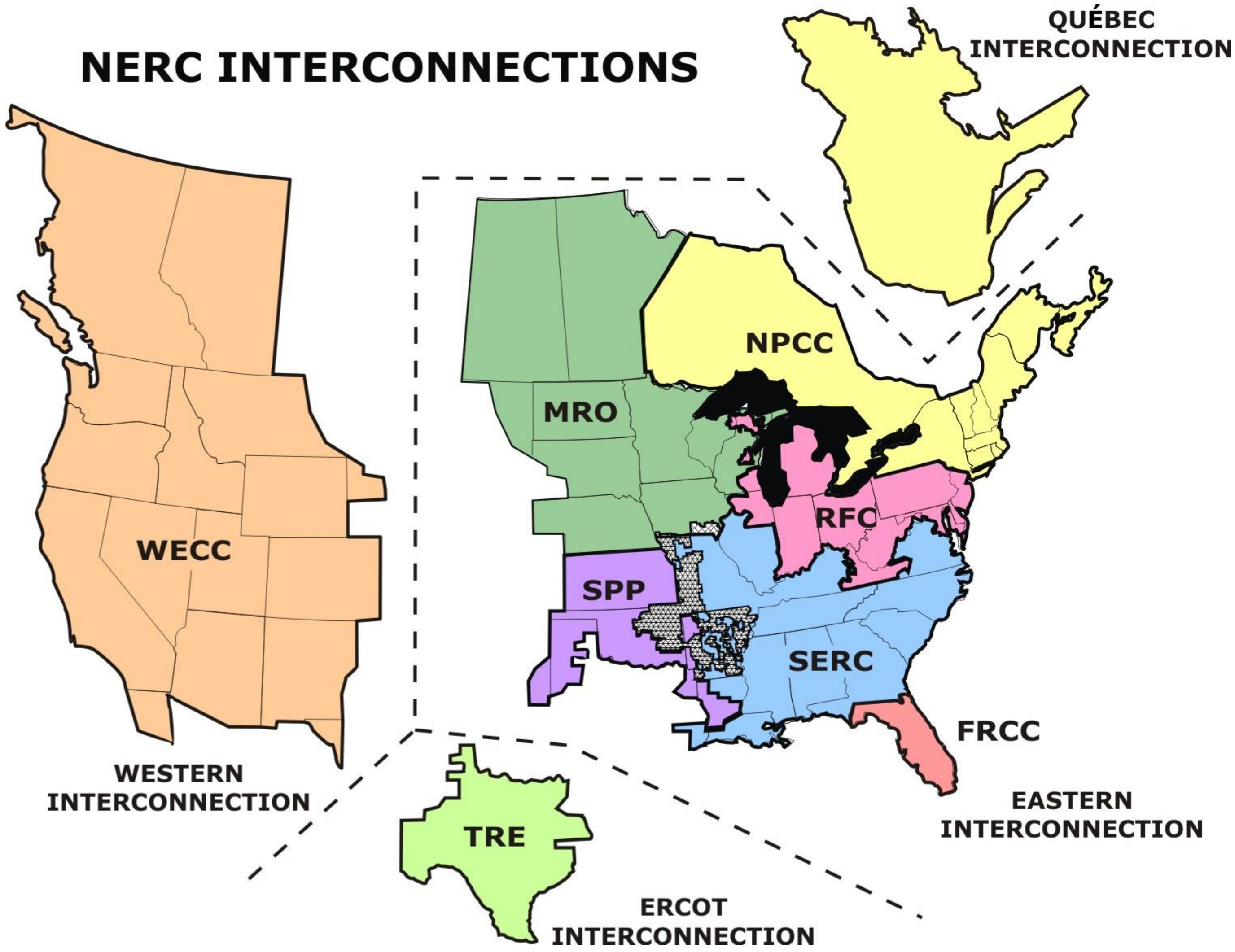
The North American Bulk Power System





Generation	Transmission	Distribution
Over 5,000 plants	Over 483,000 circuit miles	Over 2,200,000 miles
Over 1,000,000 MW Total Peak Capacity	320 Transmission Operators	430 Distribution Providers
Peak Natural Gas Capacity – 42%	Over 2,000 Substations	Over 980,000 MW Peak Demand
Peak Coal Capacity – 27%	115kV – 735kV (AC), Some DC	<1% Peak Demand Annual Growth
Peak Renewables – 3%		~10 GW Solar PV

NERC Regions



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The Changing Resource Mix

Changing Resource Mix

- Unprecedented shift in the resource mix occurring:
  - Renewable variable energy resources
  - Distributed energy resources
  - Distribution-centric resources
  - Micro- and smart-grids
  - Demand response technology
  - Just-in-time delivery of natural gas to fuel new generating capacity

More Variable Energy Resources

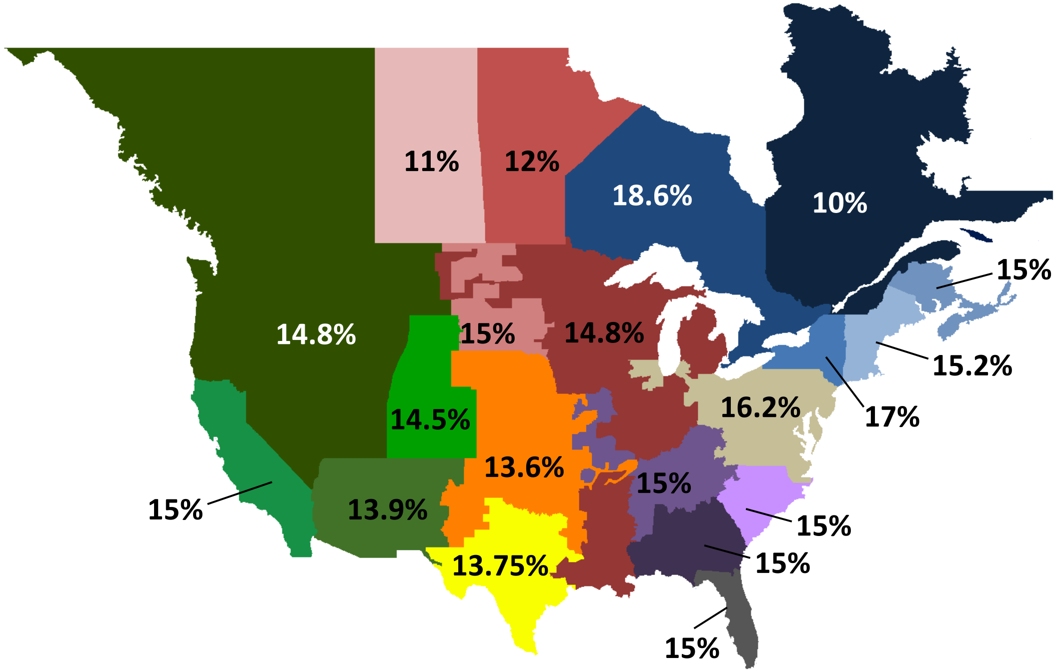
- Continent-wide trend ↑ differing regionally only in magnitude
- Increased penetration of renewables driven by policies:
  - Regional portfolio standards (provincial, state, or federal)
  - Financial incentives: feed-in tariffs, investment and production tax credits
- Distributed energy resources (DER) also ↑, creating uncertainty
  - Some DER not visible or controllable (e.g., behind the meter)
  - System planning with DERs is more challenging

System Dynamic Character is Changing

- Retirement/displacement of conventional generation
  - Variable energy resources
  - Rapid penetration of electronically-coupled resources
- Essential Reliability Services
  - Reduced inertia
  - Frequency Reponses
  - Voltage Support
  - Ramping and flexibility needs
- Rapid penetration of new loads
- System controls and protection coordination
- Modeling and simulation constraints
- Increasing interface with distribution-centric resources

NERC Planning Criteria
Planning Reserve Margins

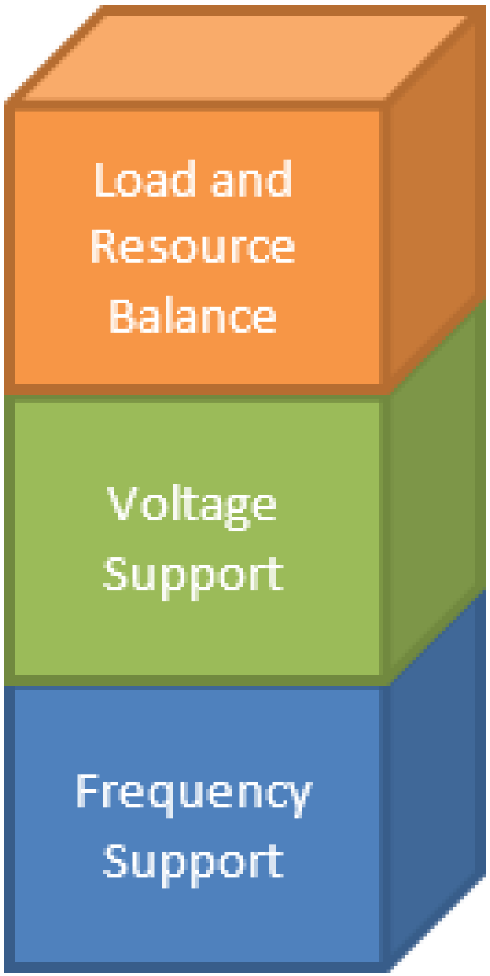
- Reference Margin Level (Target): Determined by loss-of-load expectation (LOLE) studies (varies by Assessment Area)



Planning Reserve Margin (%) = $\frac{[\text{Available Capacity} - \text{Net Internal Demand}]}{\text{Net Internal Demand}}$

Essential Reliability Services

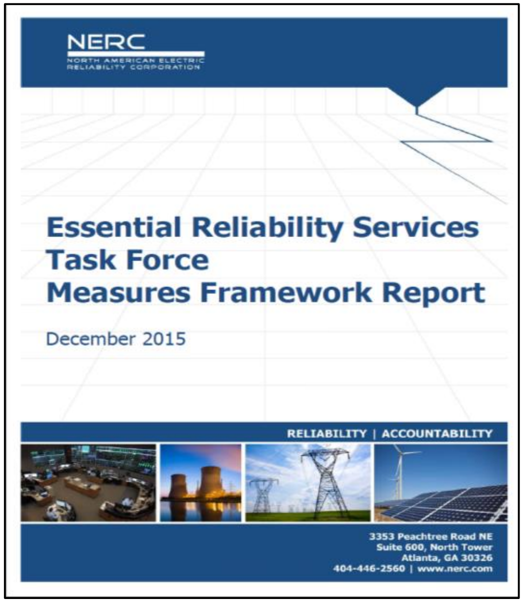
ERS Fundamentals



- “Building blocks” of physical capabilities
- Accentuated by resource changes
- Not all MWs are equal
- Some partly covered through ancillary services
- Accommodate local/regional needs

Essential Reliability Services Education

Framework Report | Abstract Document | ERS Videos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Essential Reliability Services Task Force Measures Framework Report

December 2015

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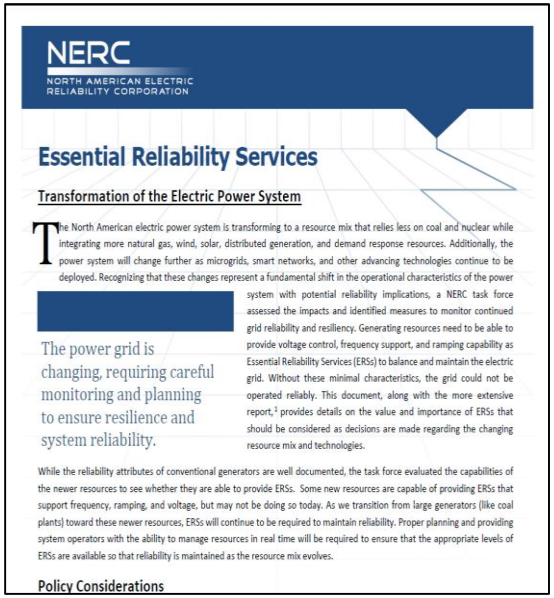
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Essential Reliability Services

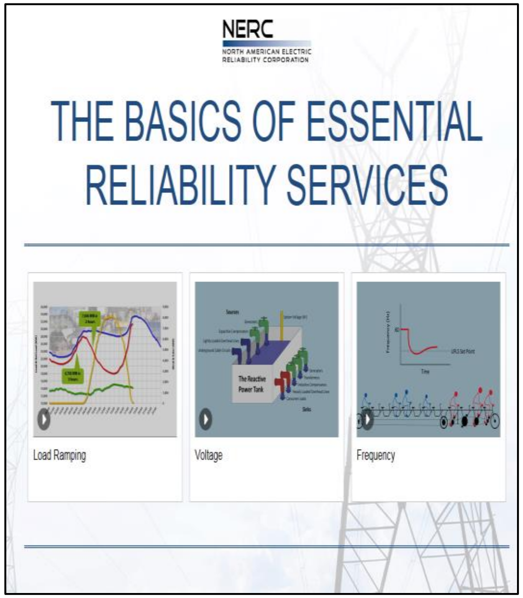
Transformation of the Electric Power System

The North American electric power system is transforming to a resource mix that relies less on coal and nuclear while integrating more natural gas, wind, solar, distributed generation, and demand response resources. Additionally, the power system will change further as microgrids, smart networks, and other advancing technologies continue to be deployed. Recognizing that these changes represent a fundamental shift in the operational characteristics of the power system with potential reliability implications, a NERC task force assessed the impacts and identified measures to monitor continued grid reliability and resiliency. Generating resources need to be able to provide voltage control, frequency support, and ramping capability as Essential Reliability Services (ERSs) to balance and maintain the electric grid. Without these minimal characteristics, the grid could not be operated reliably. This document, along with the more extensive report,[1] provides details on the value and importance of ERSs that should be considered as decisions are made regarding the changing resource mix and technologies.

The power grid is changing, requiring careful monitoring and planning to ensure resilience and system reliability.

While the reliability attributes of conventional generators are well documented, the task force evaluated the capabilities of the newer resources to see whether they are able to provide ERSs. Some new resources are capable of providing ERSs that support frequency, ramping, and voltage, but may not be doing so today. As we transition from large generators (like coal plants) toward these newer resources, ERSs will continue to be required to maintain reliability. Proper planning and providing system operators with the ability to manage resources in real time will be required to ensure that the appropriate levels of ERSs are available so that reliability is maintained as the resource mix evolves.

Policy Considerations



Risk to Reliability

- Potential for lower inertia with retirement of coal and oil-fired synchronous generators
- Higher penetration of renewables with potentially lower frequency response
- No assurance of adequate inertia or frequency response capability for some resource dispatch scenarios
- Trade-offs between inertia and Primary Frequency Response

Conservative approach

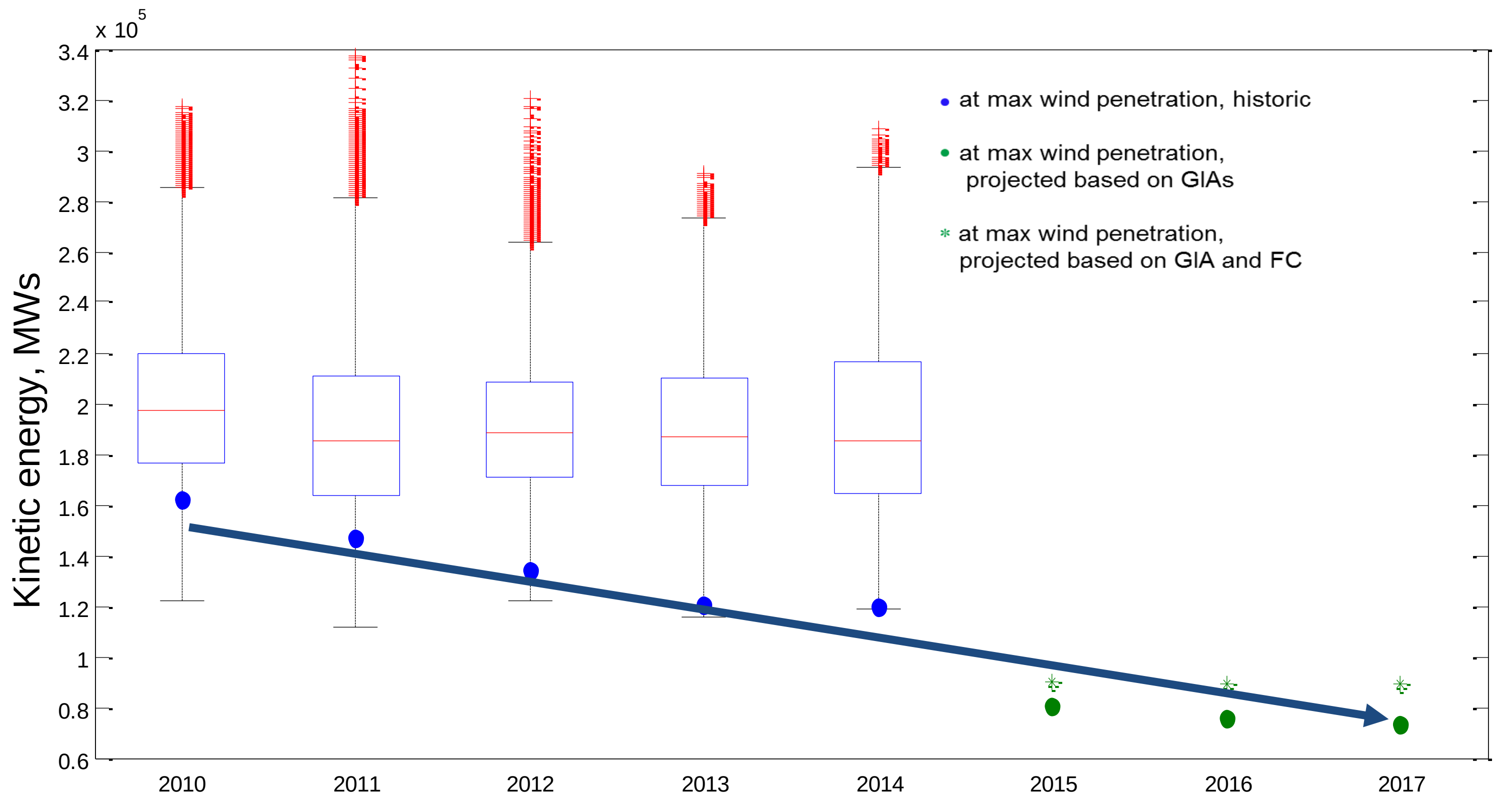
All resources should have frequency responsive capability to assure that frequency response is available for any resource dispatch.

Essential Reliability Measures

- Synchronous Inertial Response – Interconnection level
- Initial Frequency deviation following largest contingency
- Synchronous Inertial Response – Balancing Authority level
- Ramping capability
- Voltage performance
- Overall system reactive performance

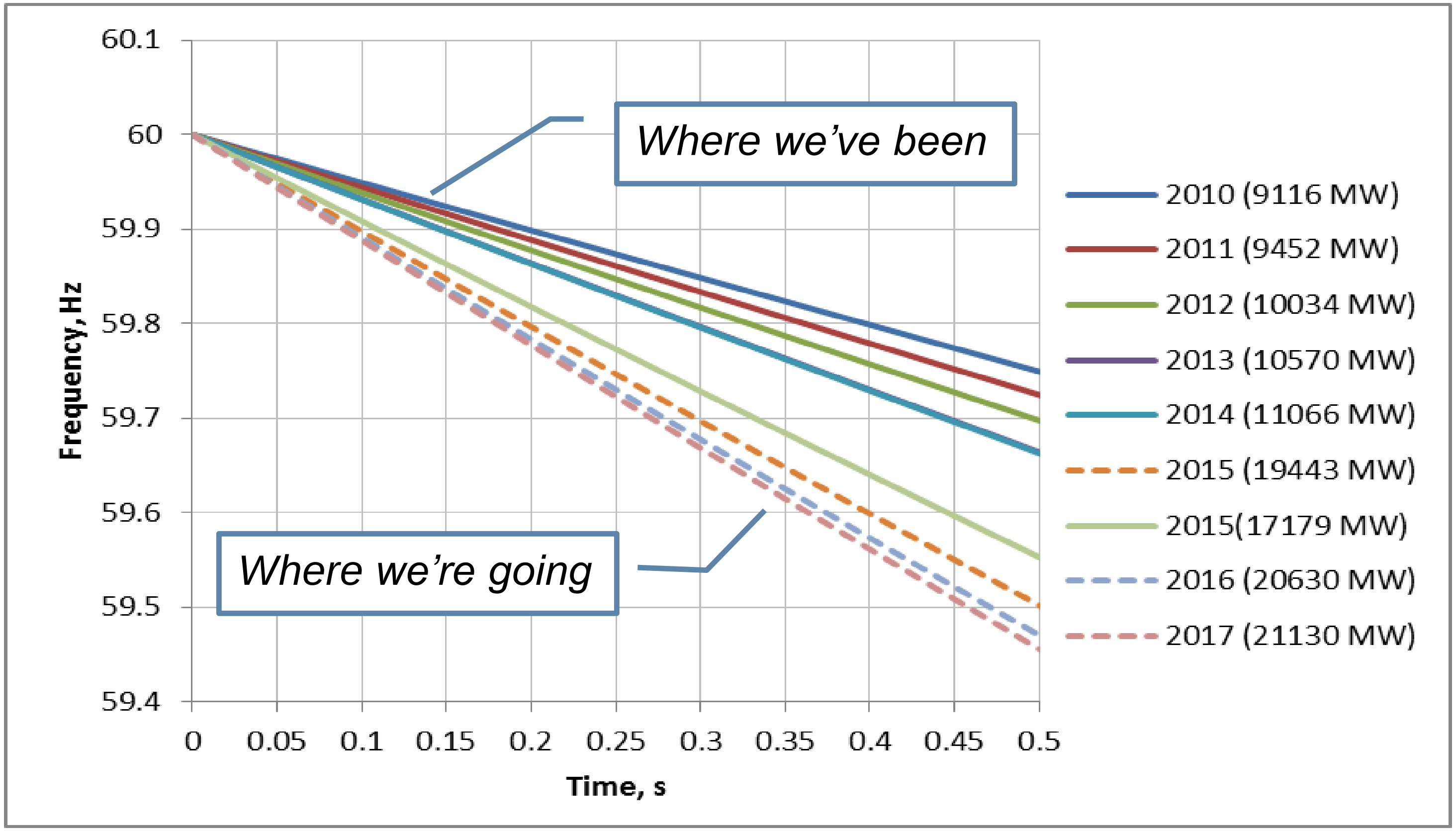
Monitor Trends in Frequency

Synchronous inertia is declining……



ERCOT Historic Kinetic Energy Boxplots (2010–2017)

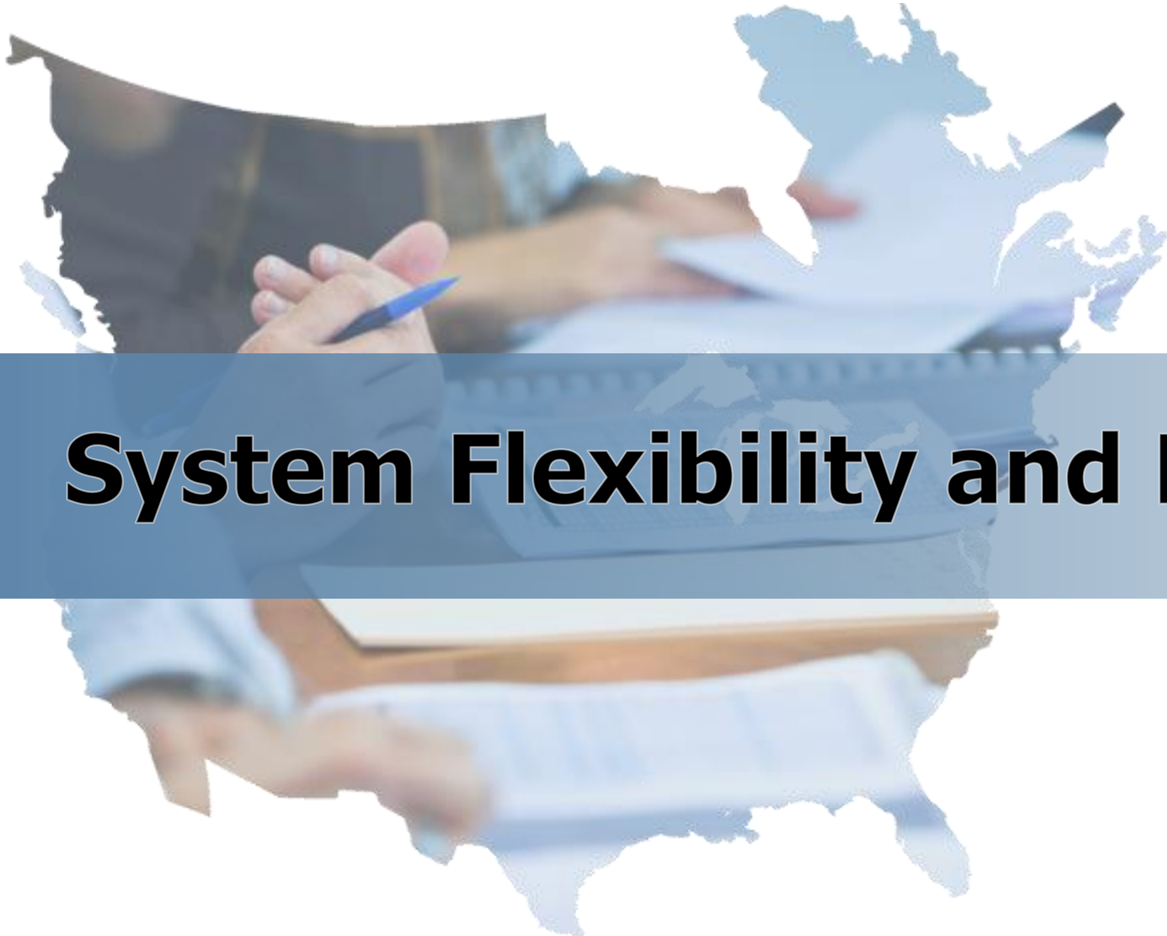
Decline in inertia → Increase in Frequency Deviation



Calculated ERCOT System Frequency after 2750 MW Generation Trip (2010-2017)

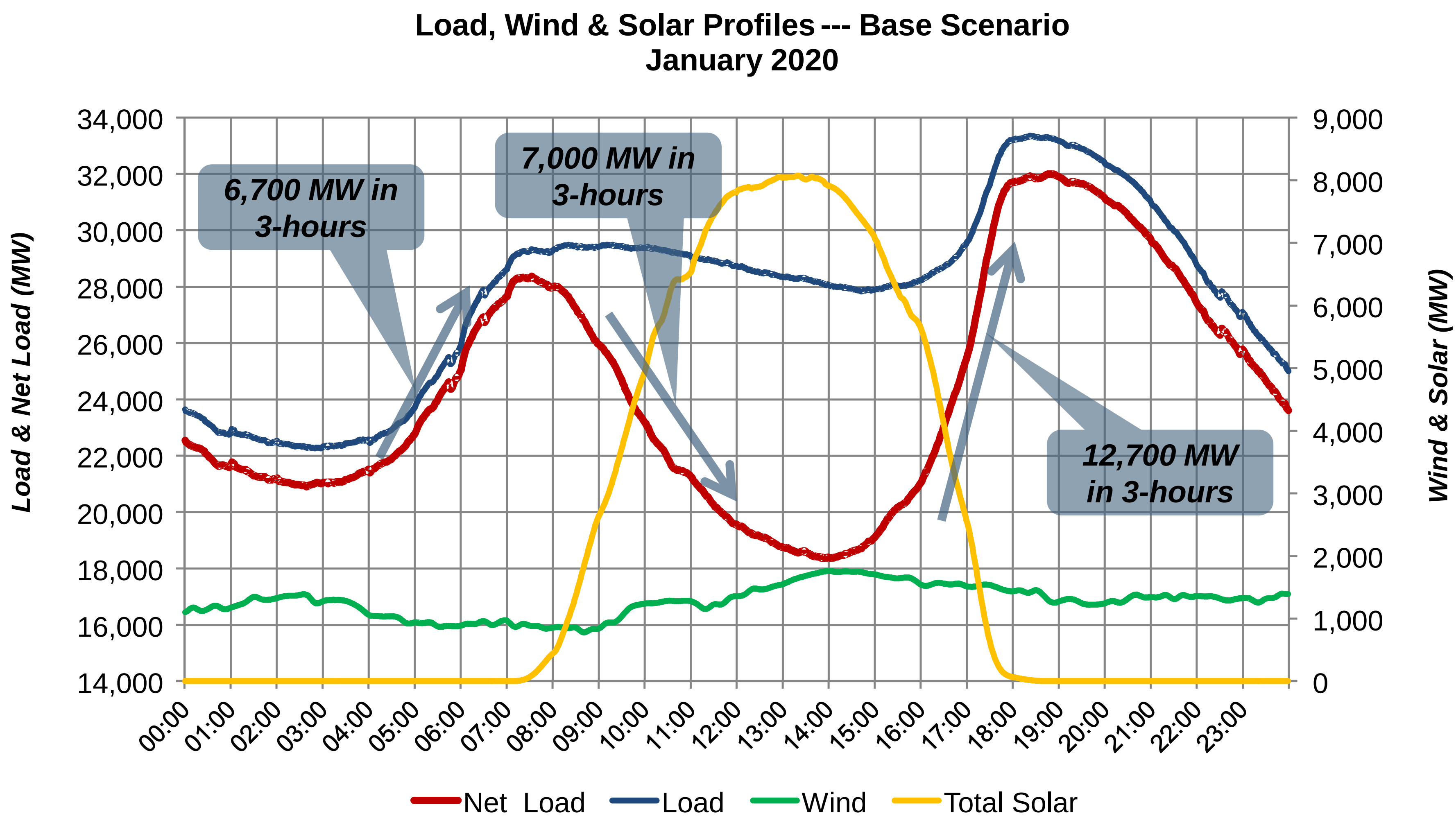
Focus Areas of Frequency Response

- BAL-003 Standard
  - Does not guarantee performance for each event, measured by median performance
  - Provides consistent methods for measuring Frequency Response and determining the Frequency Bias Settings
- Asynchronous Resources
  - Modifying NERC Guidelines to include desired operating characteristics for all resources
  - Coordinating with IEEE on Standard 1547 for DER
  - Not currently required to have the capability to provide FR
- Planning
  - Frequency Response studies in the planning horizon



System Flexibility and Ramping

The Need For Flexibility: A Future, Not a Scenario

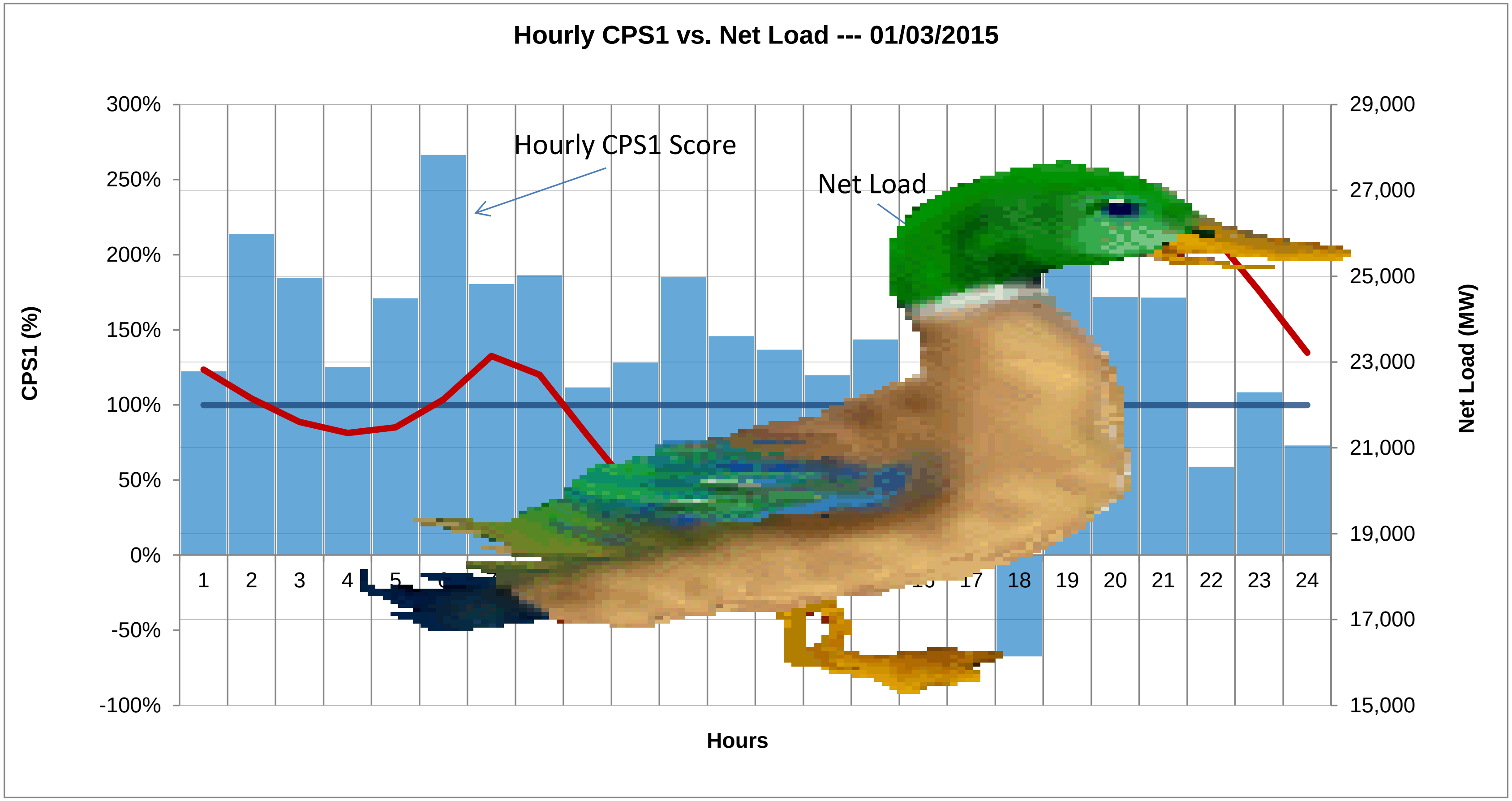


Net Load = Load - Wind - Solar

Slide 21

Hourly monitoring of CAISO's CPS1 Survey Found a Trend

CPS1 score dropped below 100% at steep evening upward net load ramps



Accommodating High Levels of Renewables

Three Key Considerations

Reliably integrating these resources into the bulk power system will require significant changes to traditional methods used for system planning and operation

Forecasting

- Variable Fuels Must Be Used When Available
- Forecast is only information; operator must make informed decisions
- "It's the ramps, not the ripples"
- Methods for calculating expected on-peak capacity

Flexibility

- More Ancillary Services
- Larger Balancing Authorities
- Flexible Resources
  - Storage
  - PHEV
  - Leverage fuel diversity of other variable resources

Transmission

- Interconnect variable energy resources in remote areas
- Construct/site/permit transmission to deliver power across long distances

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Accommodating Large Amounts of Variable Resources

- No fundamental, technical barrier
- Evolution of transmission planning, system operating policy, market development and cross-border cooperation
- Solutions will be needed in the following areas:
  - Large balancing areas
  - Remove barriers to transmission
  - Need for forecasting
  - Grid codes
  - Dynamic models
  - Probabilistic planning methods
  - Incorporating need for flexibility in G&T planning
  - DSM and EV as sources of flexibility

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*
  - *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

When is VER Integration More Difficult?

- Inefficient VER 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 VER output is high

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

When is VER Integration Easier?

- Large system with diverse and dispersed generation fleet
- Majority of generators are dispatched every five minutes
- VER plants are efficiently dispatched (using a forecast that reflects their implicit resource characteristics)
- Generators (including VER) with “ride-through” capabilities
- Most generators (including VER) provide reactive support
- Even with a slow-ramping fleet (e.g., mostly coal plants), ramping is not a concern
  - Ramping capability actually increases during periods of high VER output because other units are backed down
  - More challenging when integrating distributed resources

Need for Transmission

High levels of variable generation will require ***significant transmission additions*** *and reinforcements.*

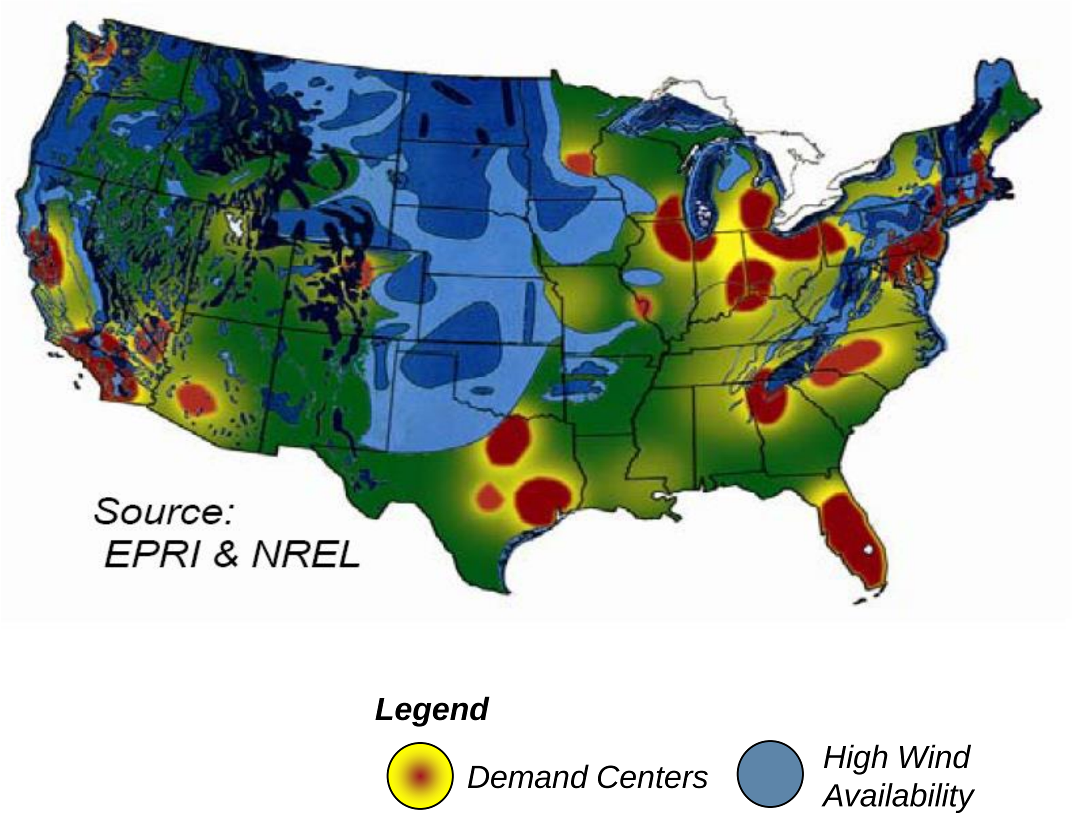
- **Challenge**

  Interconnect variable energy resources in remote areas

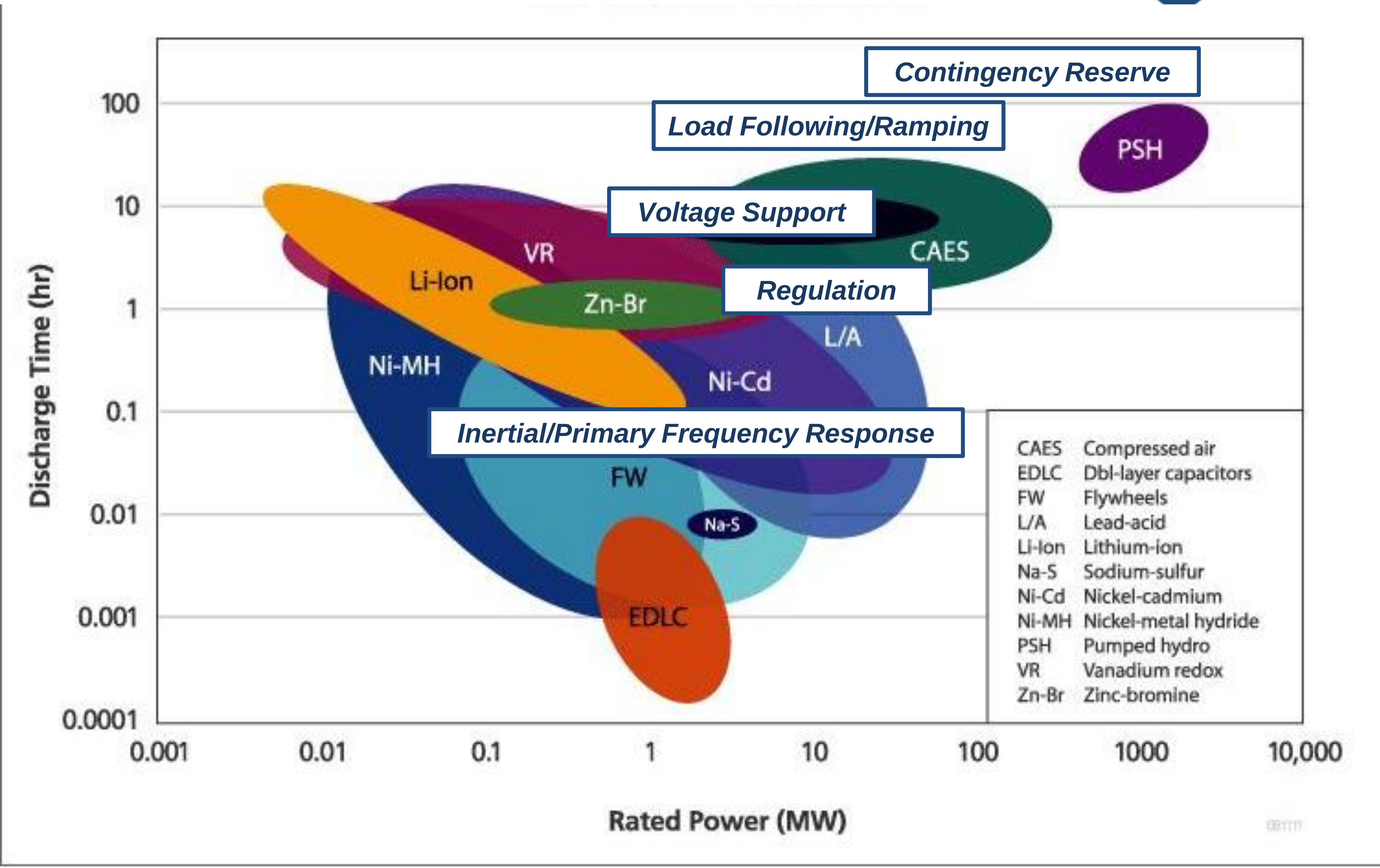
  Smooth the variable generation output across a broad geographical region

  Deliver ramping capability and ancillary services.

  Construct/site/permit transmission to deliver power across long distances.



Storage and Flexibility Functions

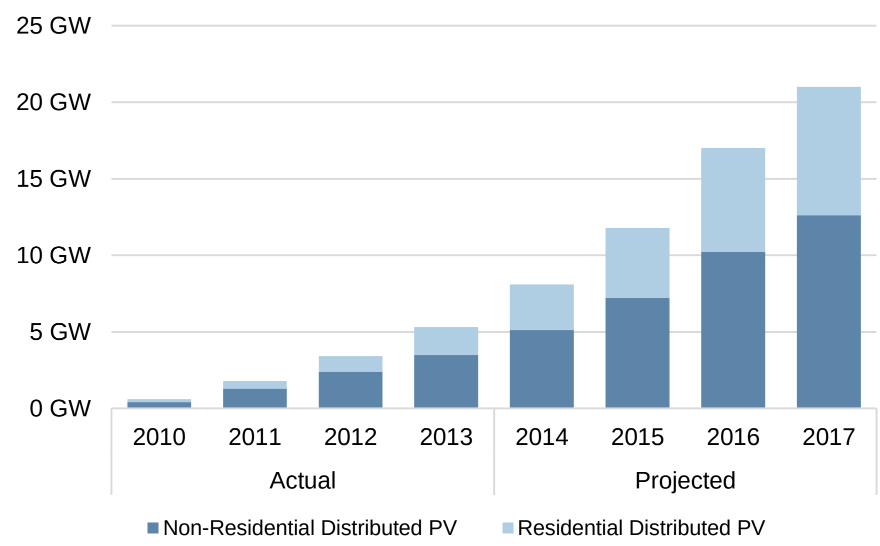


Distributed Generation

Reliability Finding #3: Operators and planners face uncertainty with increased levels of distributed energy resources and new technologies

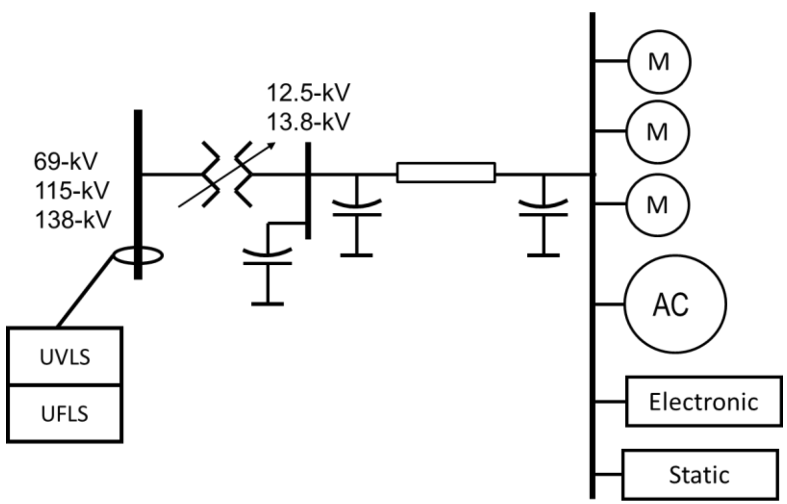
- Distributed energy resources (DERs) are contributing to changing characteristics and control strategies in grid operations.
- NERC is establishing a Task Force focused on examination of reliability impacts of large amounts of DER on the BPS.

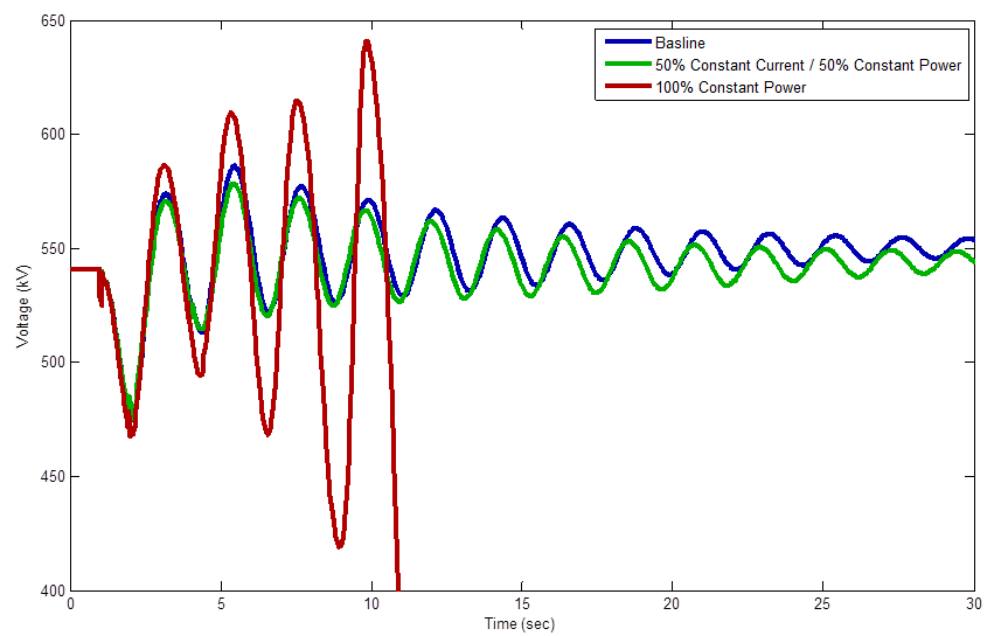
Actual and Projected Cumulative Distributed PV Installed Capacity in U.S. Since 2010



Changing Loads

- Load composition is changing
  - Electric vehicle charging
  - LED lighting
  - Variable speed drive motors
- This is changing fundamental assumptions for transmission system modeling





Disturbance Performance

- Large-scale deployment of DER without adequate voltage and frequency tolerance will negatively affect bulk system reliability and performance
- **Disconnections** during a frequency event propels frequency decay
- Disturbances on the transmission grid can cause a wide-spread, automatic, and simultaneous shutdown of distributed resources
- IEEE 1547 – inverter manufacturing standard for DERs

The Control Shift

Distribution

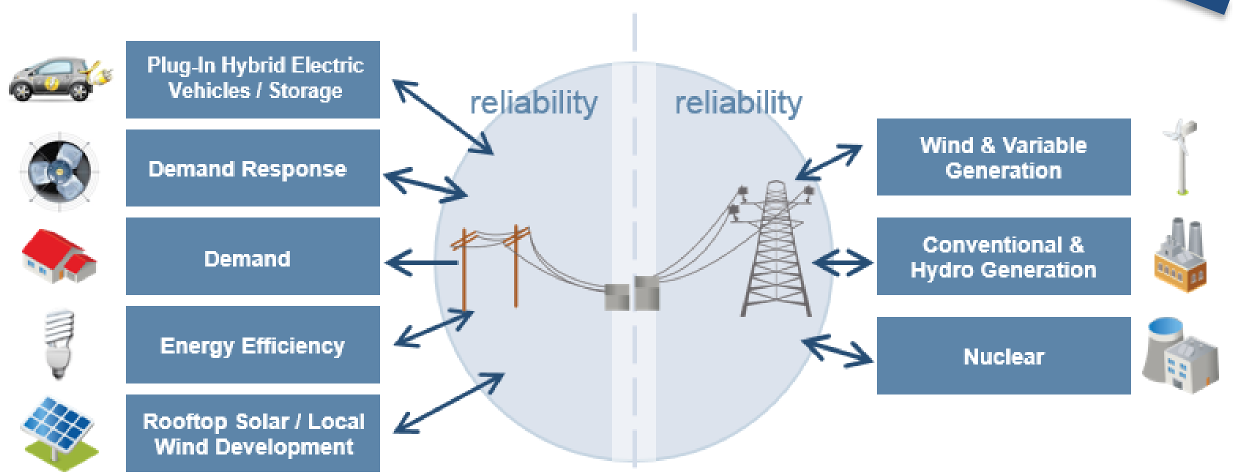
Bulk-Power System

10%

- Supports system inertia and recovery modes
- Dispatchable based on demand
- Centralized to System Operator

- Variability absorbed by load variability
- Operational characteristics do not permeate to BPS

90%



The Control Shift

Distribution

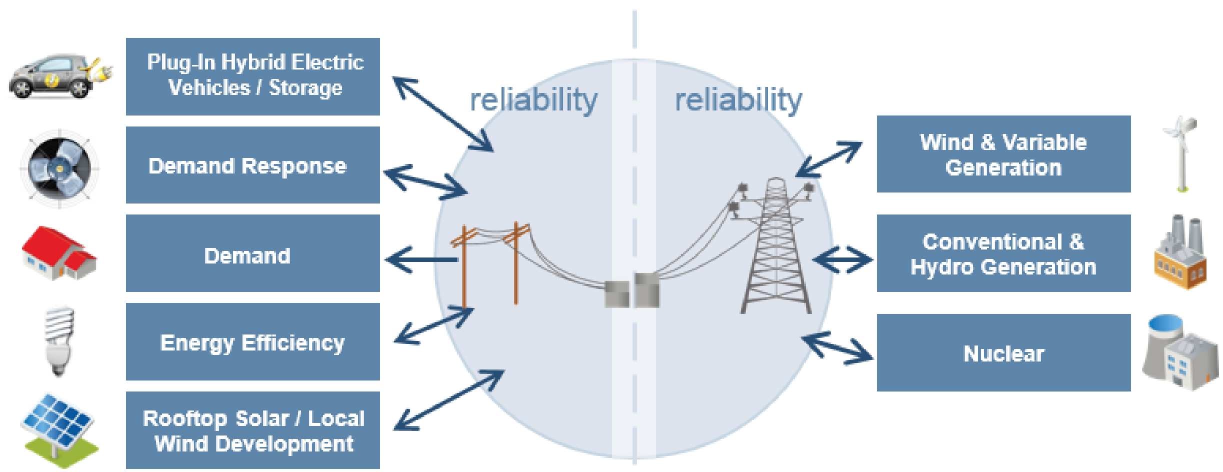
30%

- Disturbances permeate to BPS (common-mode)
- Dynamic and fast demand response
- Potential for overgeneration

Bulk-Power System

- More rigorous generator control Increased reliance on BPS generation
- Additional equipment to control local voltages

70%



The Control Shift

Distribution

Integrated Power System

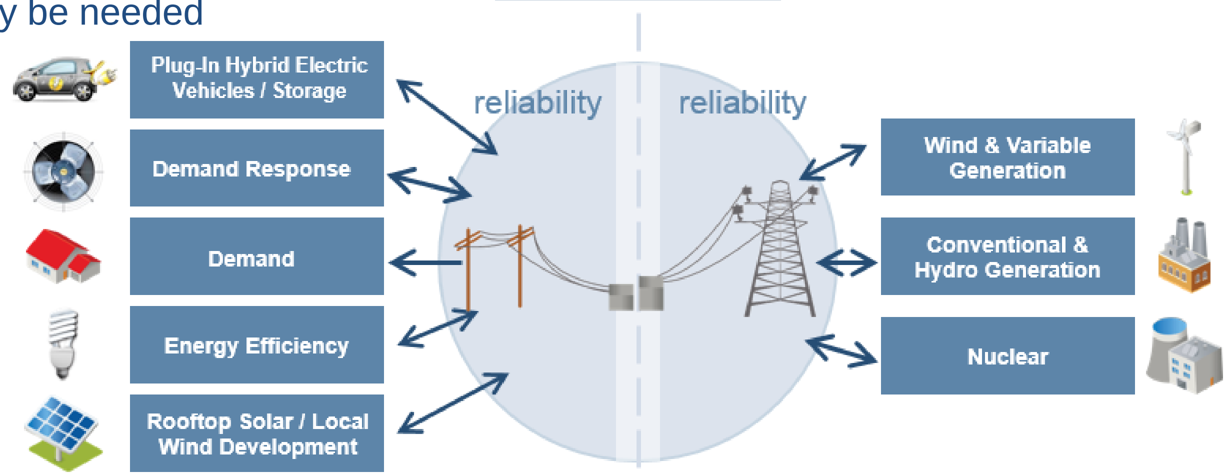
Bulk-Power System

- Supports electricity services
- Provider of long-haul power transfers
- Reliability backbone

50%

- DERs must act as a system resource
- Storage, curtailment, coordination, grid support, and control
- Operator or aggregator function may be needed

50%



Recommendations

1	2	3
All new resources should have the capability to support voltage and frequency.	Monitoring of the ERS measures, investigation of trends, and use of recommended industry practices will serve as an early warning indicator to reliability concerns if issues are not addressed with suitable planning and engineering practices.	Further examination by NERC of the forecasting, visibility, and participation of DERs as an active part of the electric grid is needed.

Questions and Answers

Additional Material

- 2015 Long-Term Reliability Assessment
  http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2015LTRA%20-%20Final%20Report.pdf

- Essential Reliability Services Task Force Measures Framework Report
  http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Framework%20Report%20-%20Final.pdf

- Essential Reliability Services – Abstract (2-pager)
  http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERS%20Abstract%20Report%20Final.pdf

- The Basics of Essential Reliability Services (Multimedia Presentation)
  https://vimeopro.com/nerclearning/erstf-1

- Essential Reliability Services Task Force Website
  http://www.nerc.com/comm/Other/Pages/Essential-Reliability-Services-Task-Force-(ERSTF).aspx

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Additional Information

NERC Reports on Accommodating High Levels of Variable Generation:

- DRAFT Joint NERC-CAISO Special Reliability Assessment: Maintaining Bulk Power System Reliability While Integrating Variable Energy Resources to Meet Renewable Portfolio Standards
- Performance of Distributed Energy Resources During and After System Disturbance
- Interconnection Requirements for Variable Generation, NERC, September 2012
- Potential Bulk System Reliability Impacts of Distributed Resources
- Methods to Model and Calculate Capacity Contributions of Variable Generation for Resource Adequacy Planning
- Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation
- Operating Practices, Procedures, and Tools
- Potential Reliability Impacts of Emerging Flexible Resources
- Variable Generation Power Forecasting for Operations
- Standard Models for Variable Generation
- Flexibility Requirements and Potential Metrics for Variable Generation

NERC Reports on Accommodating and Increased Dependency on Natural Gas

- Primer (Phase I)
- Vulnerability Assessment (Phase II)

NERC Reliability Assessments (Long-Term and Seasonal)

- http://www.nerc.com/pa/RAPA/ra/Pages/default.aspx