Briefing on Staff Initiated Frequency Response Report

Requested Meeting for NERC and Trade Associations

March 24, 2011

EEI Office in DC

Introduction by Joe McClelland

Director

Office of Electric Reliability

Background

- To determine whether metrics for frequency response could be used to assess the reliability impacts of integrating variable renewable generation
- If so, to use these metrics to assess the potential reliability impact of new variable renewable generation on the electric power system, by interconnection, following the sudden, instantaneous loss of large conventional power plants
- To identify what further work and studies are necessary to quantify and address any reliability impacts associated with the integration of variable renewable generation

Major Observations

- Metric objective, flexible, and valid in evaluating resource mixes, including wind
- Wind Resources may displace frequency responsive resources
- Eastern Interconnection Model Inadequate
- Frequency responses of the three Interconnections are different
  - ERCOT - Exemplary
  - WECC - Marginal
  - Eastern Interconnection - of concern

Can Operate Reliably with:

- Existing transmission
- Historic levels of frequency response
- Amount of wind resources included by planners in models for 2012
  - WECC – 9 GW
  - ERCOT – 14.4 GW
  - Eastern – 10.5 GW (Engineering Judgment)

Bob Snow

Senior Engineer

Office of Electric Reliability

Meeting Information

- This is a staff presentation and does not represent the position or opinion of the Federal Energy Regulatory Commission
- This is an engineering discussion containing slides for background
- The report has undergone extensive peer review but is not perfect
- Interested in filed comments and any feedback
- A file of the presentation will be provided

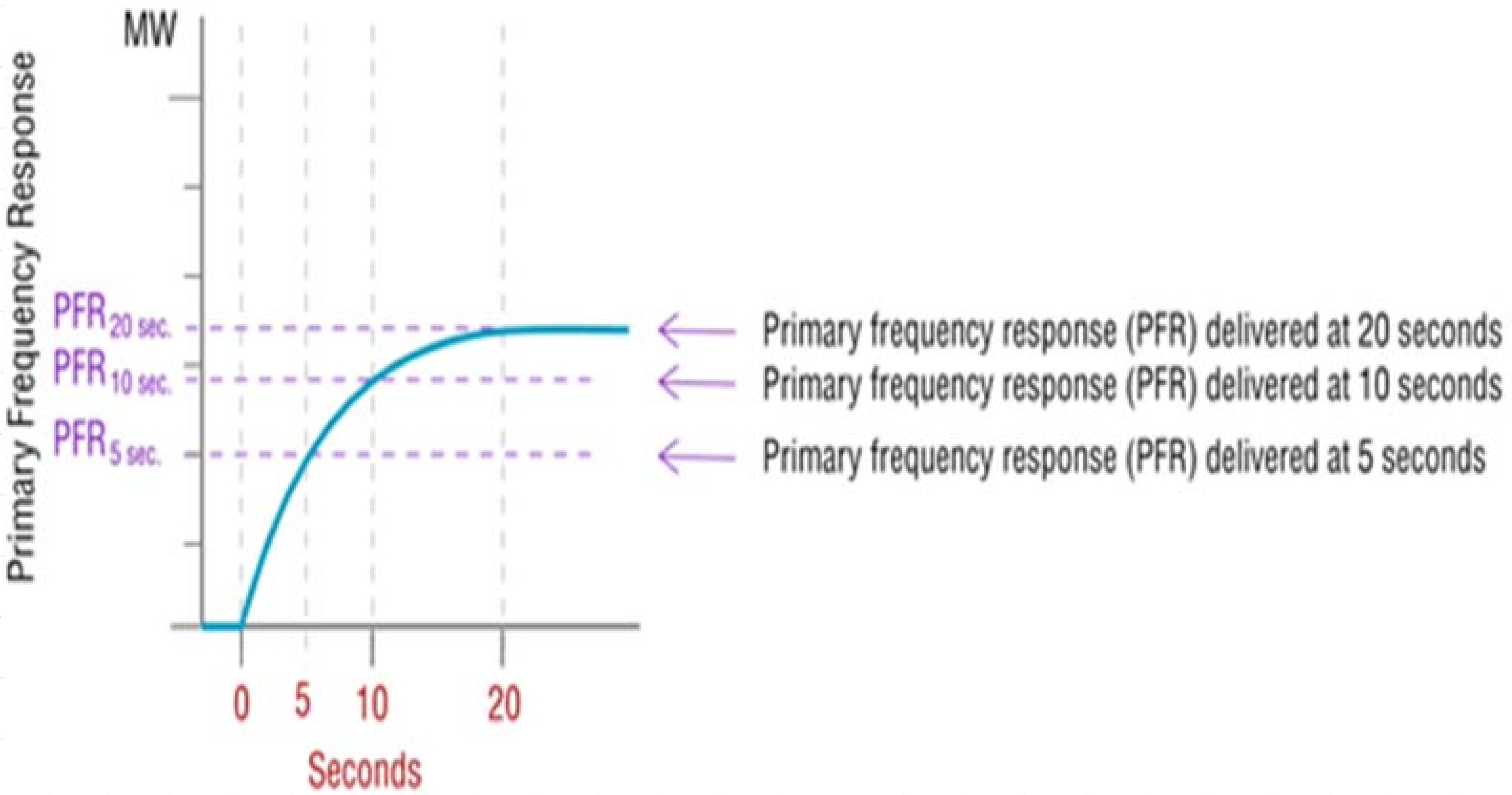
Outline

- Goals
- Terminology and key concepts (Quick)
- Reliability Implications
- Proposed Metrics
  - Technical justifications
  - Recommended applications
- Project Recommendations (Quick)
- Questions at end of sections

Goals (Major Take Away)

- The proposed metric is valid and can be used prospectively in planning and operations
- How frequency response can be used to manage wind resources
- Results not limited to wind resources
- Adequate Primary and Secondary Frequency Control are essential at all times

Major Frequency Response Metric



Terminology and Key Concepts

Included in presentation for reference

Frequency

- How fast does something vibrate - measured in cycles per second or Hertz. (One note from an instrument)

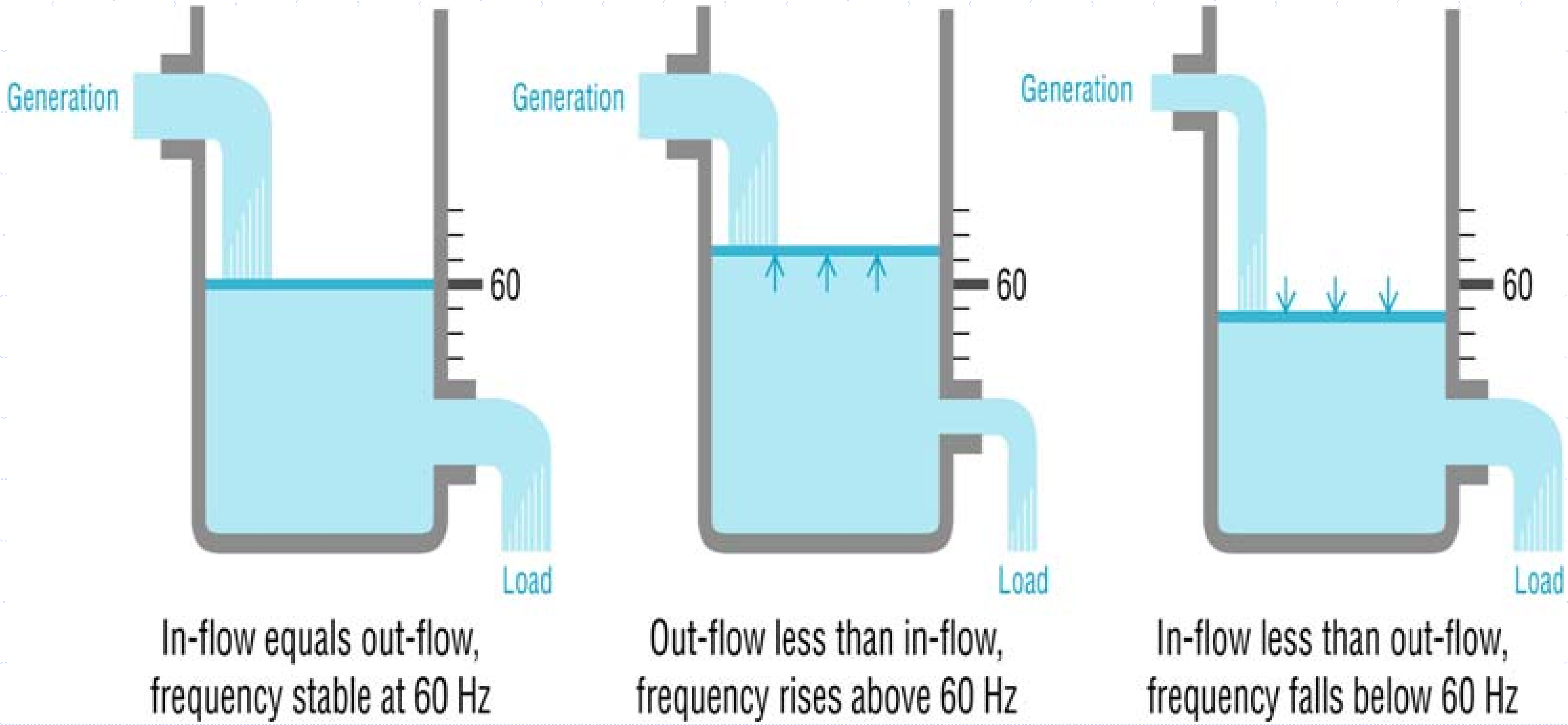
Frequency Response

- How large a power imbalance does it take to observe a 0.1 Hz change in Frequency – measured in MW/0.1 Hz (force needed to tilt an object by one degree)

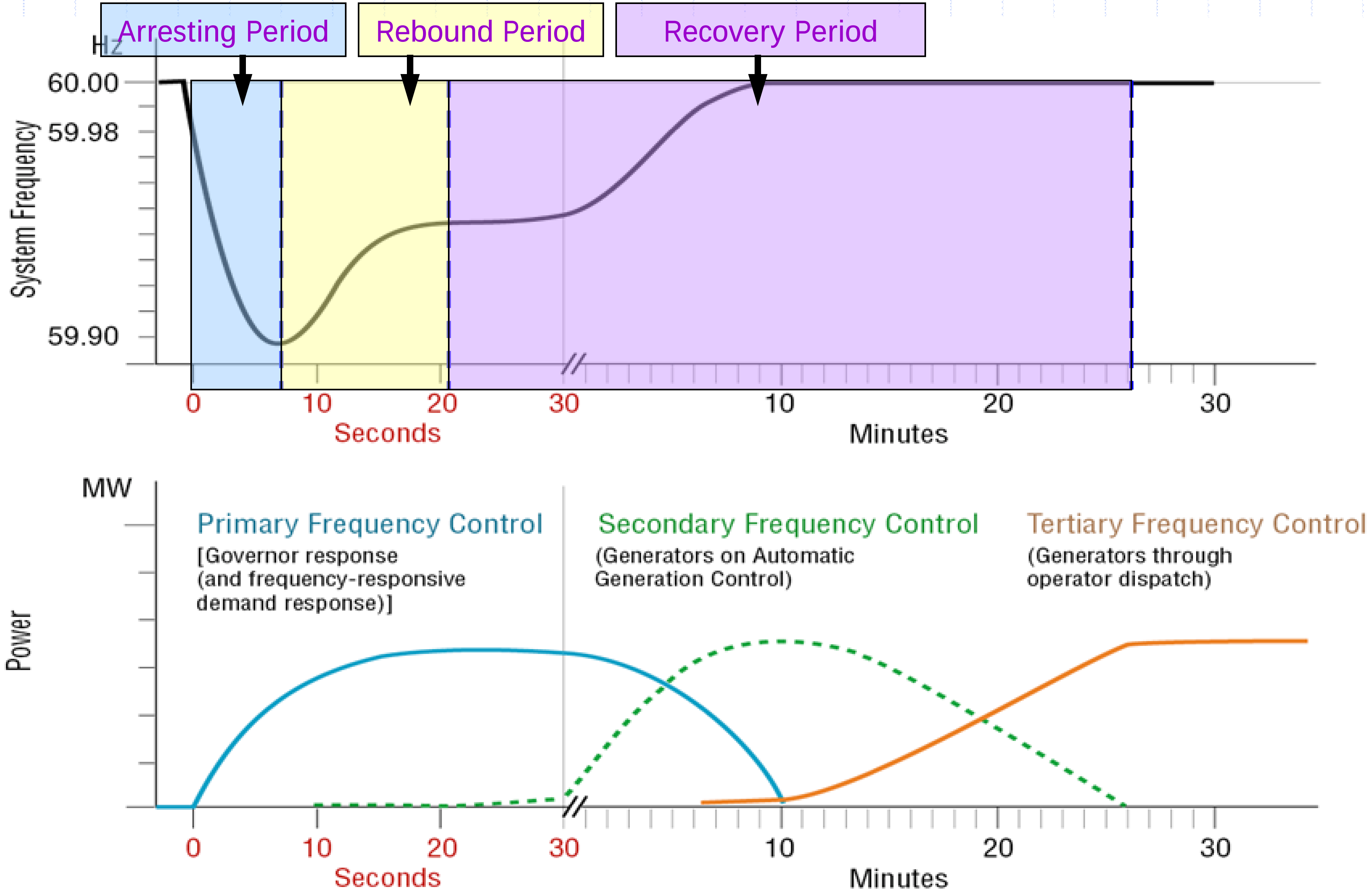
Key Concepts

- Power Balance
- Frequency Control Performance
- Variables driving Frequency Response
- Propagation of frequency Disturbance
- Safety Nets (UFLS)
- Governors and Droop

Power Balance

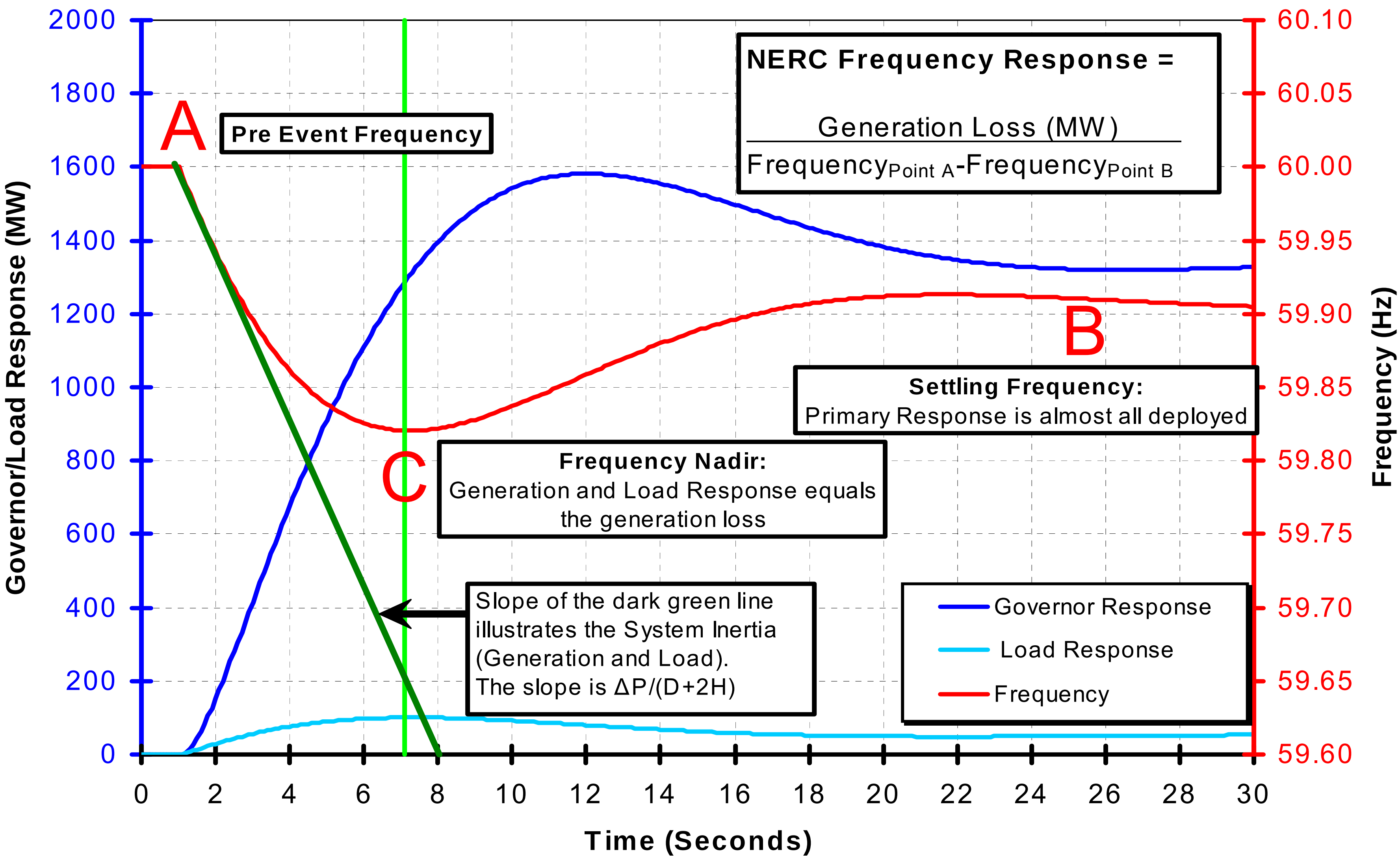


Frequency Performance

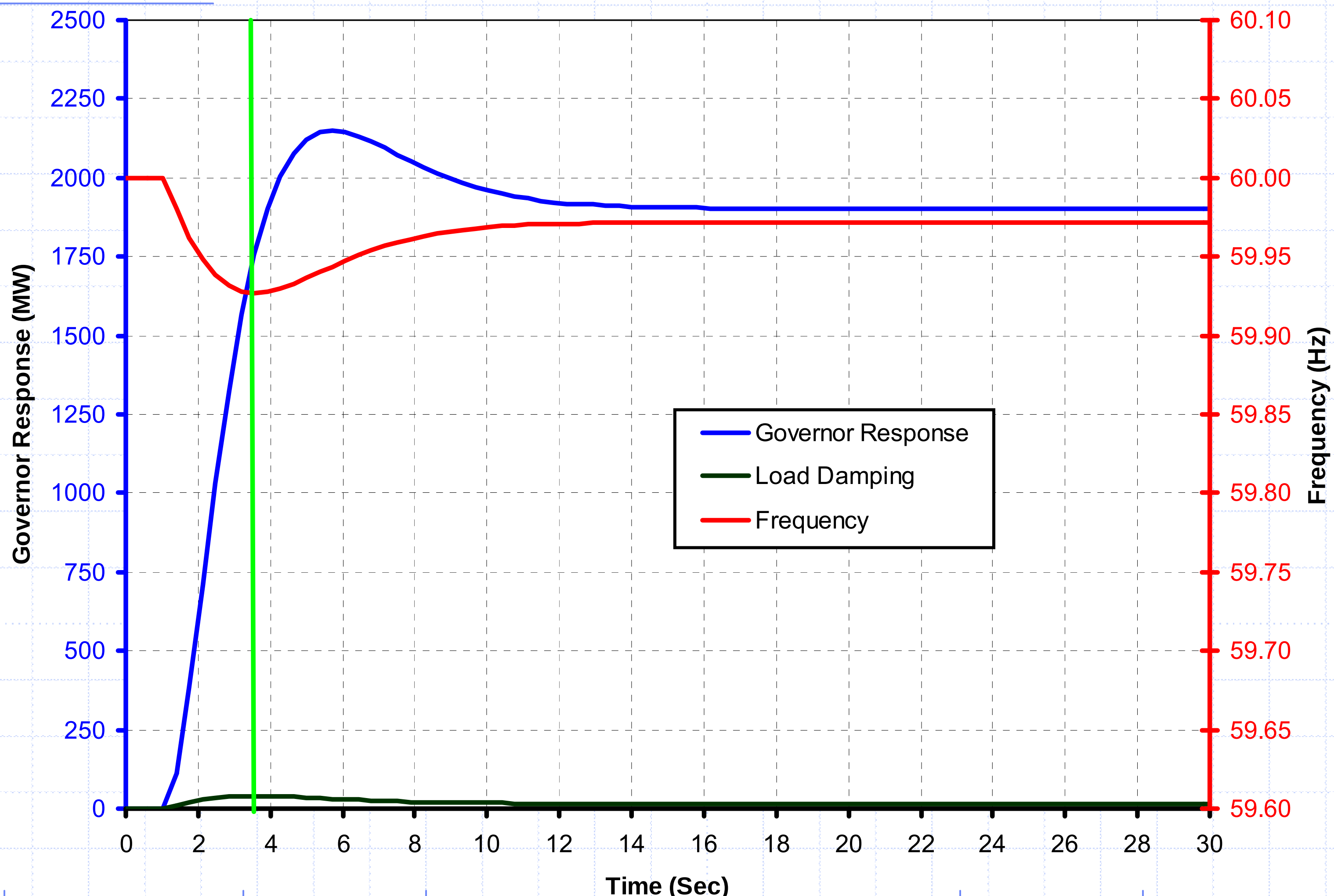


Frequency Response Basics

(Using a 1400 MW generation loss event as an example)



Single Area System Model
All units responding



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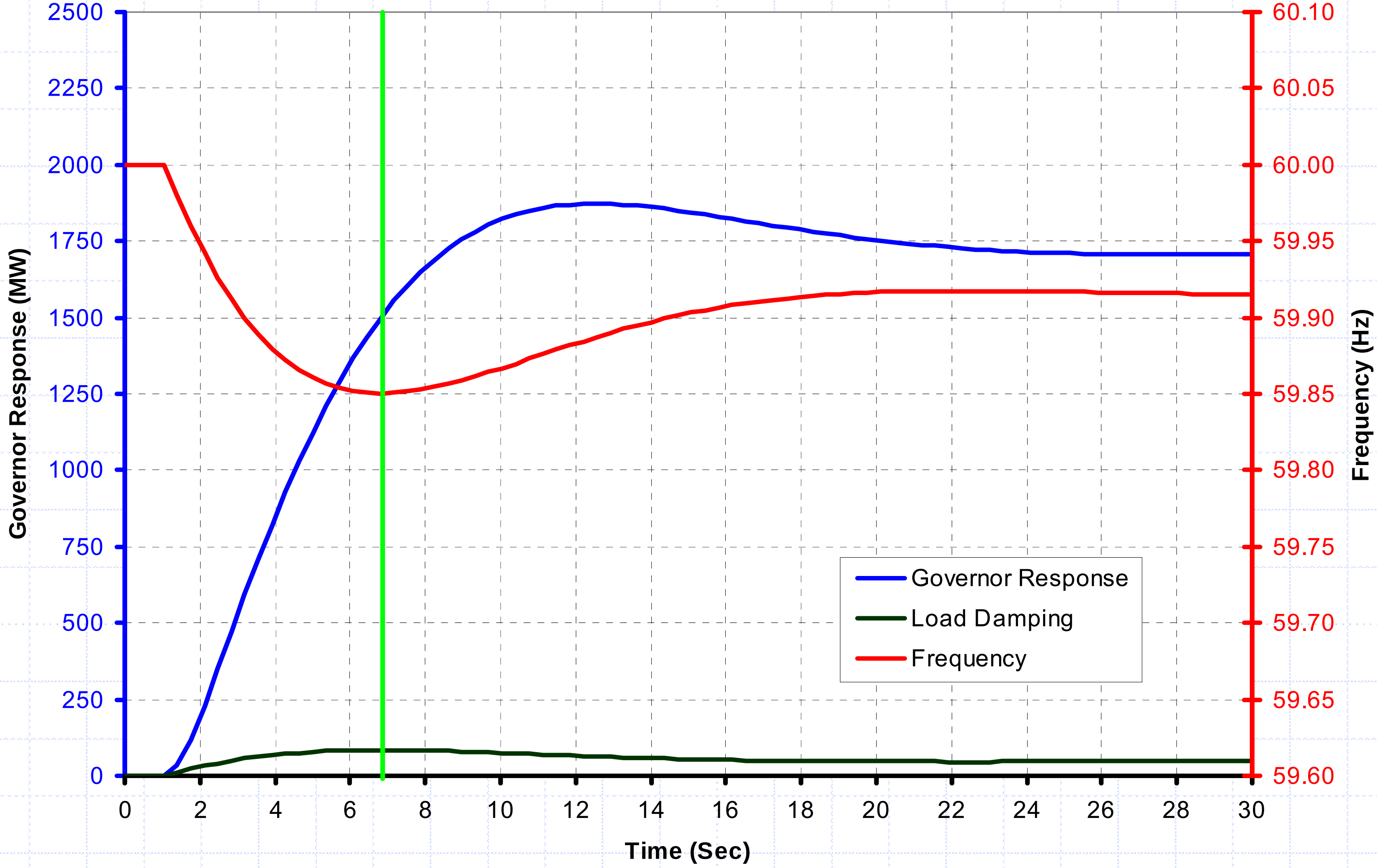
Single Area System Model
30% of units responding



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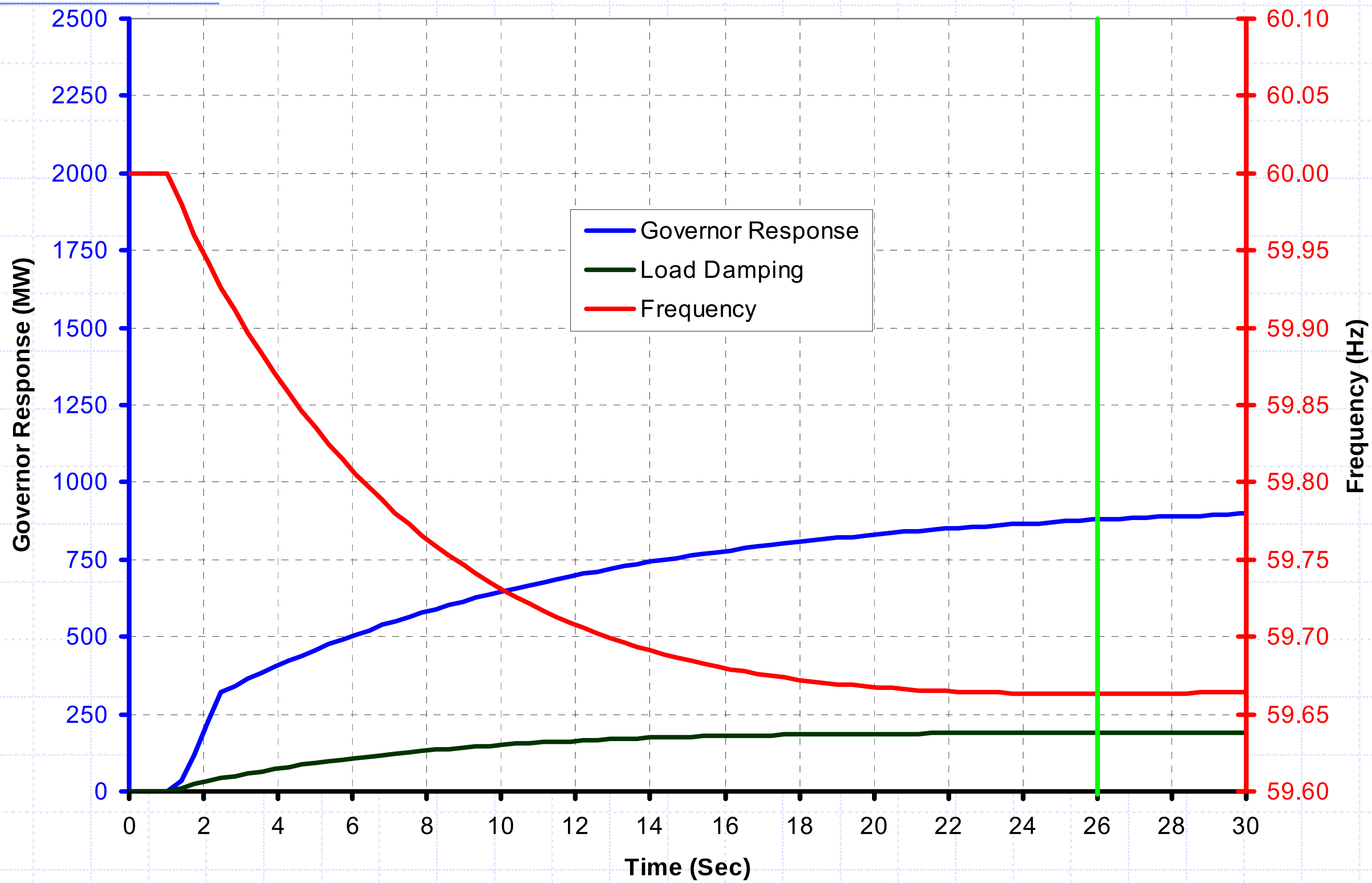
Single Area System Model
30% units responding, limited to .005 PU



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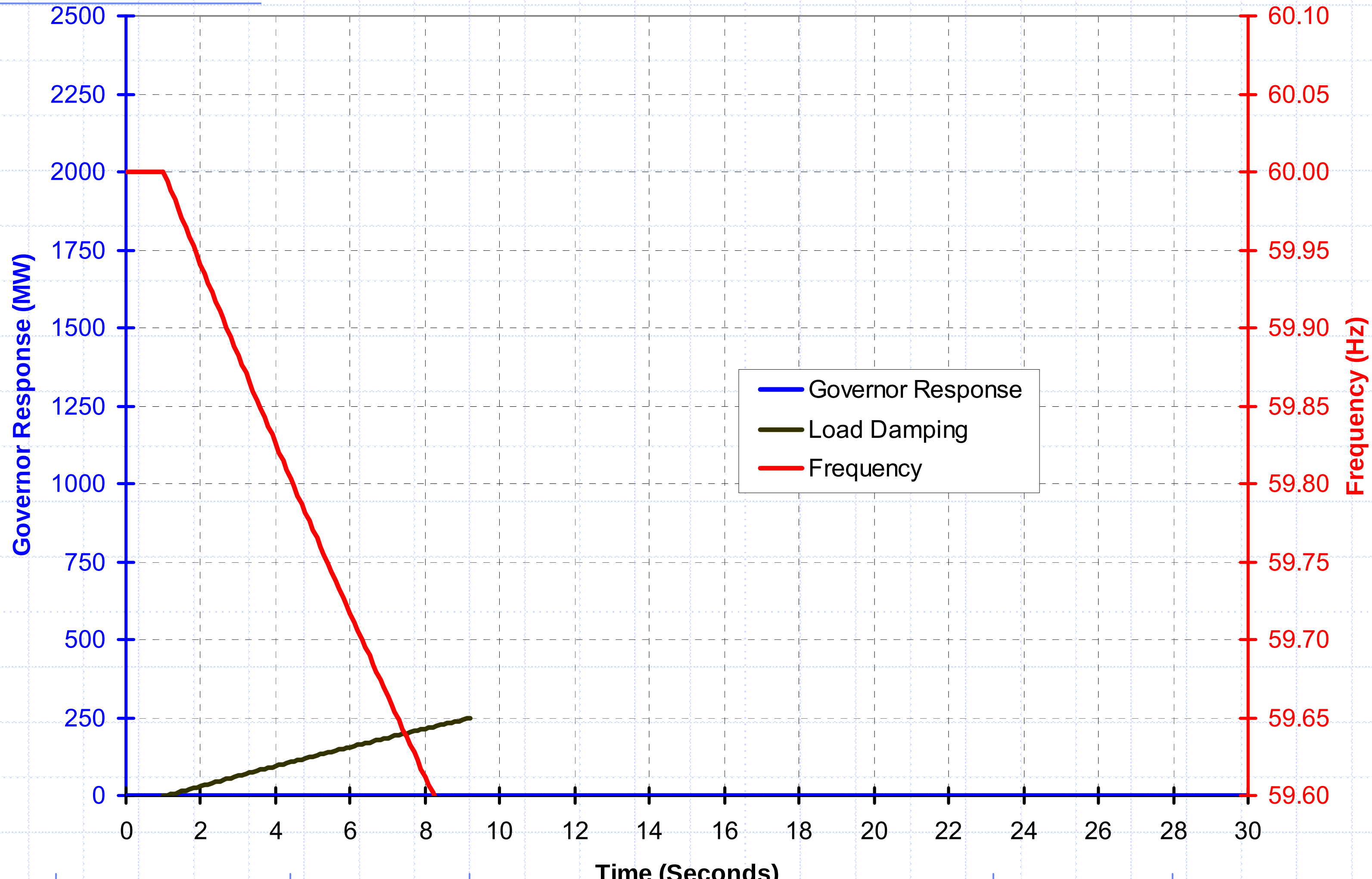
Single Area System Model
no units responding



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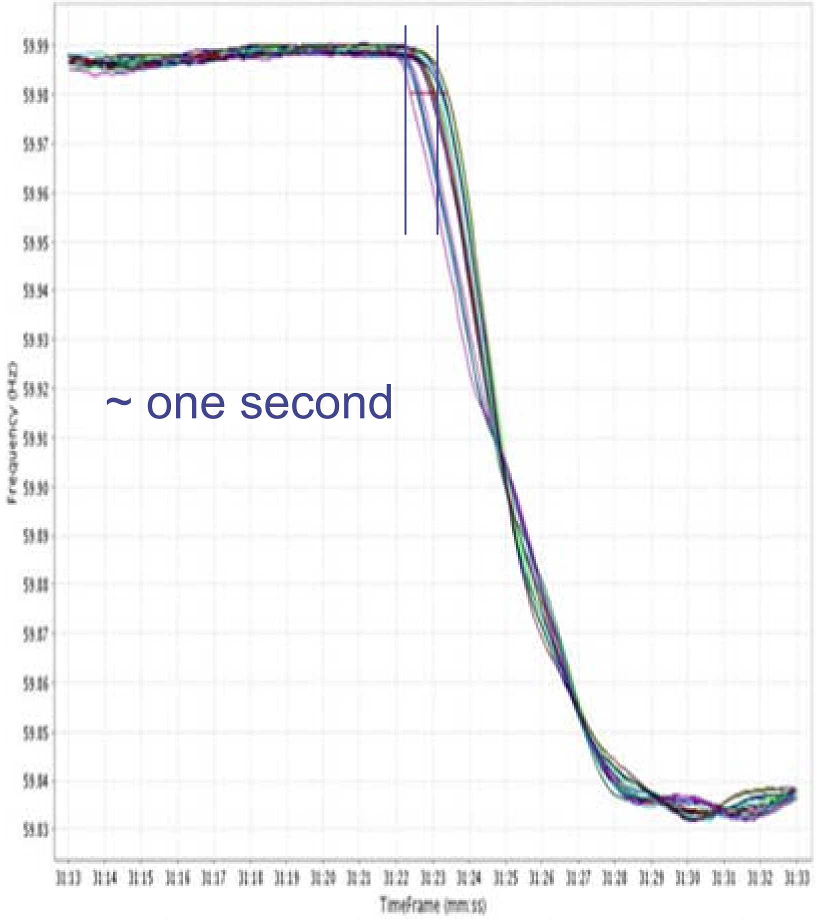
Propagation of Frequency as viewed from Different Locations within the Western Interconnection Following the Sudden Loss of a Large Generator



- Frequency changes are propagated over the interconnection with a short time delay
- All generators experience similar frequencies and may contribute response

Source: Courtesy of Genscape

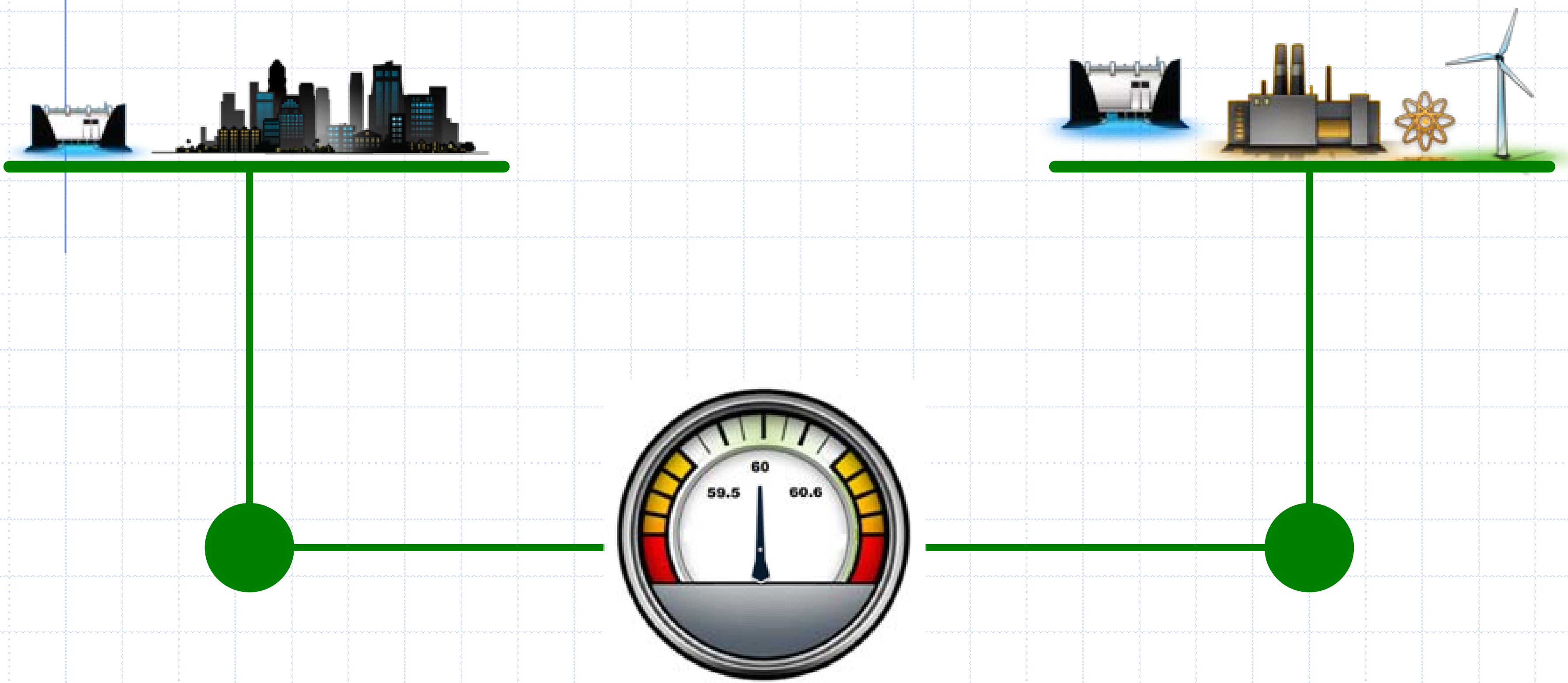
Safety Nets (i.e. UFLS)

- Last resort systems
  - Should not operate for design conditions
  - Relied upon during limited operation in unknown conditions
- Usually in islanding conditions
- Design goal to preserve generation

Frequency impact for loss of generation

(with governor action, secondary resources, and demand response)

First the loss of generation and frequency decline → Governors react to the frequency and increase generation → Governors, secondary and demand side resources are deployed to return frequency back to schedule



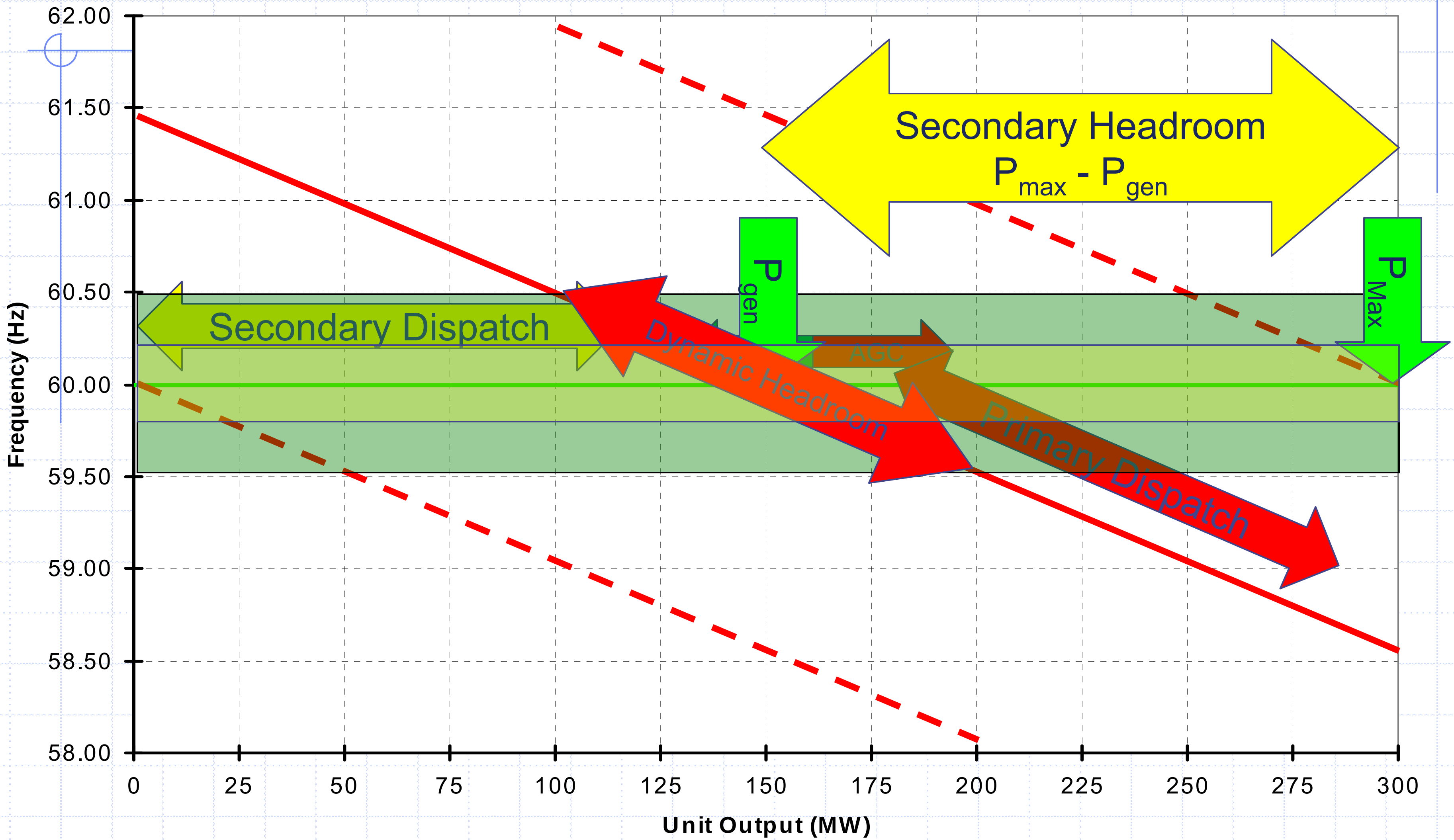
Droop

All generator governors have a droop setting. NERC recommends all generator governors be set at a 5% droop.

Source: NERC

Speed of Primary Frequency Control deployment is critical.

Generator Characteristic Curve with 5% droop



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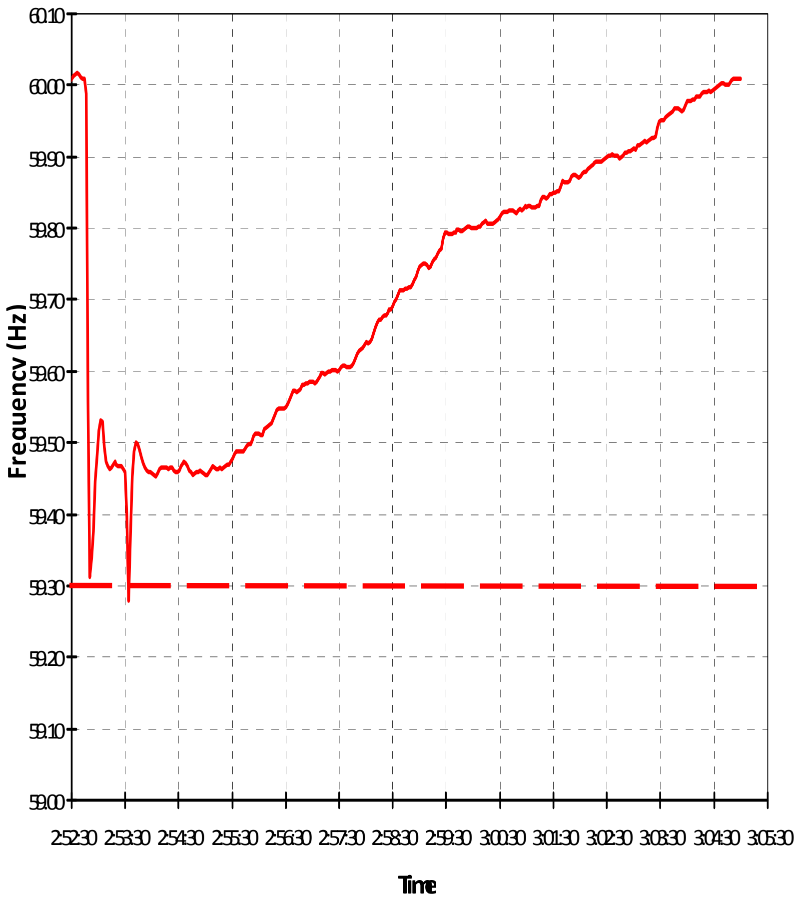
Reliability Indications

- Malaysia Loss of half of their system
- New York system collapse in 2003 event
- 2003 event in ERCOT
- 2007 “Near Miss”
- NERC 2008 Industry Advisory on Turbine Combustor Lean Blowout
- Eastern Interconnection performance not duplicated by simulations

New York System Collapse in 2003 Blackout

- Frequency declined until North West New York UFLS activated
- Low Response resulted in high frequency from amount of load shed
- High frequency tripped remaining generation
- System could not maintain islanding operation and collapsed

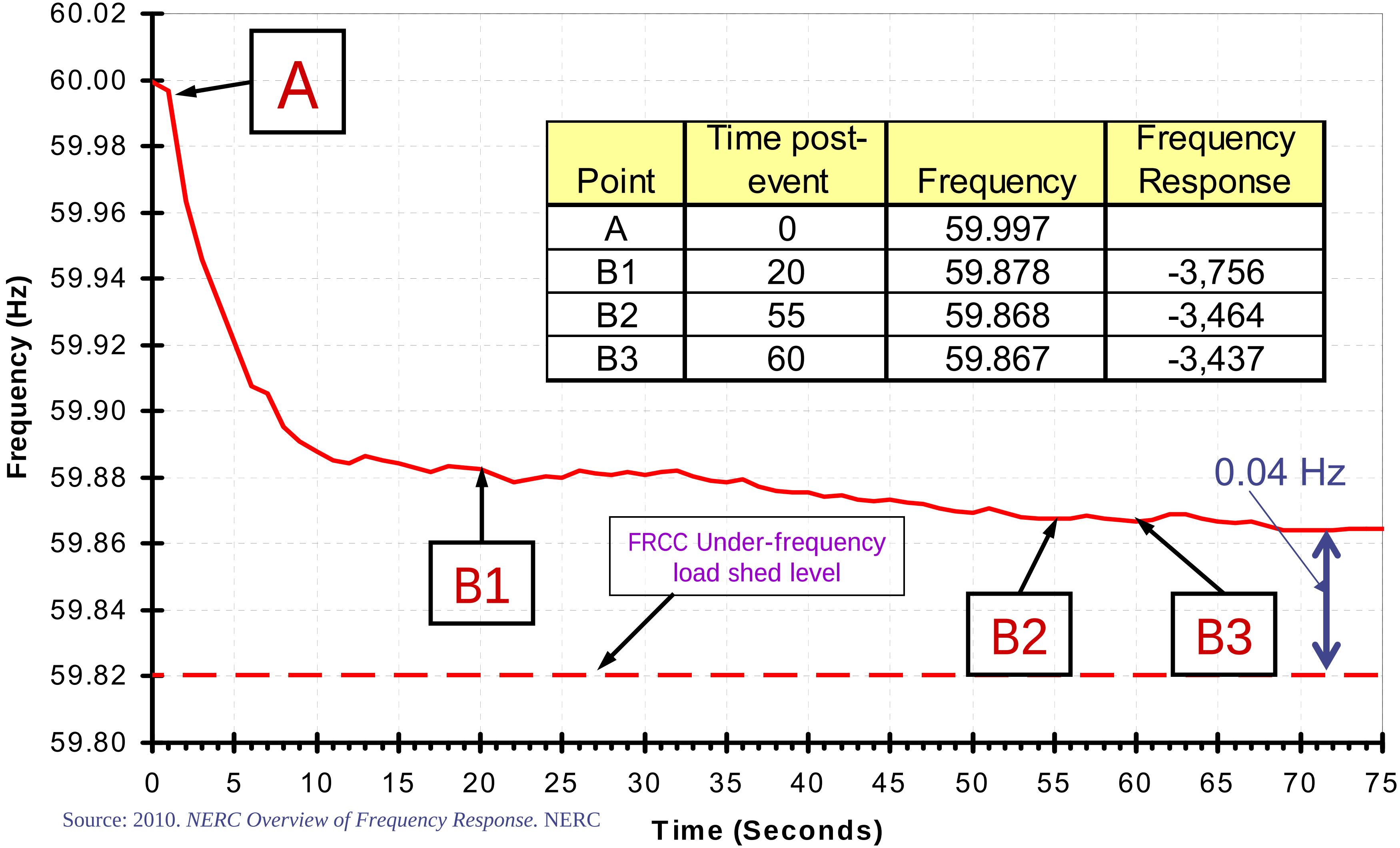
ERCOT May 15, 2003 Event



Source: ERCOT and IEEE Task Force Report

- Initial single line to ground fault on 345 kV line resulting in 7,200 MW of generation trip
- Simulations predicted a minimum frequency of 59.6 Hz.
- Measured frequency was 59.26 Hz
- Lessons learned resulted in ERCOT Model and frequency response initiatives

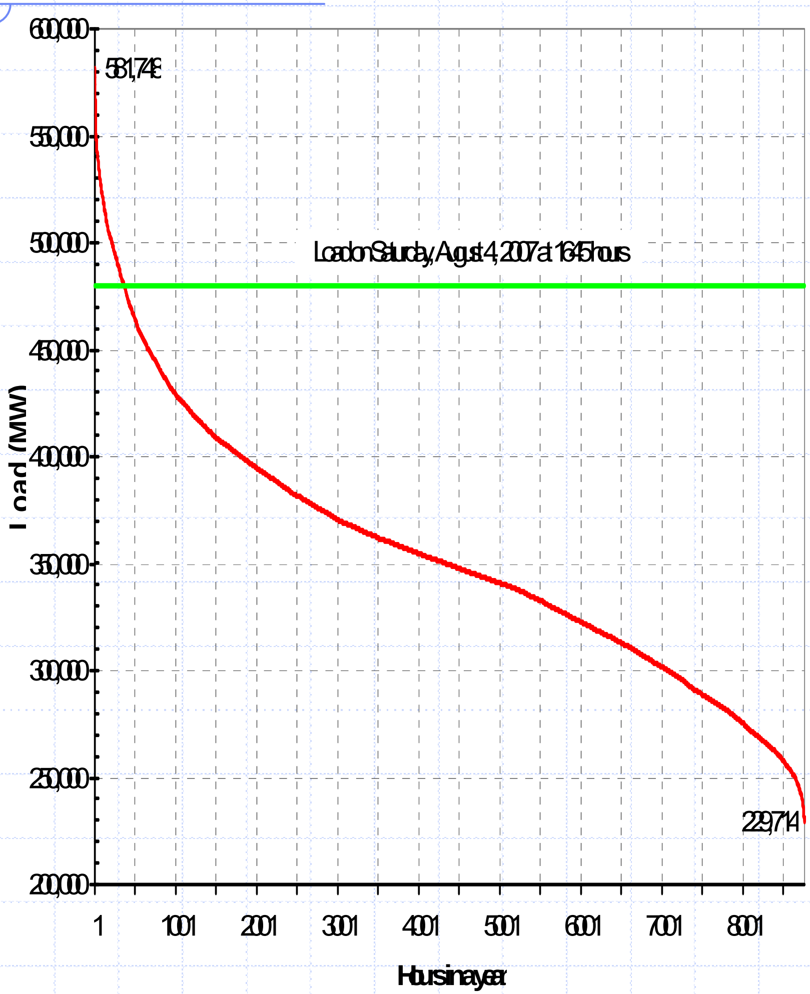
August 4, 2007 1744 Hours Event



Point	Time post-event	Frequency	Frequency Response
A	0	59.997	
B1	20	59.878	-3,756
B2	55	59.868	-3,464
B3	60	59.867	-3,437

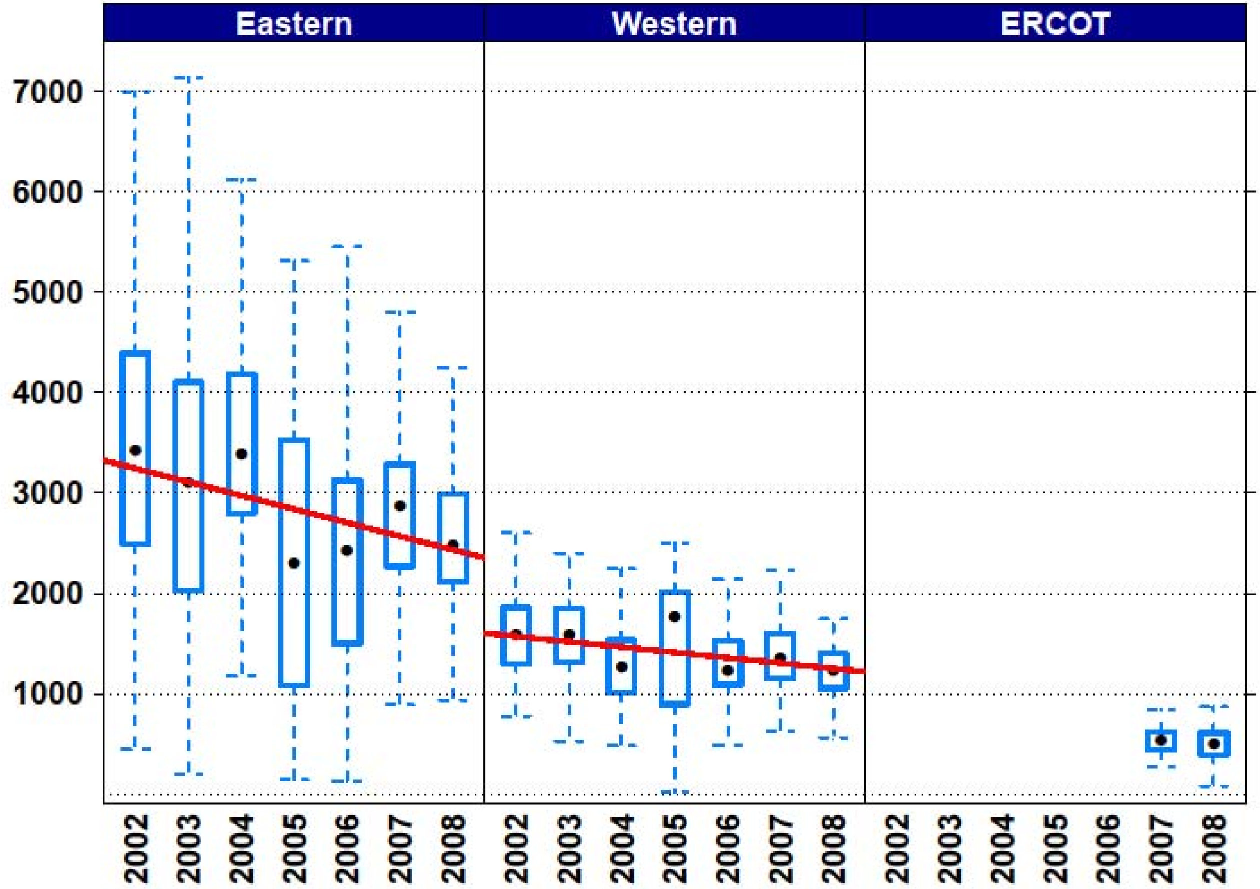
Source: 2010. *NERC Overview of Frequency Response*. NERC

Eastern Interconnection Load Duration Curve for 2007

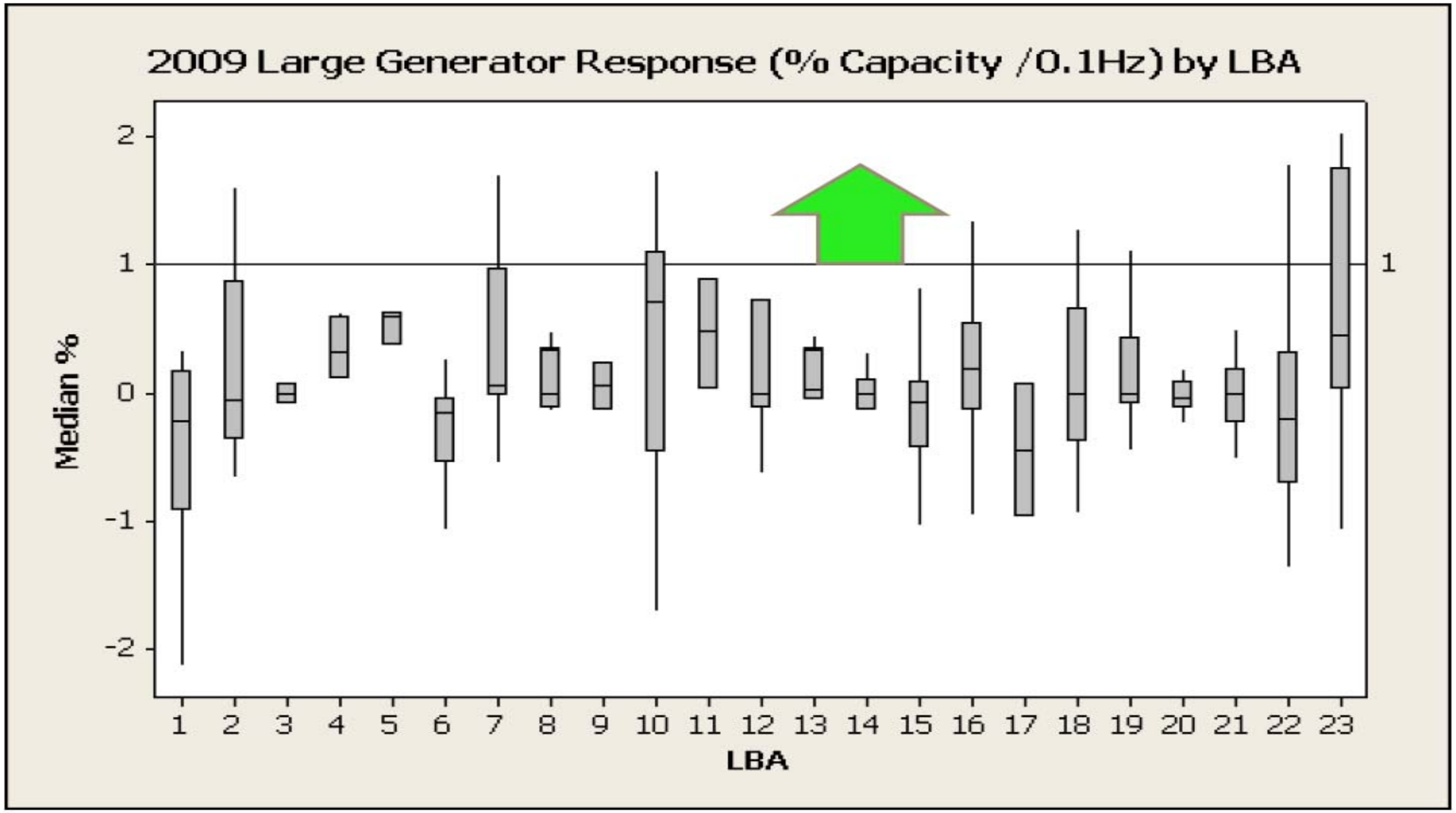


- Top 5% of demand in interconnection
- Considerable amount of generation on line
- Expected and measured high frequency response

Historic Frequency Response

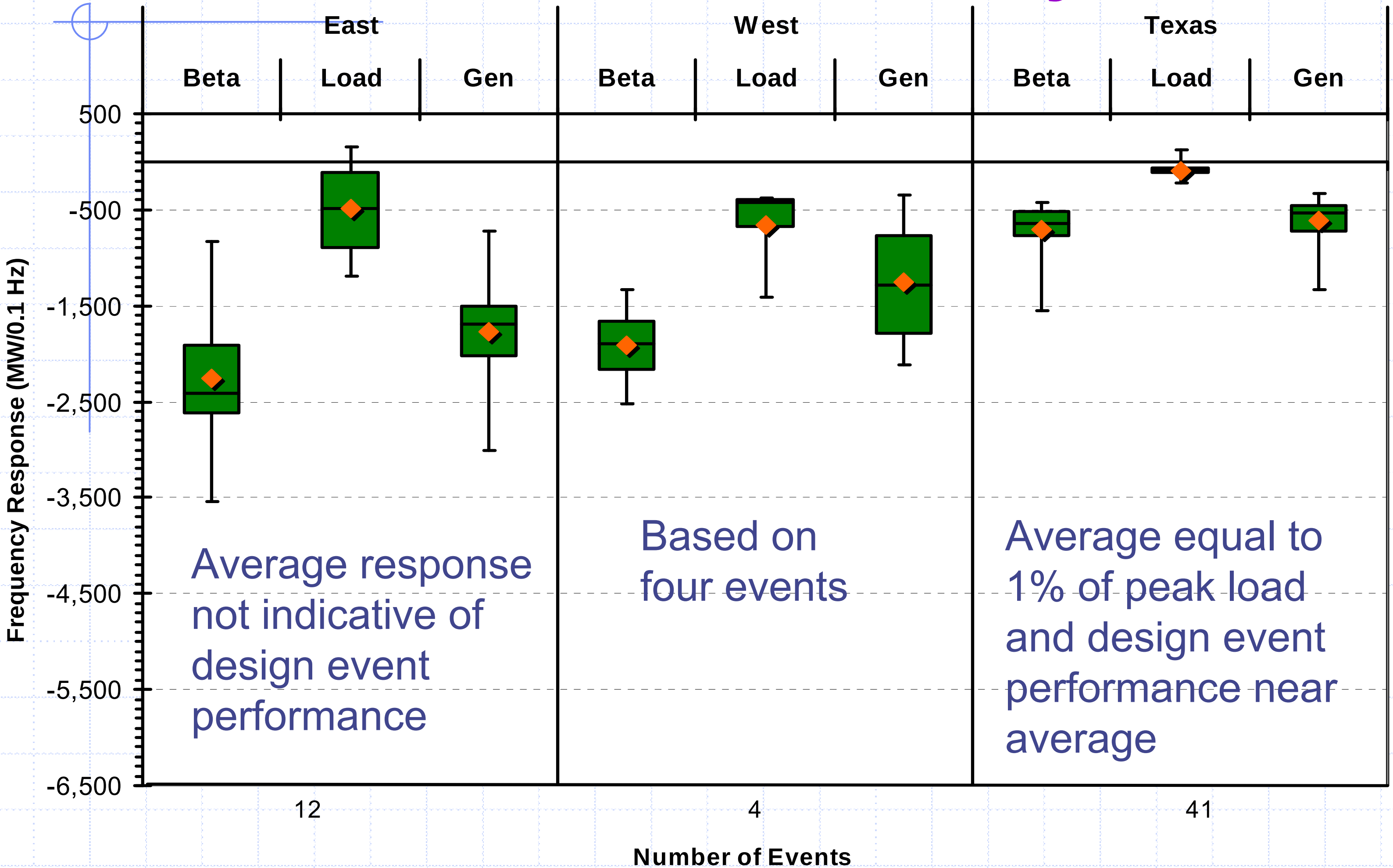


Additional MISO Confirmation



Source: MISO Reliability Subcommittee

NERC BA Alert Survey Results



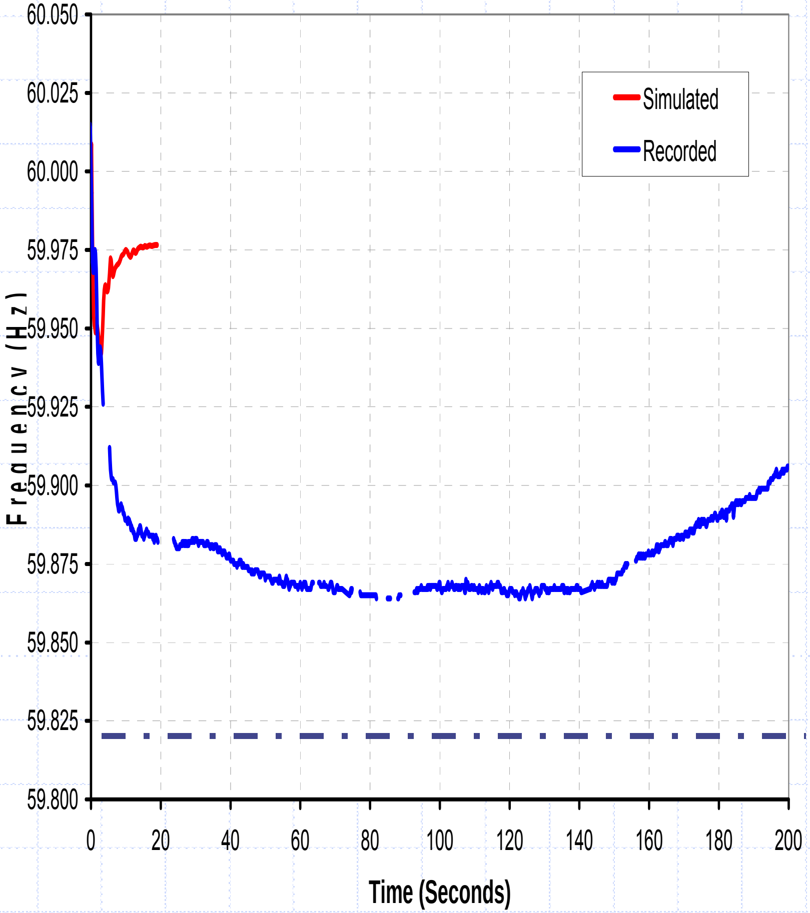
Observations on 2007 Event

- Occurred on a Saturday in August
- Response of event was in upper quartile
- UFLS would have operated if at:
  - -2500 MW/0.1 Hz (Highest UFLS in 2007)
  - -1500 MW/0.1 Hz (today – 59.7 Hz)
- Lower 50% and lower 25% respectively
- Consistent with NERC BA alert survey which shows a -750 to -3500 MW/0.1 Hz
- Reason why we call it a “near miss” is 0.04 Hz above highest UFLS with good response

NERC Industry Advisory on Turbine Combustor Lean Blowout

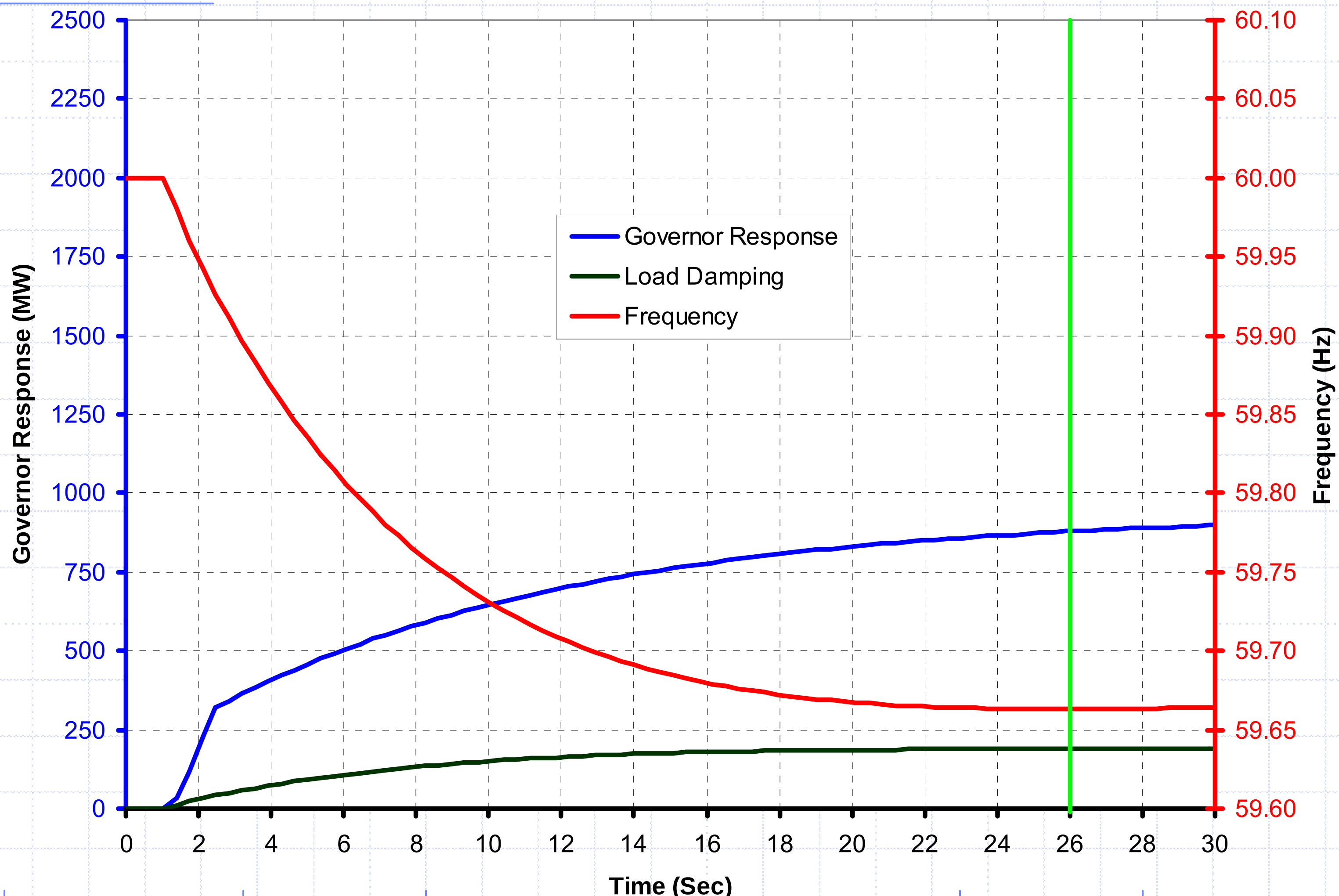
- Result of Florida Blackout analysis
- Also seen during 2003 Blackout
- Confirmed by GE
- Generation remote from fault
- Another wide spread outage related to low frequency response

Eastern Interconnection Performance not Duplicated by Simulations



- Could have been similar to 2003 ERCOT event
- Inadequate since it does not reasonably represent actual events

Simulation to Provide Insights



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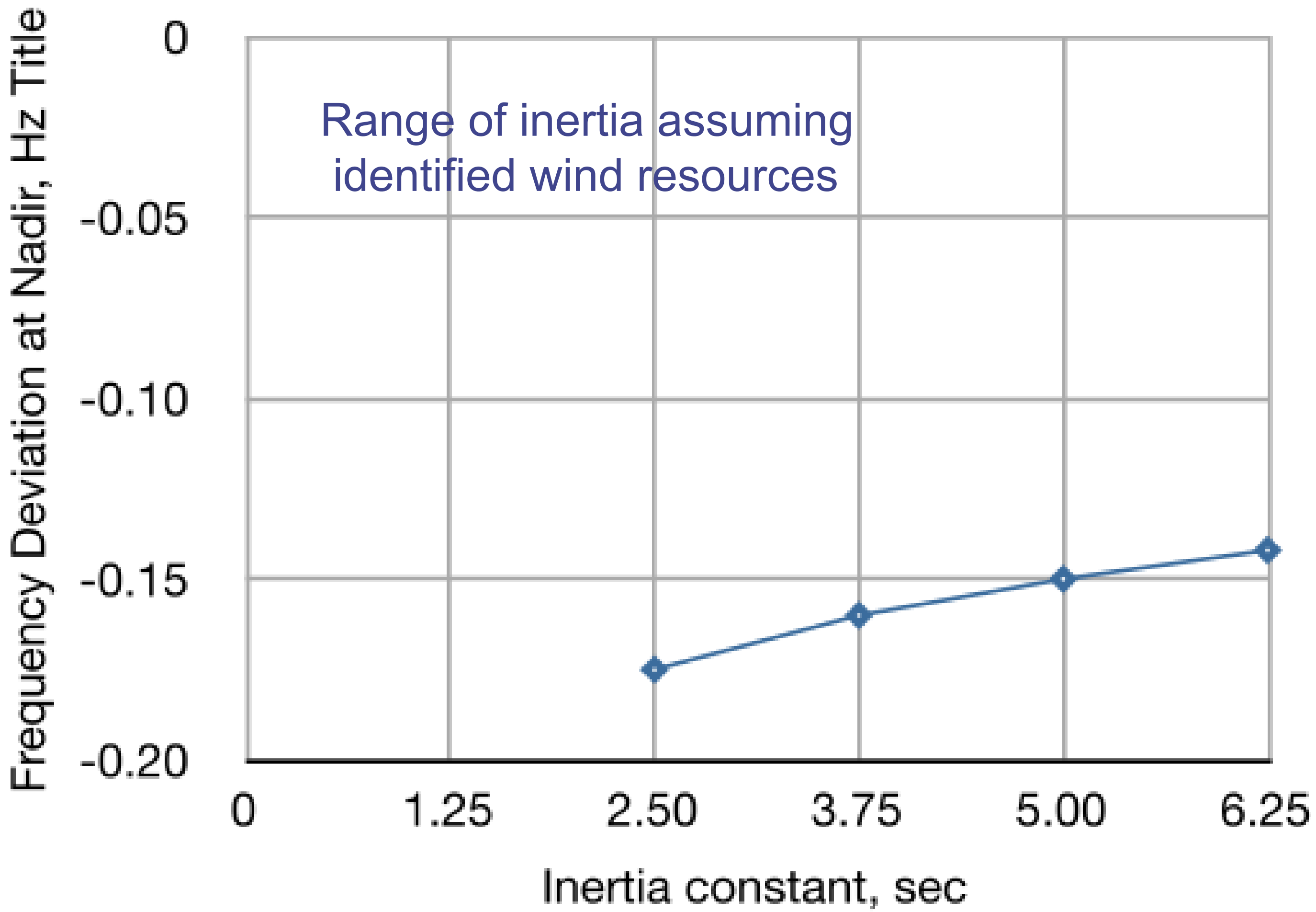
Wind Reliability Impacts

- Lower system inertia
- Displacement of primary frequency control reserves.
- Affect the location of primary frequency control reserves.
- Place increased requirements on the adequacy of secondary frequency control reserves to ensure primary frequency control is always available.

Decreasing Inertia Impacts



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Displacement of Primary

- The speed of frequency response is:
  - Related to the number of resources
  - Related to the magnitude of the frequency decline
- Some of the responsive resources may be de-committed or displaced
- The fewer resources will be slower and take larger frequency changes to obtain same response magnitude

Location of Resources

- With responsive resources on one side of a constrained interface
- With load on opposite side of interface
- Must have either:
  - Sufficient excess capability on interface
  - Sufficient responsive resources on opposite side to provide needed response

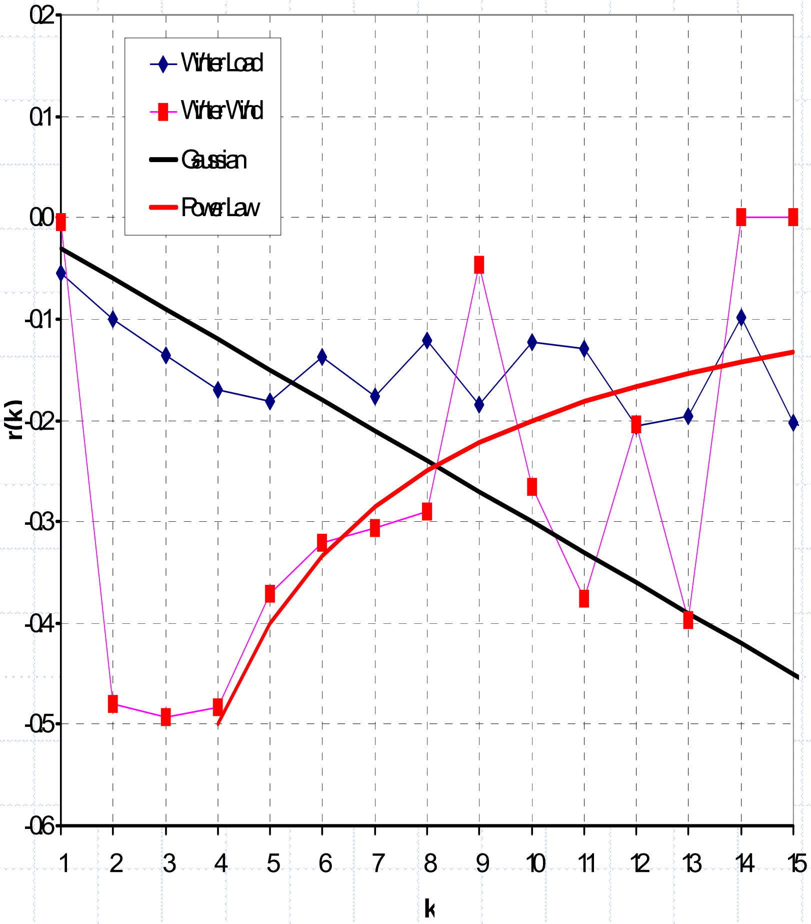
Interaction of Primary and Secondary

- Secondary consist of:
  - Prescheduled ramping
  - Resources under AGC
  - Quick start, online resources under manual control
- If do not deploy secondary:
  - Will consume primary as frequency decreases
  - If exhaust primary, system may collapse within inertia time constant (3-7 seconds)

Variations in Wind Power Output

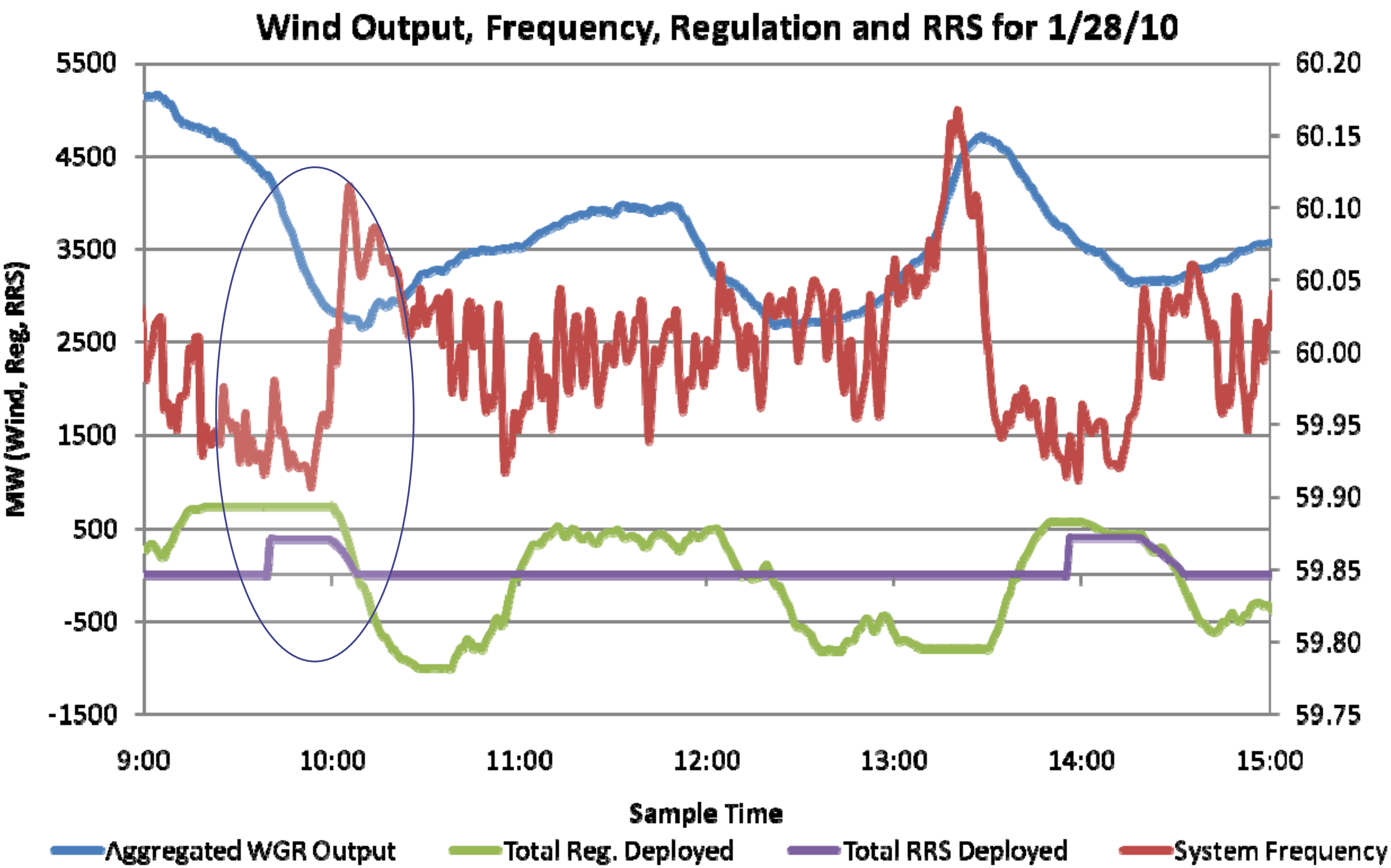
- Interested in understanding underlying statistics to:
  - Manage expected variations
  - Prepare for extreme variations
- Data analysis indicates variations follow a power law distribution
  - Need less secondary for regular variations
  - Need more secondary for 1 in 10 type variations

Analysis to Determine Underlying Statistical Distribution

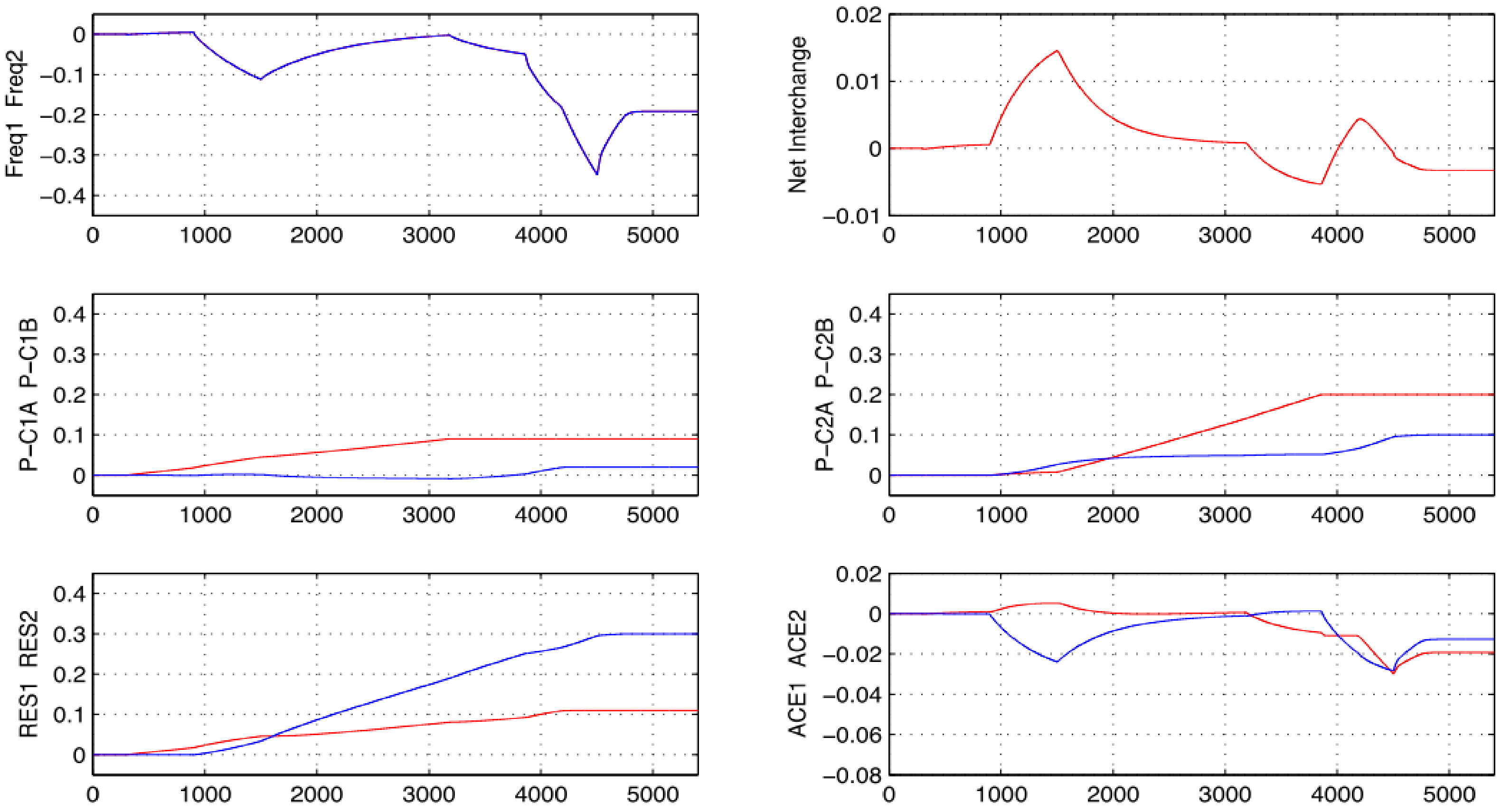


- Load variations usually follow a normal or Gaussian
- Analysis confirms
- Wind data does not follow Gaussian but appears to follow power law
- Extreme events are more probable

Actual Secondary Depletion



Confirming Simulations



Summary

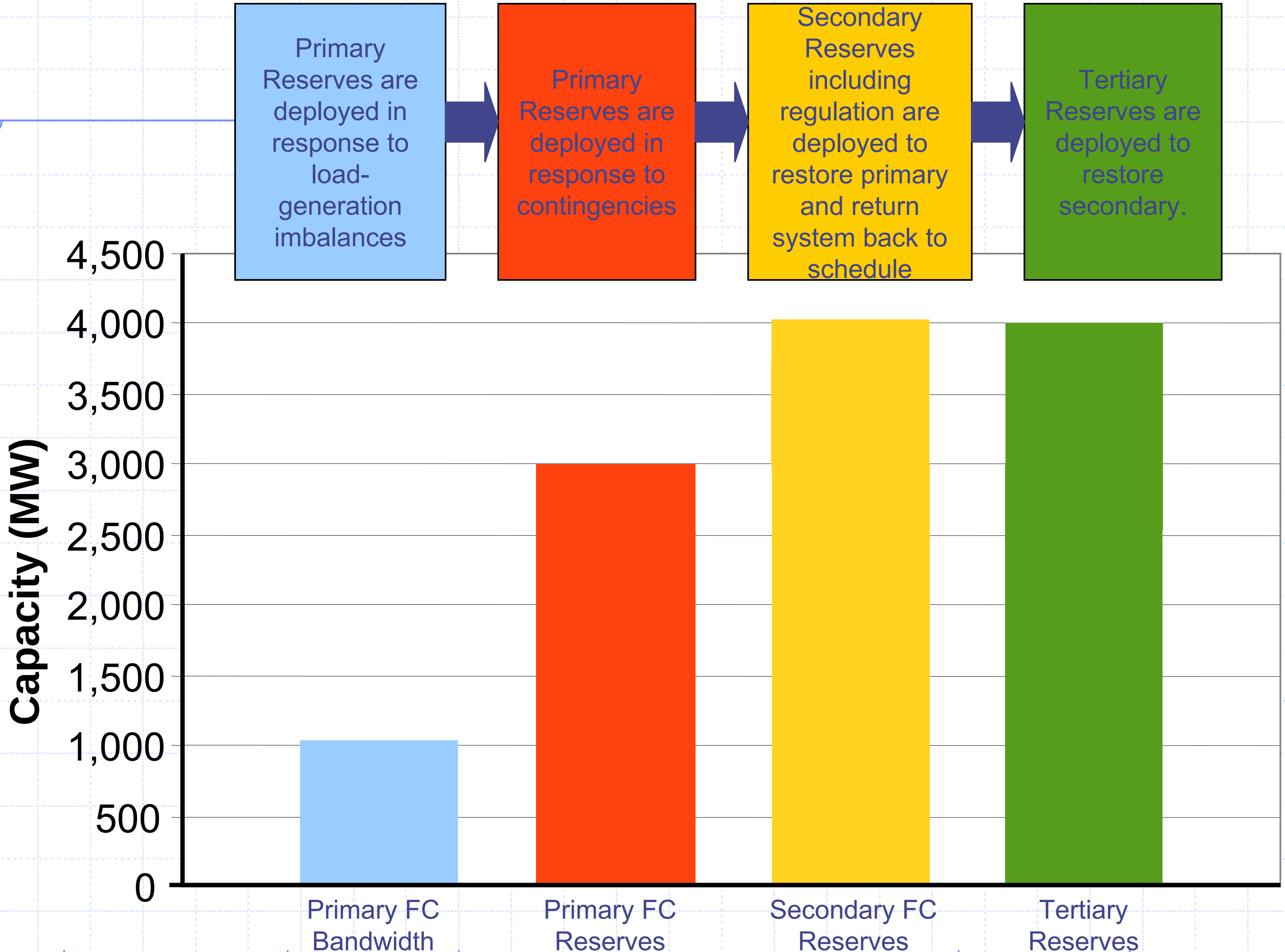
- Important to reliability as evidenced by actual events and near misses
- Change in Inertia not a significant issue
- Amount and deployment of secondary changes with more wind resources
- Must have necessary primary frequency control (magnitude and speed) at all times

Eddy Lim

Senior Engineer

Office of Electric Reliability

Summarizing Types of Control



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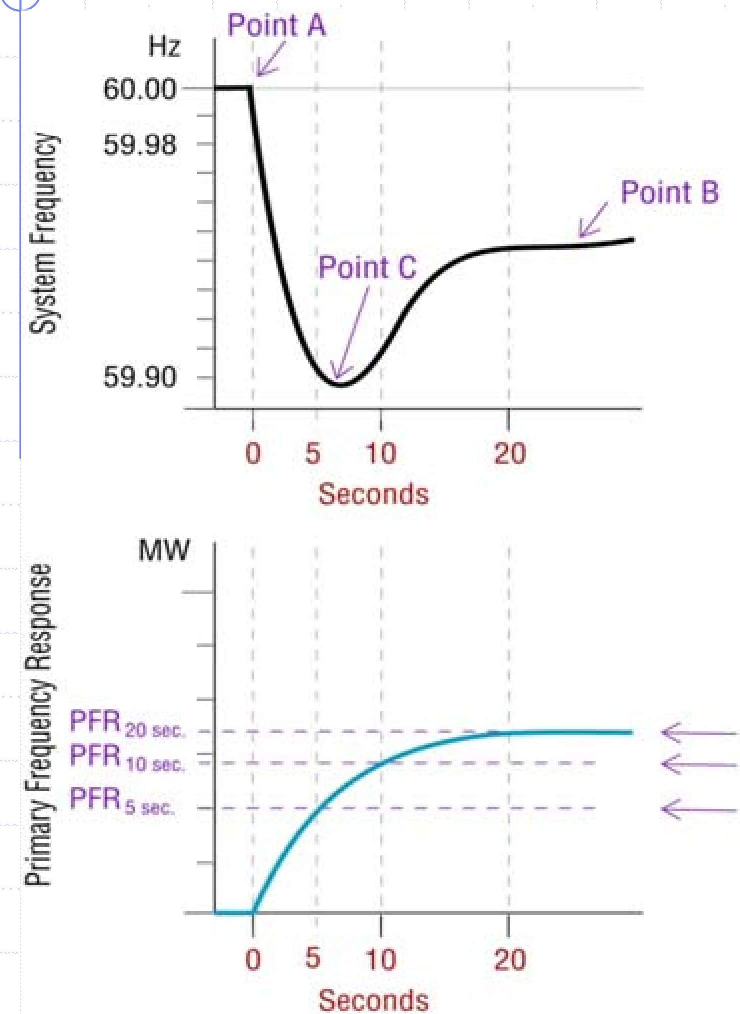
Frequency Performance Metric



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

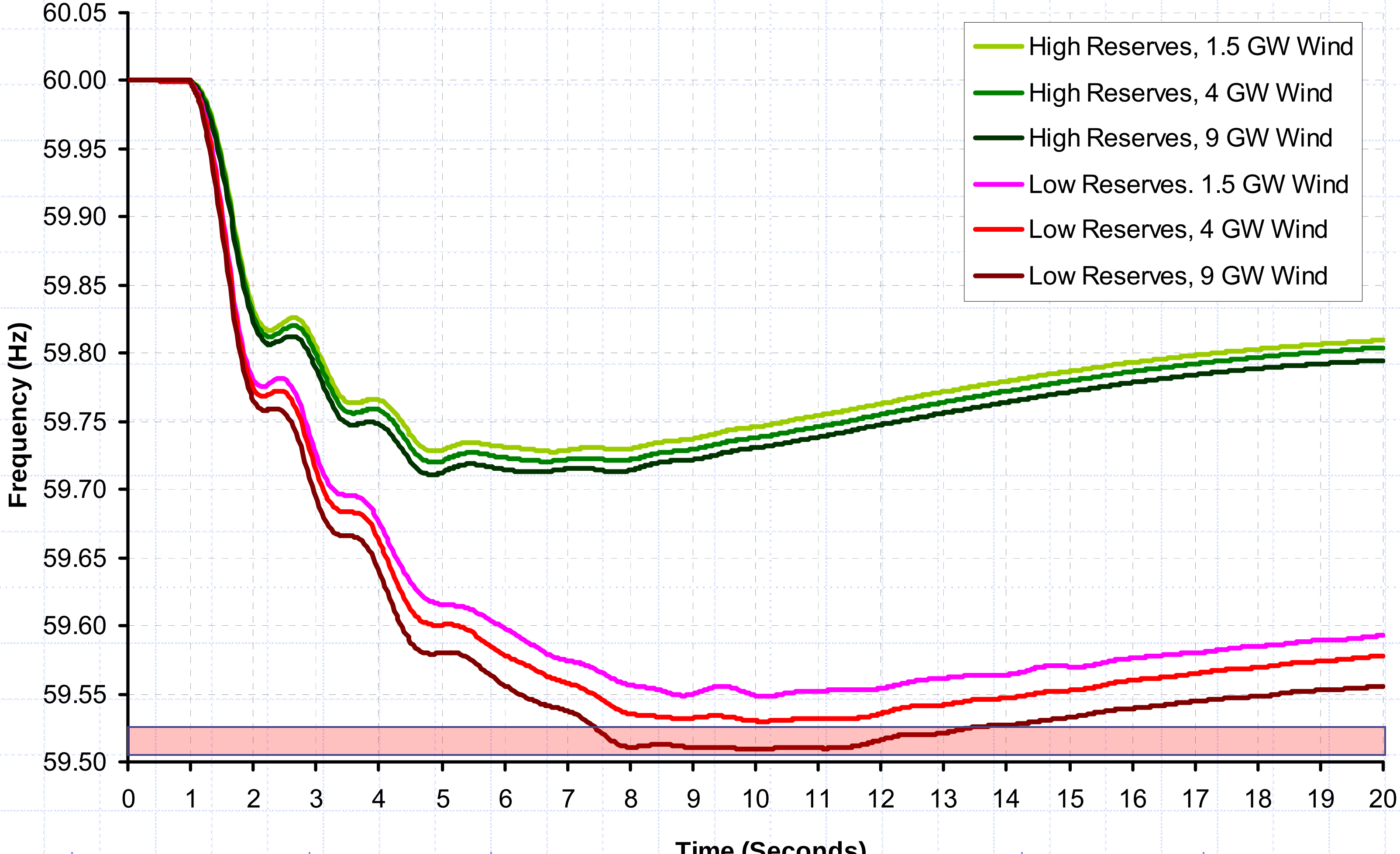
Primary frequency response (PFR) delivered at 10 seconds

Primary frequency response (PFR) delivered at 5 seconds

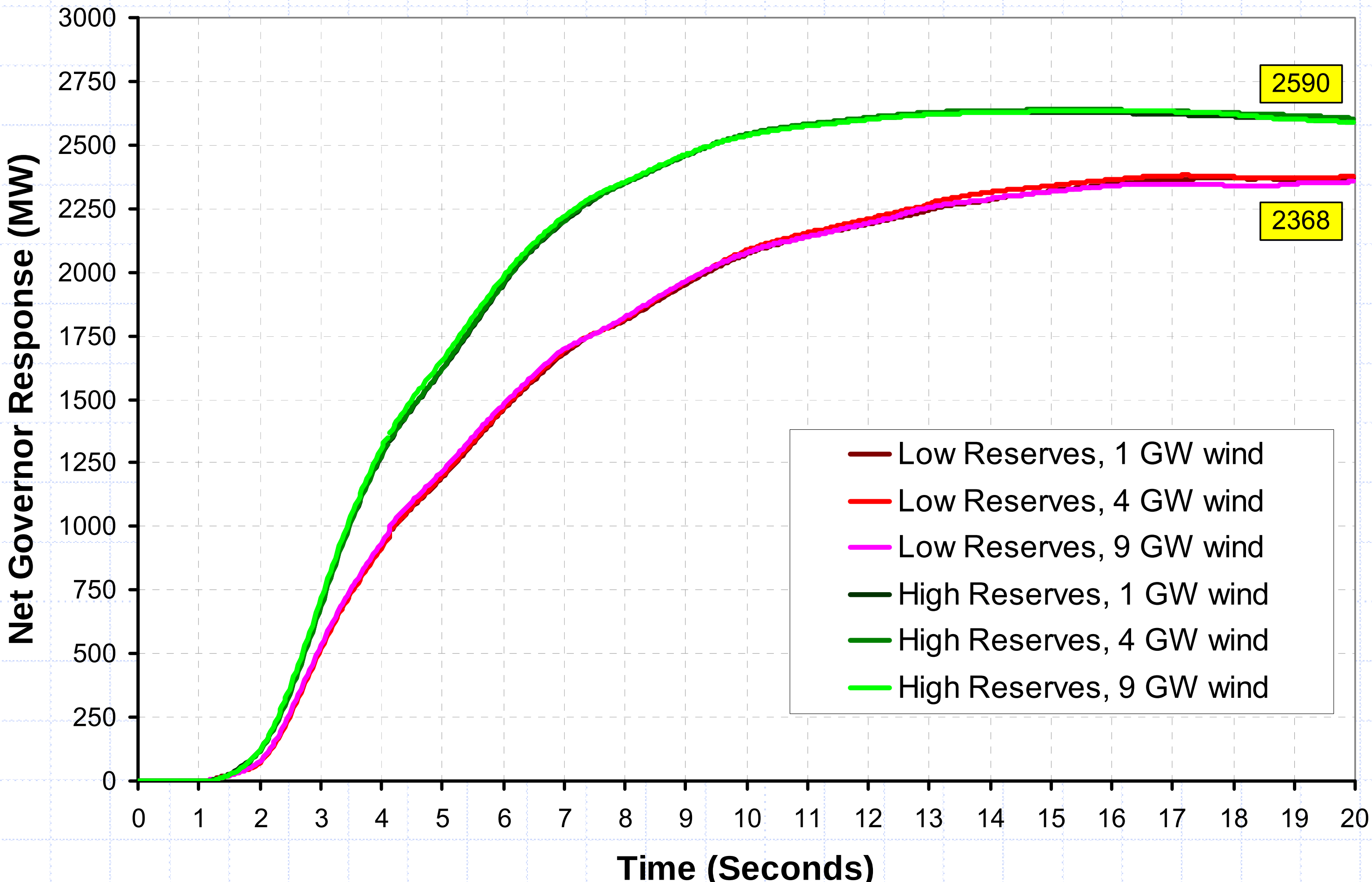
Study Conditions Assumed for 2012 Frequency Response Simulation Analysis

	2012 Minimum or Light System Load **(GW)**	Highest Level of Wind Generation Examined **(GW)**	Size of Loss of Generation Event Studied **(MW)**	Highest Under-Frequency Load Shedding Set Point **(Hz)**
Western Interconnection	80	9	2,800	59.5
Texas Interconnection	34	14.4	2,450	59.3
Eastern Interconnection	309	10.5	4,500	59.7

Simulated Western Interconnection System Frequency Over the First 19 Seconds Following the Sudden Loss of the 2,800 MW Generation



The Power Delivered by Primary Frequency Control Actions via Generator Governors in the Low and High Reserves Cases for the Western Interconnection



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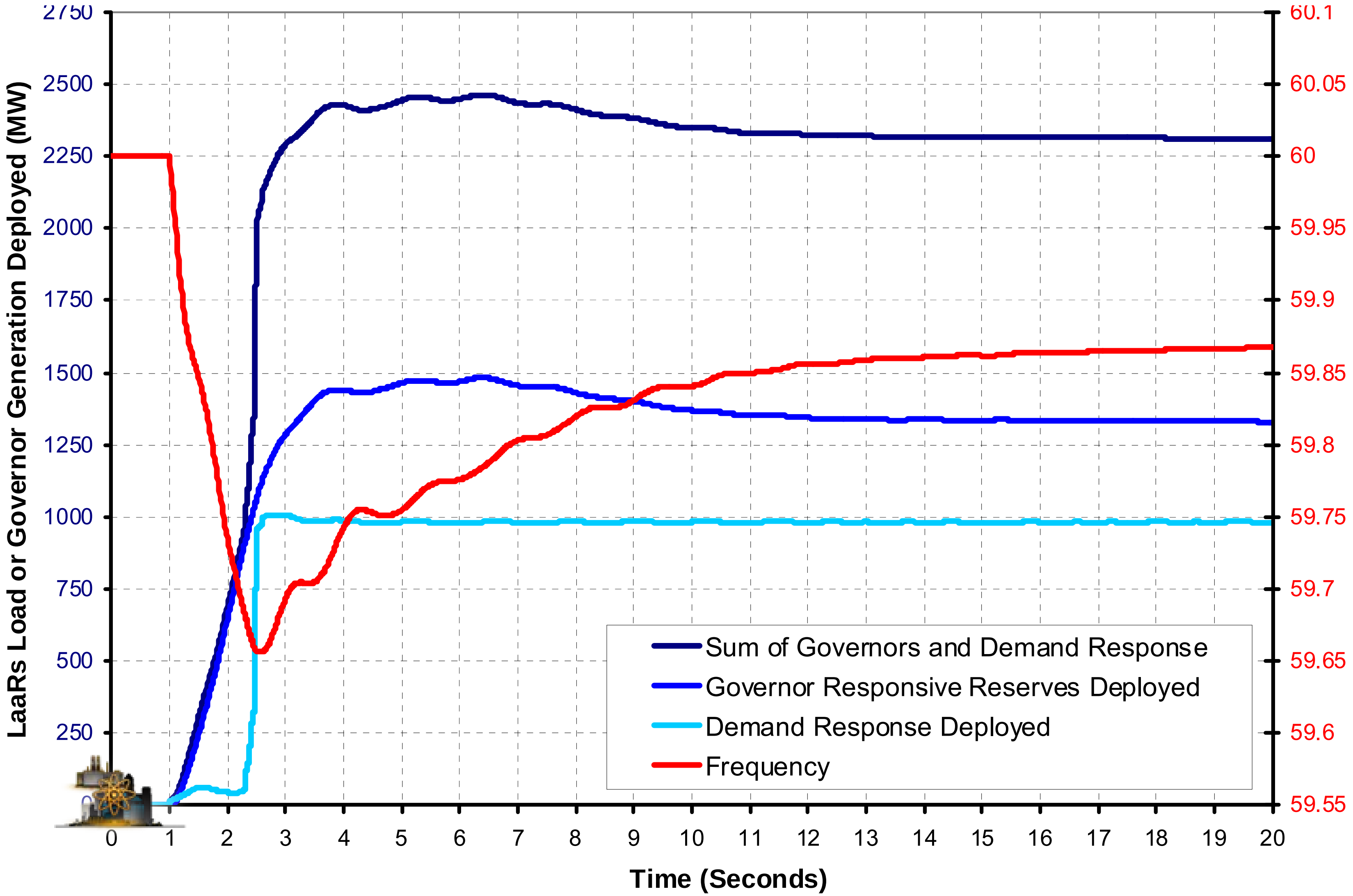
Summary of Dynamic Simulation Results for the Western Interconnection

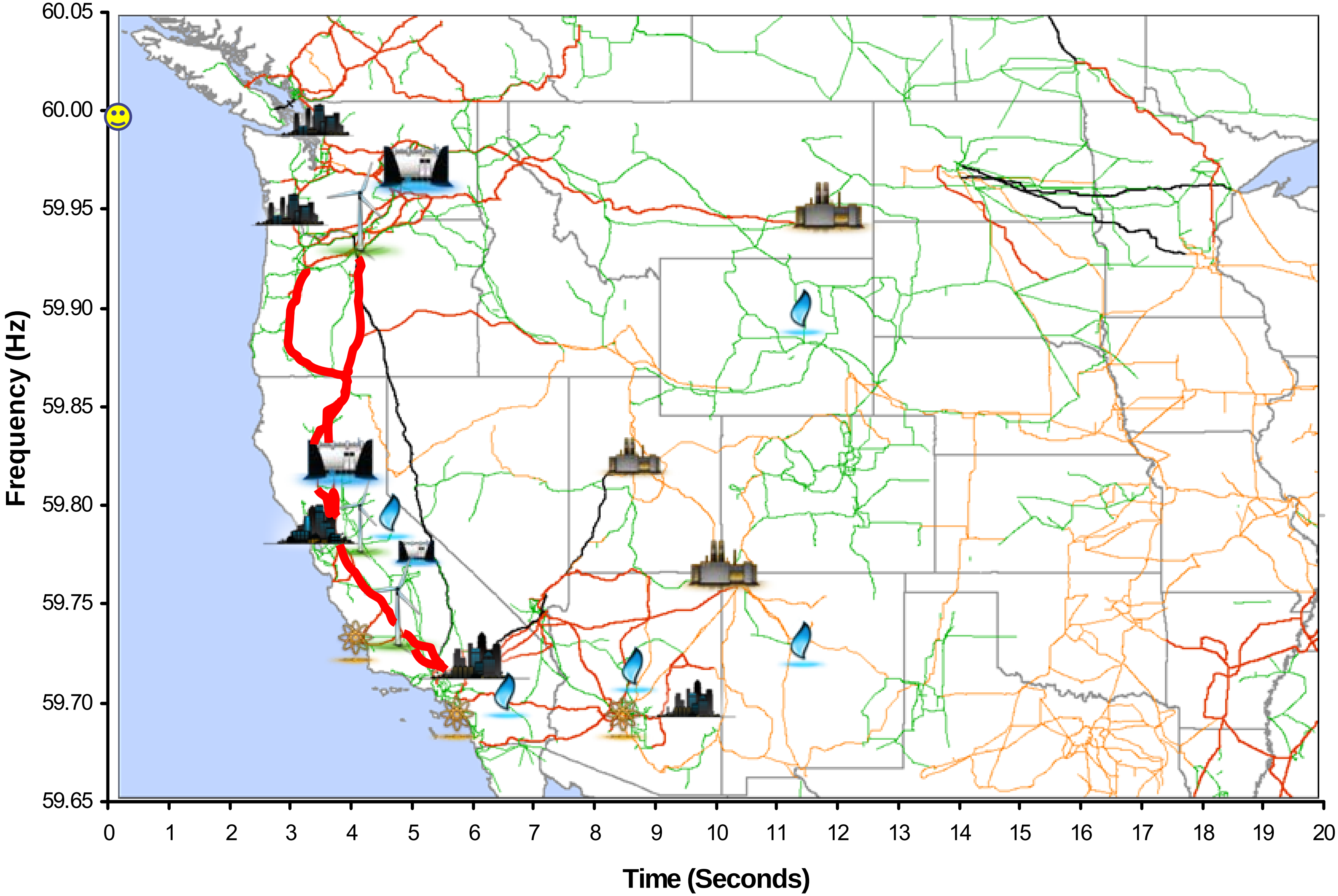
Reserves	Wind Generation (GW)	Frequency Nadir (Hz)	Nadir-Based Frequency Response (MW/ 0.1 Hz)	Primary Frequency Response at 4 seconds (MW)	Primary Frequency Response at 9 seconds (MW)	Primary Frequency Response at 19 seconds (MW)
High Reserves	1	59.73	1037	1,629	2,541	2,590
	4	59.72	1000	1,633	2,562	2,604
	9	59.71	966	1,665	2,537	2,589
Low Reserves	1	59.55	622	1,202	2,072	2,368
	4	59.53	596	1,208	2,086	2,380
	9	59.51	571	1,227	2,078	2,357

ERCOT Simulations

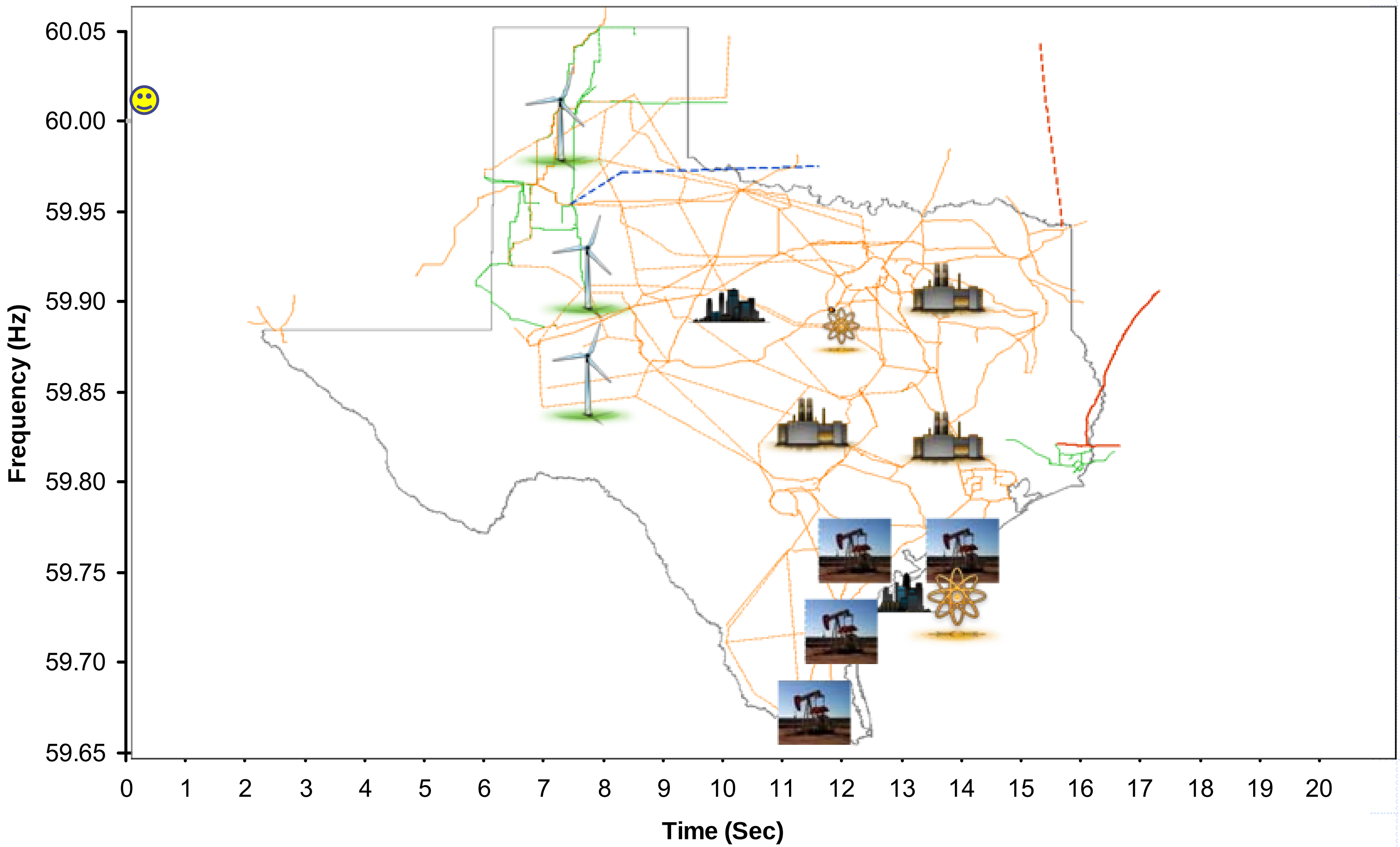
(Governor and Demand response)



Governor/Demand Response to a contingency in WECC



Governor/Demand Response to a contingency in ERCOT



Application of Metric in Planning

- Need to identify what size event that is to be accommodated
- Define highest UFLS setting and delay time in interconnection
- Accurate model assuming minimum load level
- Model range of resources and performance of minimum primary frequency control (generation and DSM)
  - Head room and percentage of fast response
  - Droop
  - Percentage of governors responding as expected
  - Percentage of governors responding opposite of expected
- Identify appropriate margins
  - Starting frequency due to deadbands and depleted primary
  - Between Nadir and highest UFLS
- Results of dynamic simulation respecting deliverability

Application of Metric in Operations Planning

- With results from planning (needed frequency control)
  - Magnitude
  - Speed
  - Sustainability
  - Deliverability
- Account for primary frequency control (PFC) of generation chosen for next day operation
  - Head room on each resource
  - Number of resources to provide needed speed
  - Understanding of secondary plant controllers that may or may not withdraw governor control
- Adjust as needed to achieve minimum frequency control magnitude and speed
- Confirm deliverability with above generation mix and dispatch

Application of Metric in Real Time Operations

- With results from operational planning
  - Account for status of resources providing Primary Frequency Control
  - Calculate and display expected magnitude and speed compared with operational requirement in real time
- If Primary Frequency Control trending toward limit, commit additional resources to replenish frequency control
- Remember the summary slide about the three frequency controls

Recommendations:

- Understand interconnection and Balancing Authority requirement for Frequency Control (especially in the Eastern Interconnection)
- Interconnections must schedule and deploy adequate primary and secondary frequency control reserves

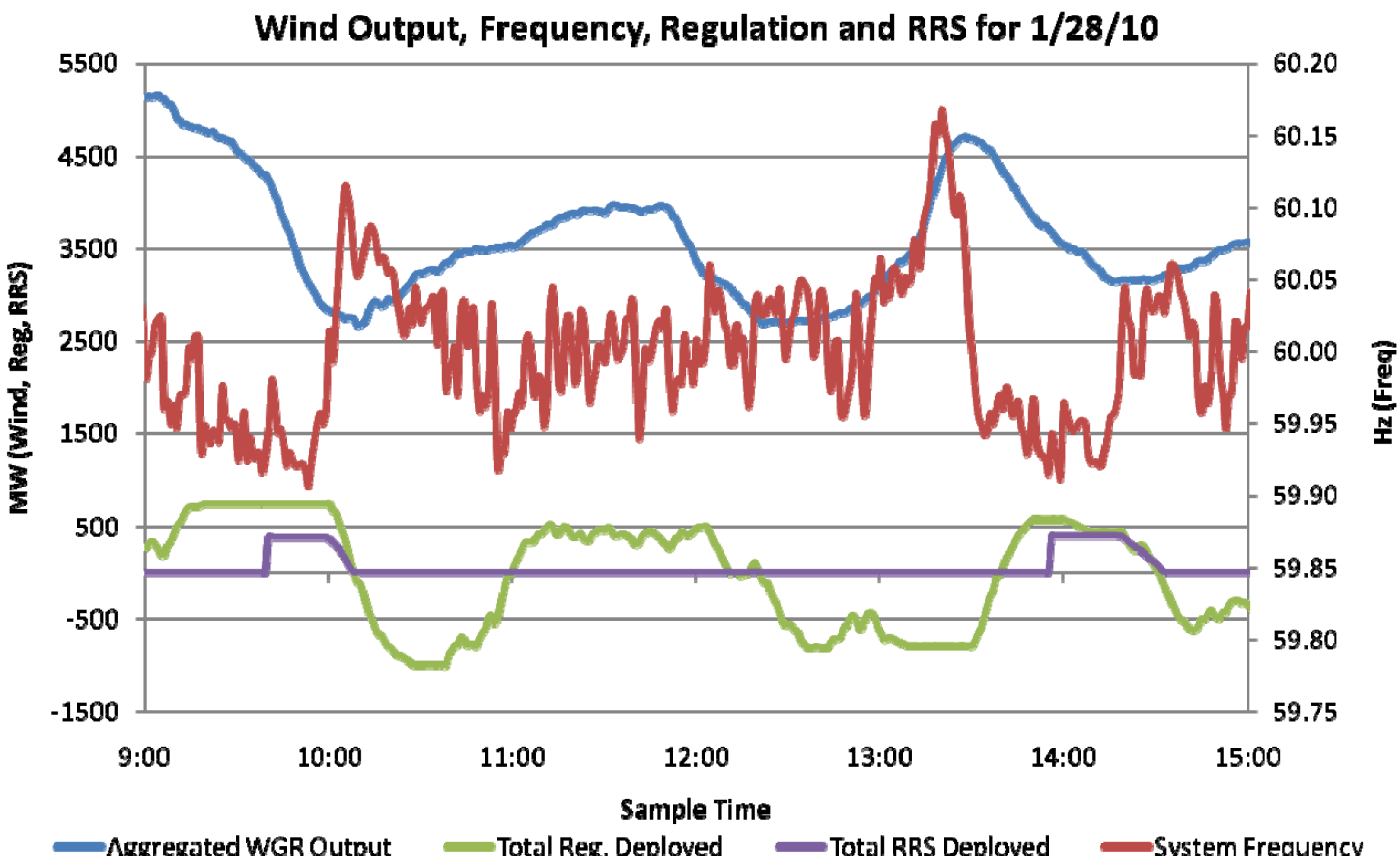
Recommendations: The frequency control capabilities of the interconnections should be expanded, including:

- Expanded use of the existing fleet of generation (improved generator governor performance, increased operating flexibility of base load units, faster start-up of units, etc.);
- Expanded use of demand response (potentially including smart grid applications), starting with broader industry appreciation of the role of demand response in augmenting primary and secondary frequency control reserves;
- Expanded use of frequency control capabilities that could be provided by variable renewable generation technologies (primary frequency control, etc.); and
- Expanded use of advanced technologies, such as energy storage and electric vehicles.

Recommendations:

- 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.
- 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, such as solar and additional nuclear generation and the retirement of existing generation

Recommendations: Comprehensive planning and enhanced operating procedures

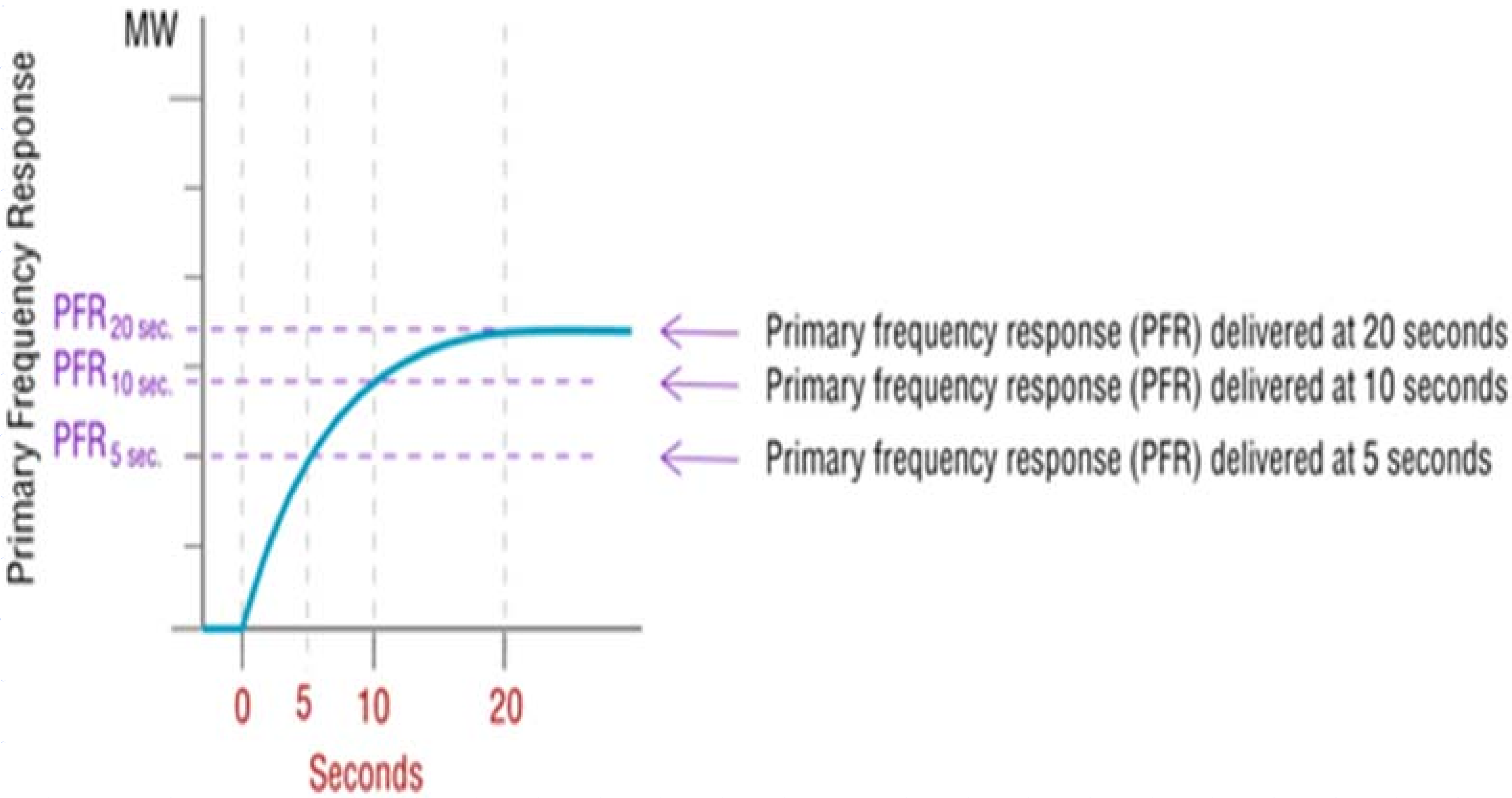


Source: ERCOT (2010)

The Key Findings

- The proposed metric is valid and can be used prospectively in planning and operations
- How frequency response can be used to manage wind resources
- Results not limited to wind resources
- Adequate Primary and Secondary Frequency Control are essential at all times

Remember this Metric



Questions