Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable operation of the BES

Presented to:
NERC Standard Drafting Team
June 1-2, 2011
Washington, DC

Reliability Issues

- Integration of renewable impacts:
  - Lower system inertia (lower impact compared to the three below)
  - 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.
- International events
- Interconnection events and 2003 Blackout

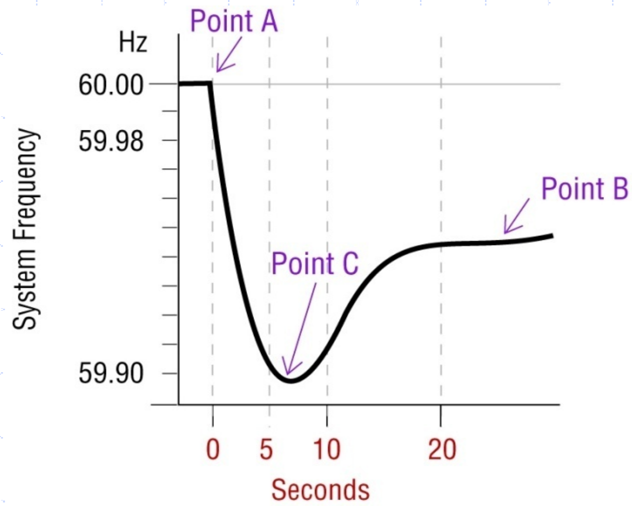
Overview

- Frequency Performance Metric
  - Background – Fundamentals
- How primary and secondary frequency controls affects Reliability
- Simulation Results/Findings
- Recommendations

What you should take away

- Primary and Secondary Frequency Control are critical metrics
- Both the magnitude and speed of primary frequency control deployment are needed to arrest the frequency decline
- Provision of primary frequency control must be sustainable and deliverable
- Need to establish the minimum/maximum primary and secondary frequency control
- Events will happen!

Frequency Performance Metric

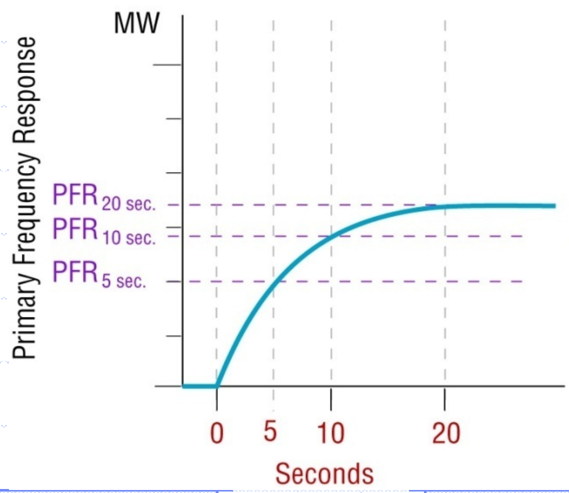


Pre-disturbance Frequency: $\text{Frequency}_{\text{point A}}$
Settling Frequency: $\text{Frequency}_{\text{point B}}$
Frequency Nadir: $\text{Frequency}_{\text{point C}}$

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

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

Metric Opportunity



Primary frequency response (PFR) delivered at 20 seconds
Primary frequency response (PFR) delivered at 10 seconds
Primary frequency response (PFR) delivered at 5 seconds

Appropriate Deployments of Frequency Control for loss of generation (with governor action and secondary resources)

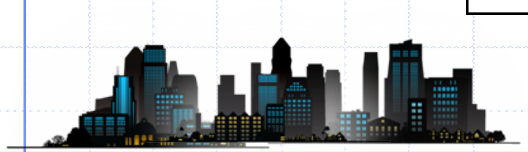
First, the loss of generation and frequency decline at the rate of ΔP/(D+2H)

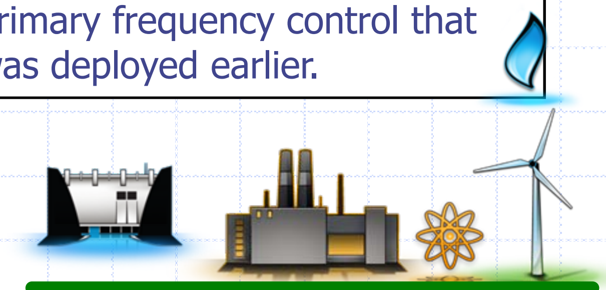
→

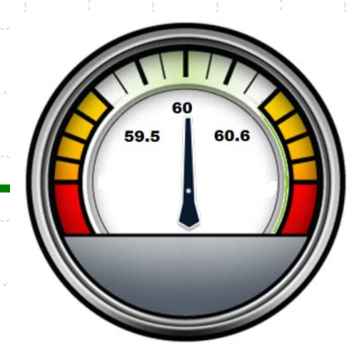
Turbine Governors react to the frequency decline and increase generation (primary frequency control) to arrest the frequency decline within several seconds and then restore it to a settling frequency.

→

Secondary frequency control resources are deployed to return frequency back to schedule (60 Hz) and fully replenish the primary frequency control that was deployed earlier.



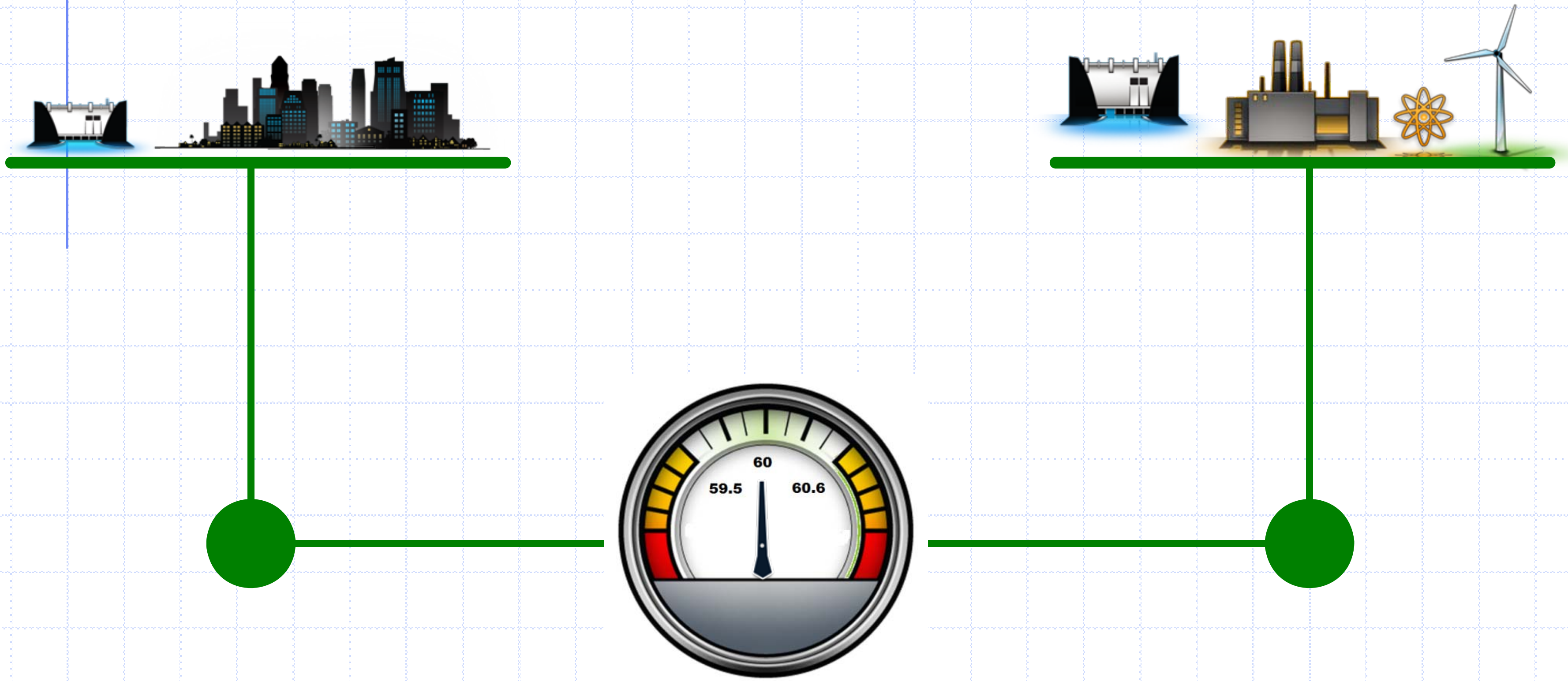




Frequency impact for loss of generation

(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



Generators and Governors

- Governors
  - Turbines follow governor control systems to control the shaft’s speed of rotation. The governor system senses generator shaft speed deviations and initiates adjustments to the mechanical input power of the turbine to increase or decrease the generator’s speed as required. By controlling the mechanical power, the electrical power output is controlled.

Why are Governors important?

- Governors are the key to maintaining frequency to within acceptable range by providing primary frequency control
  - It is autonomous and automatic and not dependent on system operator actions or automatic generation control.
- In response to a frequency deviation, they withdraw or inject power into the system to help maintain generation and load balance to maintain scheduled frequency within the desired range
- Primary Frequency Response is the capabilities (i.e. MW magnitude, speed of delivery and sustainability) that can be deployed from the unit to provide acceptable frequency responses – formation of a frequency nadir and the settling frequency – to ensure BES reliability following a sudden loss of generation.

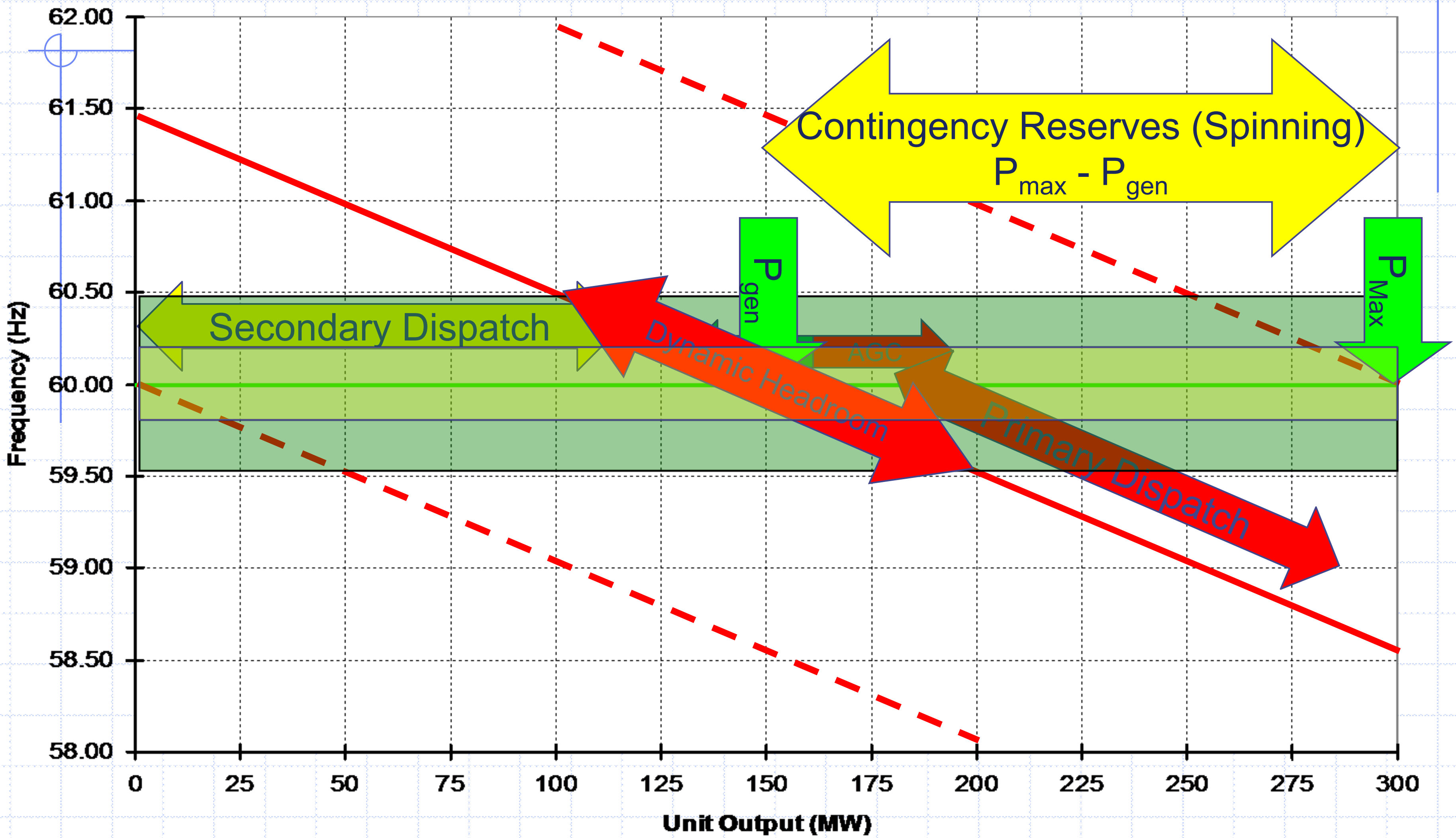
Droop

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

Source: NERC

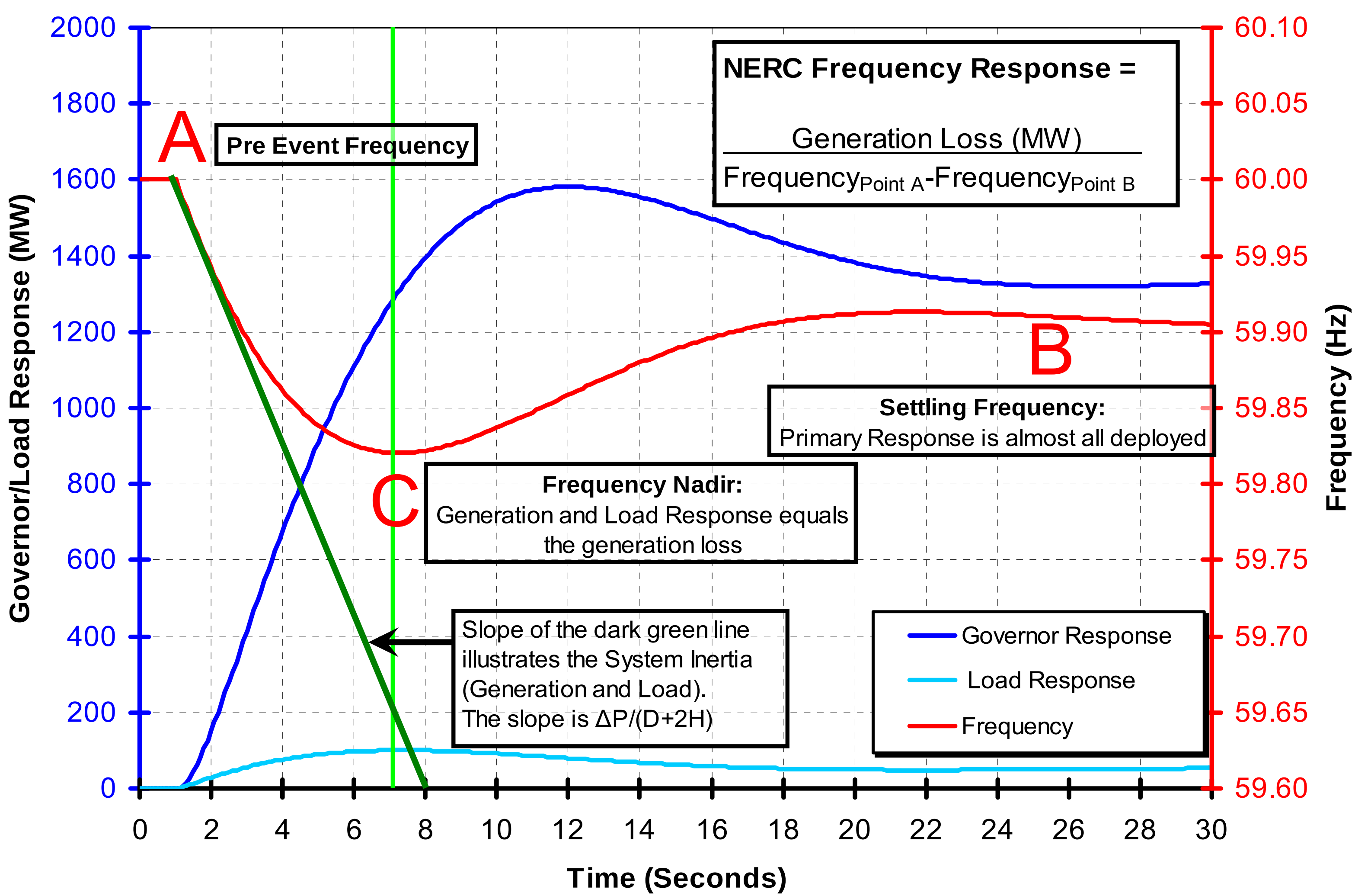
Speed of Primary Frequency Control deployment is critical.

Generator Characteristic Curve with 5% droop
Metric Opportunity: Dynamic Headroom C & B

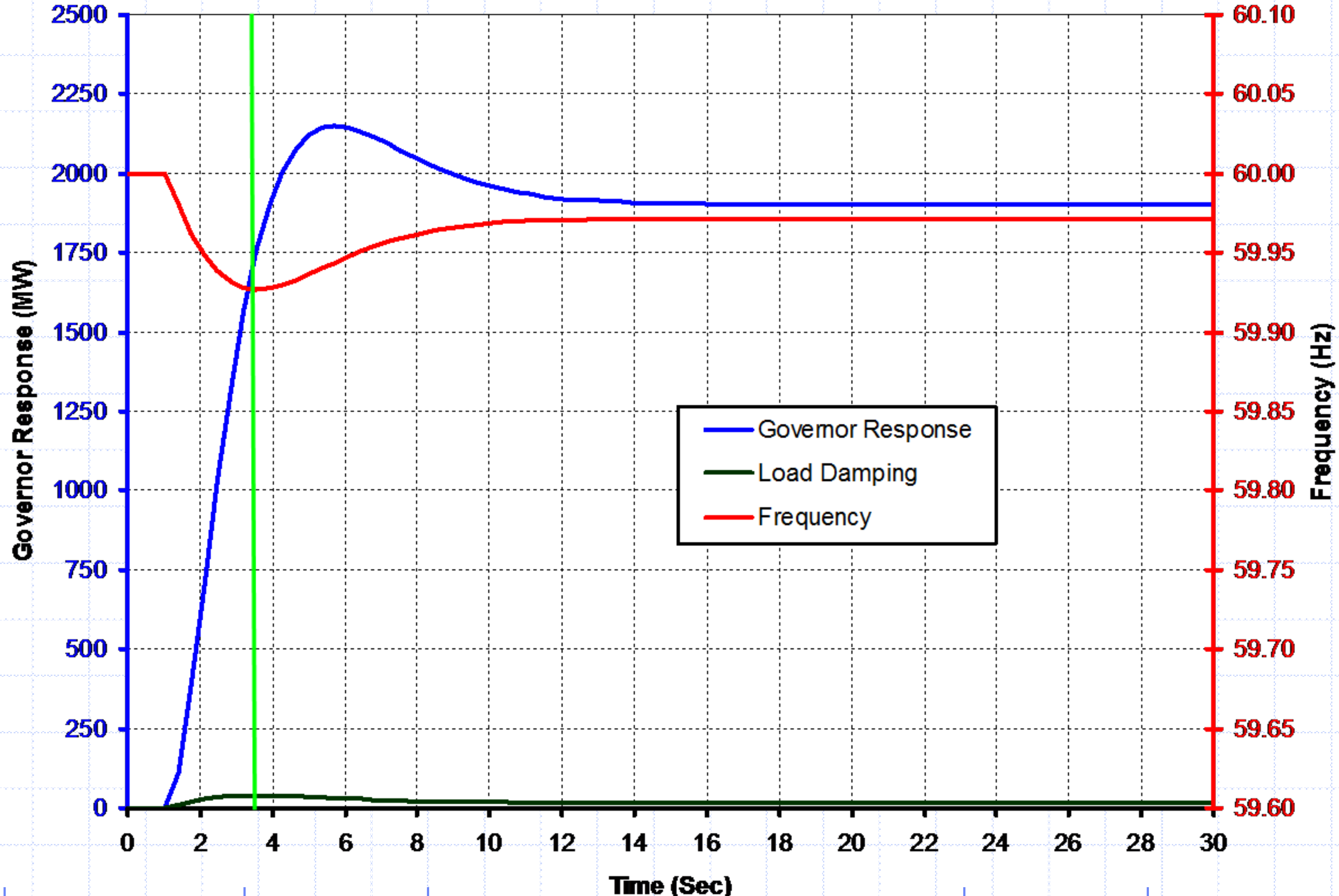


Frequency Response Basics

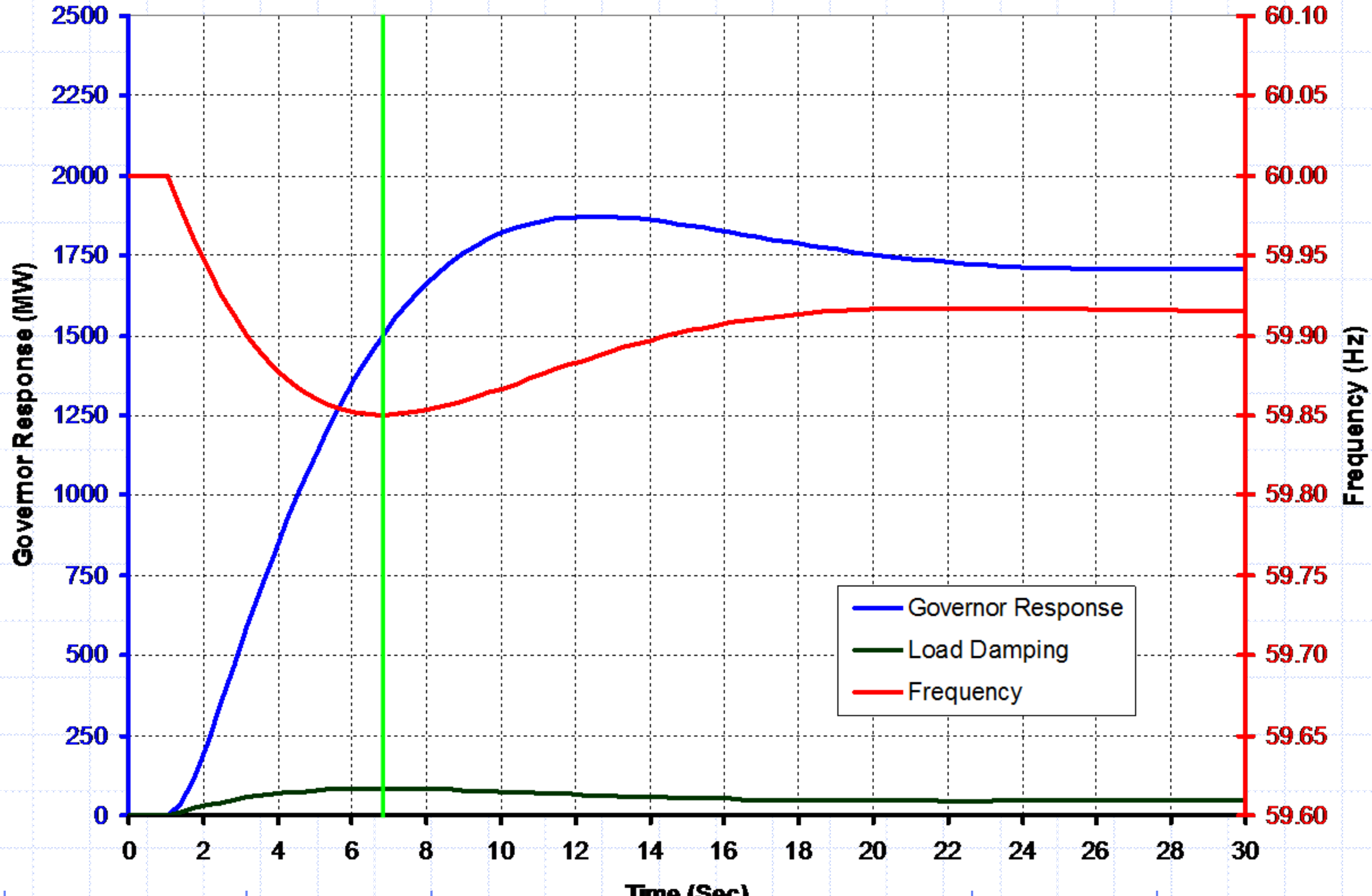
(Using a 1400 MW generation loss event as an example)



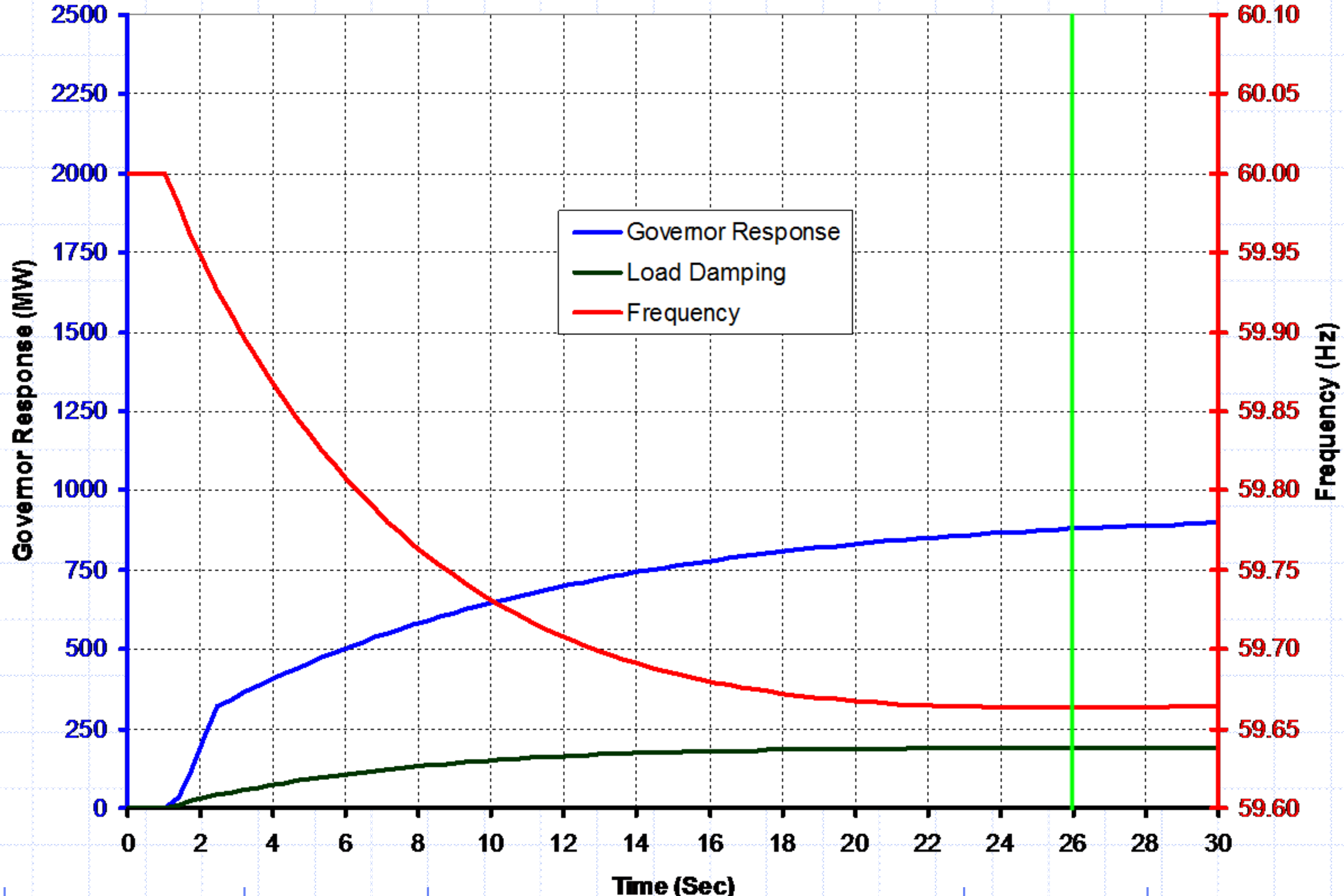
Single Area System Model
All generation units responding



Single Area System Model
30% of generation units responding

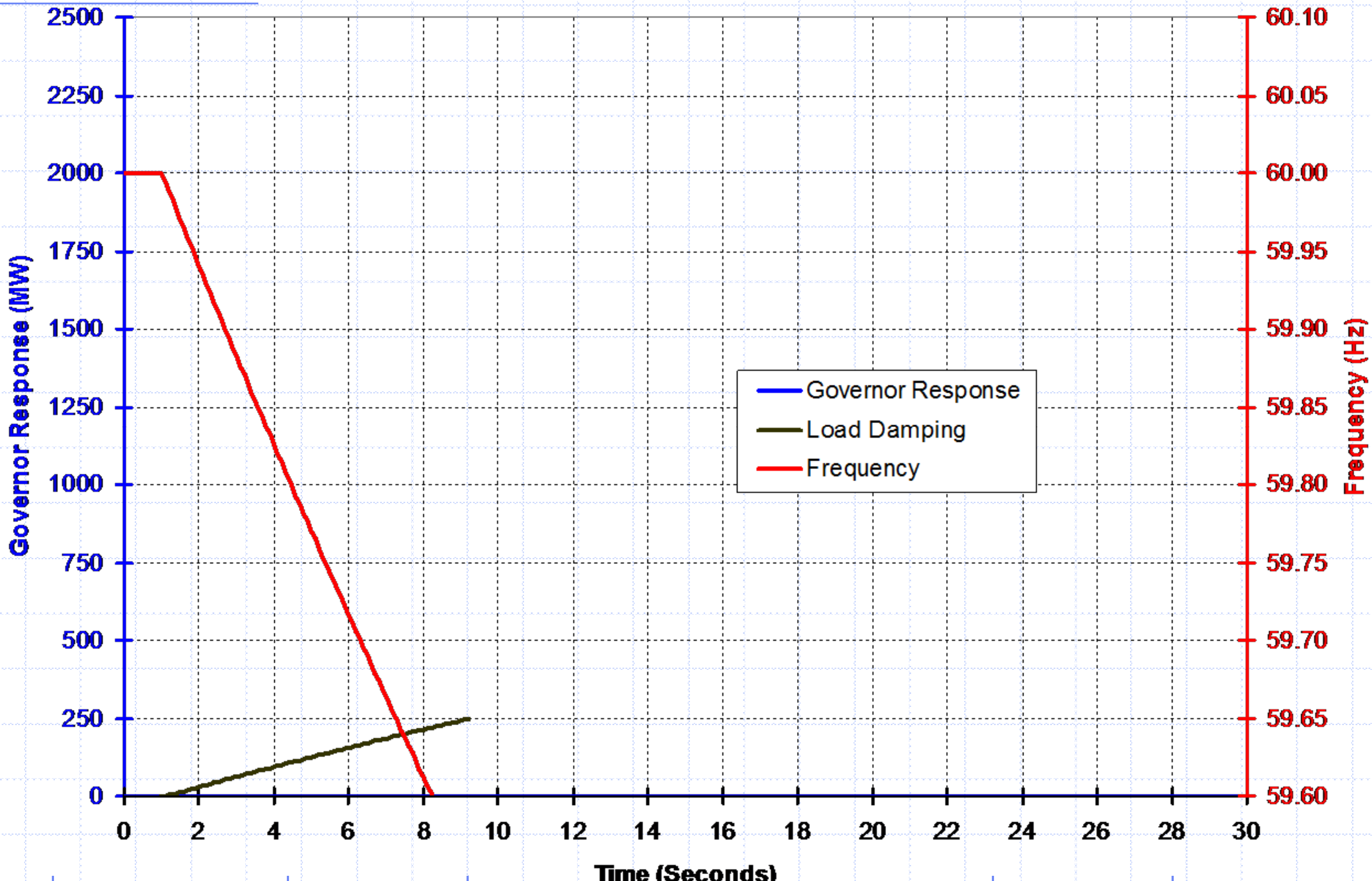


Single Area System Model
30% generation units responding, responding units limited to .005 PU



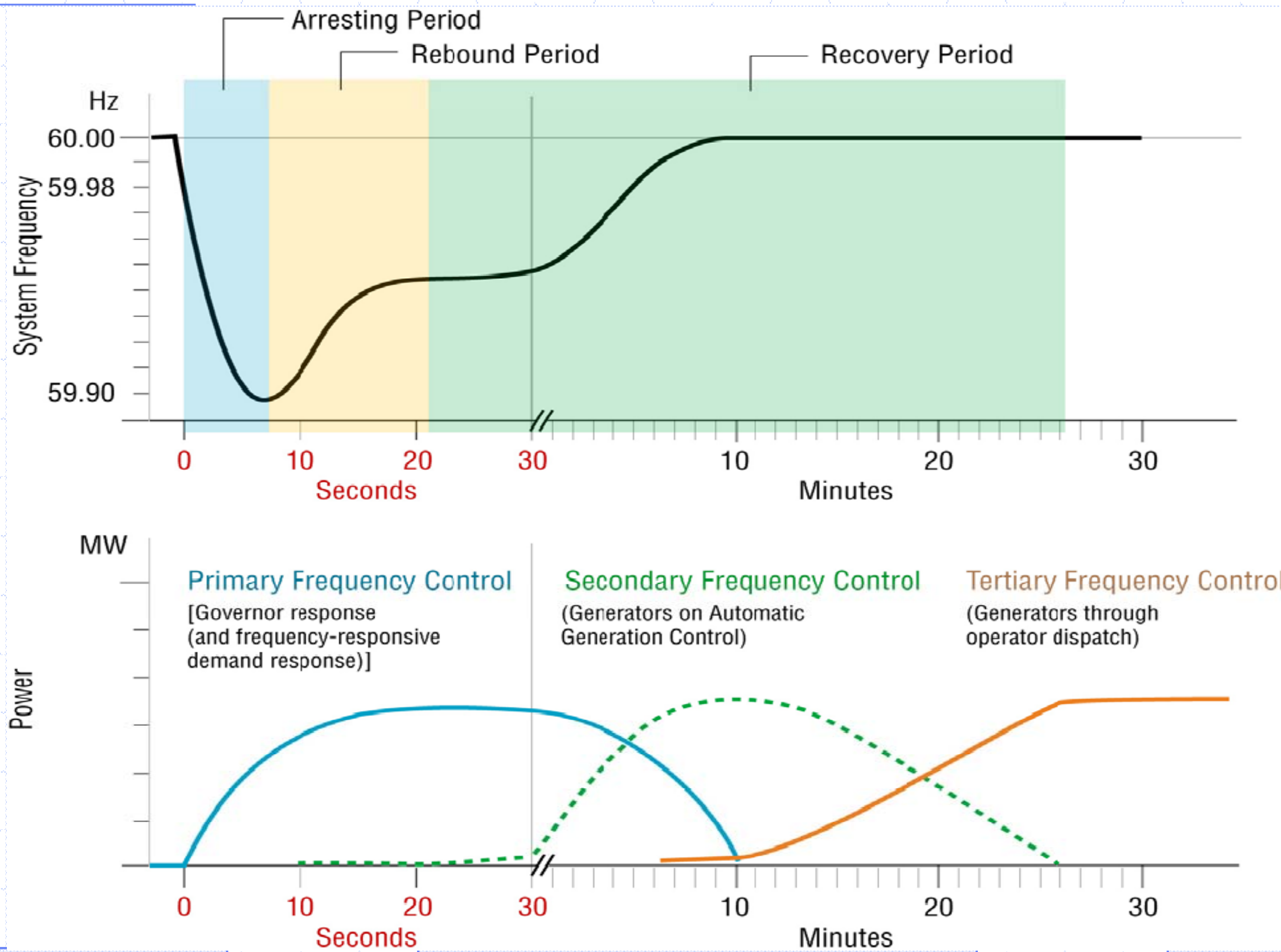
This does not represent the opinion or policy of the Federal Energy Regulatory Commission

Single Area System Model
0% generation units responding



Background

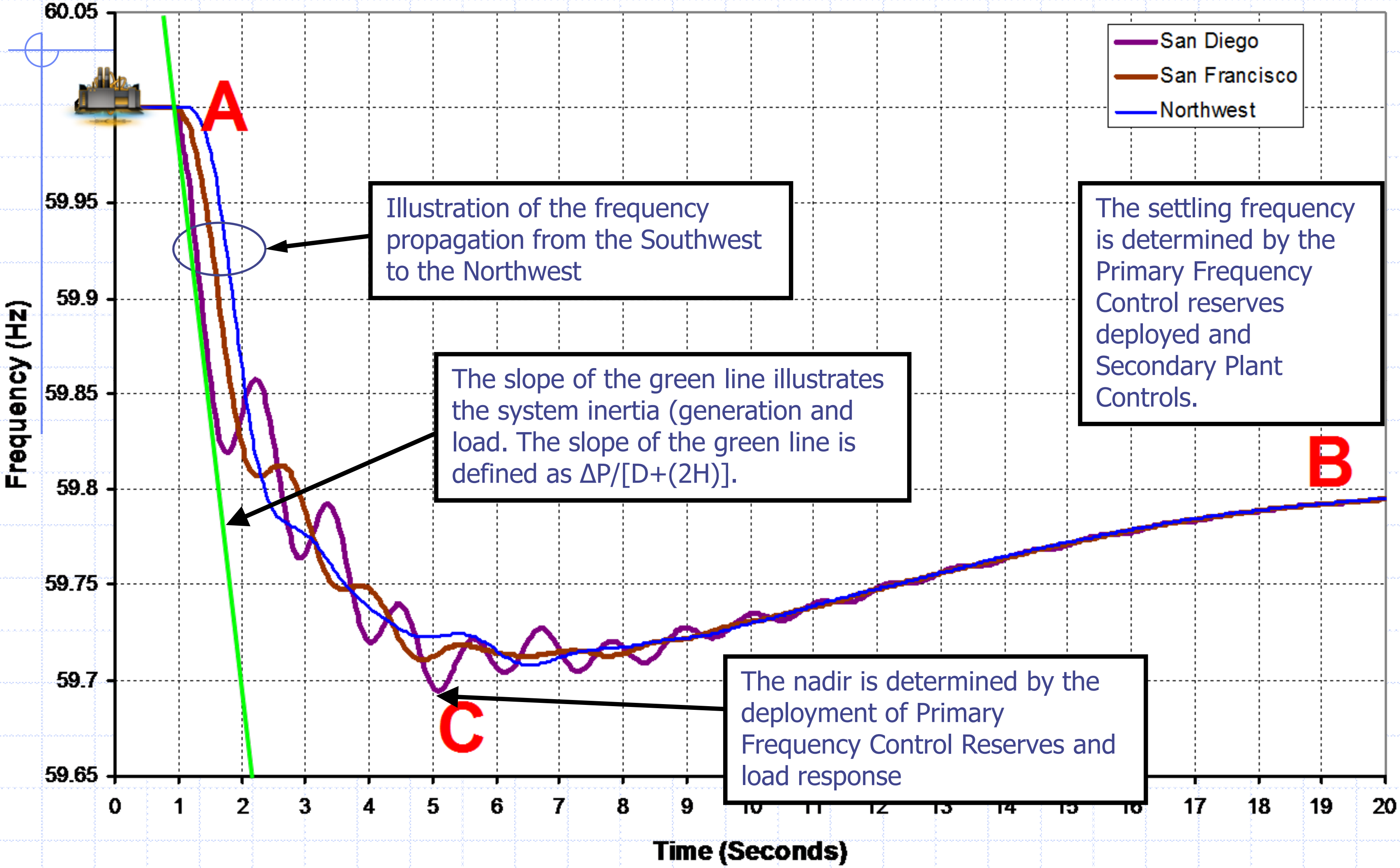
(Primary, Secondary, Tertiary Frequency Control, timing and deployment)



Adequate Primary Frequency Control must be Preserved at all Times

- Inadequate secondary frequency control in response to net load changes will deplete primary frequency control resources
- Secondary frequency control resources must be deployed timely and with adequate amount in response to net system load changes.
  - Otherwise primary frequency control will be automatically deployed and could be depleted.
- A power system without primary frequency response is inherently unstable to deal with load changes and/or loss of generation events.

Frequency Propagation in the Western Interconnection
Initiating event is in Phoenix AZ



How Frequency Control affects Reliability

- *Primary frequency control* involves the autonomous, automatic, and rapid action (i.e., within seconds) of a generator (and specific types of demand response) to change its output to oppose a change in frequency.
- *Secondary frequency control* involves slower, centrally (i.e., externally) directed actions that affect frequency more slowly than primary control as part of automatic generation control (i.e., in tens of seconds to minutes).
- *Tertiary frequency control* refers to centrally coordinated actions (i.e., it is a form of what we have called secondary frequency control) that operate on an even longer time scale (i.e., minutes to tens of minutes) than primary frequency control and secondary frequency control provided through AGC.
- Therefore, it is essential to have comprehensive operating strategies to ensure adequate primary, secondary and tertiary frequency control reserves with the appropriate response characteristics are in place at all times.

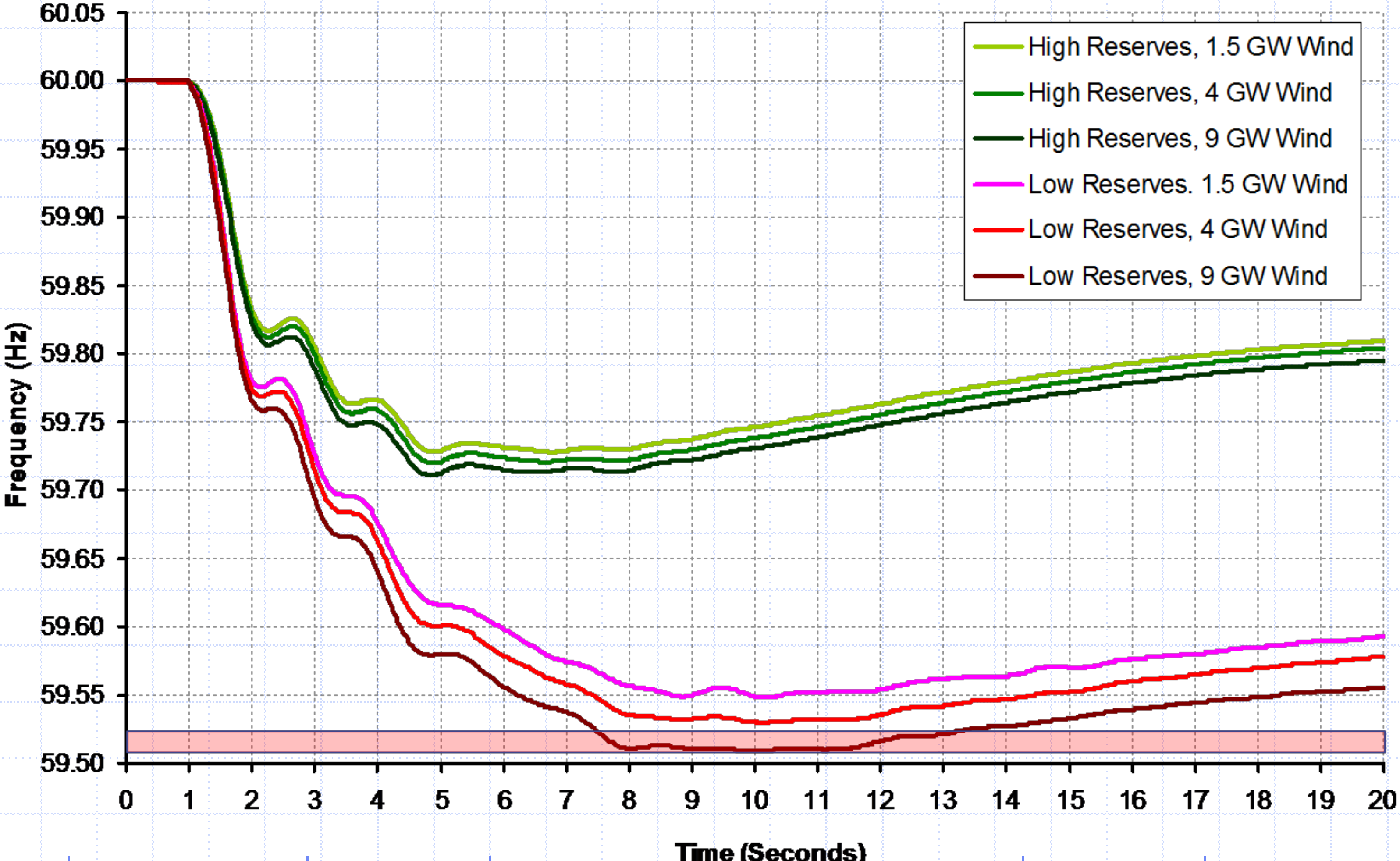
Under-frequency Load Shedding is a safety net!

- Drastic form of emergency frequency control that is designed for use in extreme conditions to stabilize the balance of generation and load after an electrical island has been formed, dropping enough load to allow frequency to stabilize within the island.
- Prevent damage to generators during the extreme imbalances
- A safety net to prevent complete blackout of the island and allows faster system restoration afterwards.
- Primary frequency control is to restore the frequency of the Interconnection to an acceptable range while the Interconnected is intact, as opposed to the preservation of **islanding** operation intended by UFLS.

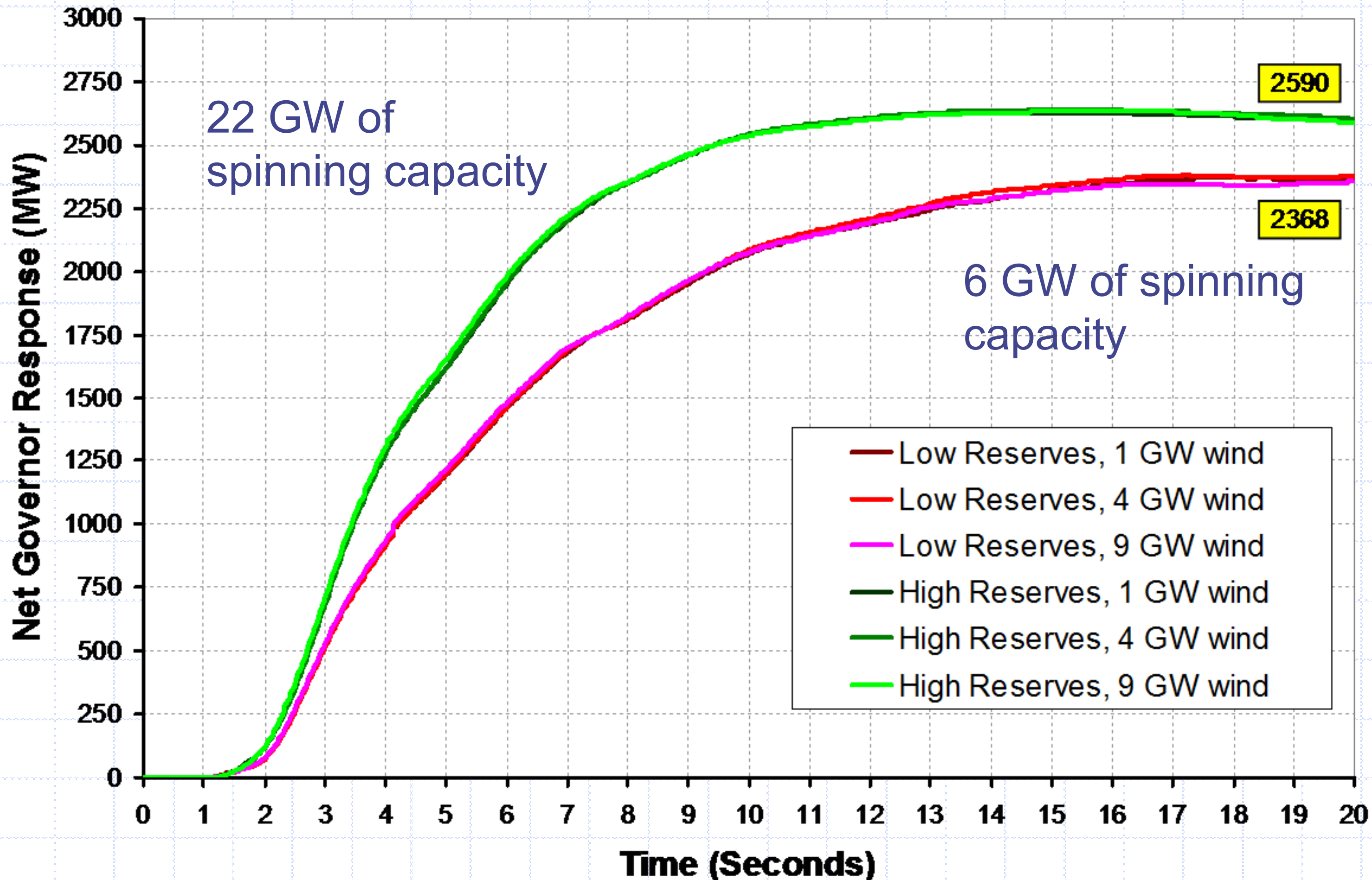
Study Conditions Assumed for 2012 Frequency Response Simulation Analysis

	2012 Minimum or Light System Load **(GW)**	Highest Level of Wind Generation Examined **(GW)**	Size of Loss of Generation Event Studied **(GW)**	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



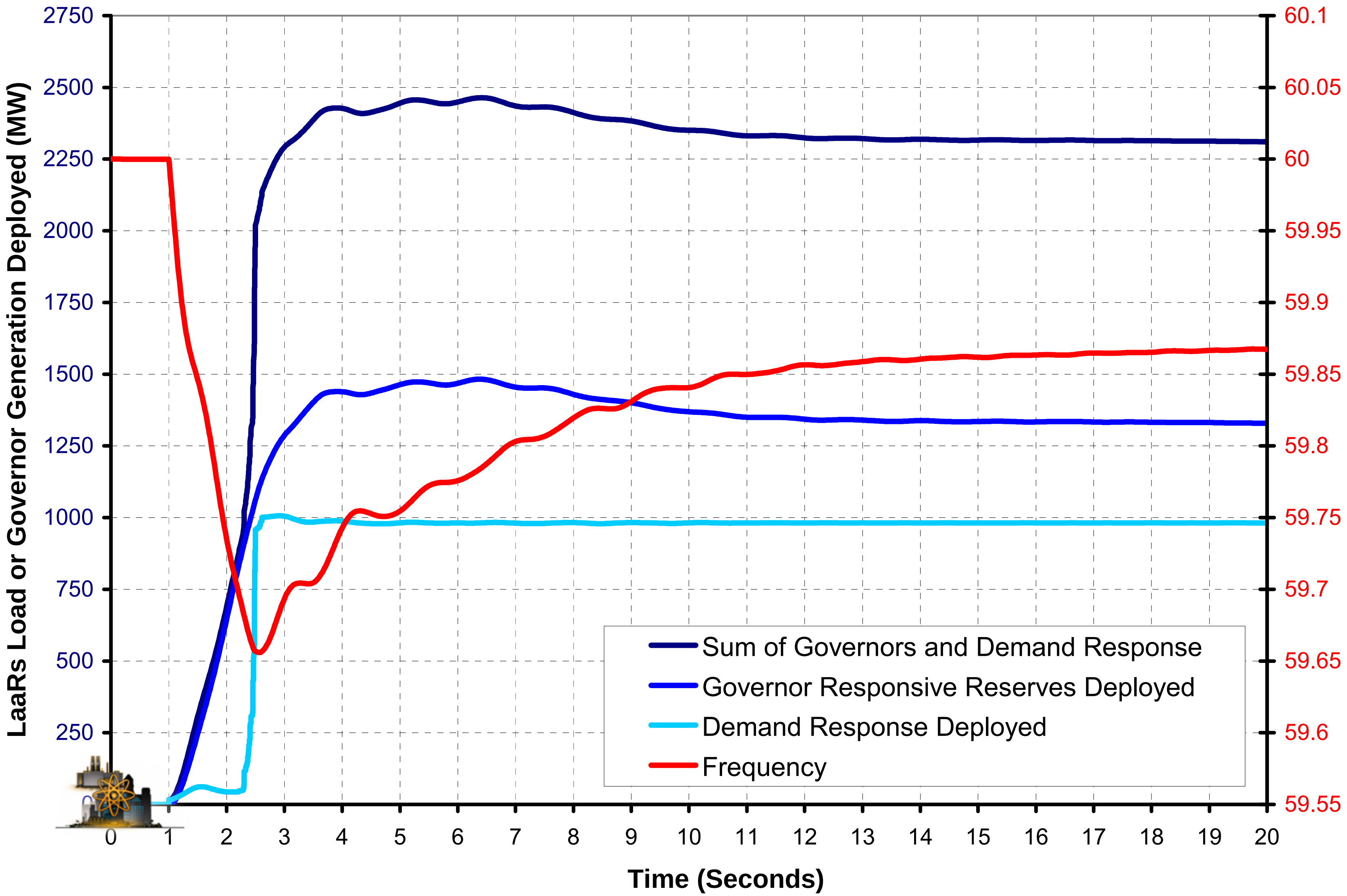
The Power Delivered by Primary Frequency Control Actions via Generator Governors in the Low and High Reserves Cases for the Western Interconnection



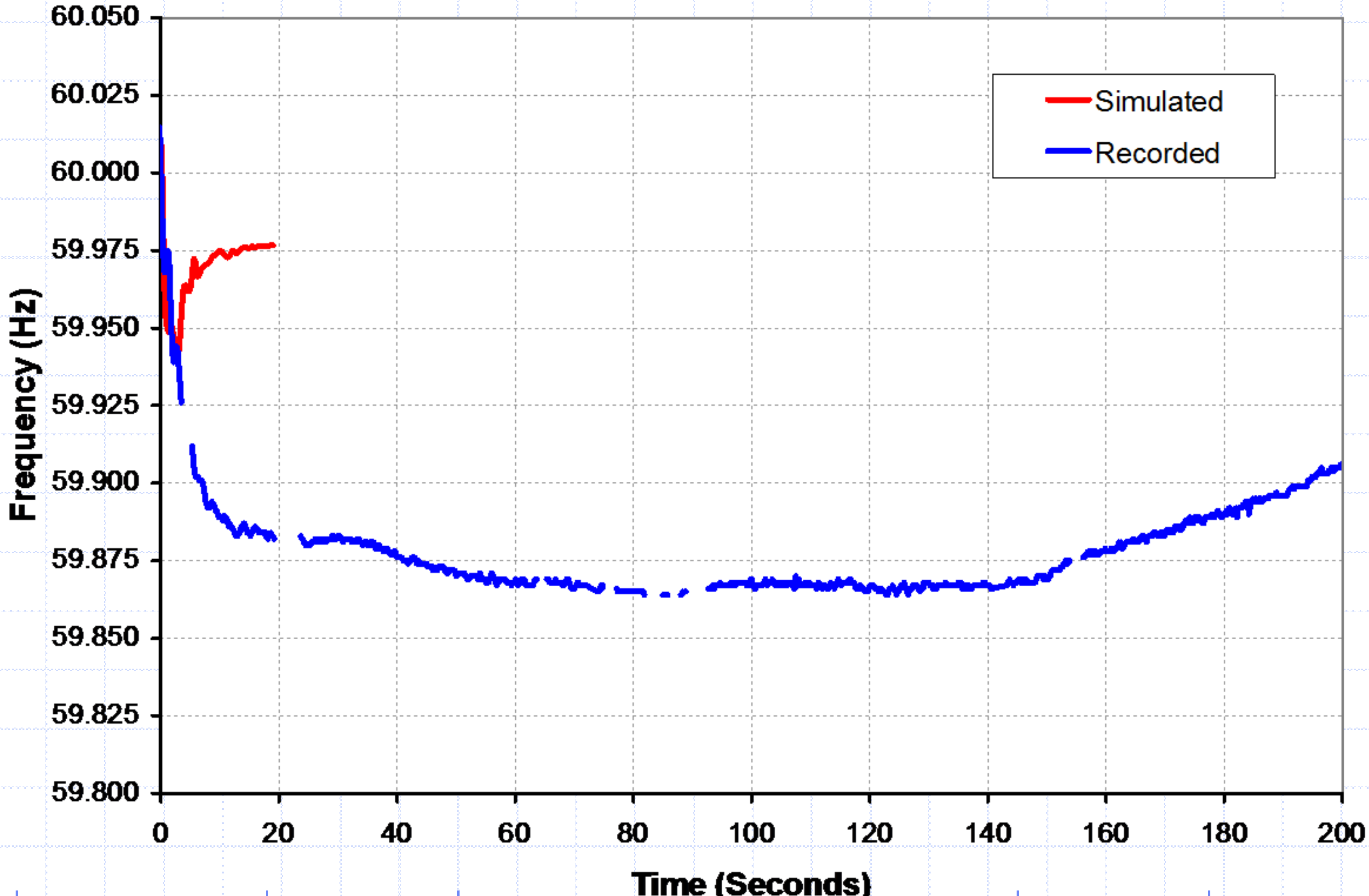
Summary of Dynamic Simulation Results for the Western Interconnection

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

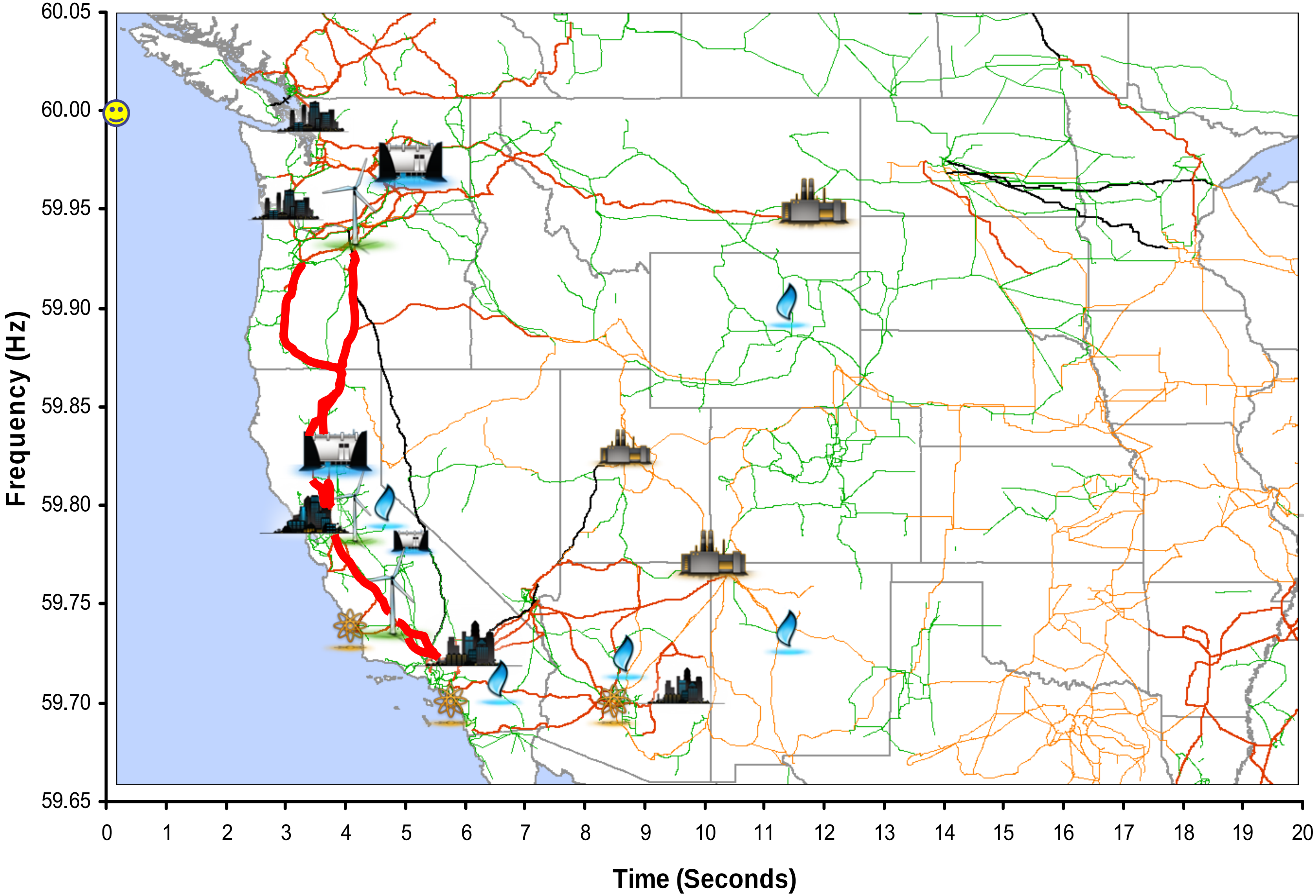
Governor and Demand response



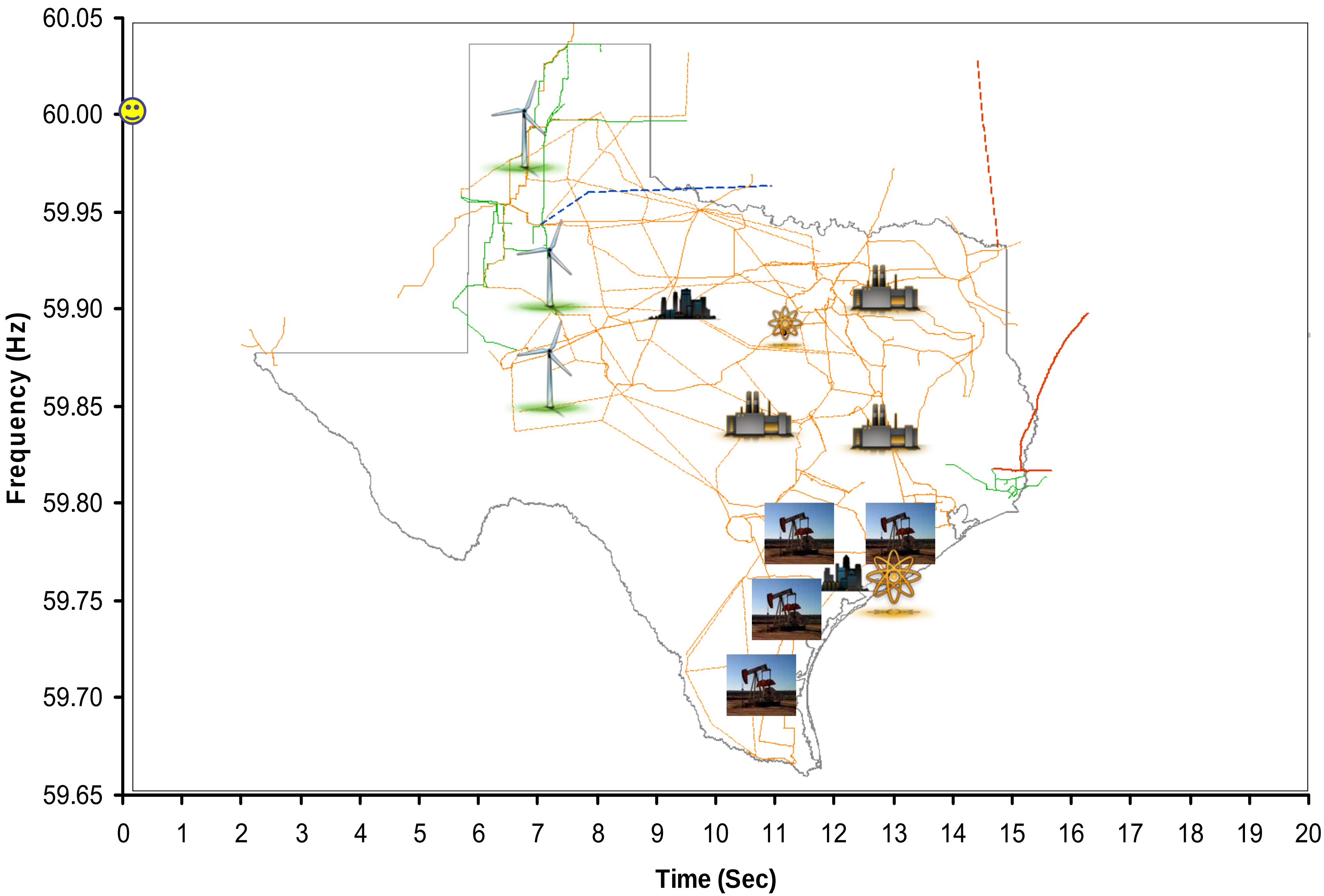
Frequency of the Eastern Interconnection following the Loss of 4,500 MW of Generation–Comparison of Recorded Data with Results from a Simulation of the Event



Governor/Demand Response to a contingency in WECC



Governor/Demand Response to a contingency in ERCOT



Recommendations:

- Understand interconnection and Balancing Authority requirement for Frequency Control (especially in the Eastern Interconnection)
- Interconnections must schedule and deploy/deliver 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

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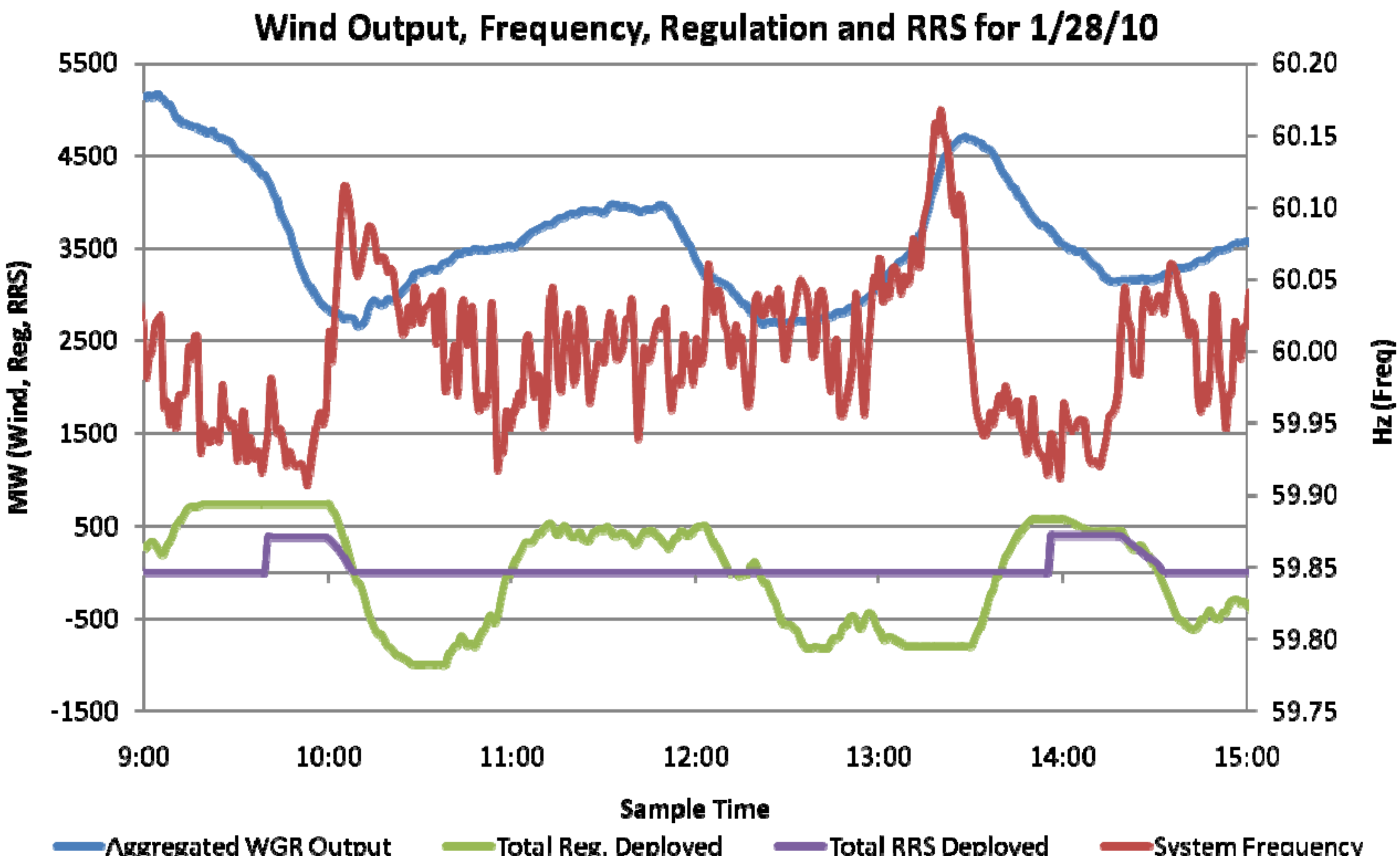
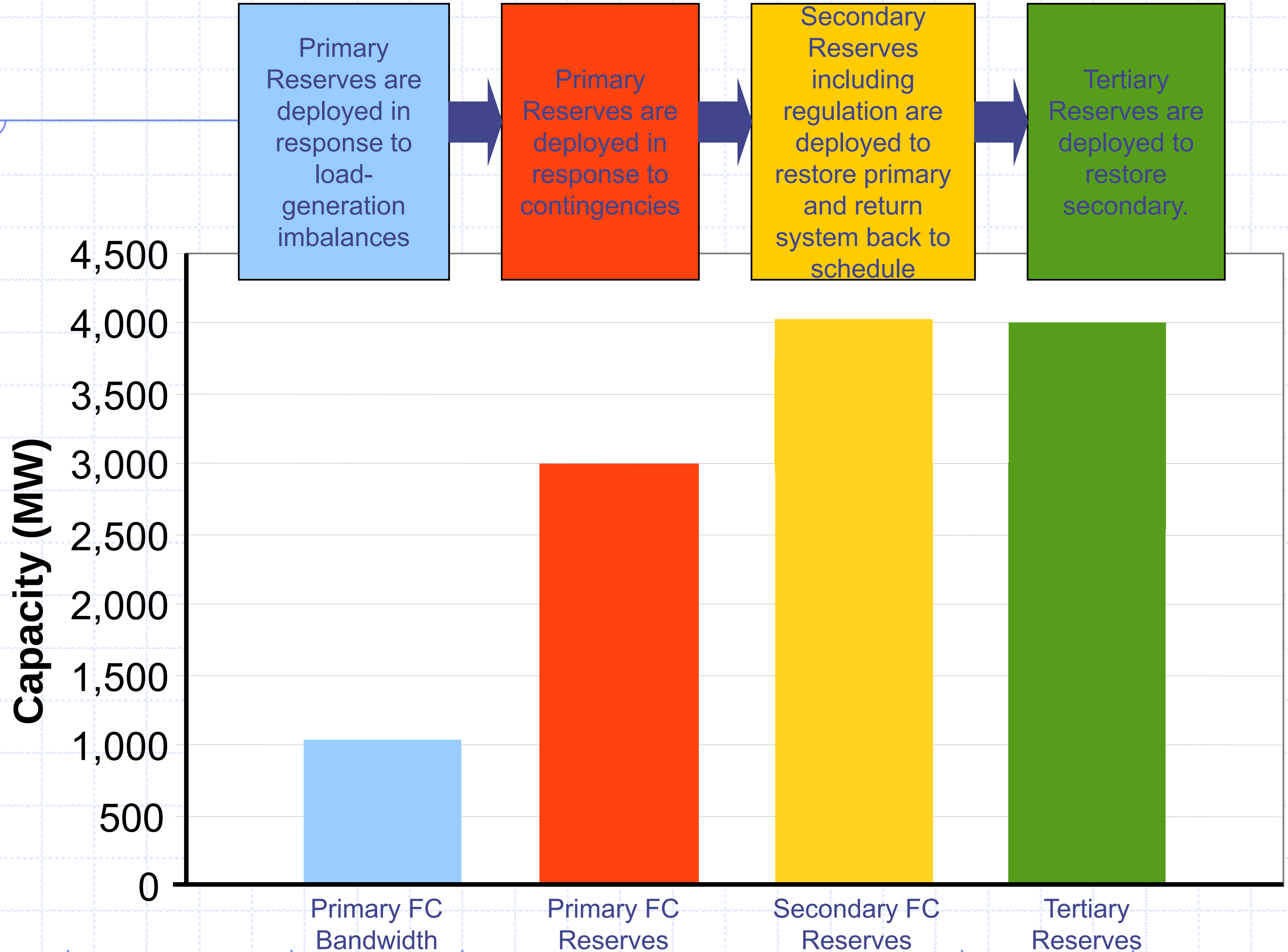
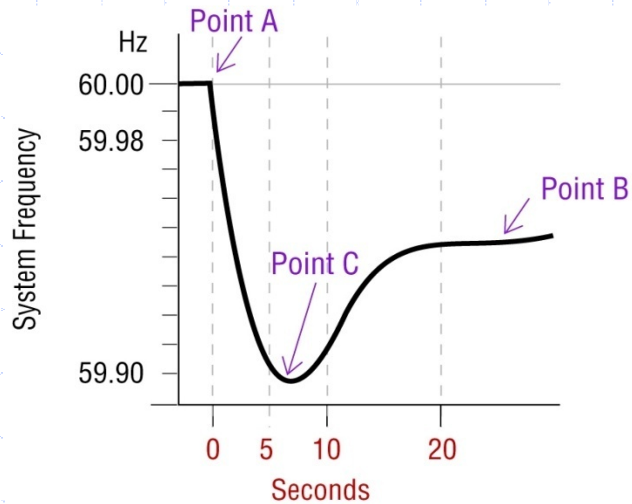


Source: ERCOT (2010)

Generic Interconnection



The Metric



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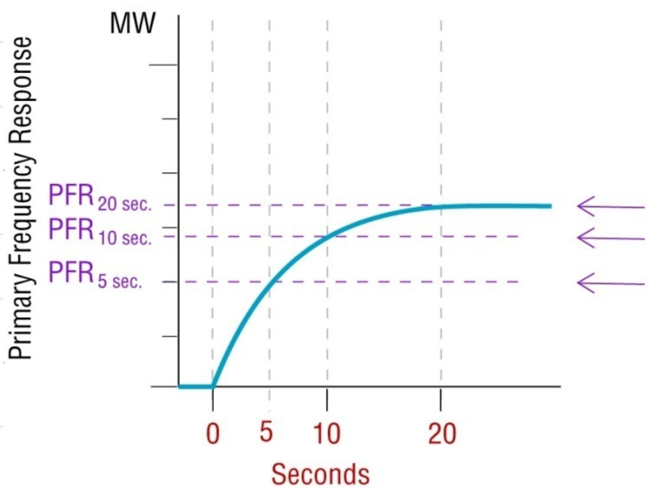

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- Need to establish the minimum/maximum primary and secondary frequency control
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Questions