Use of
Frequency Response Metrics to Assess the
Planning and Operating Requirements for Reliable Integration of
Variable Renewable Generation

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Office of Electric Reliability
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Overview of This Presentation

Project objectives

Power system frequency control and metrics

Reliability impacts of variable renewable generation

Findings from the dynamic simulation studies conducted

Project recommendations

Project Objectives

1. Determine whether a metric for frequency response could be used to assess the reliability impacts of integrating variable renewable generation

2. If so, use a frequency response metric to assess the reliability impact of variable renewable generation on the electric power system, by interconnection, following the sudden, instantaneous loss of large conventional power plants; and

3. Identify what further work and studies are necessary to quantify and address any reliability impacts associated with the integration of variable renewable generation

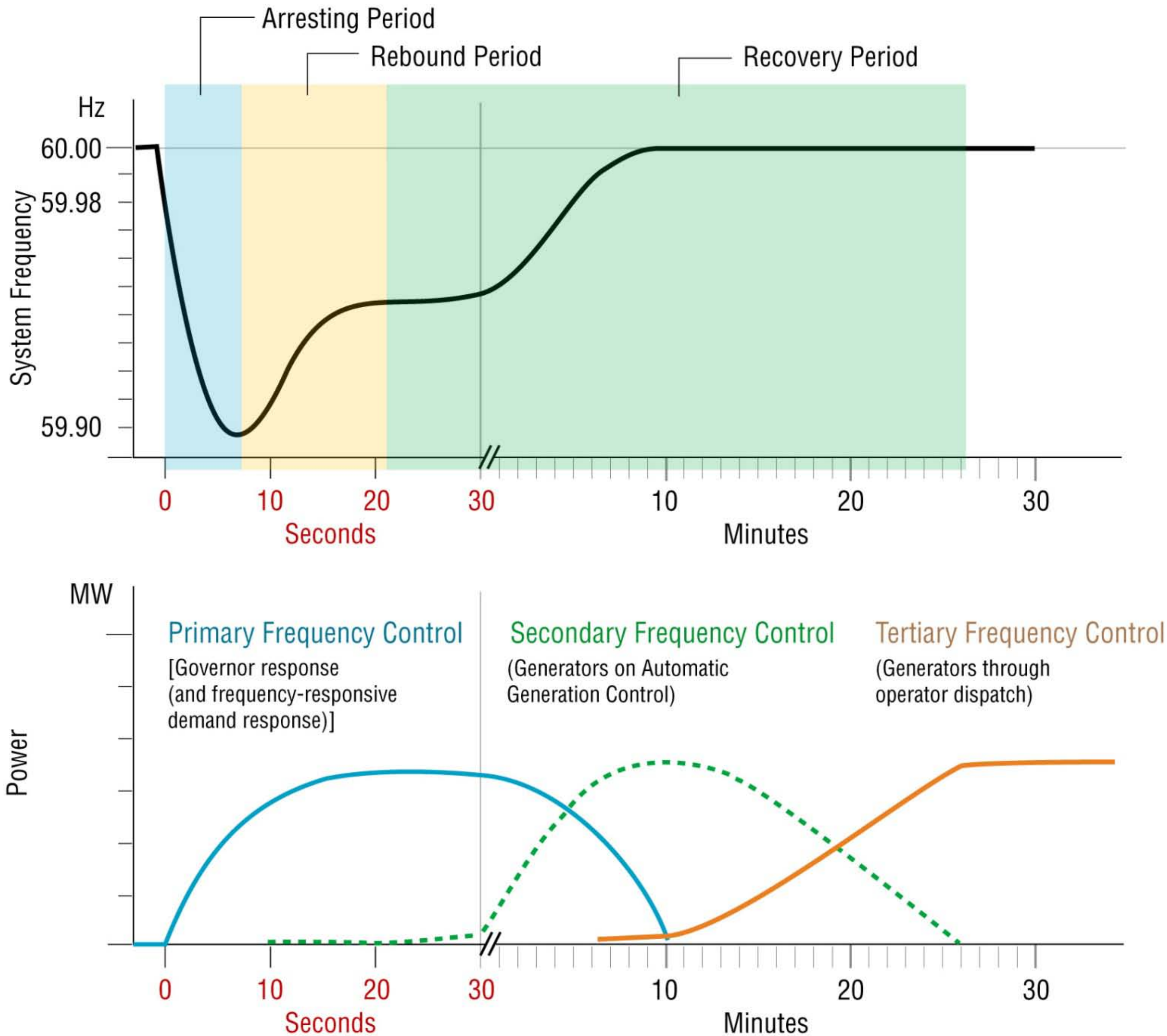
Note: The scope of this project was broadened from the original scope announced in May, 2009 as the research progressed, revealing the general applicability of frequency response metrics to analyze a broad range of changes that a complex interconnected electric system must manage to ensure reliability

Power System Frequency Control

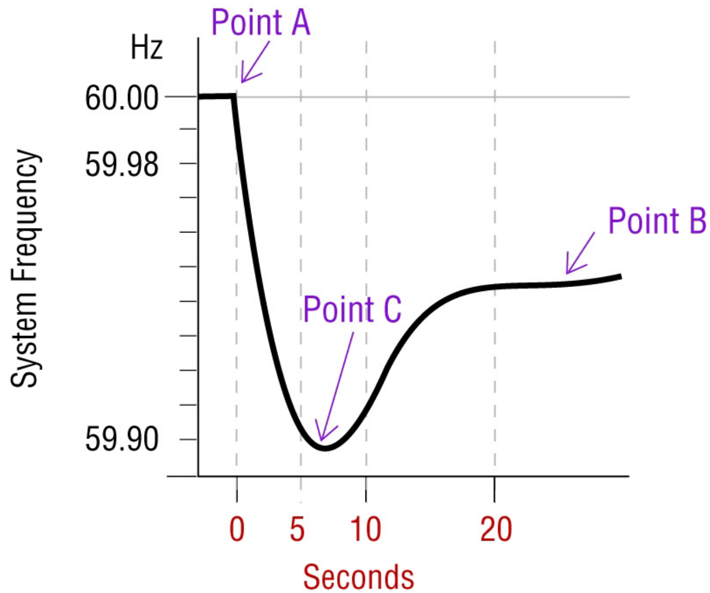
The sequential actions of primary, secondary, and tertiary frequency control restore system frequency following the sudden loss of generation

Primary frequency control because it is fast and automatic is irreplaceable and therefore essential for ensuring reliability following the sudden loss of generation

Very few studies of wind integration have examined requirements for primary frequency control – most focus only on secondary frequency control



Frequency Response Metrics



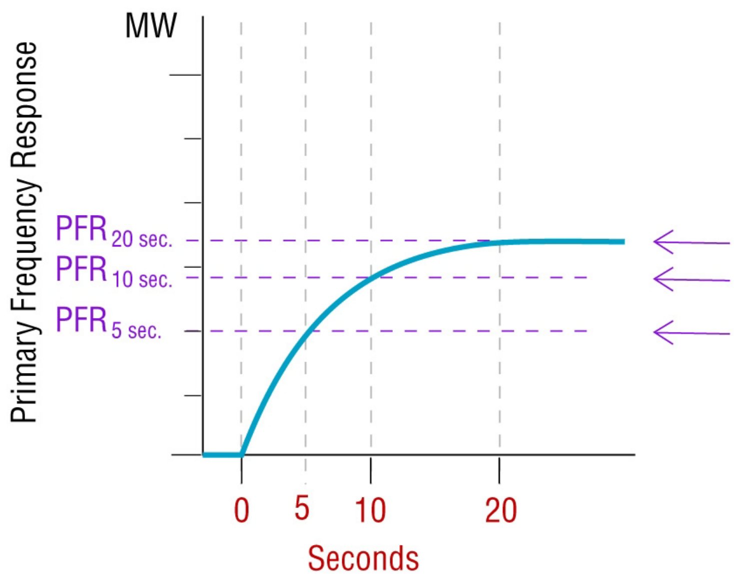
Pre-disturbance Frequency: $\text{Frequency}_{\text{point A}}$

Settling Frequency: $\text{Frequency}_{\text{point B}}$

Frequency Nadir: $\text{Frequency}_{\text{point C}}$

$$\text{Frequency Response (current practice)} = \frac{\text{Generation Lost (MW)}}{\text{Frequency}_{\text{point A}} - \text{Frequency}_{\text{point B}}}$$

$$\text{Nadir-Based Frequency Response} = \frac{\text{Generation Lost (MW)}}{\text{Frequency}_{\text{point A}} - \text{Frequency}_{\text{point C}}}$$



Primary frequency response (PFR) delivered at 20 seconds

Primary frequency response (PFR) delivered at 10 seconds

Primary frequency response (PFR) delivered at 5 seconds

Frequency Response Impacts of Variable Renewable Generation

1. Will Lower System Inertia – *requires increased reserves for primary frequency control*

2. May Displace Primary Frequency Control Reserves – *requires procedures for ensuring adequate reserves for primary frequency control*

3. May Affect the Location of Primary Frequency Control Reserves – *requires consideration of transmission system limits and deliverability of primary frequency control actions*

4. Will Place Increased Requirements on the Adequacy of Secondary Frequency Control Reserves – *requires better forecasting and improved operating practices*

Note: The rapid ramping of variable renewable generation output is not considered a frequency response event comparable to the sudden loss of conventional generation – but rapid ramping represents an important new operating challenge directly related to Impact 4

Dynamic Simulation Study Overview

Western, Texas, and Eastern Interconnections were studied individually

Using commercially available dynamic simulation tools and system models provided by industry for the generation and transmission infrastructure expected in 2012

- WECC 2012-13 Light Winter – GE PSLF
- ERCOT 2012 Summer Off-Peak Base Case – PTI PSS/E
- ERAG 2009 Light Load Case – PTI PSS/E

To examine frequency performance following sudden loss of a large amount of conventional generation at a time of low or minimum system load, varying both the amount of wind generation and operating reserves

Simulation Findings

• Confirmed the validity of using frequency response as predictive metrics to assess the reliable operation of interconnected systems that are managing major changes in generation resources.

• Assuming operating reserve conditions that are representative of current practices, we find that the three interconnections can be reliably operated with the amount of wind generation and supporting transmission expected by 2012

Eastern Interconnection – 10.5 GW of wind could supply approximately 1% of 2012 electricity requirements

Western Interconnection – 9.0 GW of wind could supply approximately 3% of 2012 electricity requirements

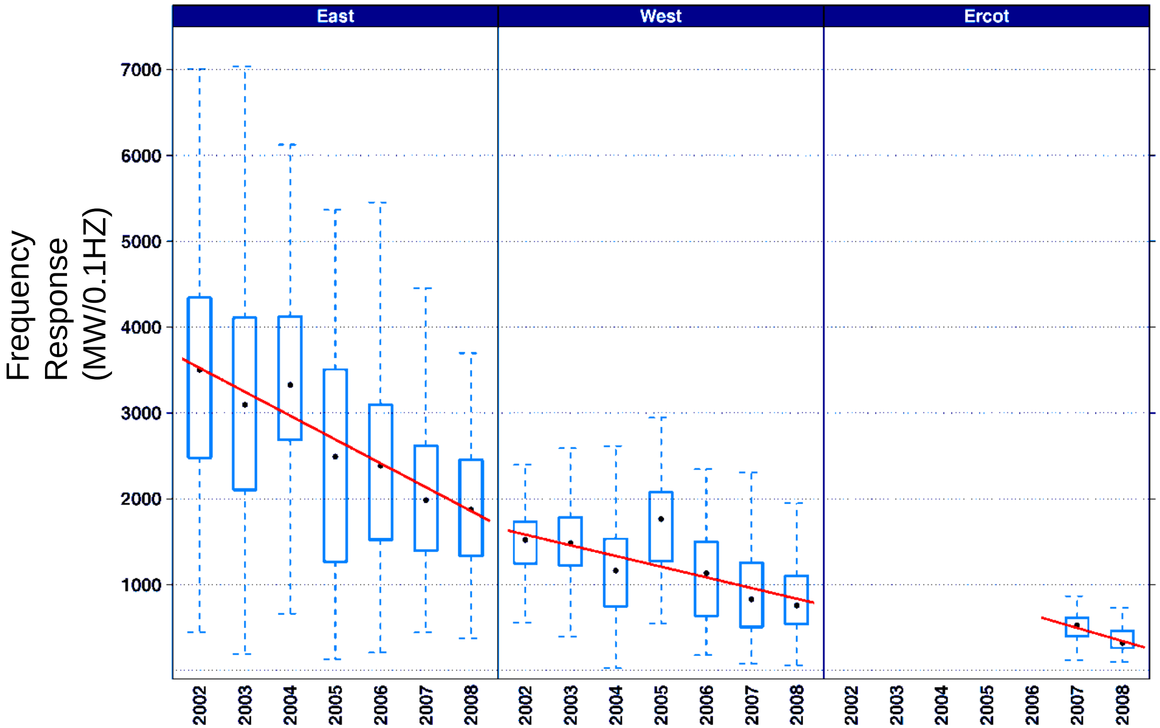
Texas Interconnection – 14.4 GW of wind could supply approximately 13% of 2012 electricity requirements

Recommendation 1

Efforts should be accelerated now to better understand interconnection- and balancing authority-specific requirements for frequency control, especially in the Eastern Interconnection, considering among other things the frequency response metrics validated in this study

It is widely acknowledged that the industry, especially in the Eastern Interconnection, is currently grappling with the implications of the declining quality of frequency control within the interconnection

Variable renewable generation has not been the cause or contributor to declines observed over past decade.

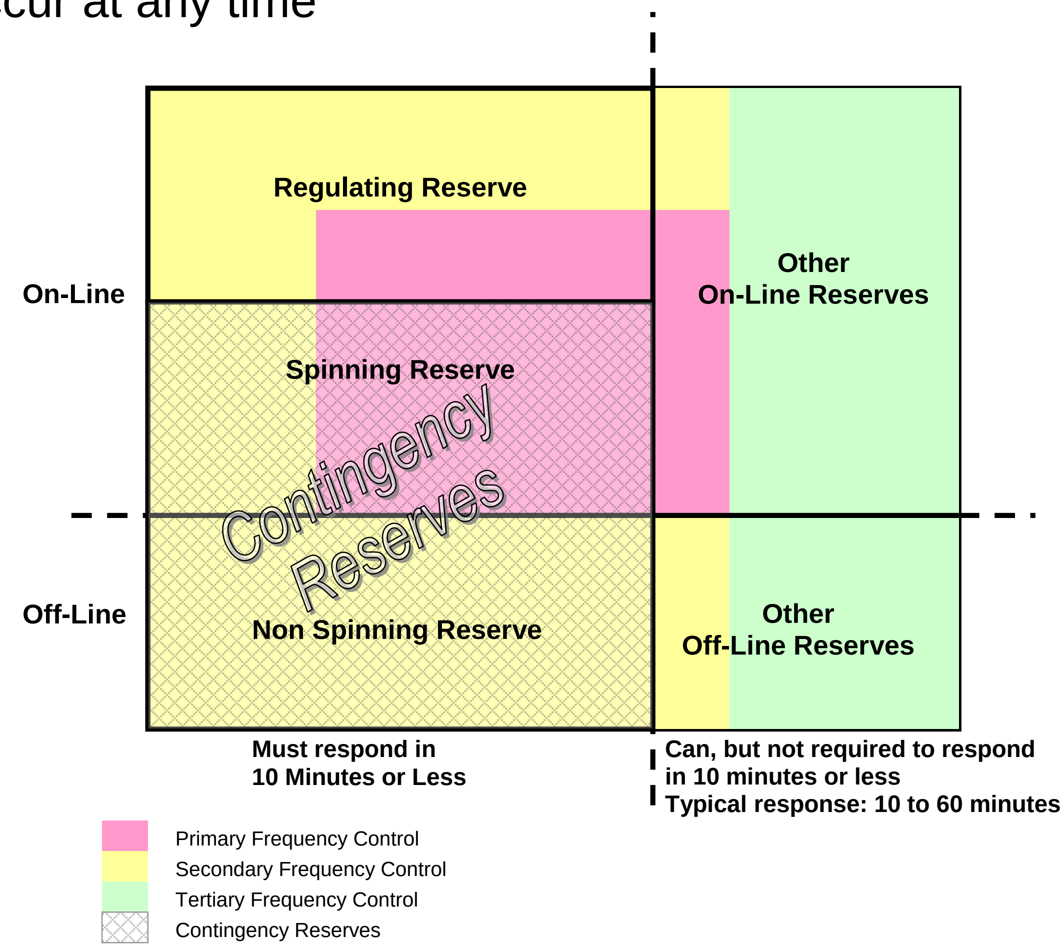


The Recorded Frequency Response of the Three U.S. Interconnections, 2002-2008. Source: Martinez, et al (2010)

Recommendation 2

Interconnections must schedule adequate primary and secondary frequency control reserves to both manage variations in net system load caused by increased levels of wind generation and withstand the sudden loss of generation, which can occur at any time

Our analytical and simulation studies have highlighted the essential roles that primary and secondary frequency control reserves play in ensuring reliability, especially the rapid and sustained provision of power from primary frequency control reserves immediately following the sudden loss of generation



Recommendation 3

The frequency control capabilities of the interconnections should be expanded, as follows:

1. Expanded use of the existing fleet of generation (improved generator governor performance, increased operating flexibility of baseload units, faster start-up of units, etc.);

2. Expanded use of demand response that is technically capable of providing frequency control (potentially including smart grid applications), starting with broader industry appreciation of the role of demand response in augmenting primary and secondary frequency control reserves;

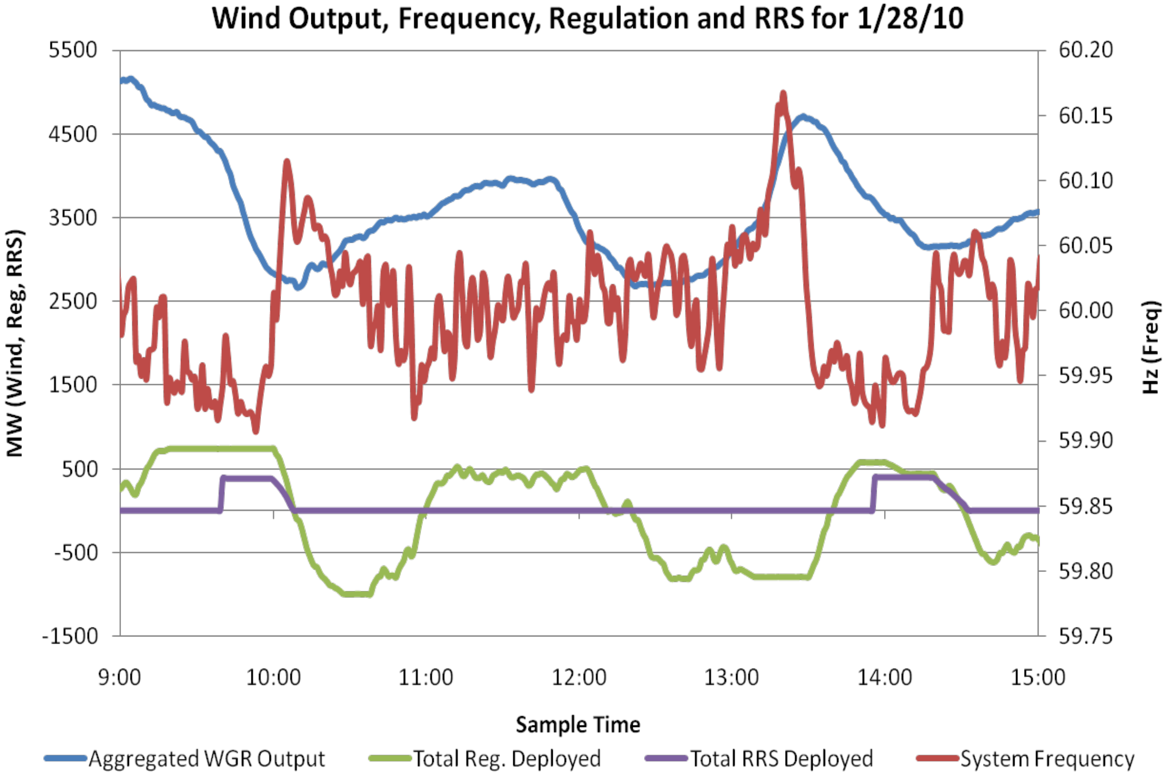
3. Expanded use of frequency control capabilities that could be provided by variable renewable generation technologies (primary frequency control, etc.); and

4. Expanded use of advanced technologies, such as energy storage and electric vehicles

Recommendation 4

Comprehensive planning and enhanced operating procedures, including training, operating tools, and monitoring systems, should be developed that explicitly consider interactions between primary and secondary frequency control reserves, and address the new source of variability that is introduced by wind generation

Although operators have extensive experience anticipating and managing regular diurnal ramping requirements to meet system load from conventional generation resources, integrating variable renewable generation will at times require much greater commitment and dispatch flexibility or fleet maneuverability than has previously been required

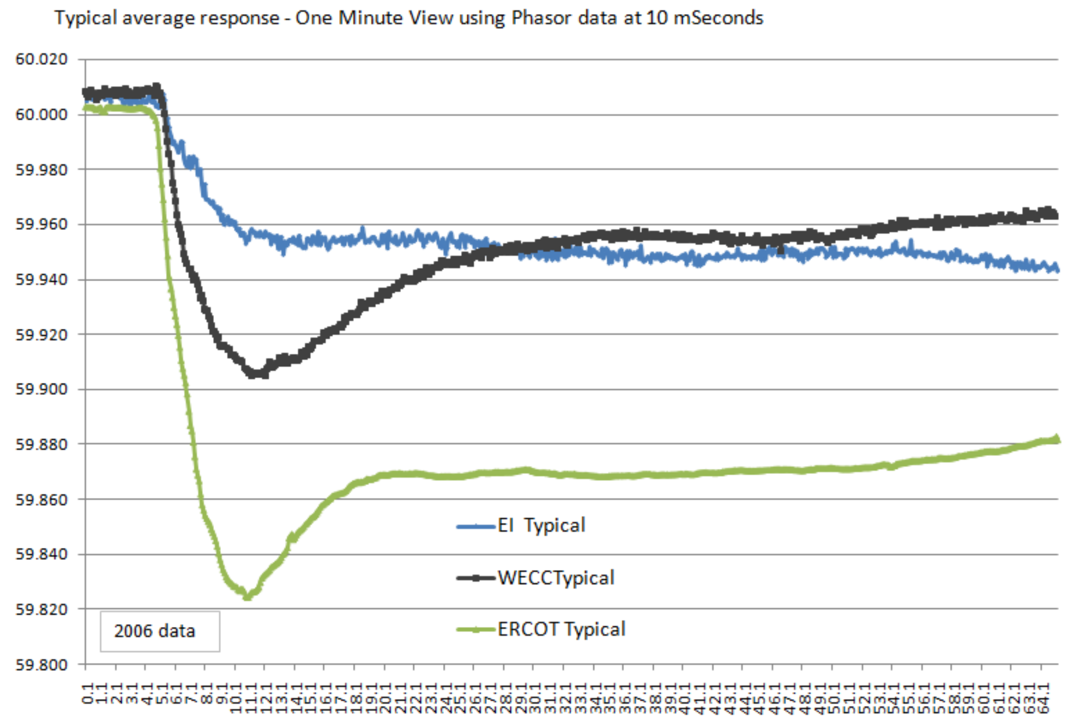


The Relationship Between Rapidly Changing Wind Output and System Frequency in the Texas Interconnection on January 28, 2010
Source: ERCOT (2010)

Recommendation 5

Requirements for adequate frequency control should be evaluated in assessments of the operating requirements of the U.S. electric power system when considering new potential sources of generation and the retirement of existing generation

New technologies, economic considerations, and public policies will continue to alter the future composition of our power system (including the addition of other forms of variable renewable generation, changes in nuclear generation, retirements of generators, and changes in the electrical characteristics of customer loads, among other factors)



Examples of the Frequency Response of the Three U.S. Interconnections Following the Sudden Loss of Conventional Generation
Source: NERC (2010)

Supporting Technical Reports

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