



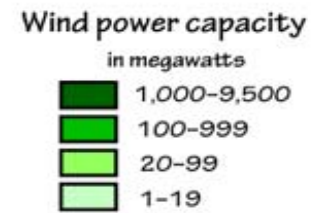
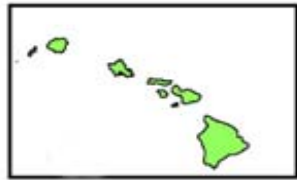
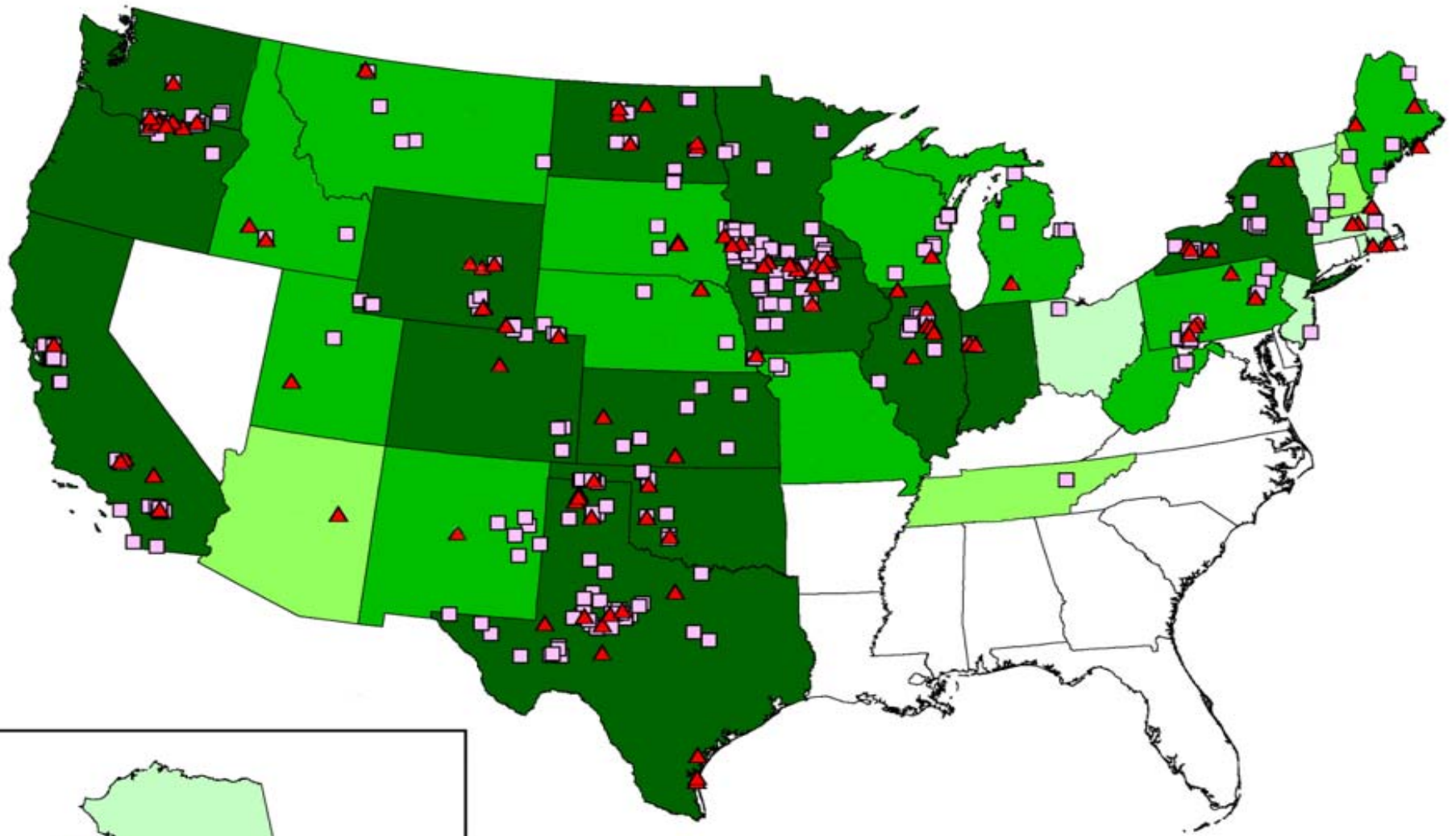
**Sandia National Laboratories**

**2011 Wind Turbine**

**Reliability Workshop**

**Albuquerque, NM**

**August 2, 2011**

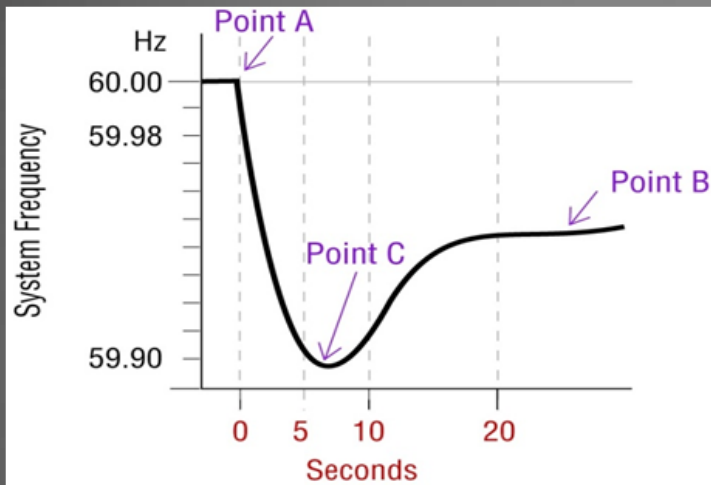




# Reliability Issues

# How Frequency Control Affects Reliability

# Frequency Performance Metrics



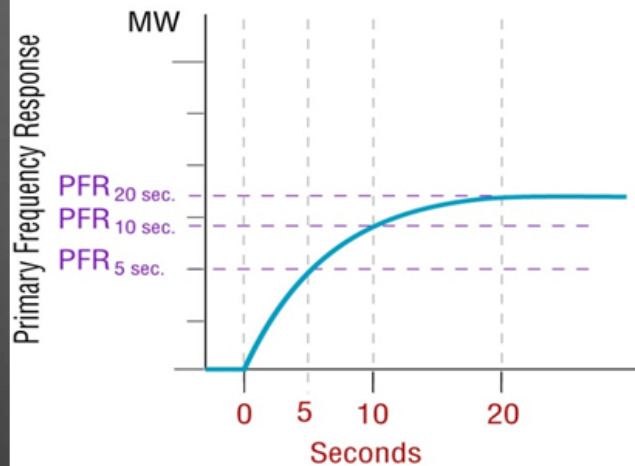
Pre-disturbance Frequency: Frequency<sub>point A</sub>

Settling Frequency: Frequency<sub>point B</sub>

Frequency Nadir: Frequency<sub>point C</sub>

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

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

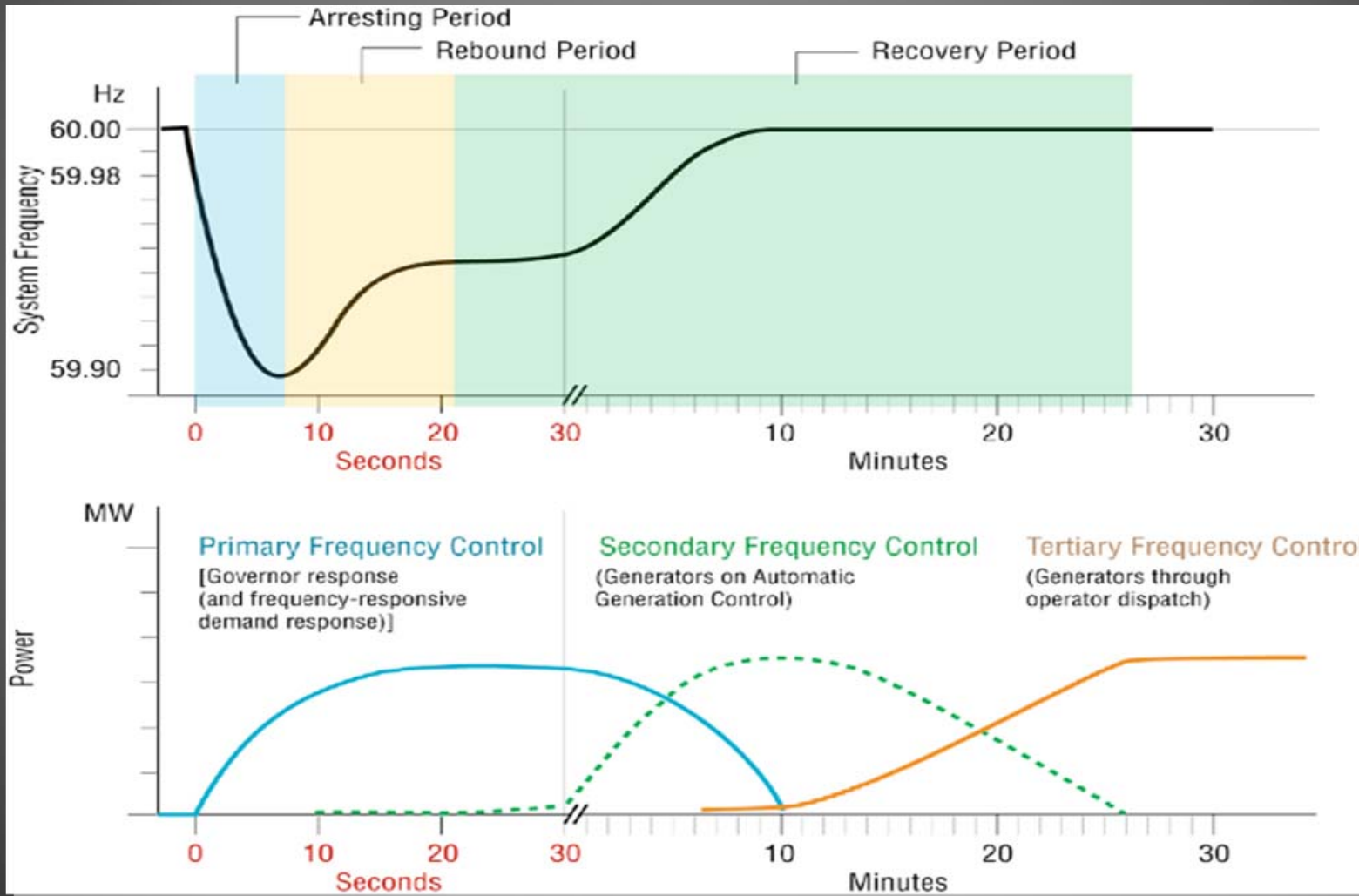


← Primary frequency response (PFR) delivered at 20 seconds

← Primary frequency response (PFR) delivered at 10 seconds

← Primary frequency response (PFR) delivered at 5 seconds

# Background

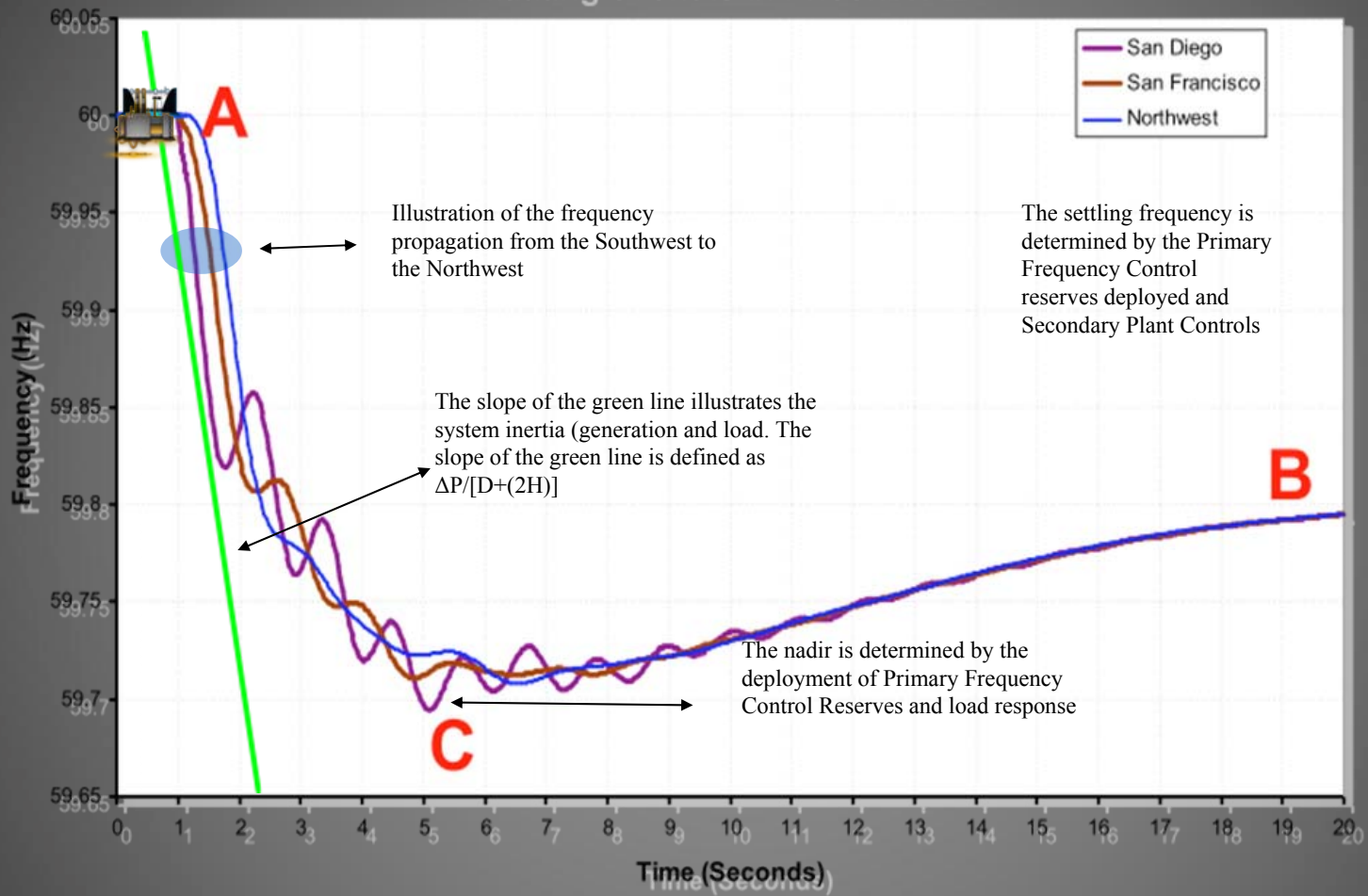


# Secondary Preserves

## Primary



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



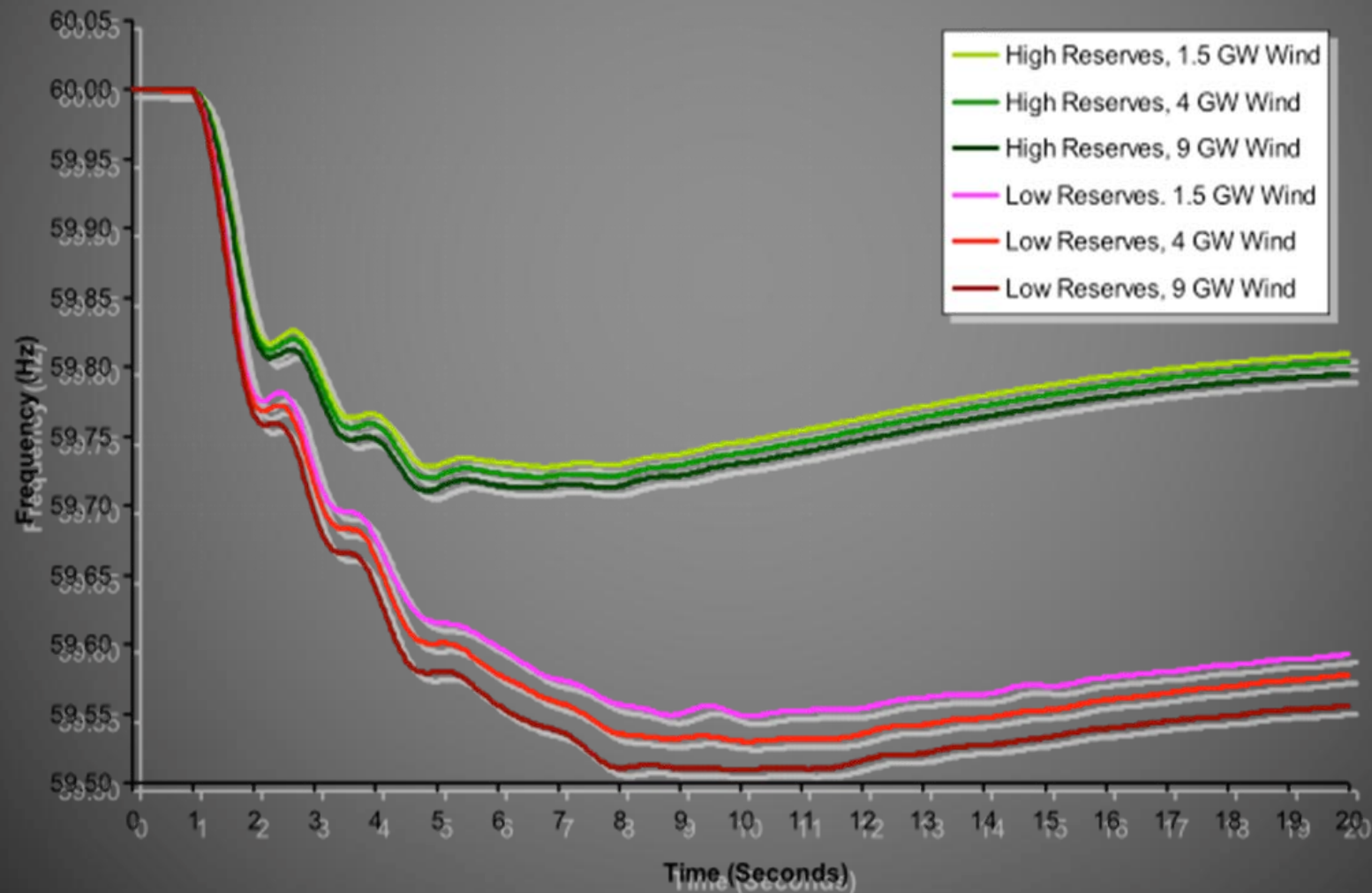
# How Frequency Control Affects Reliability

**Under-frequency Load  
Shedding is a Safety Net!**

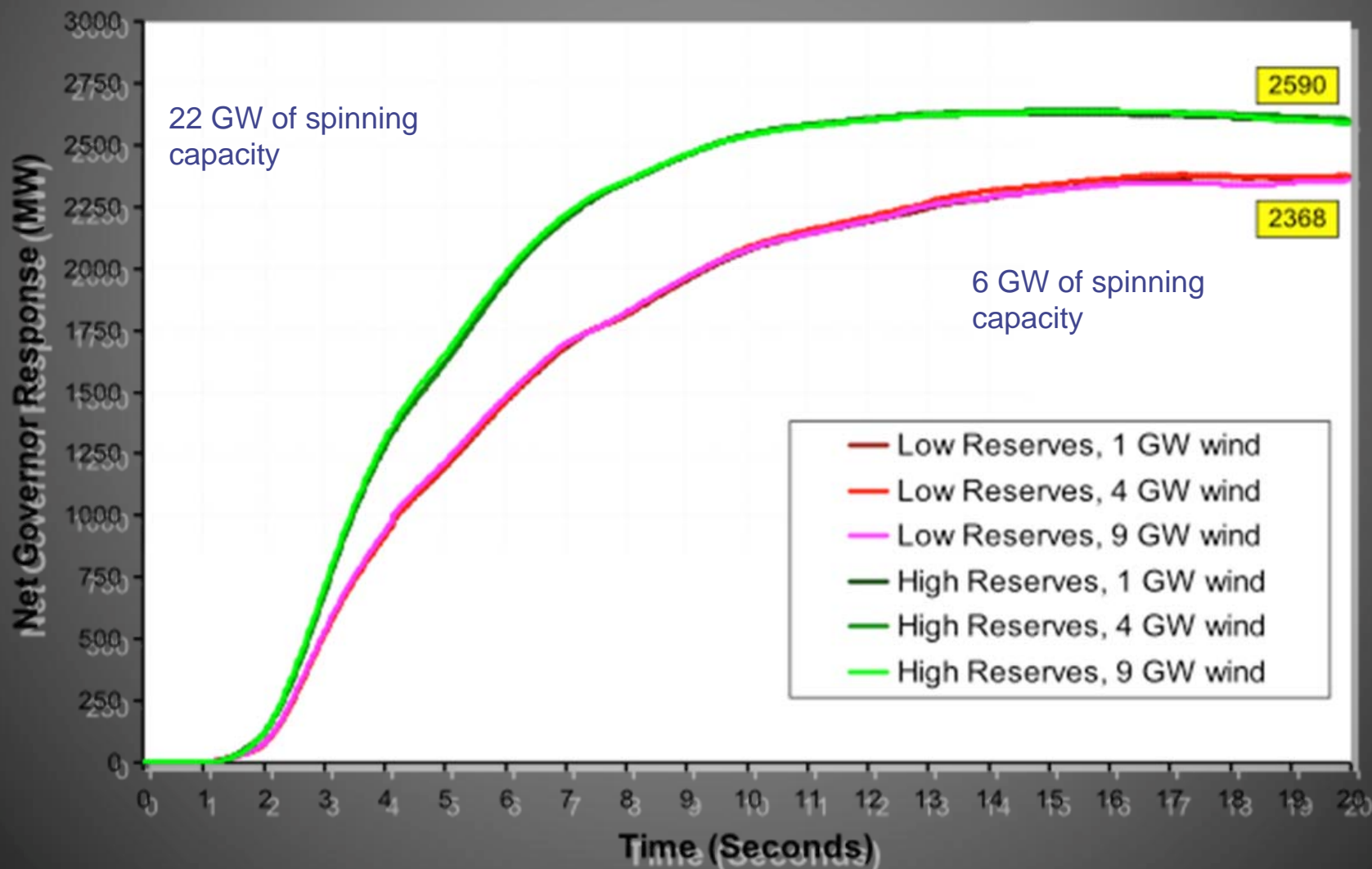
# Study Conditions Assumed for 2012 Frequency Response Simulation Analysis

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

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



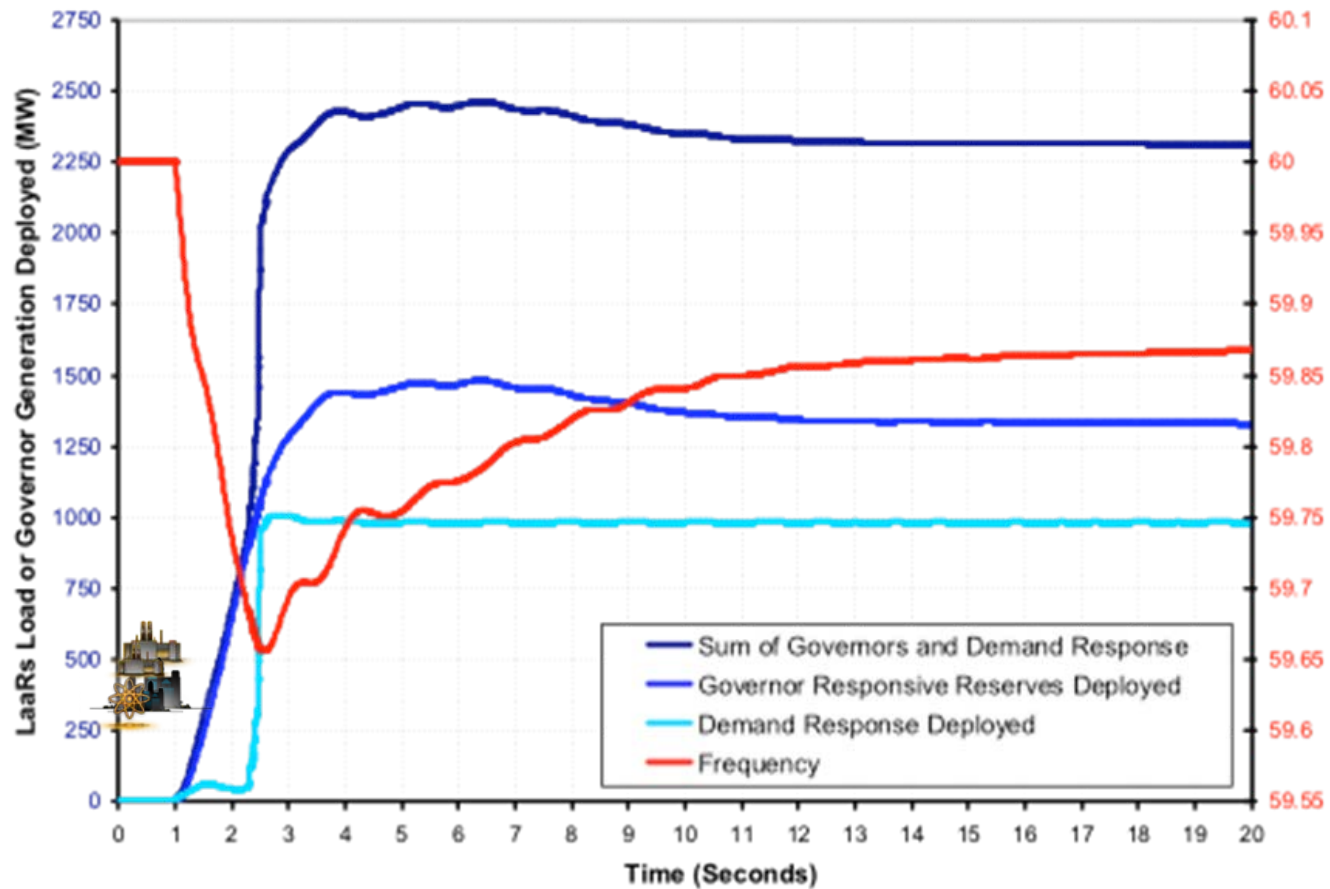
# The Power Delivered by Primary Frequency Control Actions via Generator Governors in the Low and High Reserves Cases for the Western Interconnection



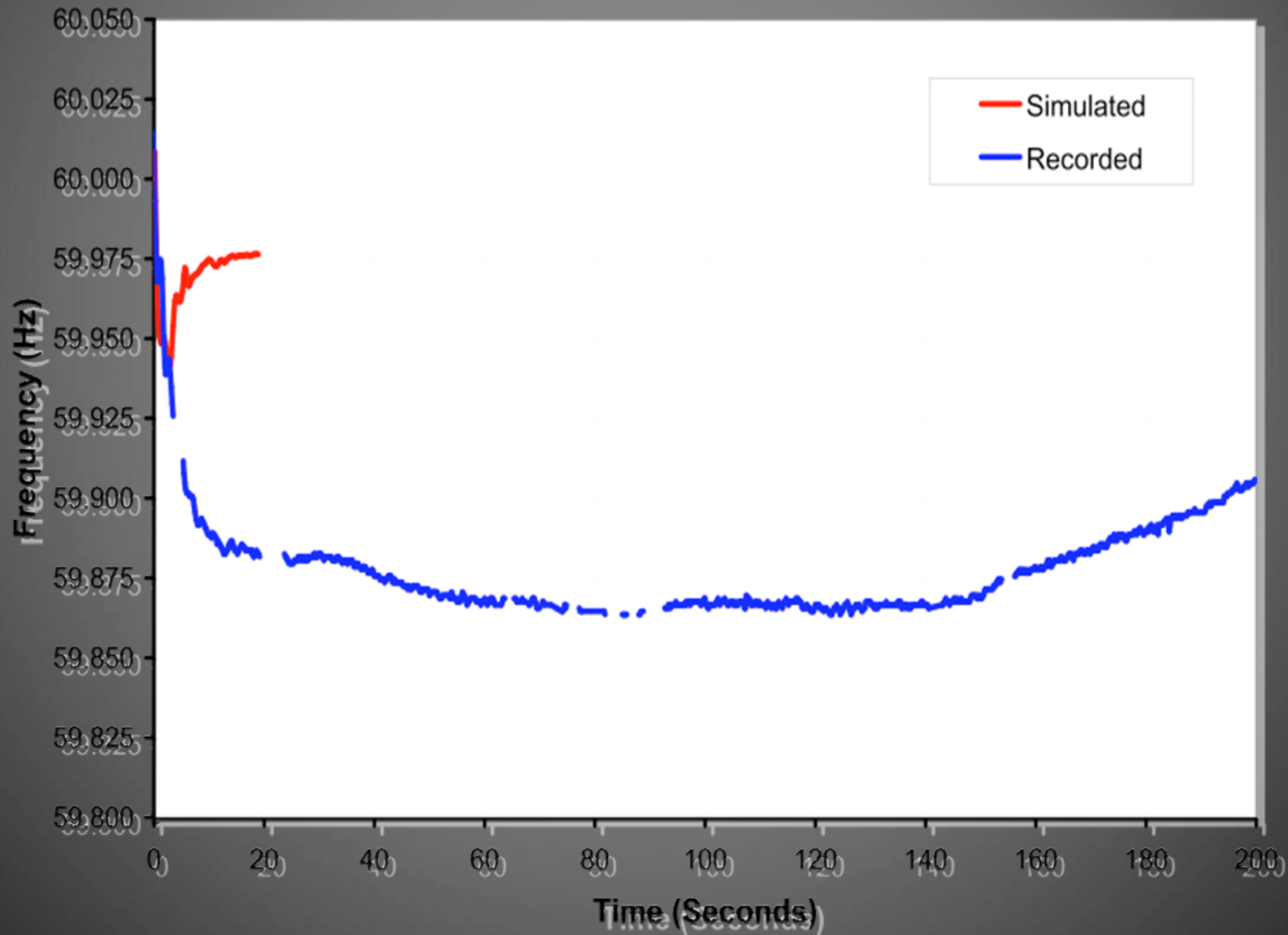
# Dynamic Simulation Results

## ERCOT

### Governor and Demand response

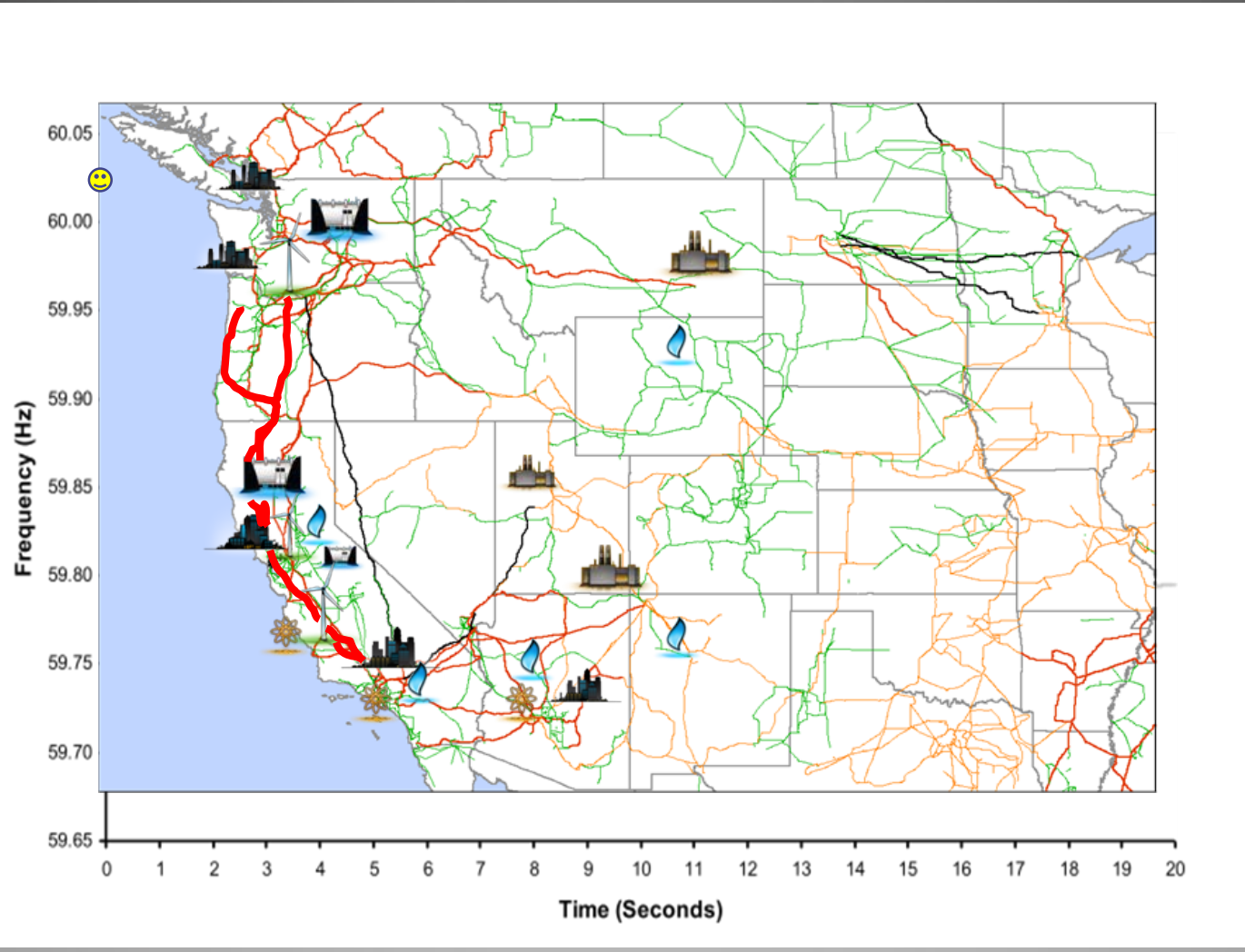


# Frequency of the Eastern Interconnection following the Loss of 4,500 MW of generation – Comparison Recorded Data with Results from a Simulation of the Event

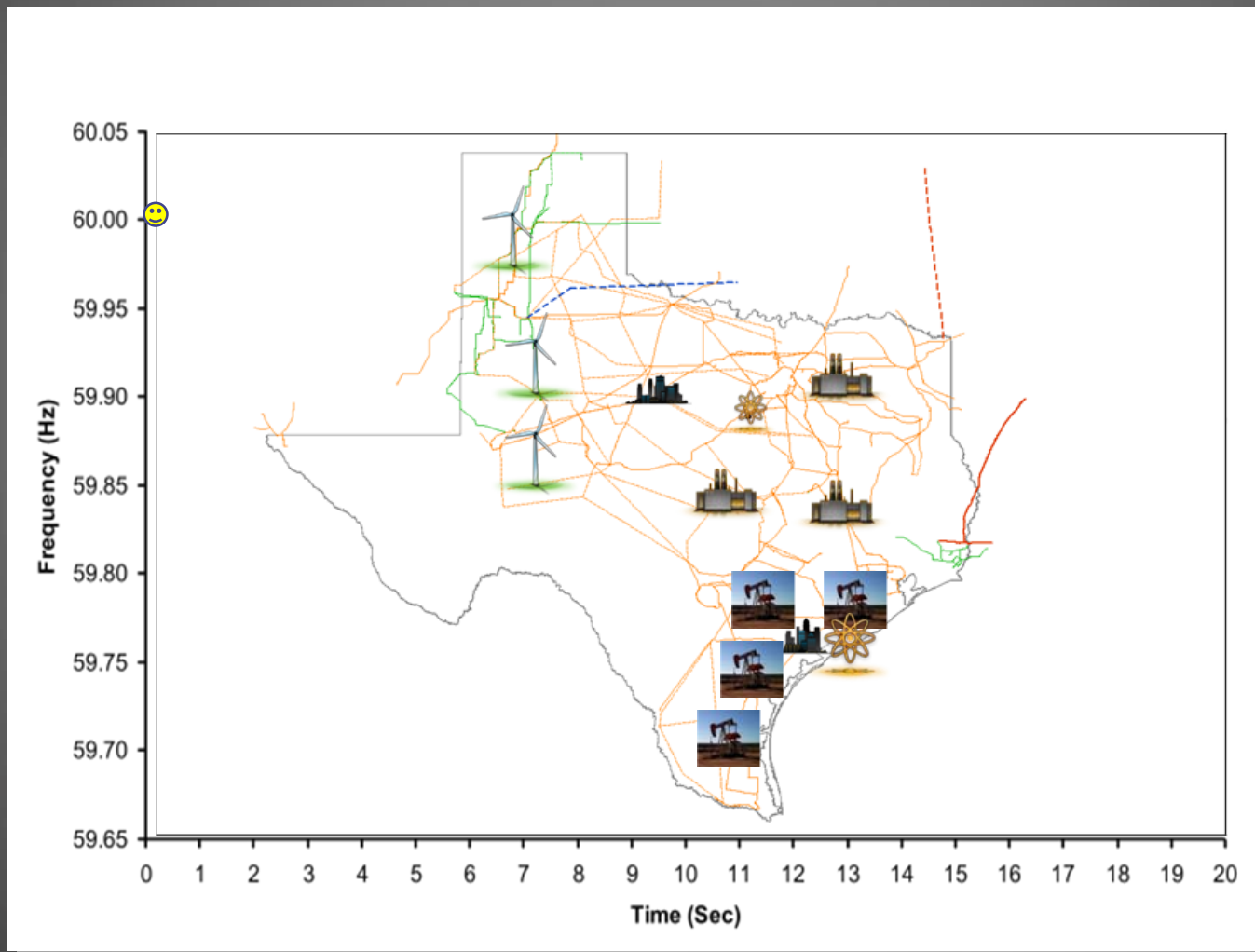




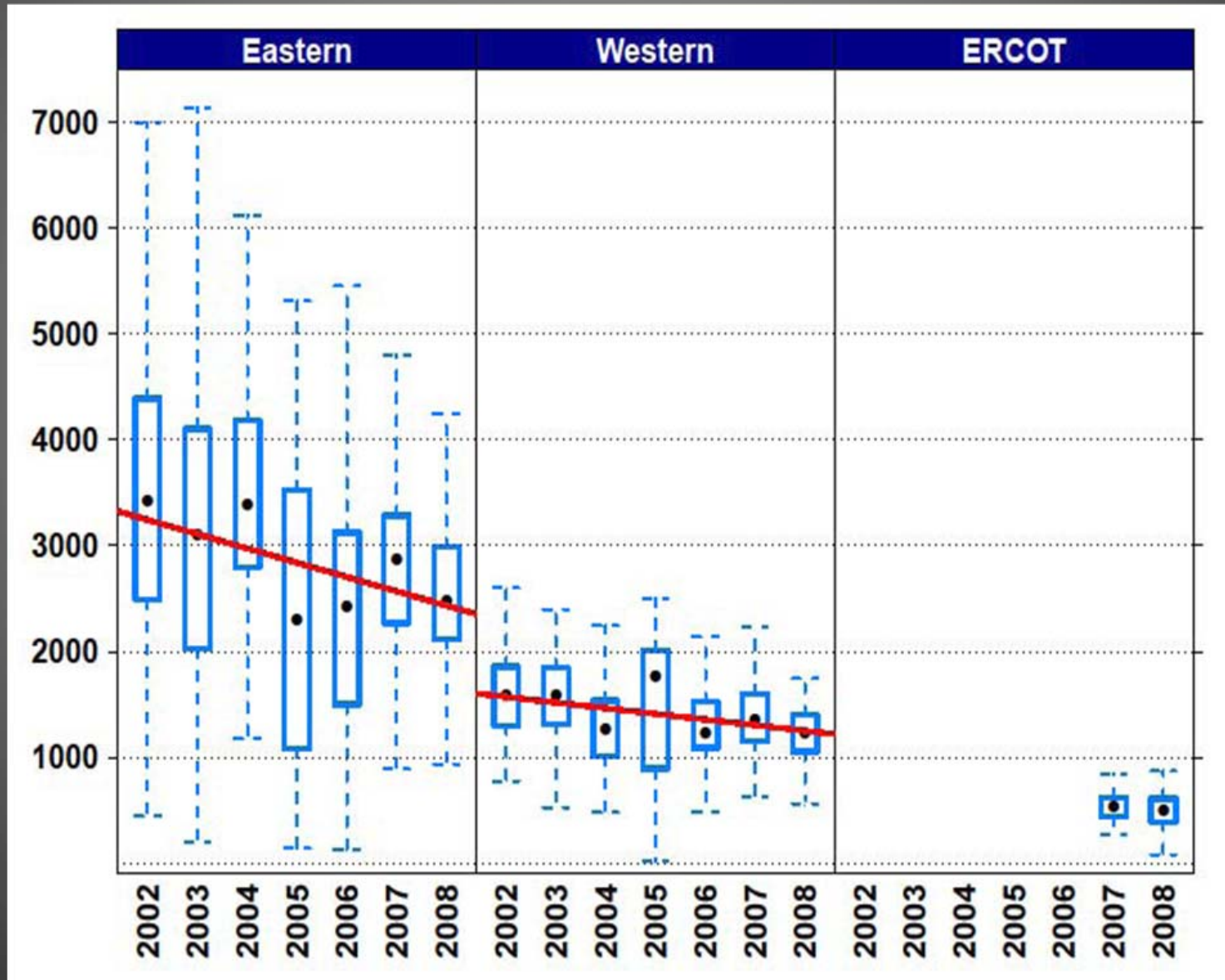
# Governor / Demand Response to a Contingency in WECC



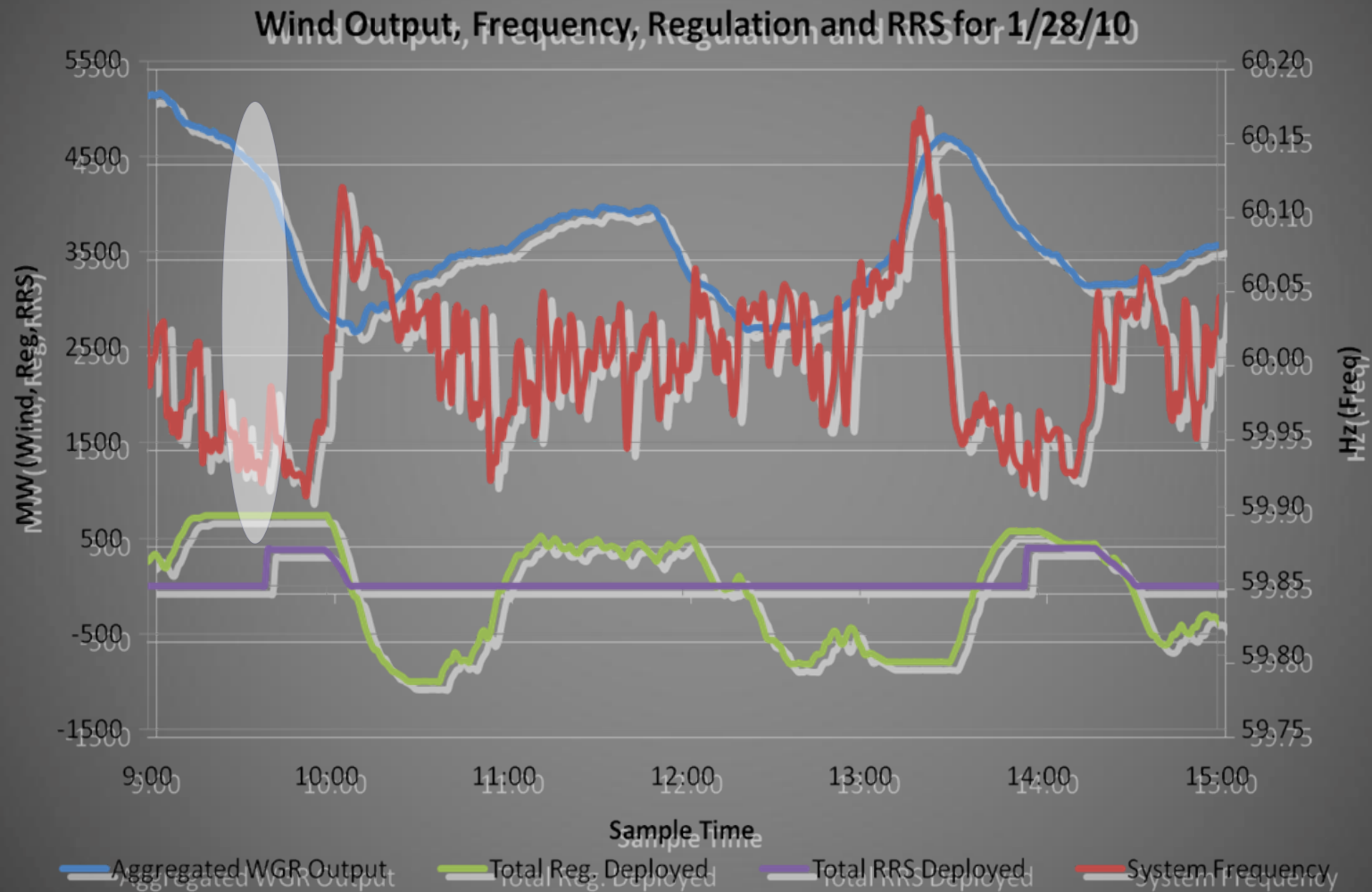
# Governor / Demand Response to a Contingency in ERCOT



# The Recorded Frequency Response of Three U.S. Interconnections, 2002-2008



# Finding: ERCOT (2010)



A photograph of three wind turbines in a field at sunset. The sky is a mix of blue and orange, with scattered clouds. The turbines are silhouetted against the bright horizon. The text "Thank you!" is centered in the middle of the image in a white, serif font with a drop shadow.

**Thank you!**