NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

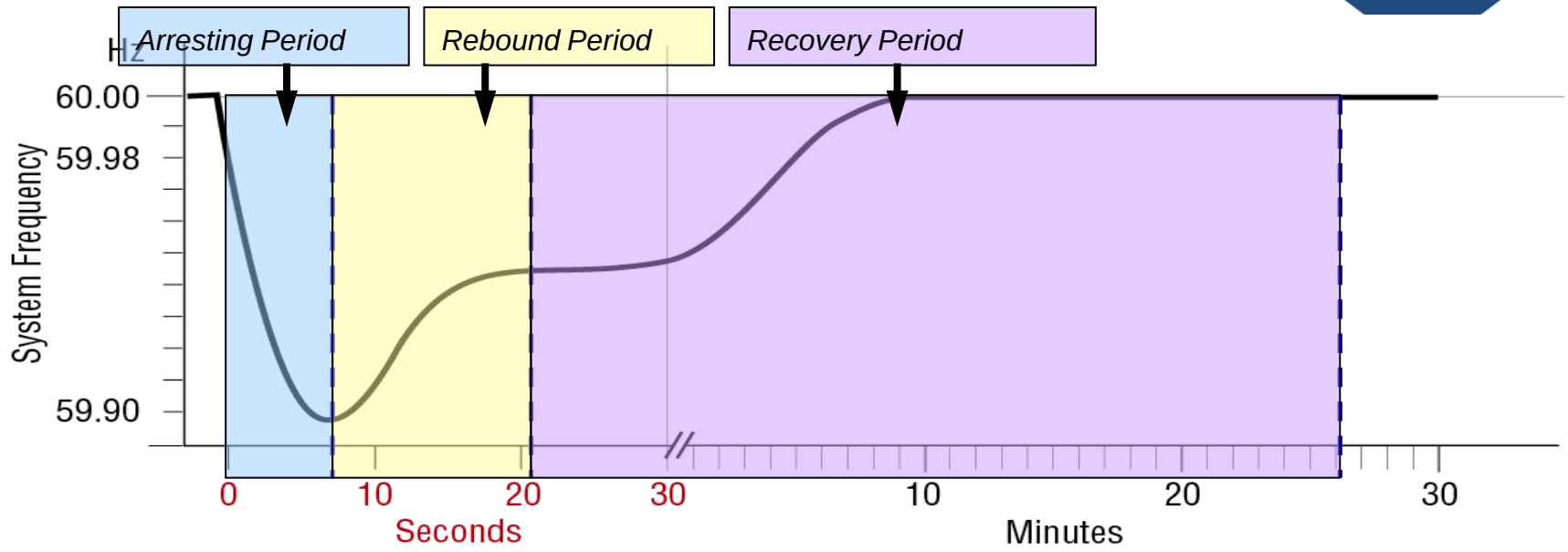
Frequency Response Technical Conference

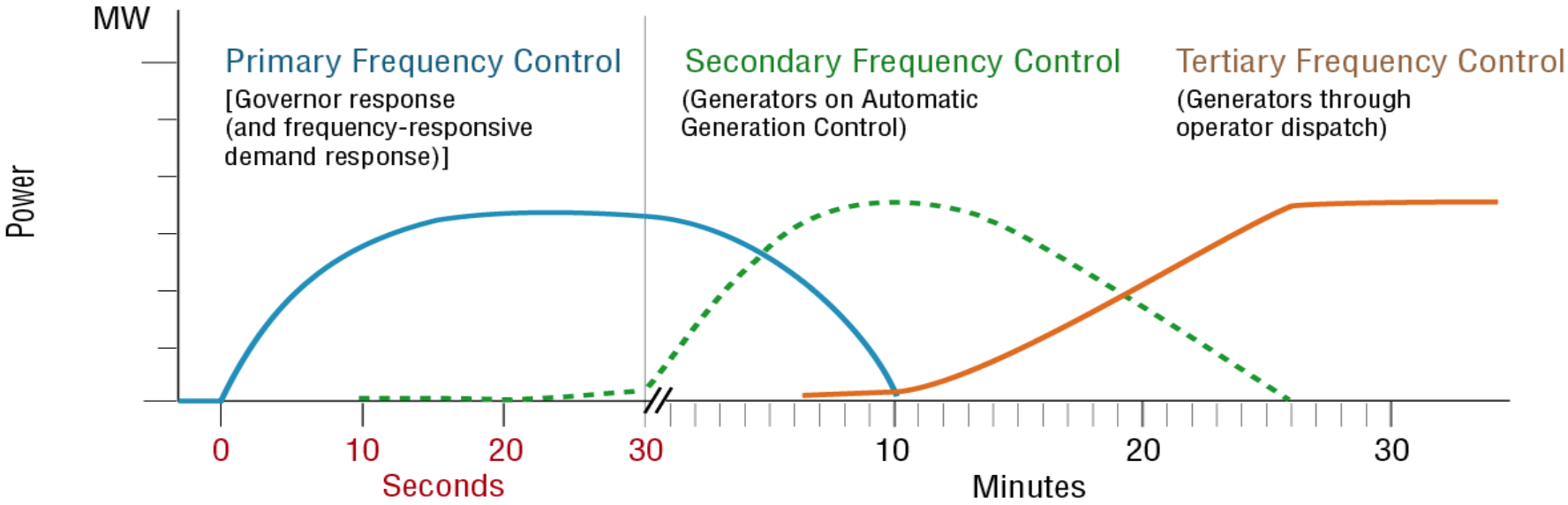
Frequency Response Trends

Robert W. Cummings – NERC

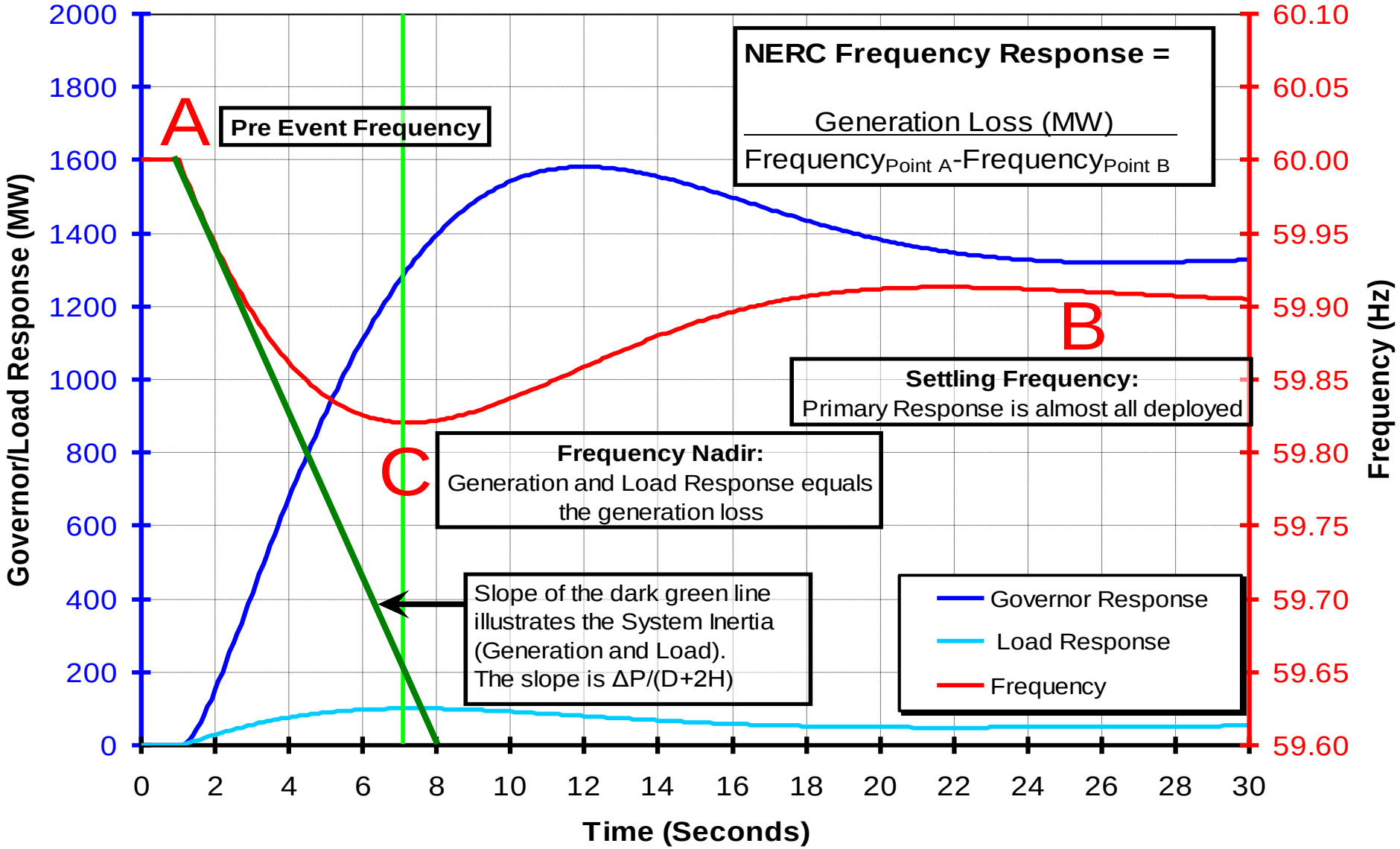
RELIABILITY | ACCOUNTABILITY

Frequency Response Performance





Frequency Response Basics



Frequency Drop Slope

Slope of frequency excursion – determined by the inertia of the system

$$Slope = \frac{\Delta Power}{D + 2H}$$

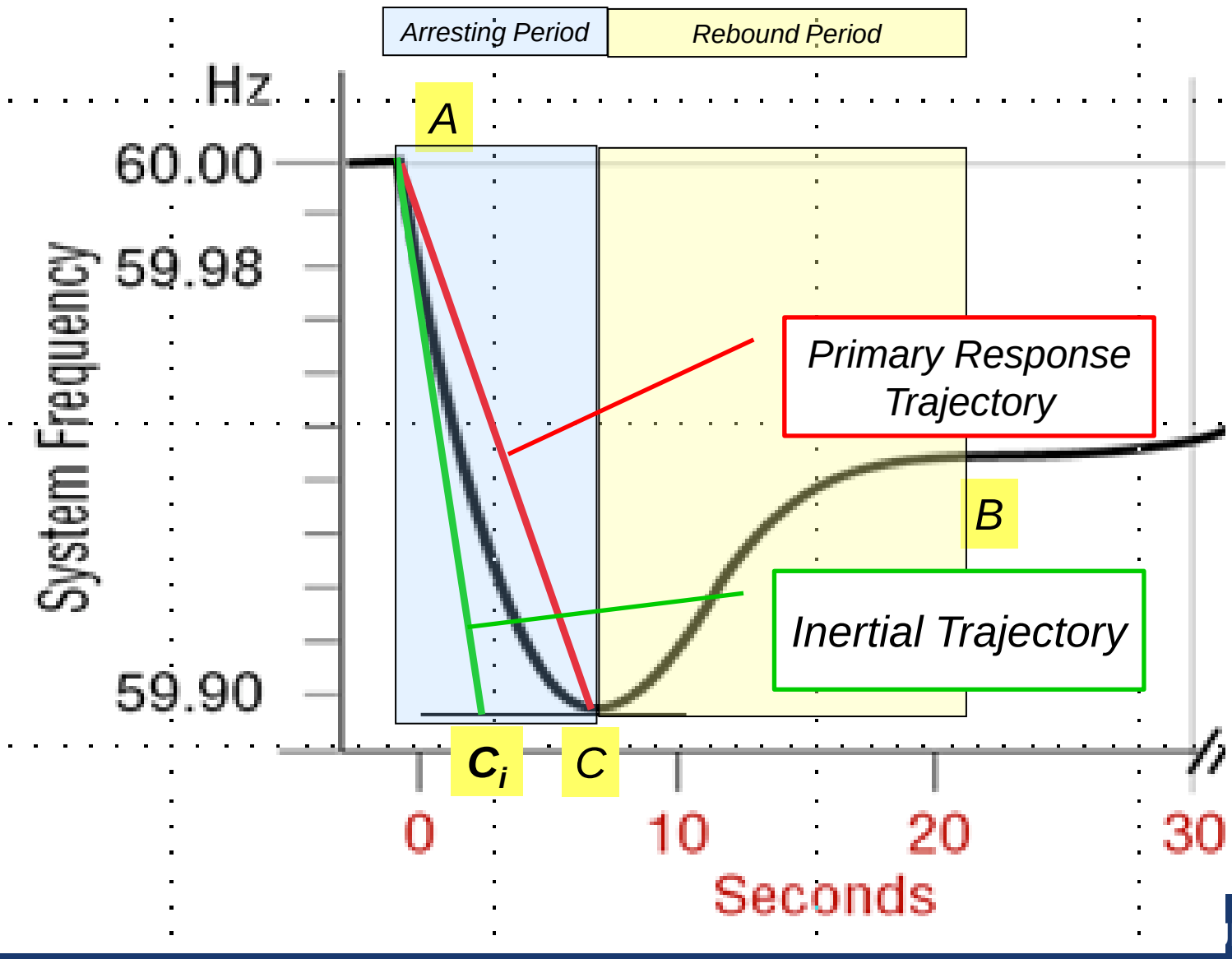
Where D = Load Damping Factor

Range of 0 to 2, where 2 = all motors

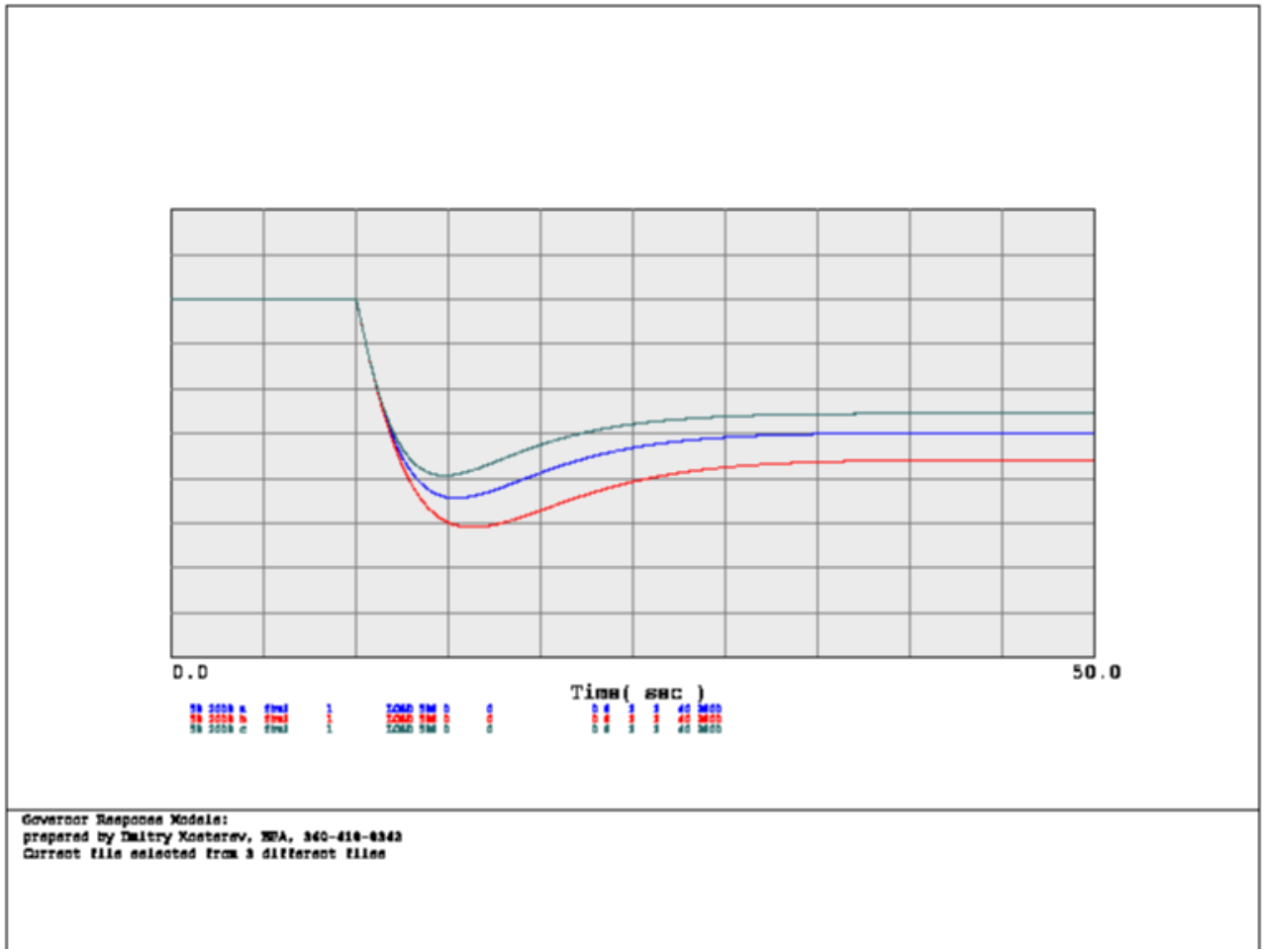
And H = Inertia Constant of the system

Range of 2.5 to 6.5

Arresting Period Analysis

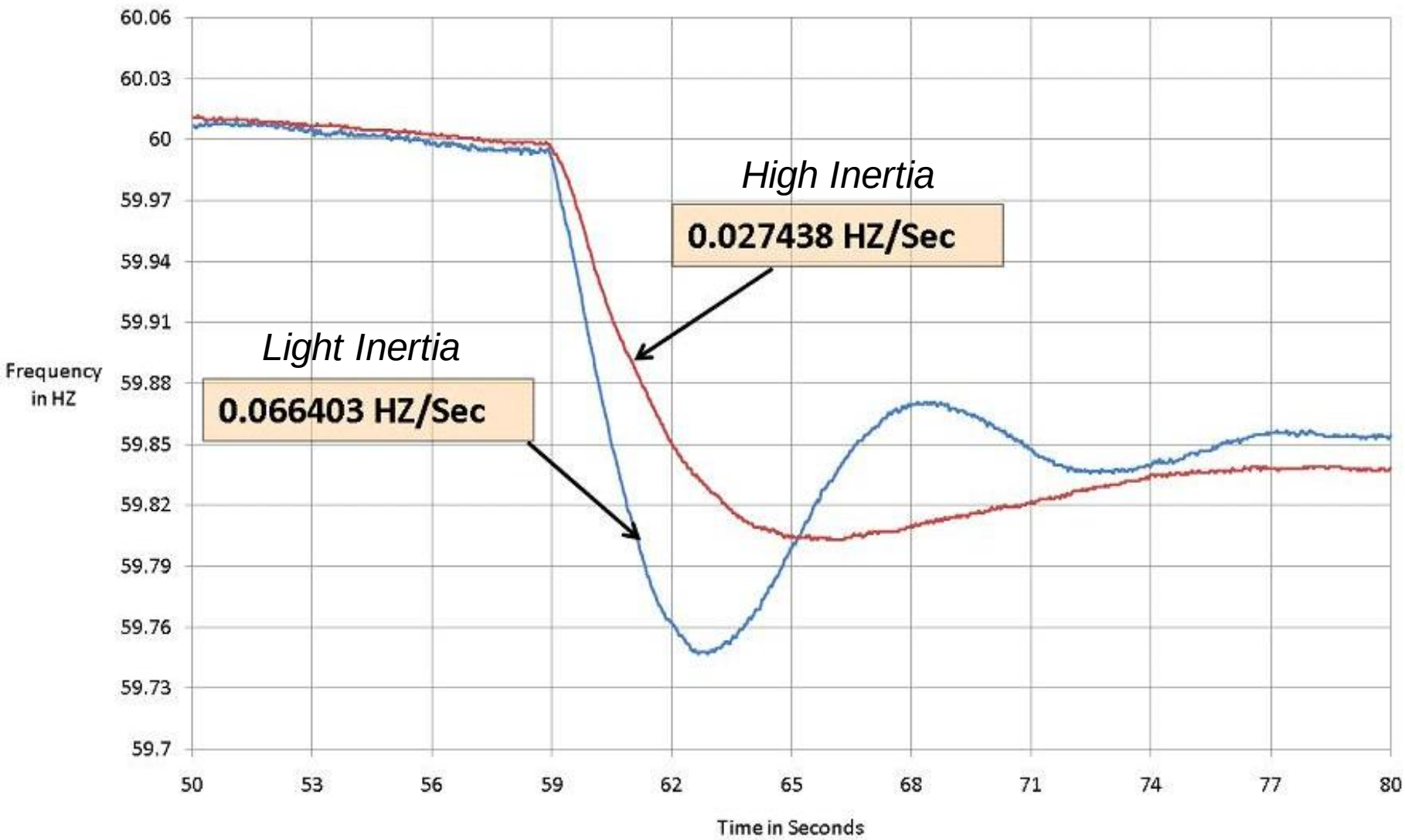


Importance of Deployment Rate

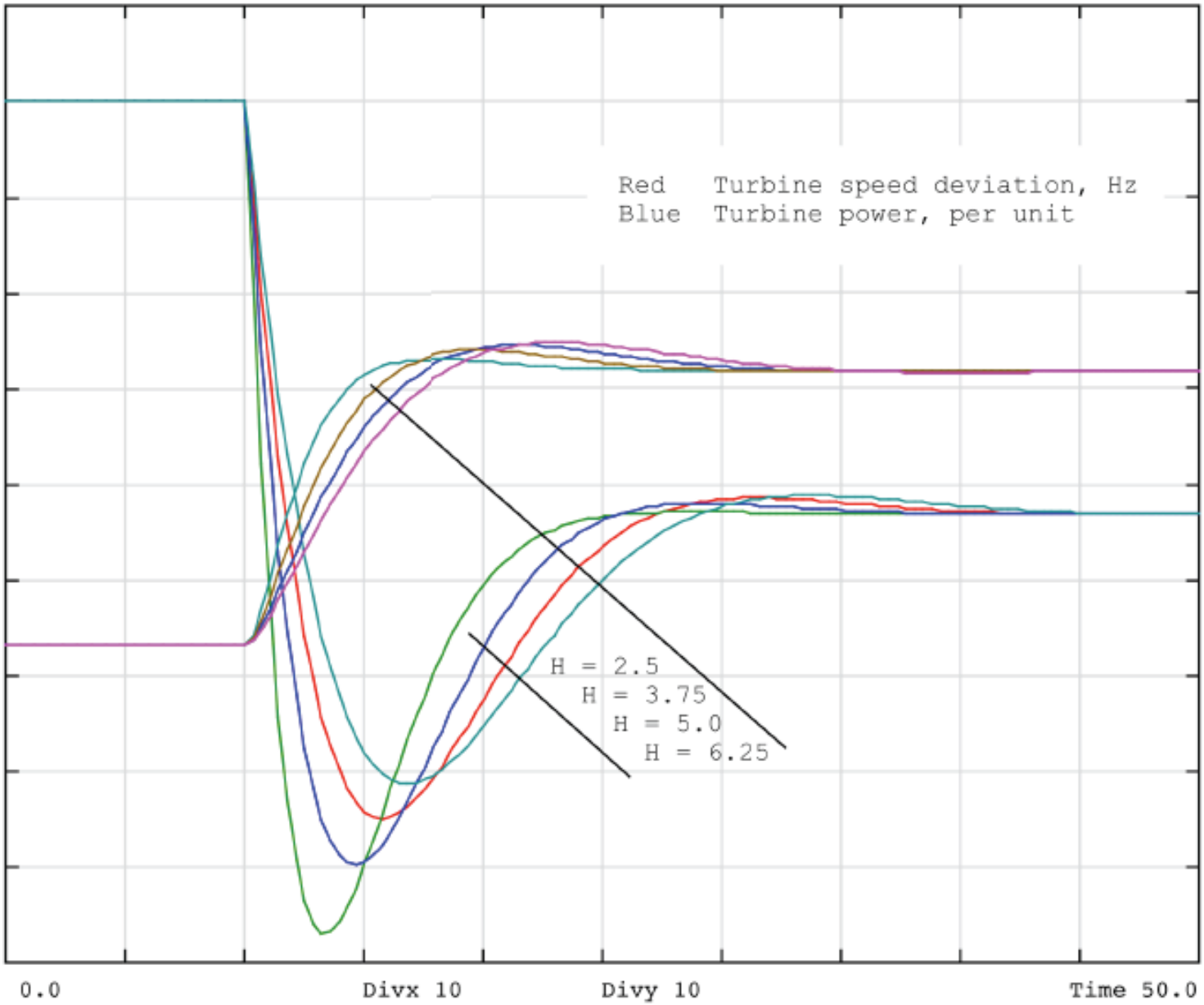


20 GW of generating capacity (red)
25 GW of generating capacity (blue)
30 GW of generating capacity (green)

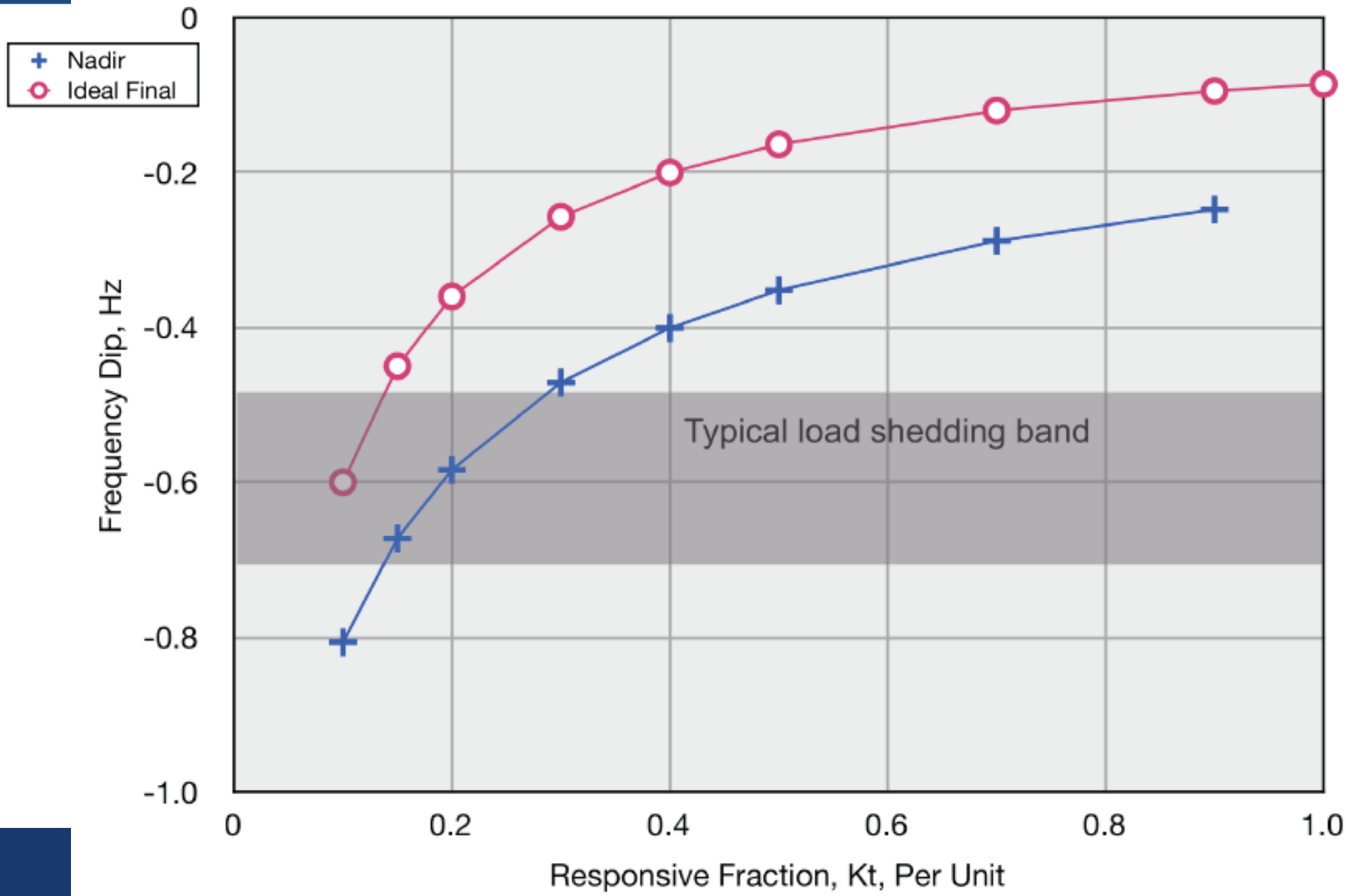
Inertial Response Sensitivity



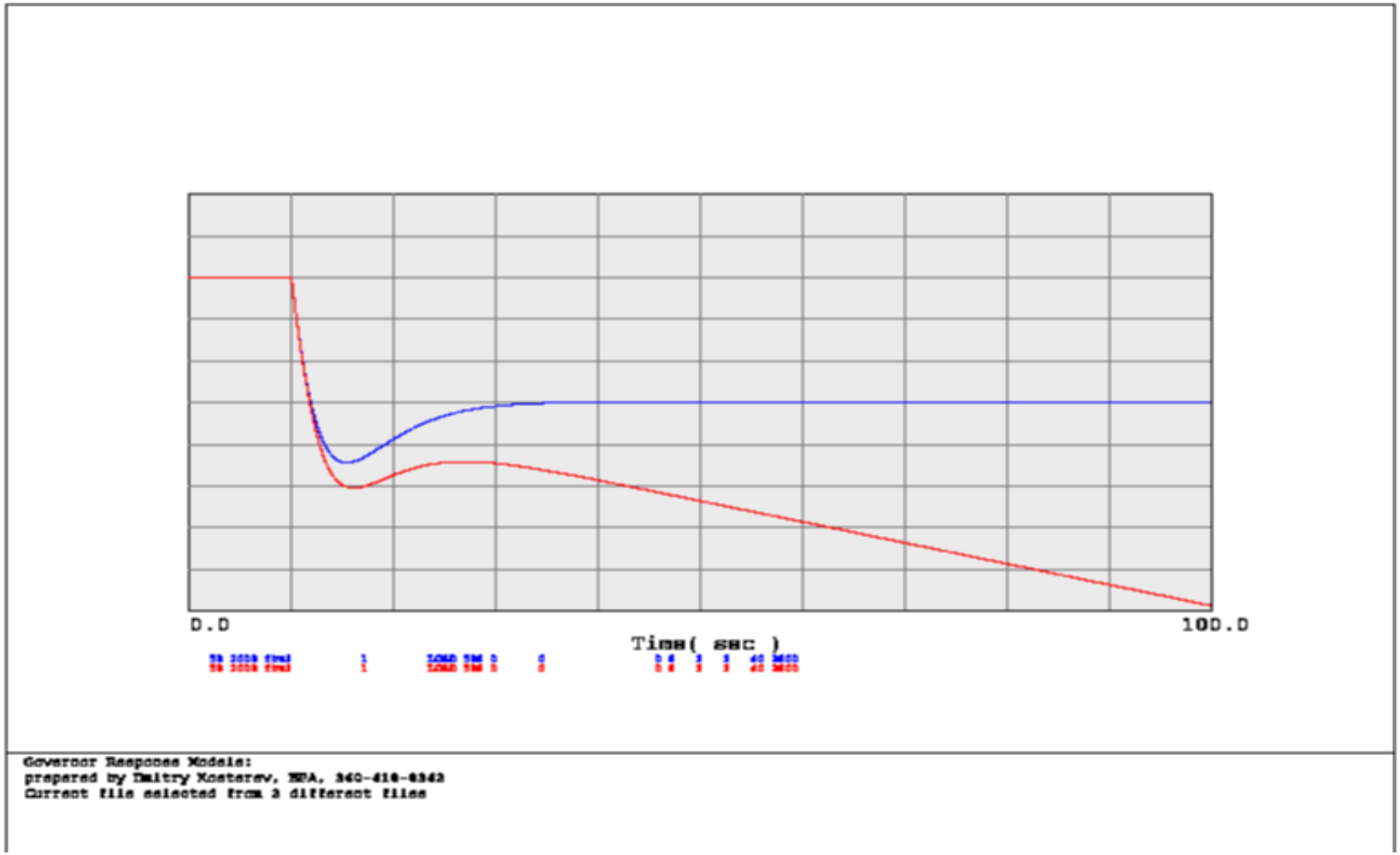
Sensitivity to System Inertia



% of Gen. PFR versus Nadir



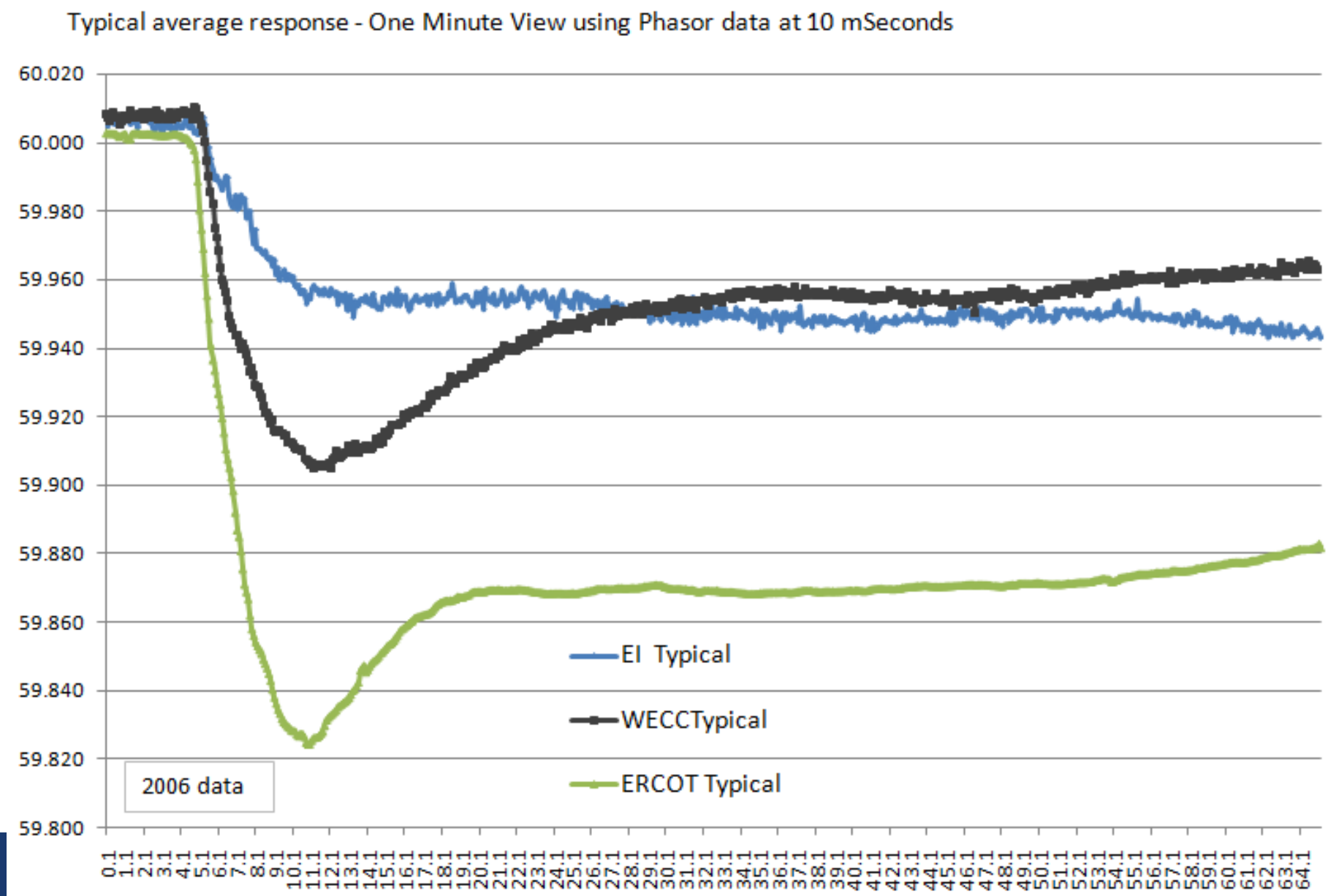
Primary Response Sustainability



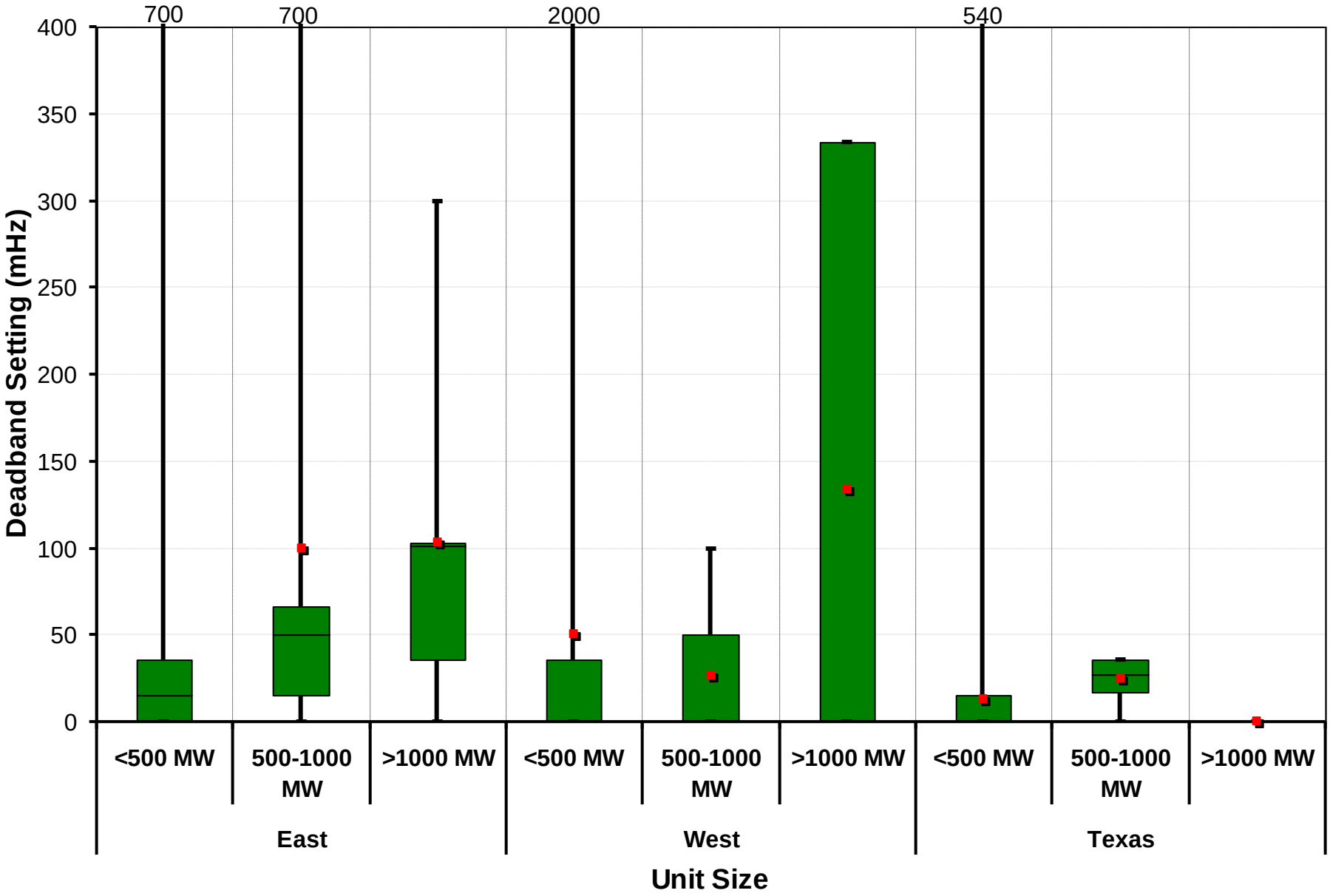
Blue = frequency response is sustained

Red = generator has a "slow" load controller returning to MW set-point

Typical Frequency Responses

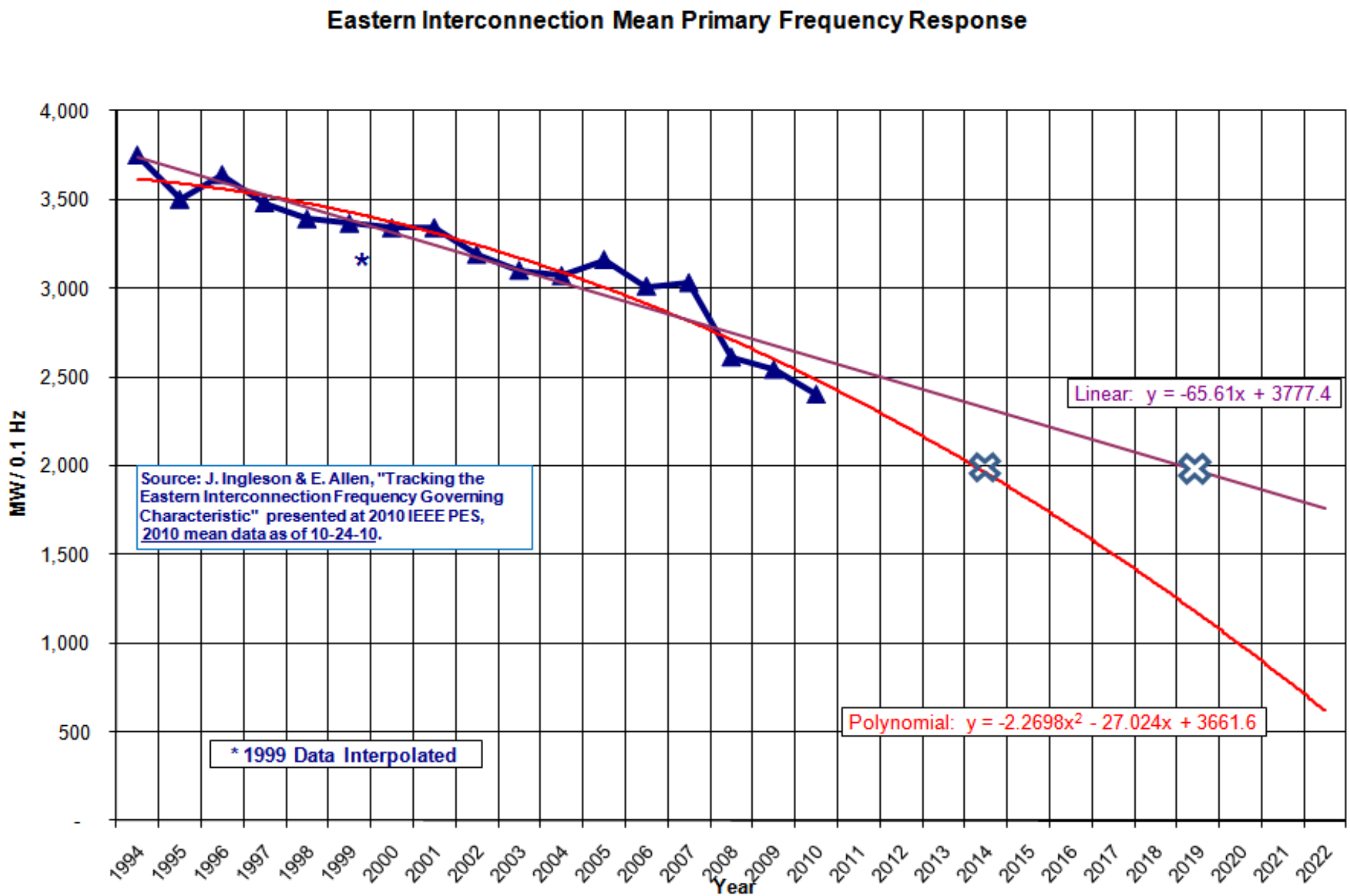


Governor Deadband Settings

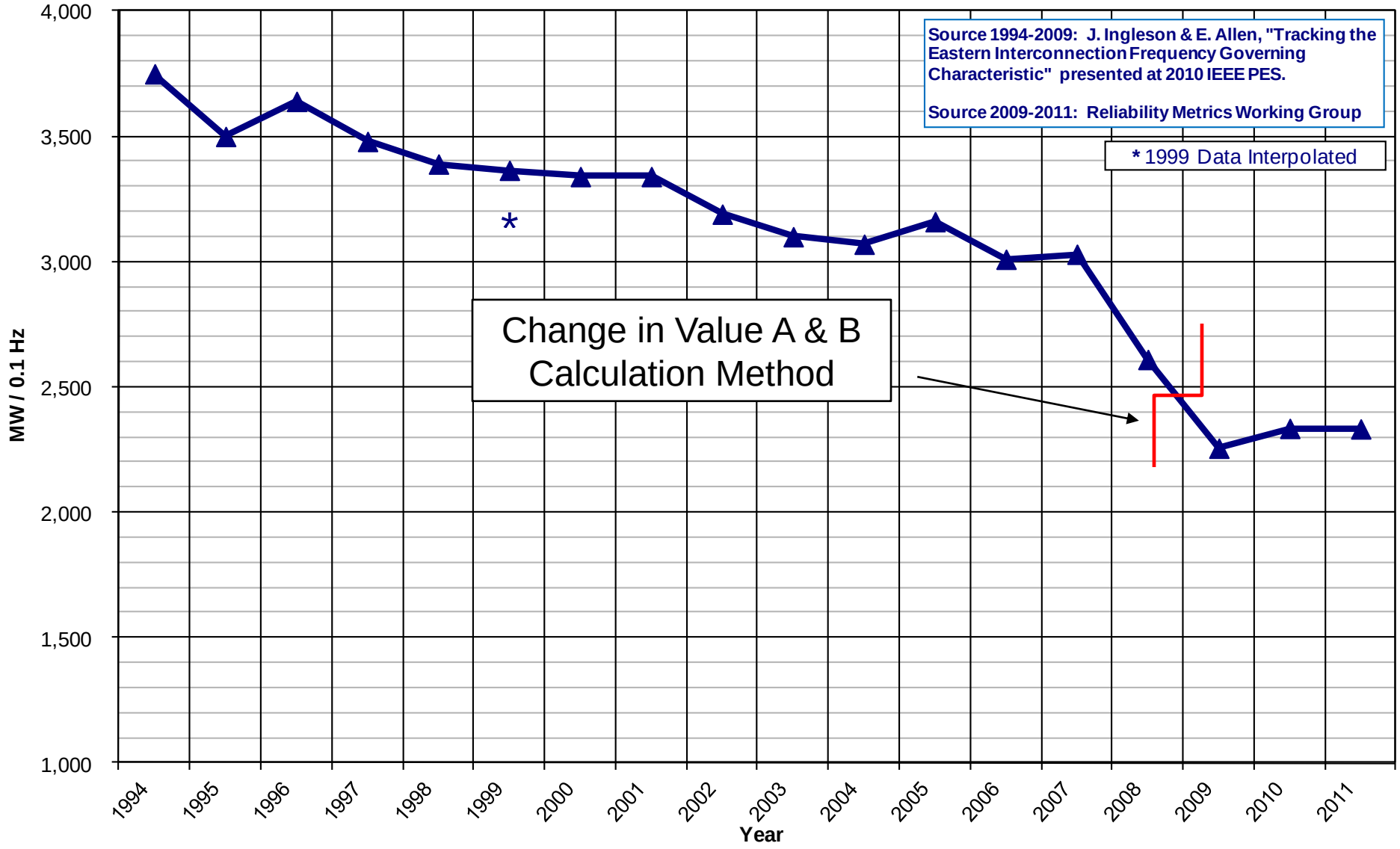


Frequency Response Trends

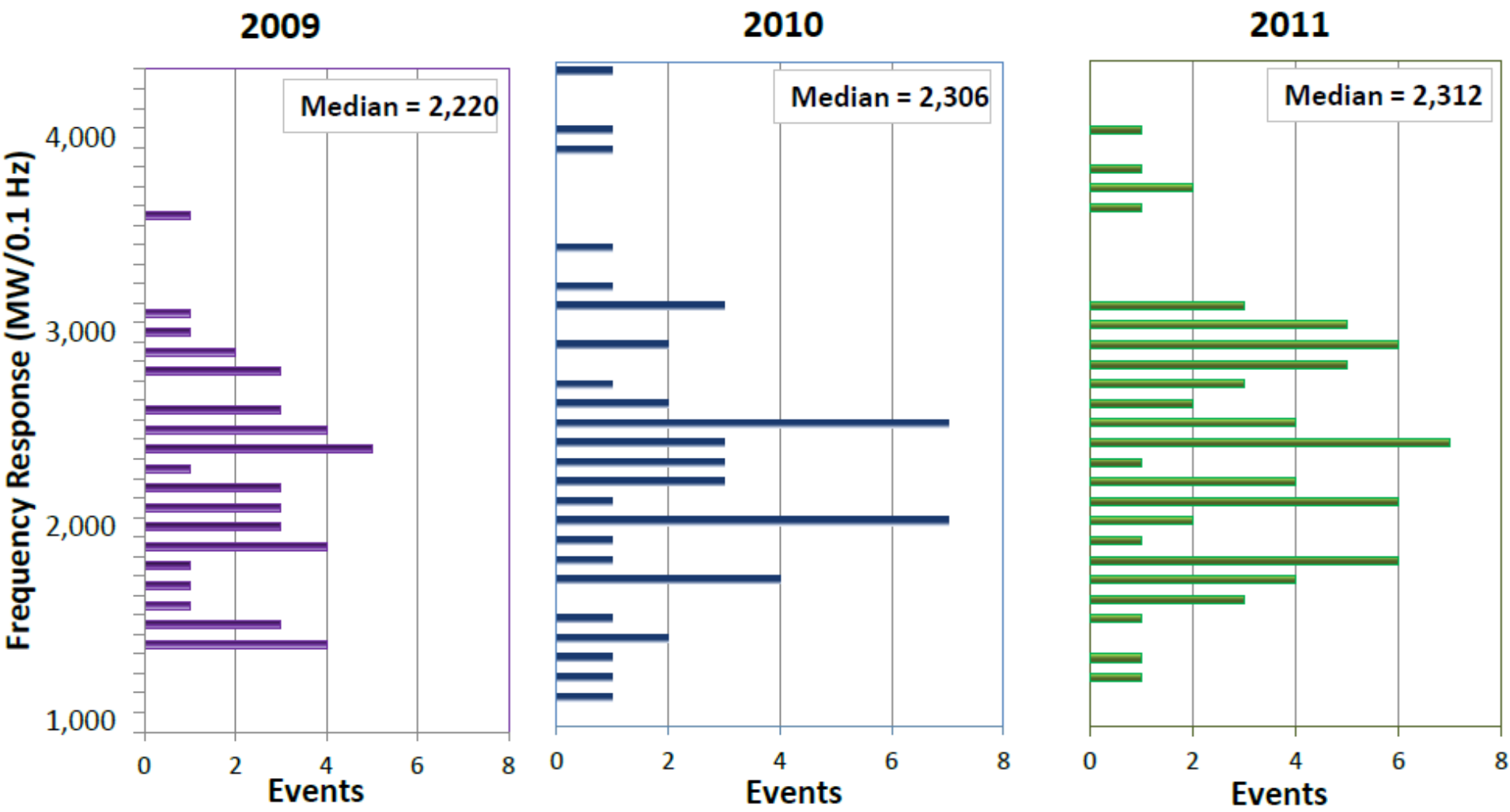
EI Historical Frequency Response



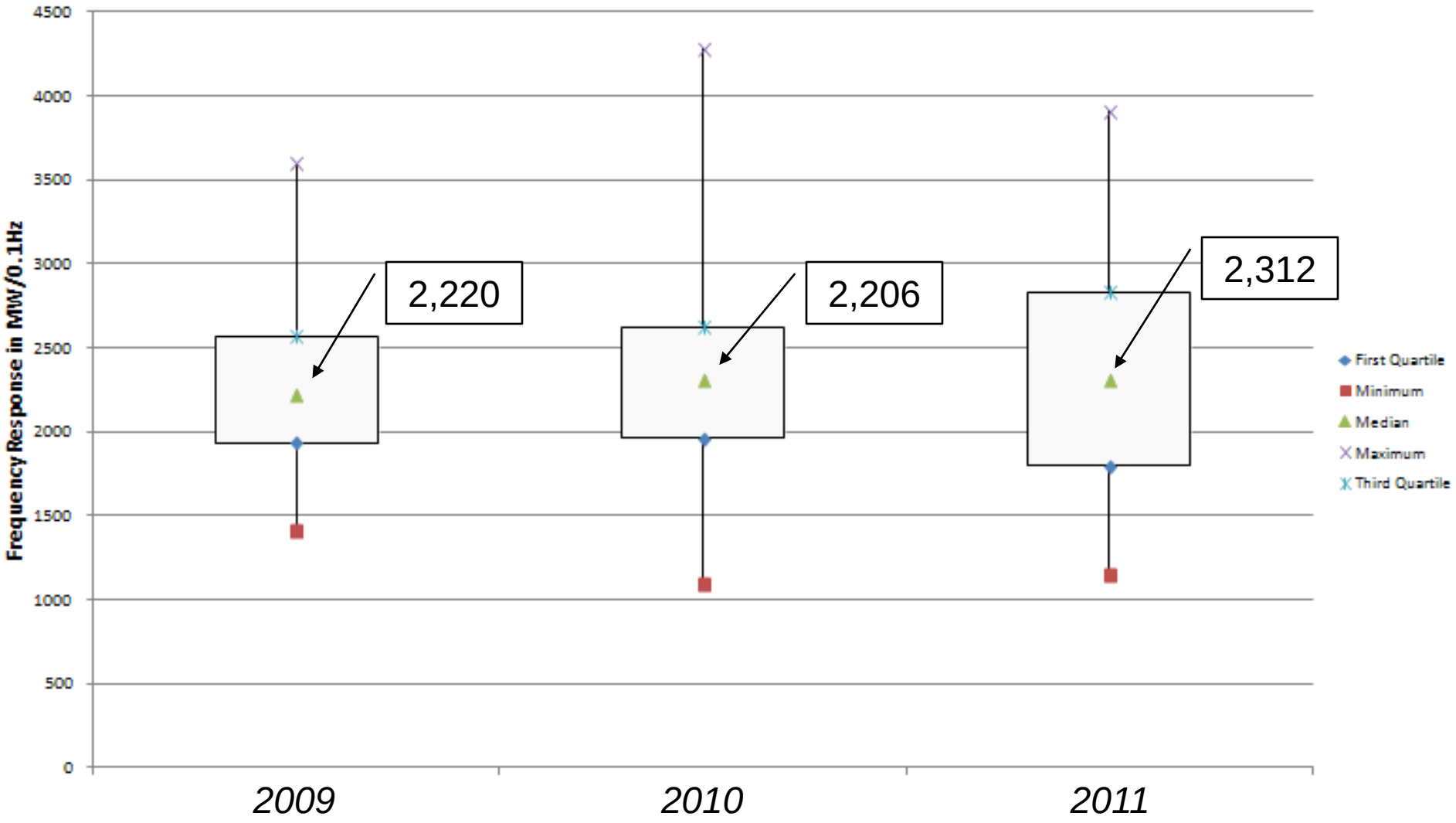
Updated EI Historical Freq. Response



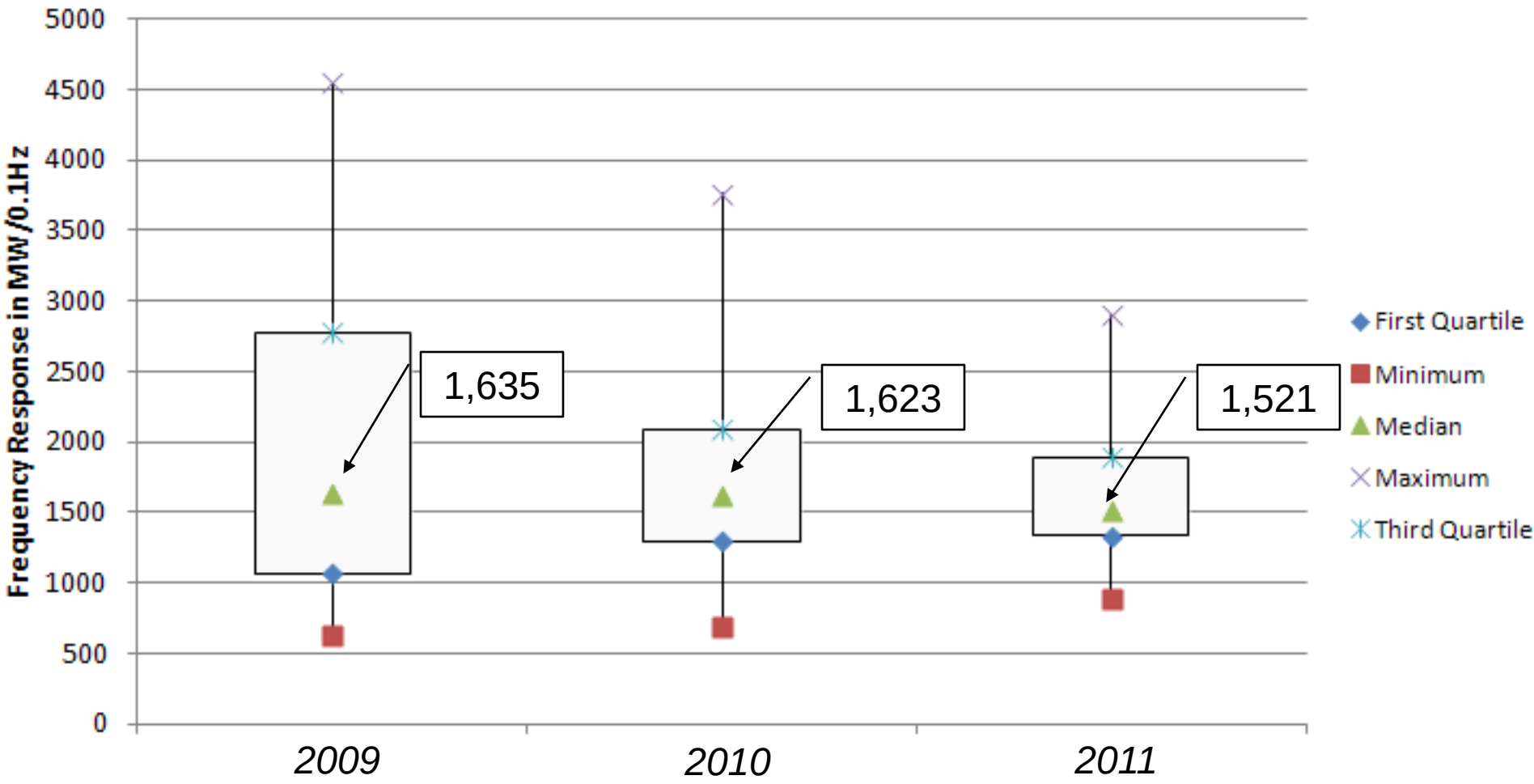
EI Freq. Response Distribution



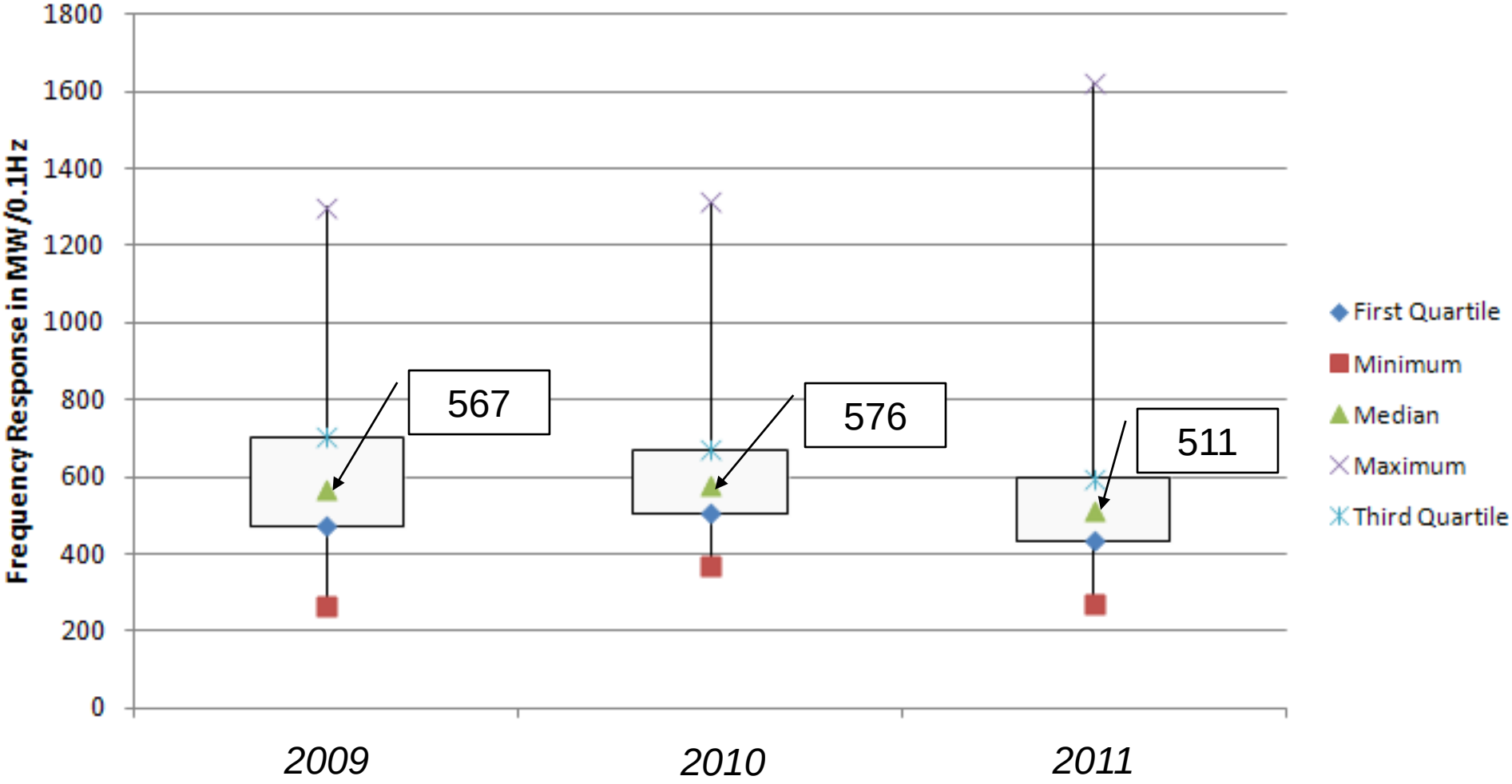
Eastern Int. Frequency Response



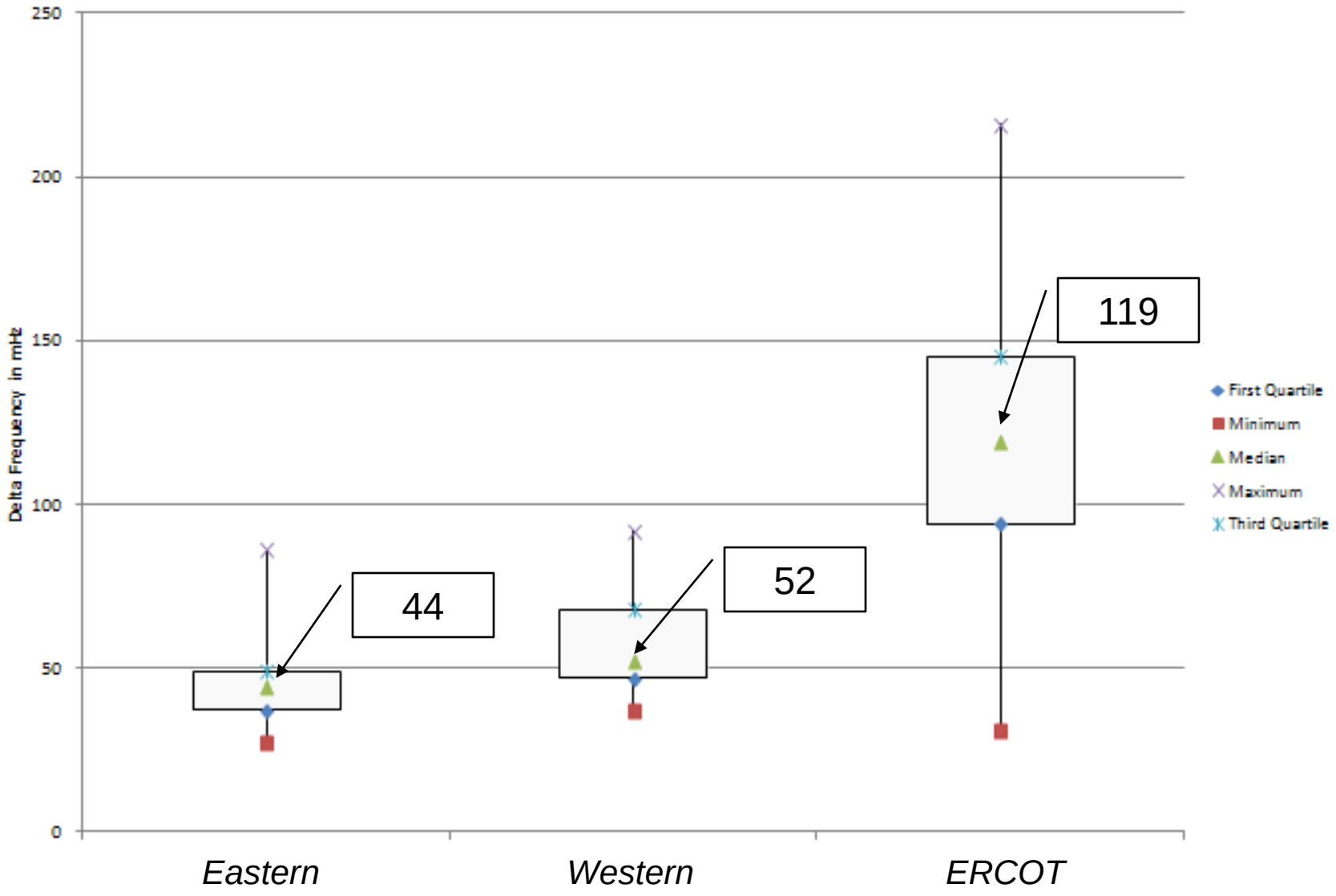
WI Box Plots for Frequency Response



ERCOT Box Plots for Frequency Response

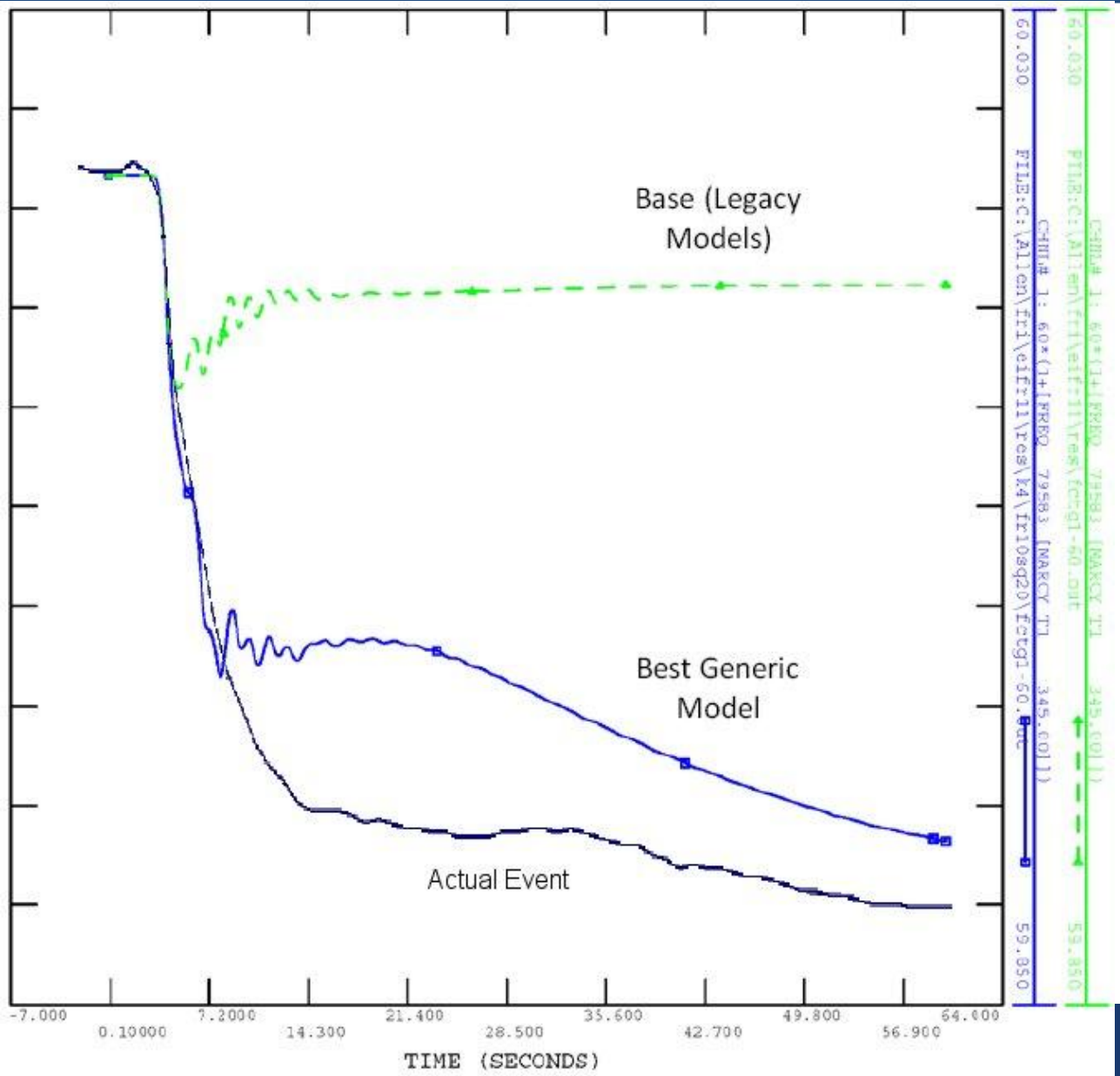


2011 Delta Freq for EI & WI & ERCOT



Modeling Eastern Interconnection Frequency Response

EI FR Modeling



- Based on 4,500 MW loss event
- ~5,400 units above 20 MW

EI ERAG/NERC Modeling Findings

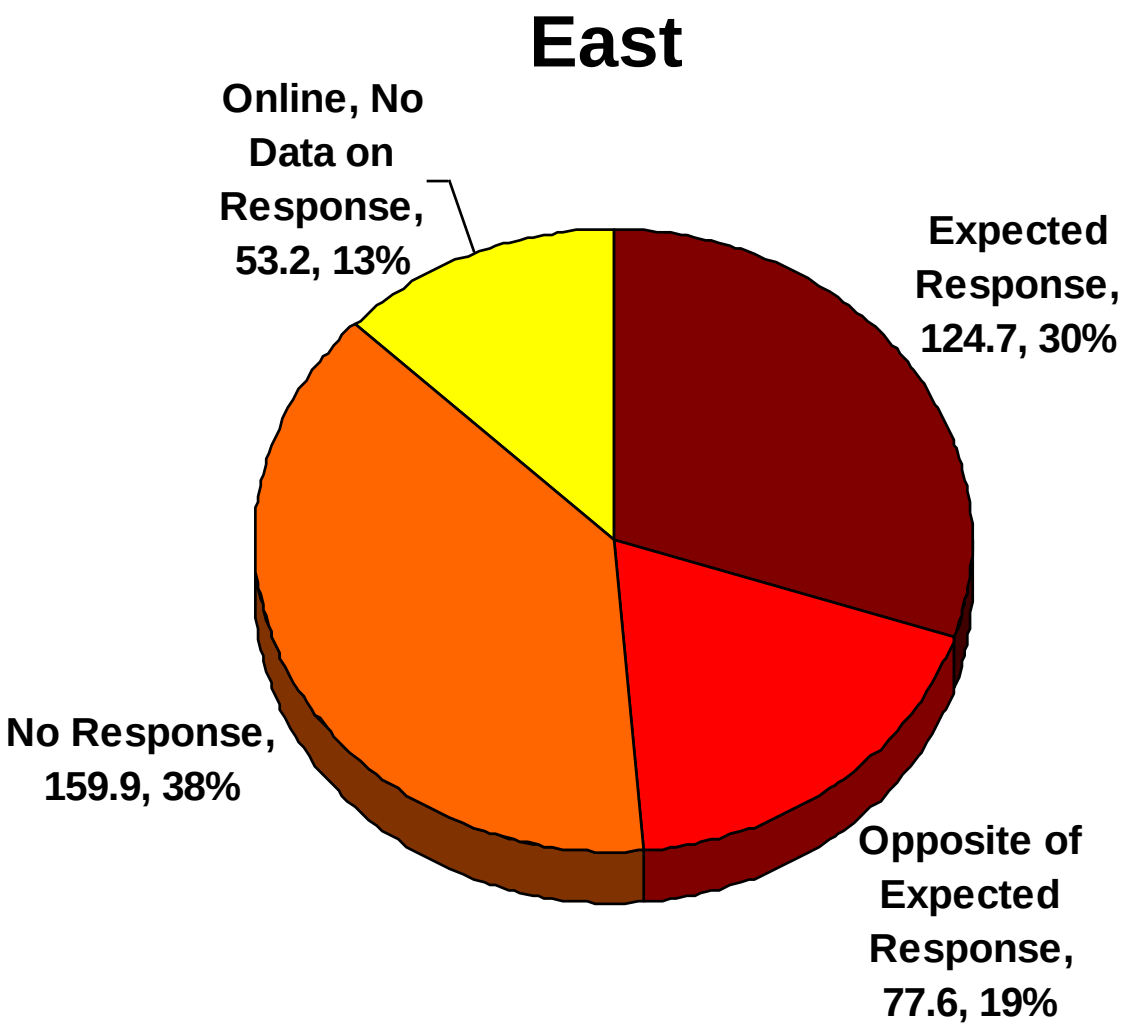
Best match performance characteristics:

- 30 % of units on line provide primary frequency response
- 2/3 of those units exhibit withdrawal
- 10 % of units on line sustain primary frequency response

Worldwide comparison (per John Undrill)

- 35 % response is typical

EI Governor Response Survey



IFRO Calculation Considerations

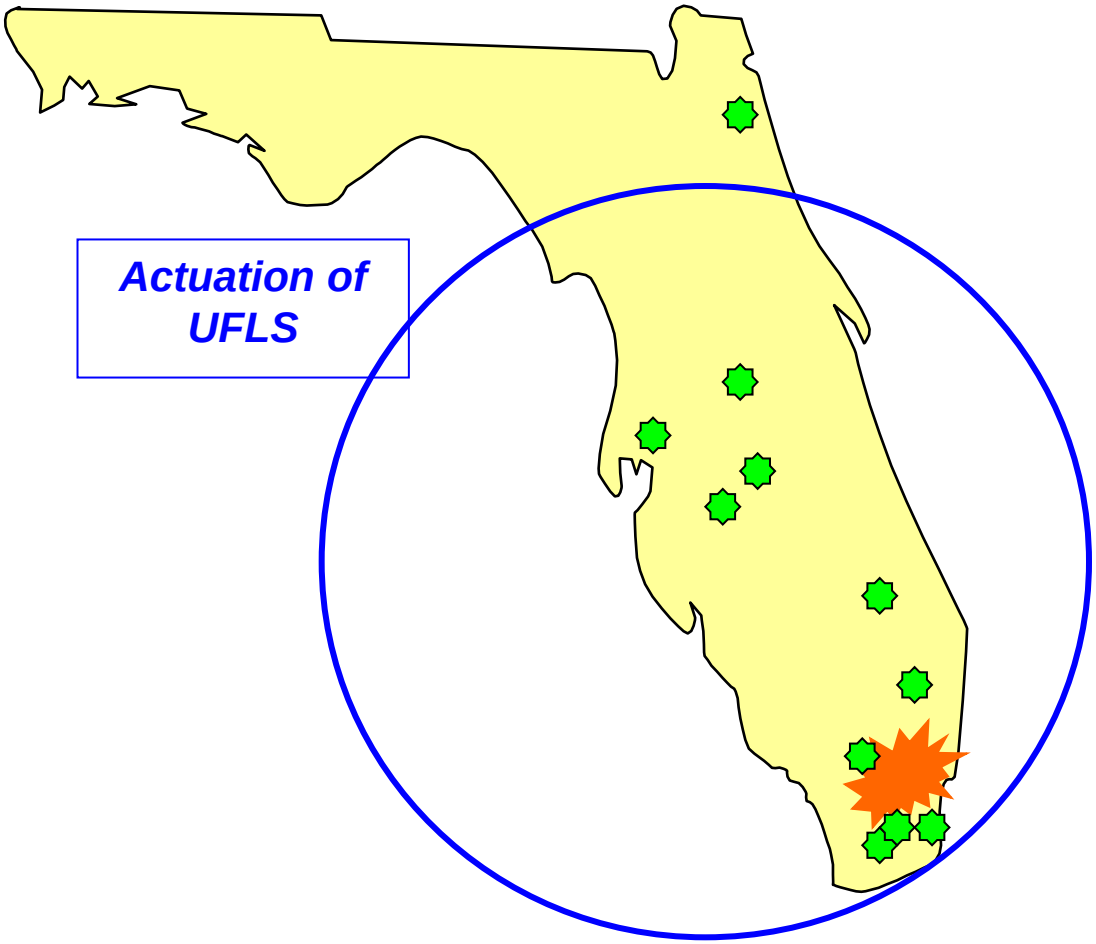
IFRO Tenets

1. Should not trigger first stage of regionally-approved UFLS Systems
2. Unavoidable local tripping of first-stage UFLS systems for severe frequency excursions
   - Protracted faults
   - Systems on edge-of the interconnection
3. Some frequency-sensitive loads may trip
4. Other frequency-sensitivities have to be considered
   - PV inverters tested trip at 59.4 Hz instead of 59.2 Hz specified in IEEE Standard 1547
   - Electronically coupled loads with common-mode frequency sensitivities

Florida Disturbance Feb. 26, 2008

Generation Trips

Location of 138 kV – 3θ fault



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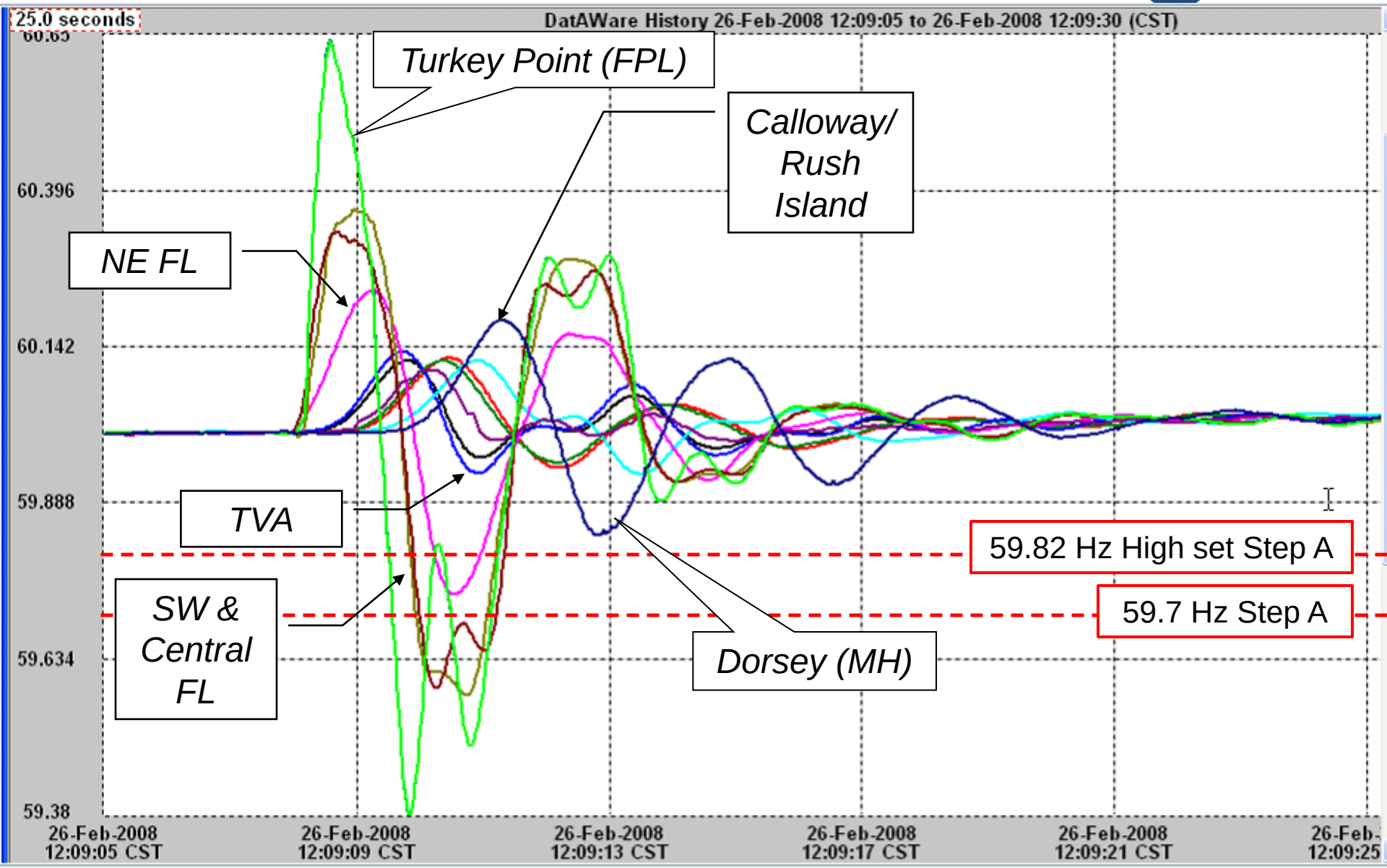
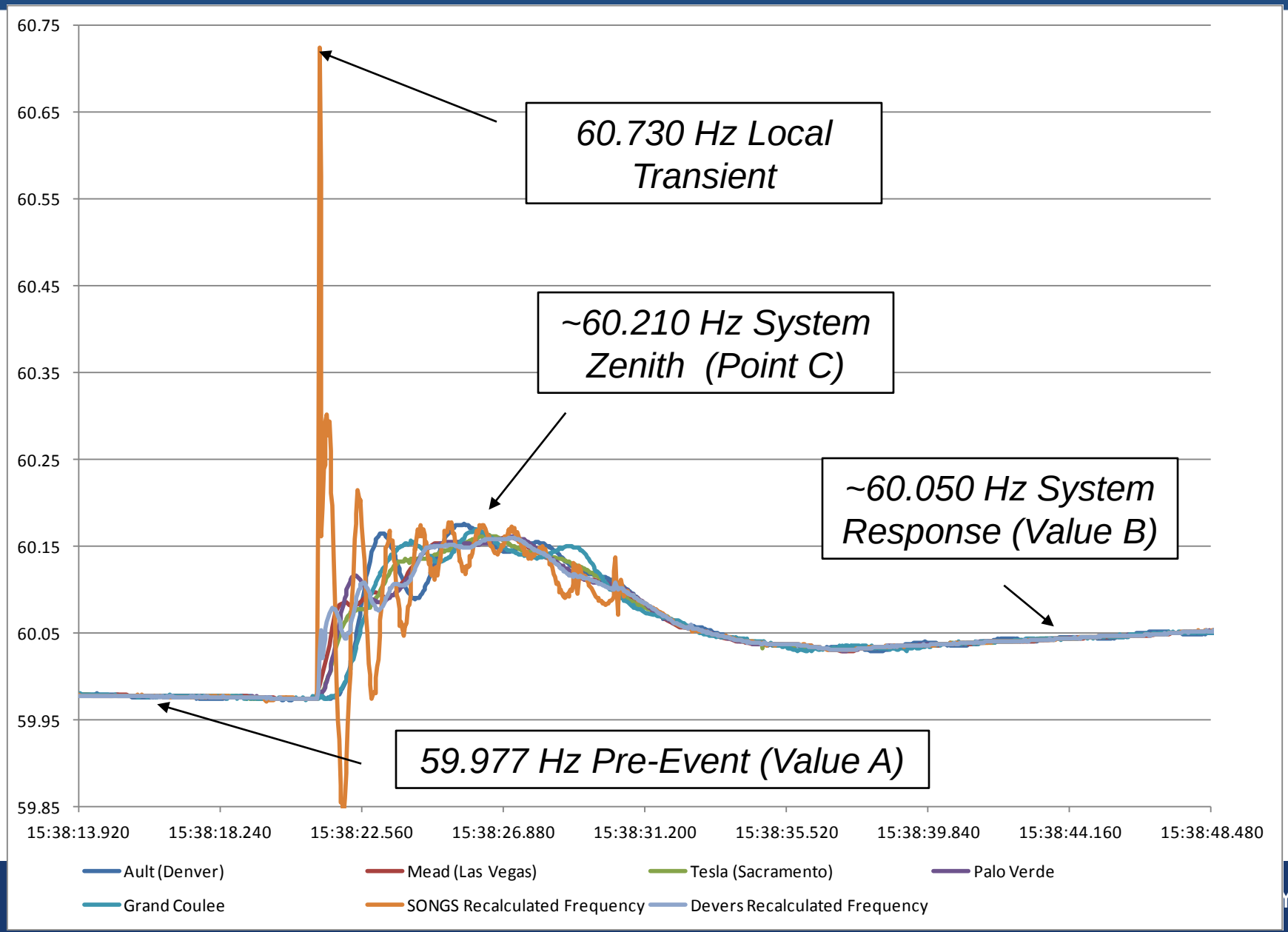
2008 Florida Event Frequency Impacts



PSW 2011 Dist. Frequency Impacts

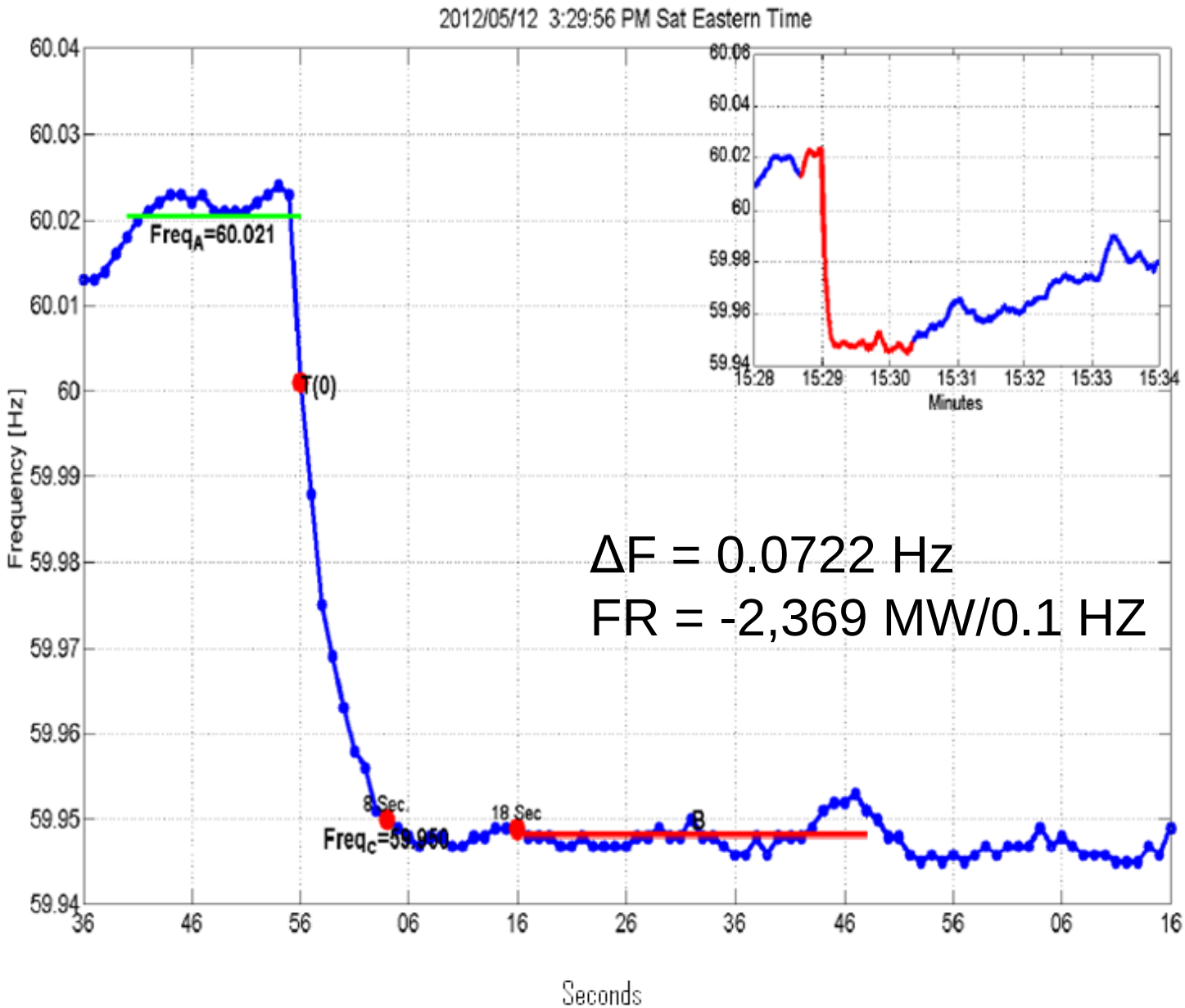


Frequency Response Withdrawal

Frequency Response Withdrawal

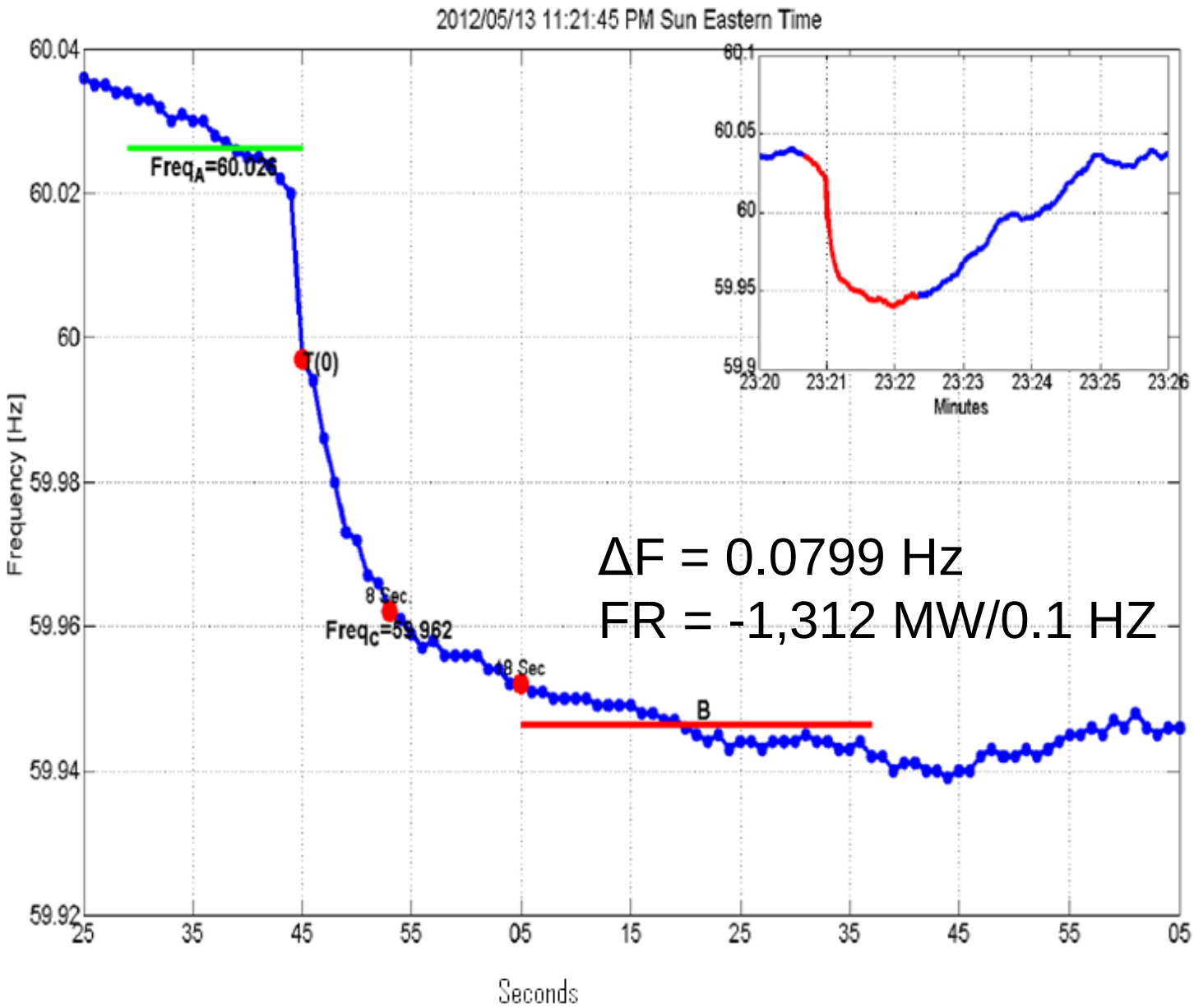
- Function of dispatch – what types of units are on line and responding
- Typical causes:
  - Plant outer-loop control systems – driving the units to MW set points
  - Unit characteristics
    - Plant incapable of sustaining
    - Governor controls overridden by other turbine/steam cycle controls
  - Operating philosophies – operating characteristic choices made by plant operators
    - Desire to maintain highest efficiencies for the plant

1,711 MW Loss – Sat 3:30 pm EDT



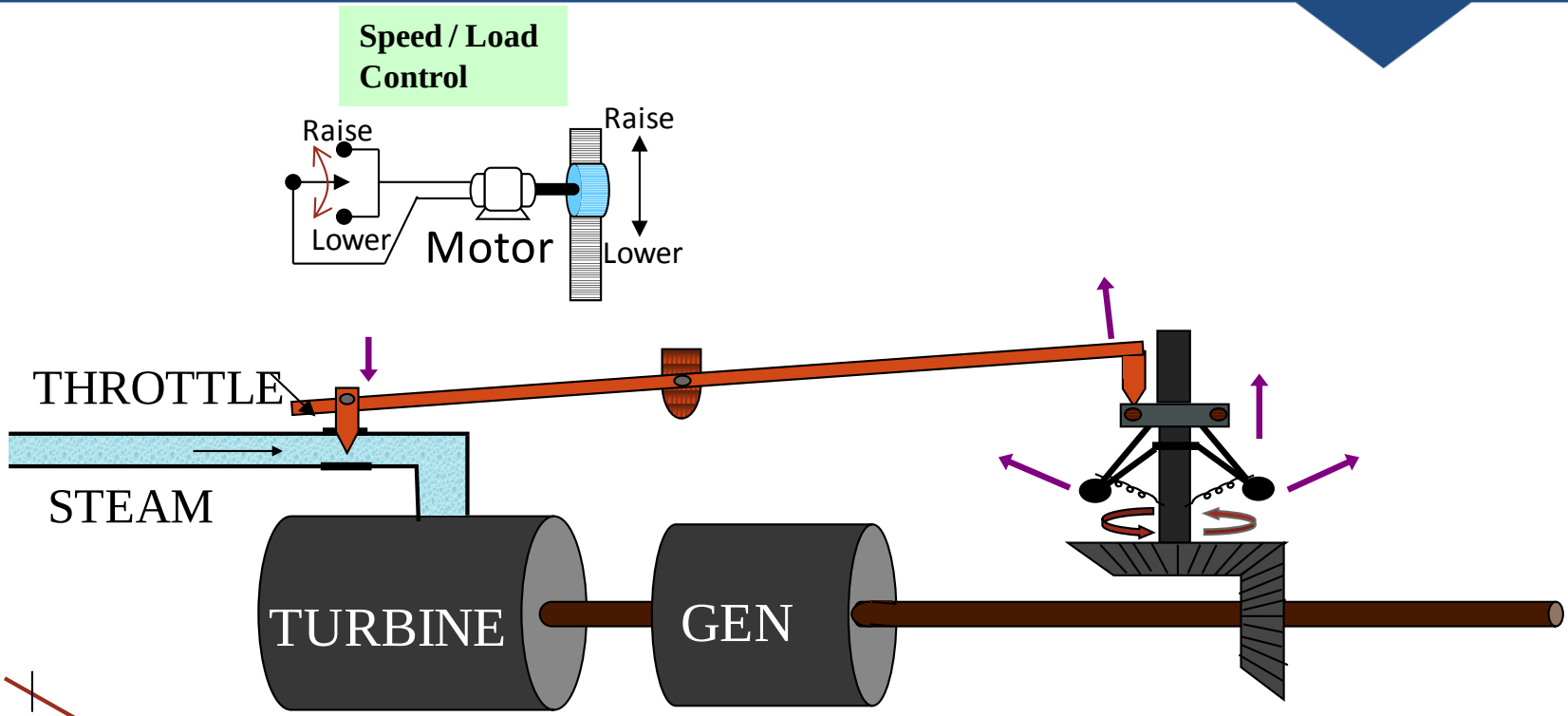
ΔF = 0.0722 Hz
FR = -2,369 MW/0.1 HZ

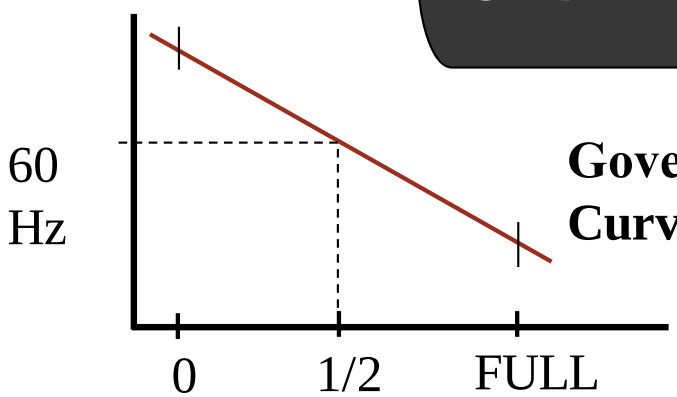
1,049 MW Trip – Sun 11:20 pm EDT



ΔF = 0.0799 Hz
FR = -1,312 MW/0.1 HZ

Response from Governors





Governor "Droop" Curve

$$\text{Slope} = \frac{\Delta\ \text{Freq}}{\Delta\ \text{Load}}$$

5% droop = 0.05 Hz/MW

Governor Droop Calculation

Expected Response = -Δ freq / Droop (Hz)
= Δ MW / rated MW

For a 1,000 MW generator

5% droop and Δ freq of 0.1 Hz

<u>To calculate expected MW output change:</u>

Convert the droop (e.g., 5%) to Frequency

0.05 x 60 = 3 Hz

-0.1 Hz / 3 Hz = ΔMW / 1,000 MW

1,000 X 0.1 / 3 = 33 MW

Expected response = 33 MW

Cost of Frequency Response

Energy

1,000 MW turbine generator – 33 MW expected response

- For 70 events per year beyond deadband
- Assume 2 minutes of full response per event
- 77 MWH additional energy (assumes avail. headroom)

Lost opportunity – operating away from full load or highest efficiency operating point

Throttling losses on steam units

Wear & tear caused by unit movement

Reference

For more on generator performance characteristics:

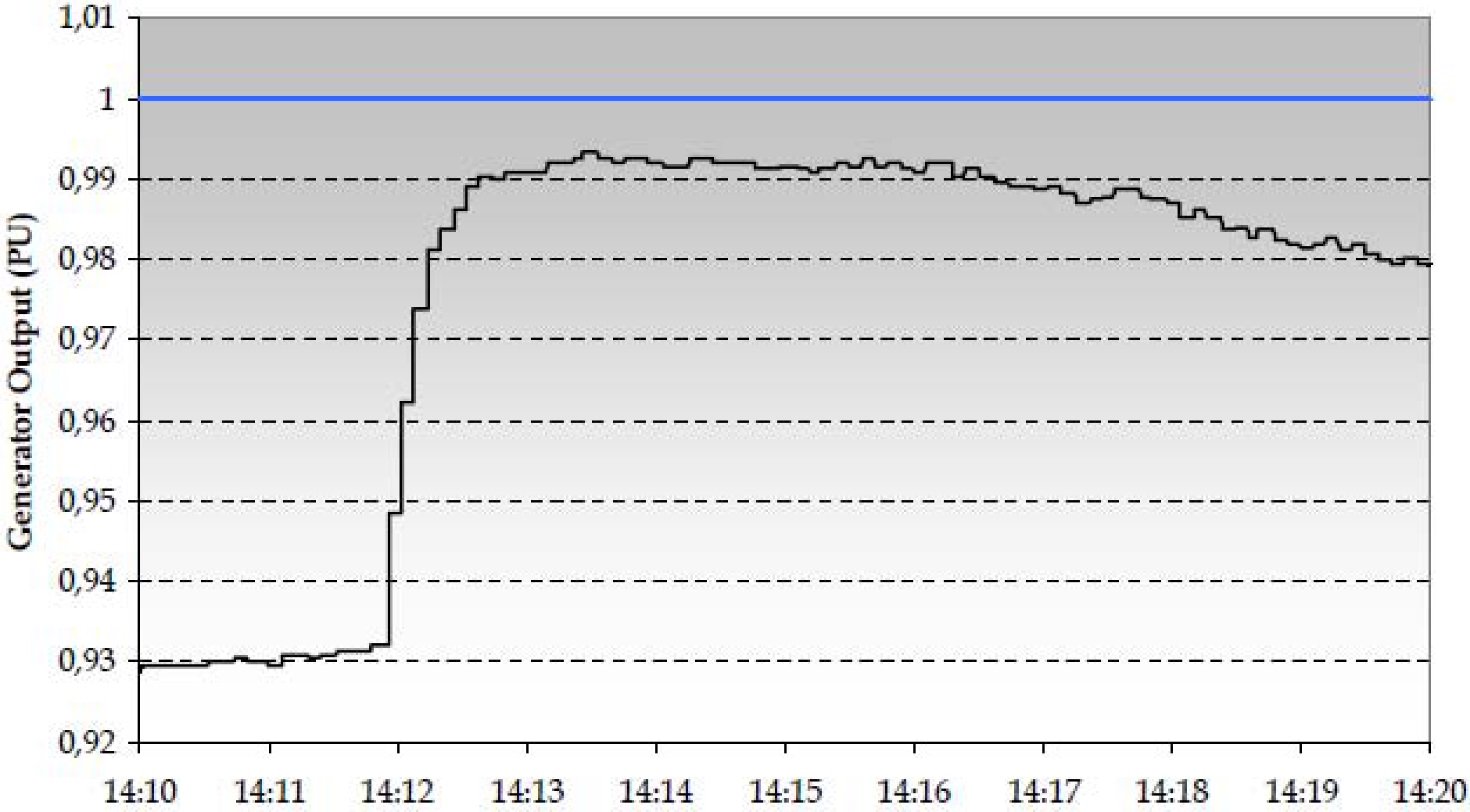
- "Power and Frequency Control as it Relates to Wind-Powered Generation" by John Undrill
- Part of the December 2010 report by Lawrence Berkeley National Laboratories

- Available at:

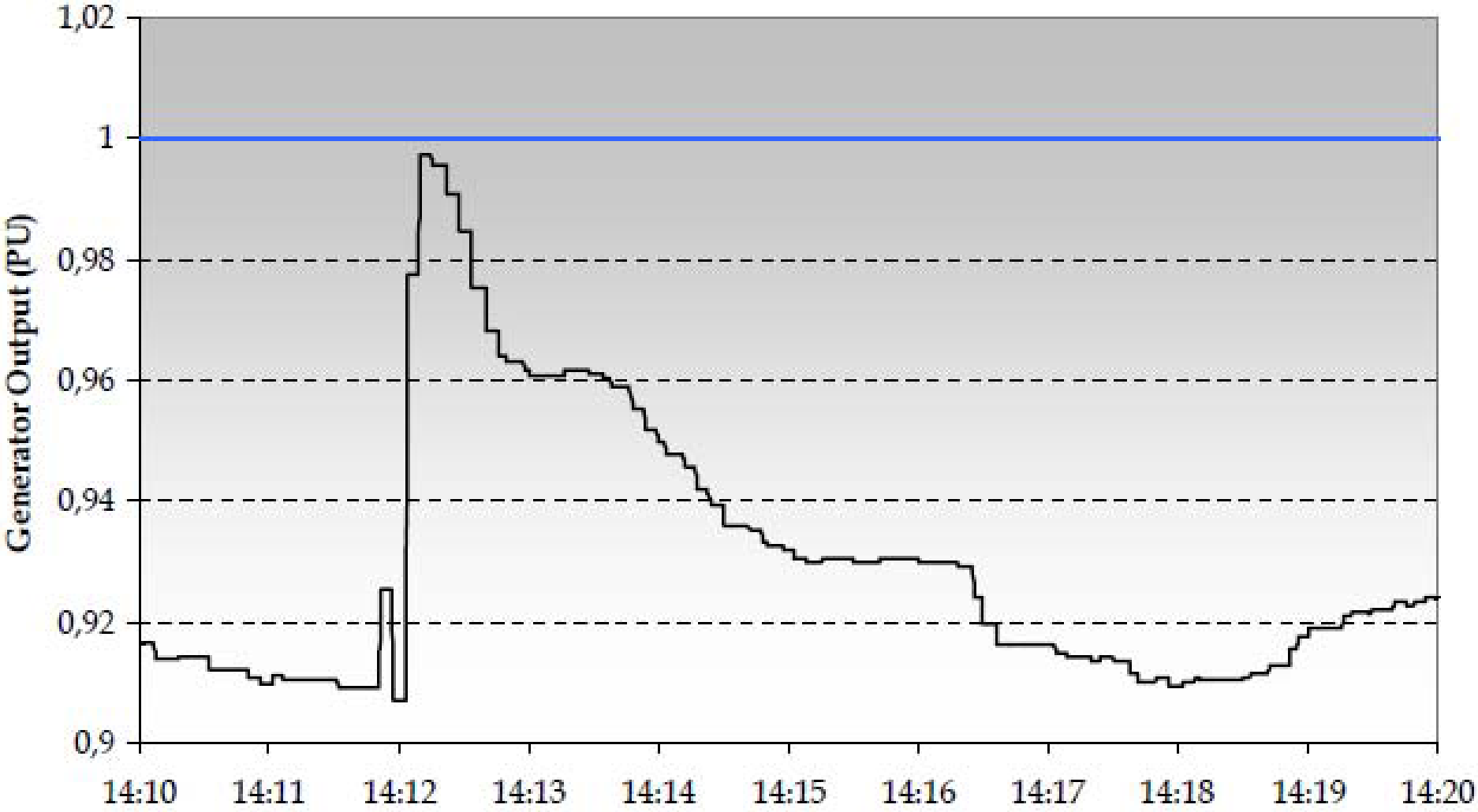
http://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf

Individual Unit Type Performance

Sustained Governor Response Example



Squelched Governor Response Example

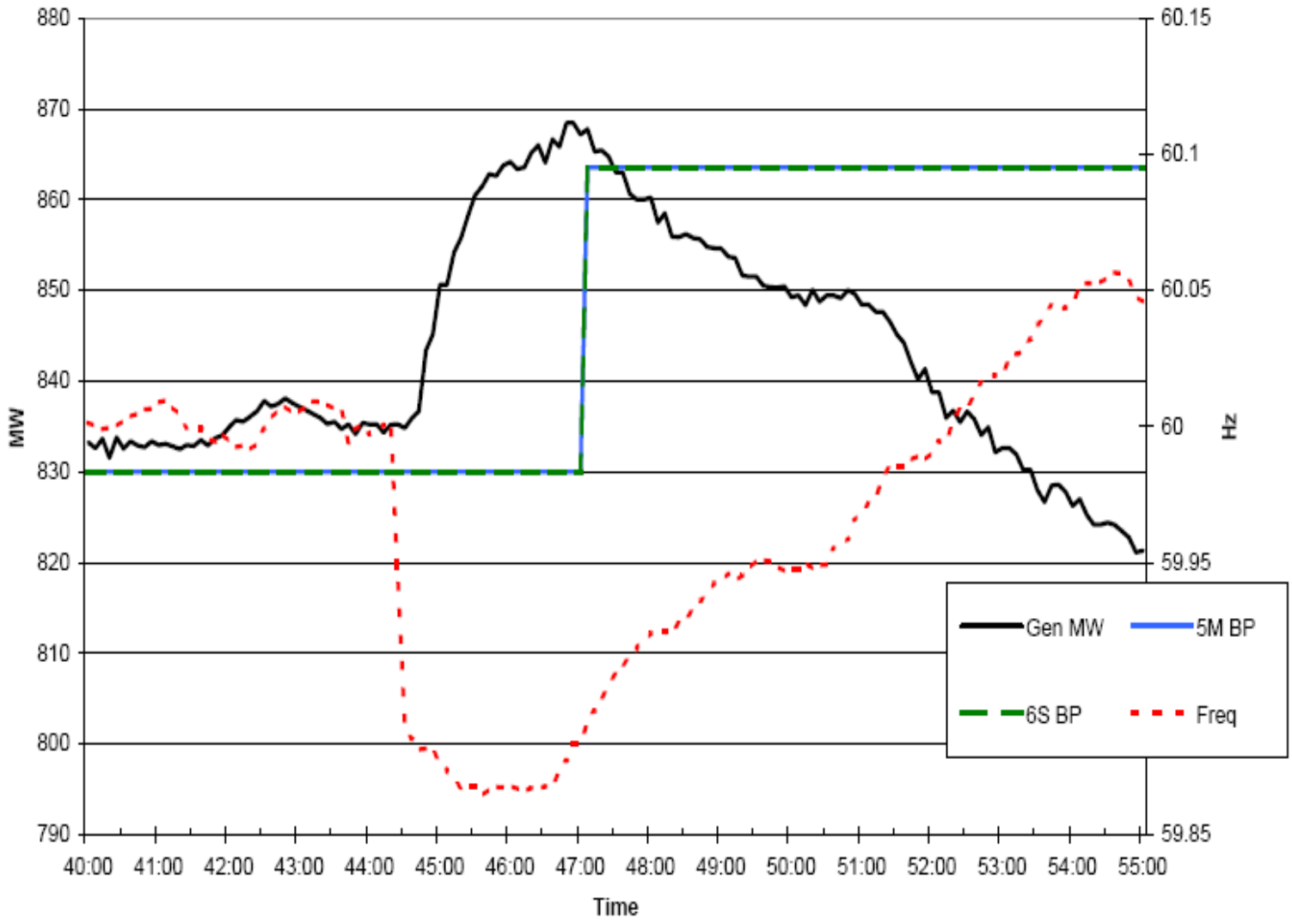


Negative Governor Response Example

Actual Unit Type Performance

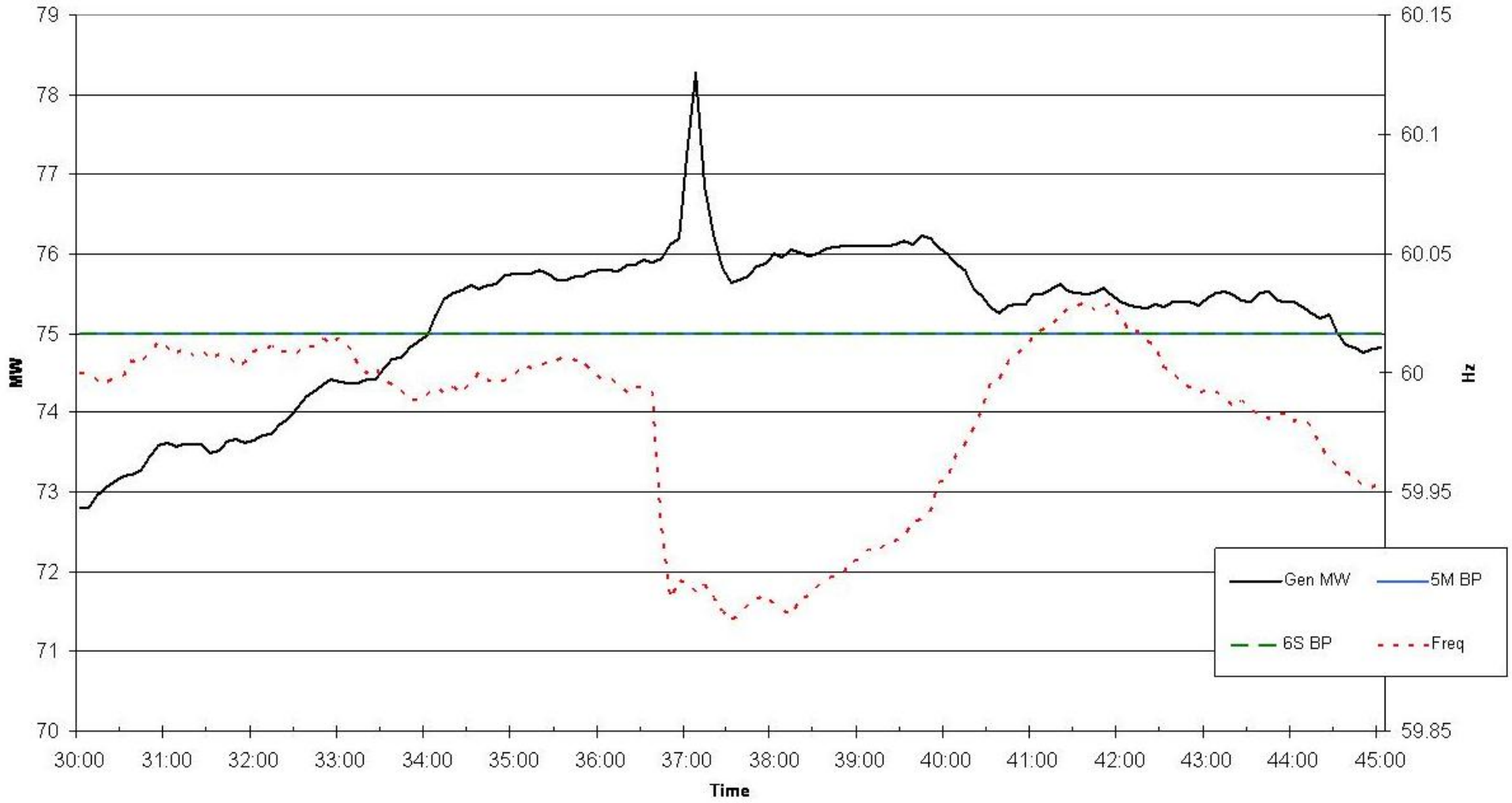
- Actual Primary Frequency Response of generators in Eastern Interconnection
  - Reflect unit operating performance characteristics
  - Reflects operating characteristic *choices* for turbine efficiency
- Examples are based on two different large capacity loss events (8-4-2007 and 4-27-2011)
- Performance for significant frequency events – beyond 36 mHz deadbands
- Governor response varies by:
  - Type of unit – not all units are the same
  - Unit-to-unit – variations between individual units of a given type

Hydro Plant Response



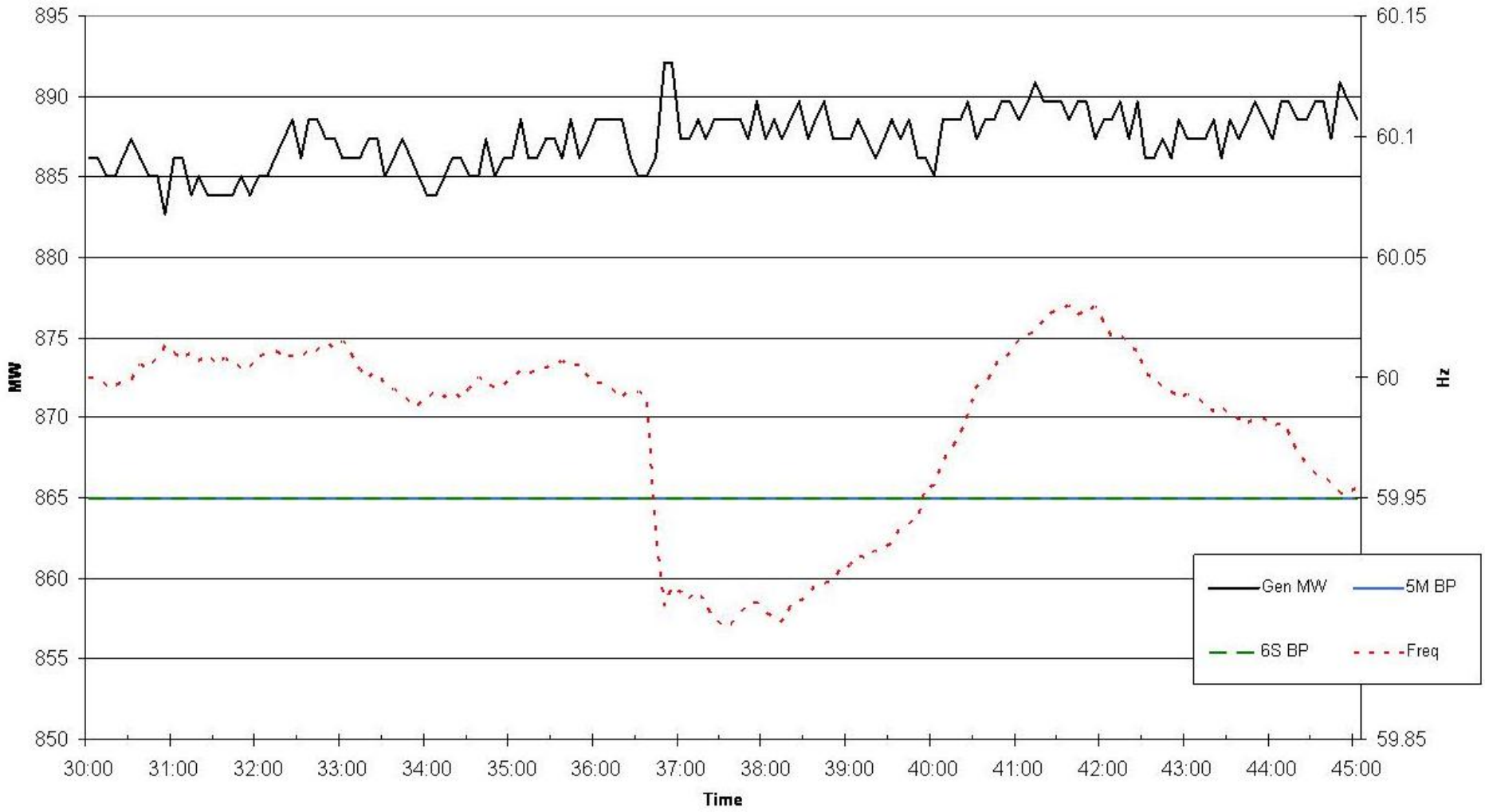
900 MW Unit
5% Droop
33 MW Expected

Small Thermal Unit Response



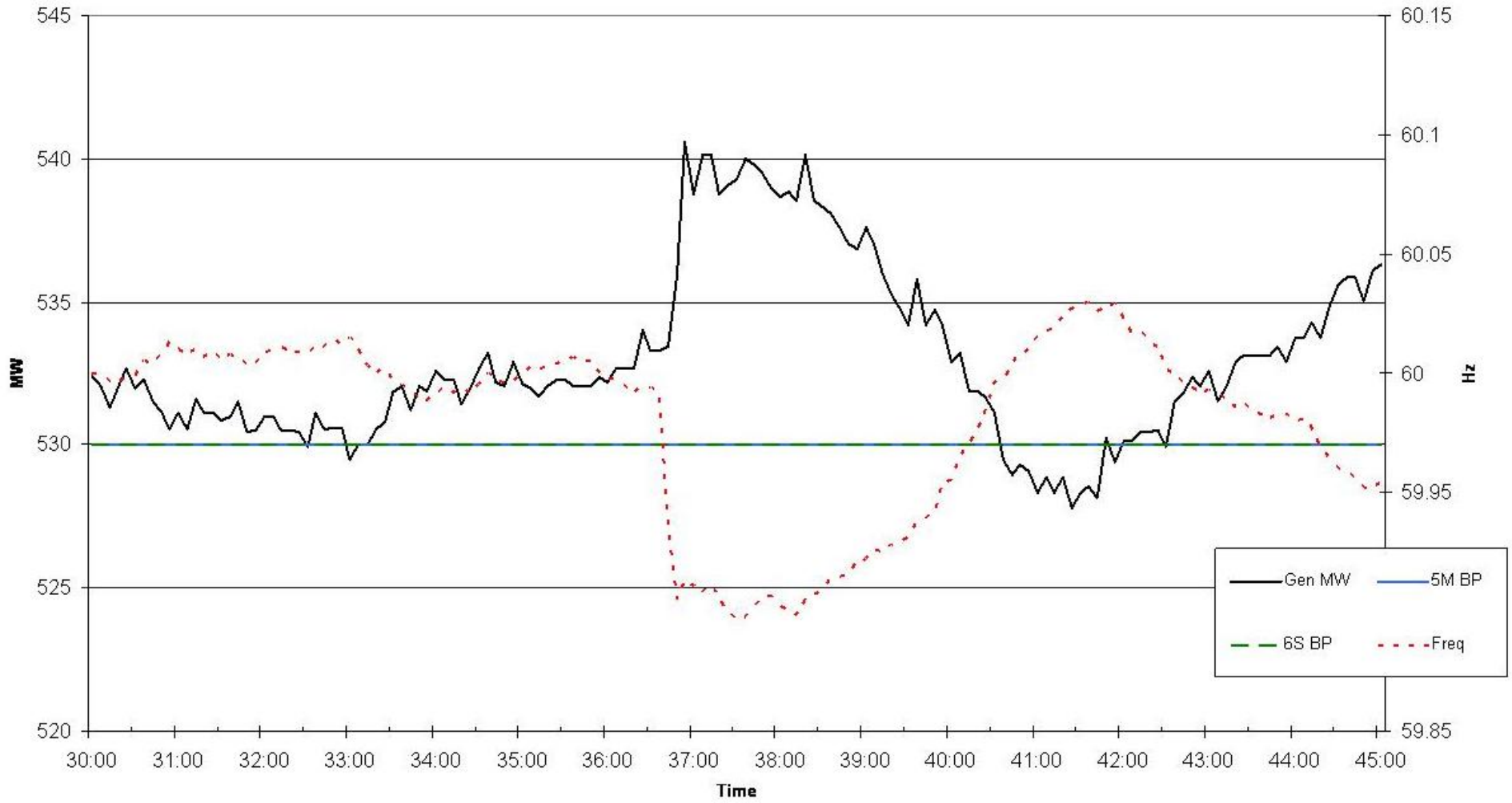
90 MW Unit 5% Droop 3 MW Expected

Large Thermal Unit Response



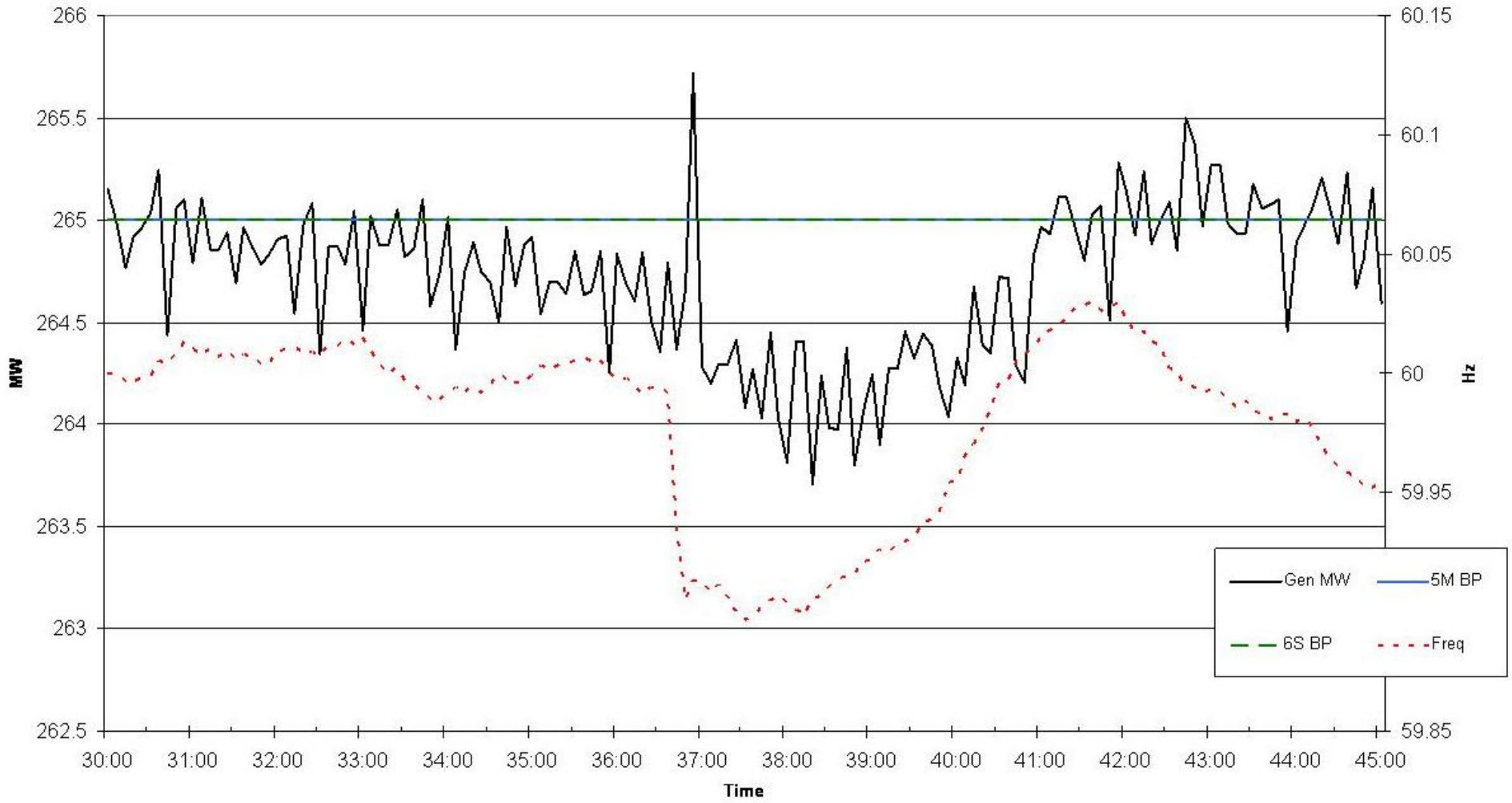
~900 MW Unit 5% Droop 35 MW Expected 7 MW Actual

Large Combined Cycle Response



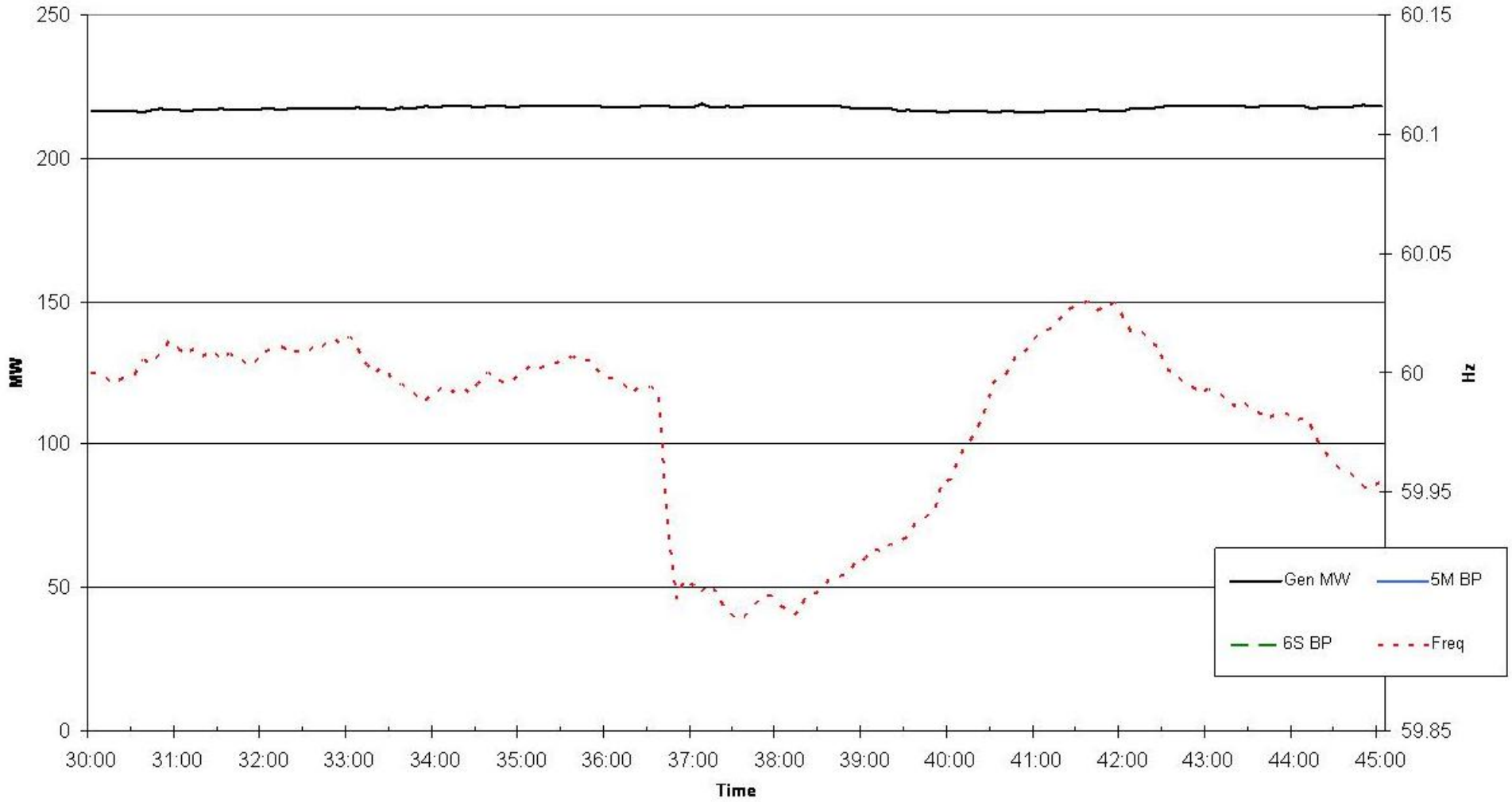
550 MW Unit 21 MW Expected 7 MW Response

Spike with Negative Response



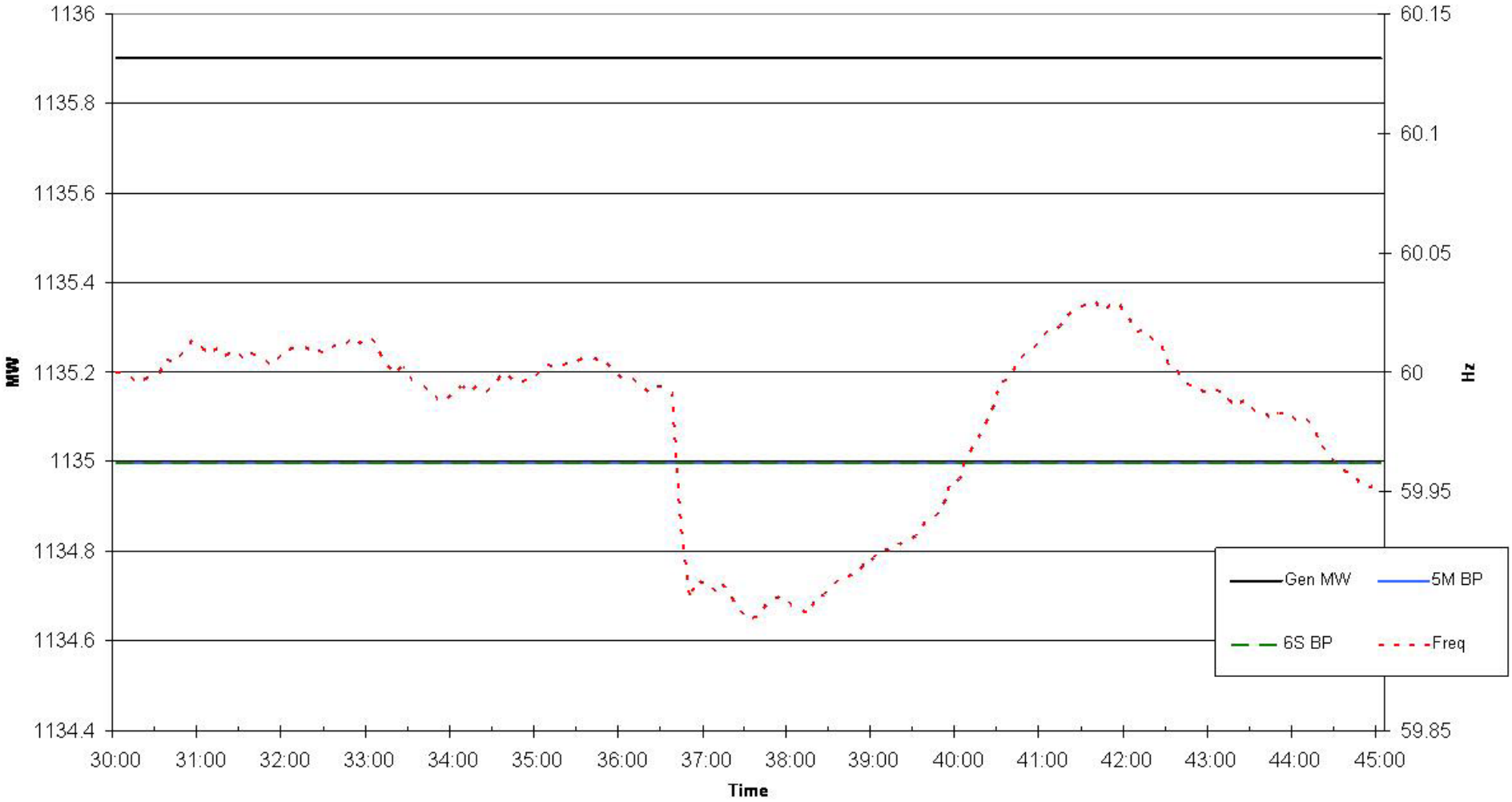
275 MW Unit 11 MW Expected ~1 MW Response

Combined Cycle Unit No Response



300 MW Unit 6 MW Expected No Response

Non-Responsive Nuclear Unit



1,150 MW Unit **None Expected** **No Response**

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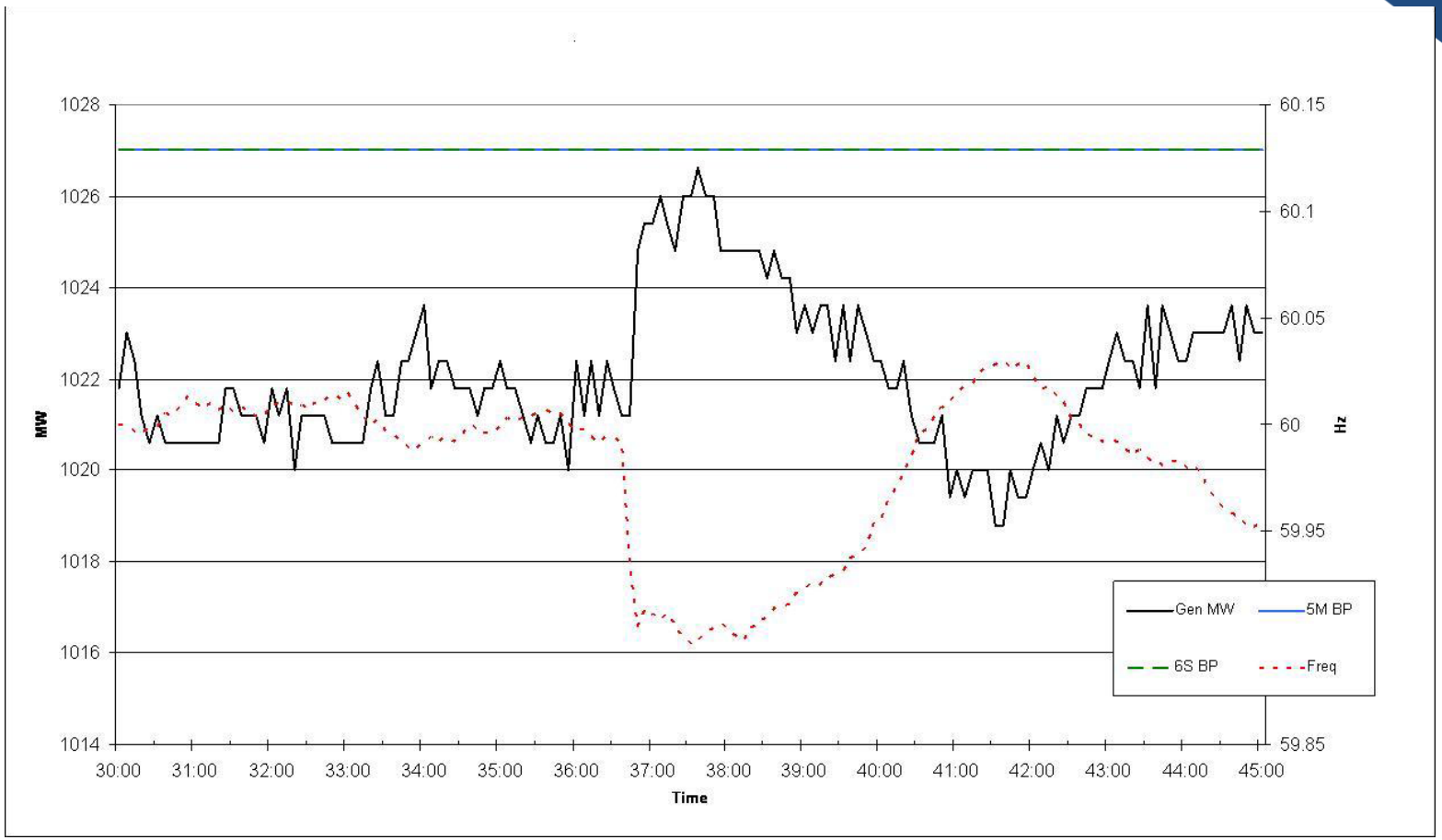
Responsive Nuclear Unit



~1,040 MW Unit **None Expected** **4 MW Response**

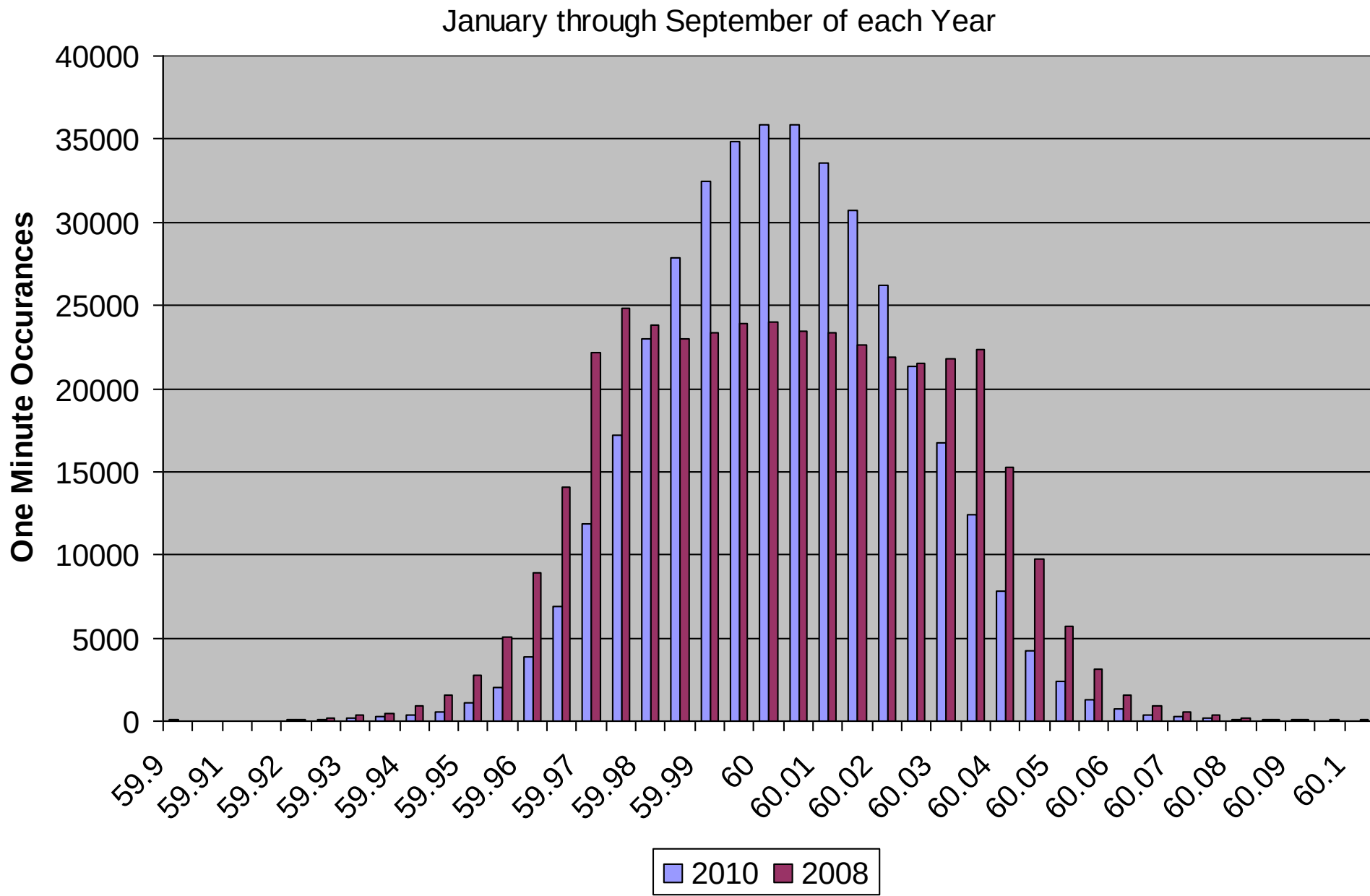
ERCOT Experience with Deadbands

Deadbands in ERCOT

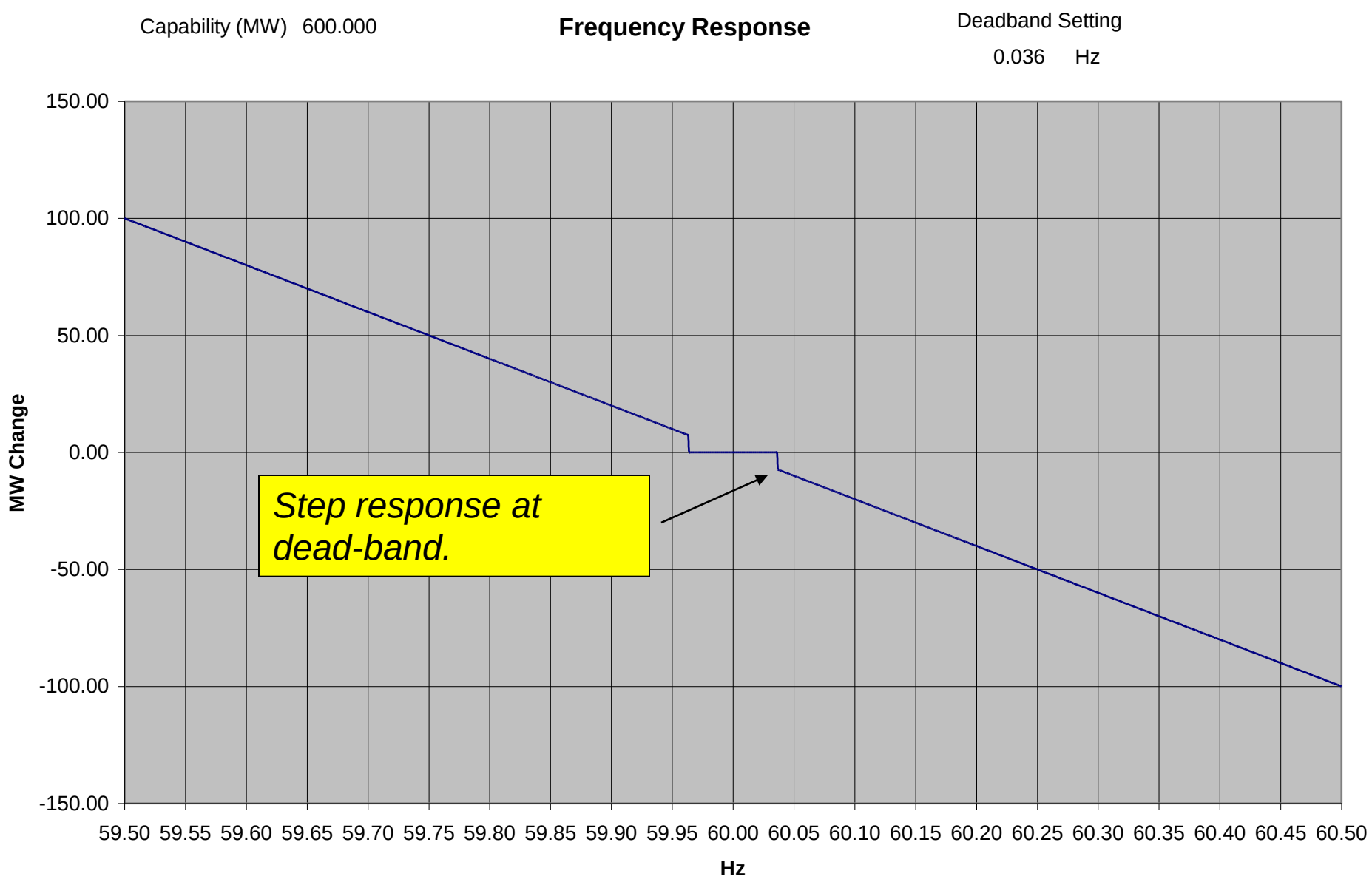
- Initially specified ±36 mHz deadbands (prior to 2010)
- Allowed stepped response at deadband

- Resulted in a flat frequency response for small disturbances
- Resulted in generators trying to respond by larger amounts when deadband was crossed
- Resulted in less stable operation when near boundary conditions of deadbands

ERCOT Frequency Profile



± 36 mHz Deadband – Step Response

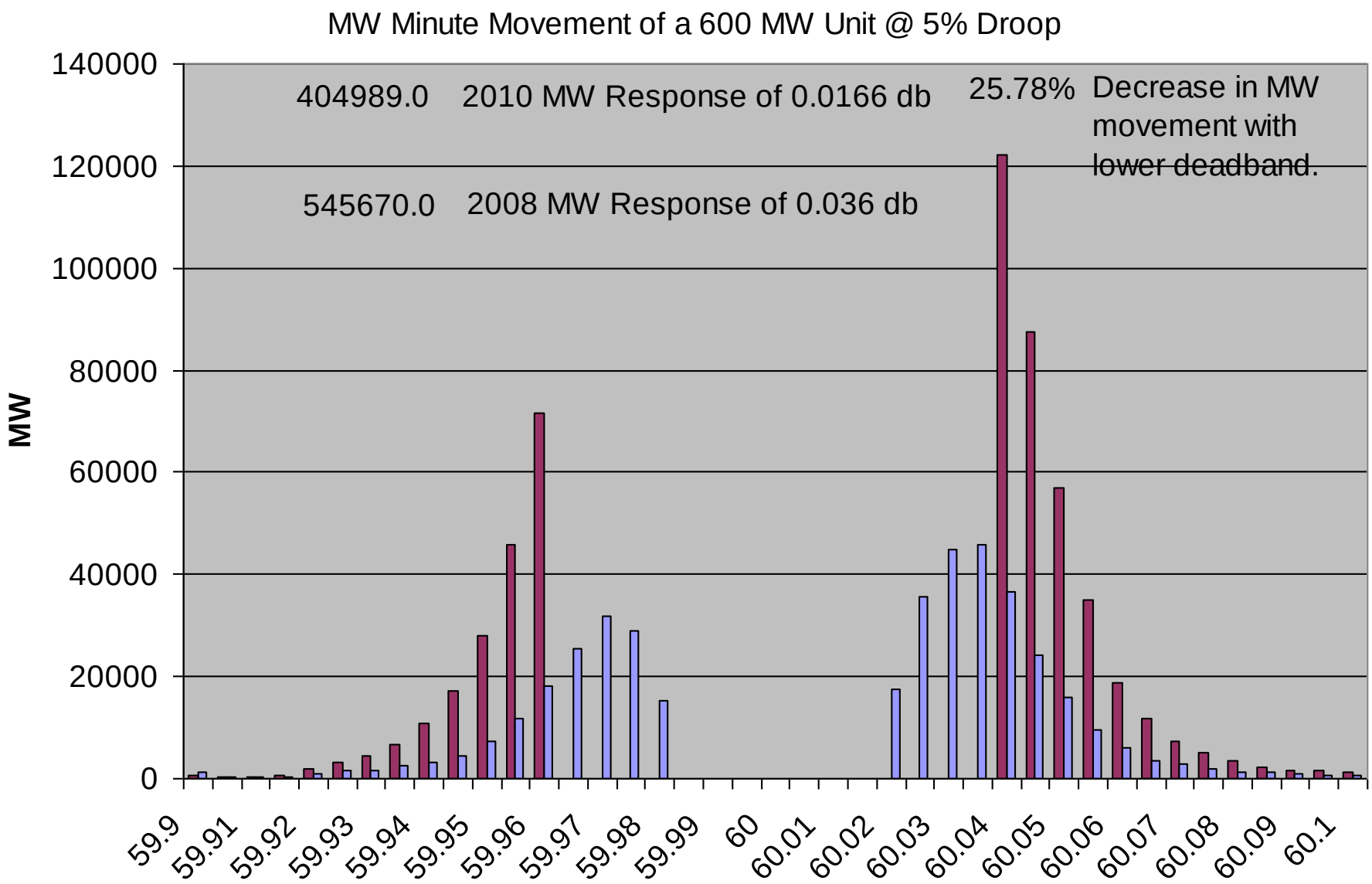


Deadbands in ERCOT

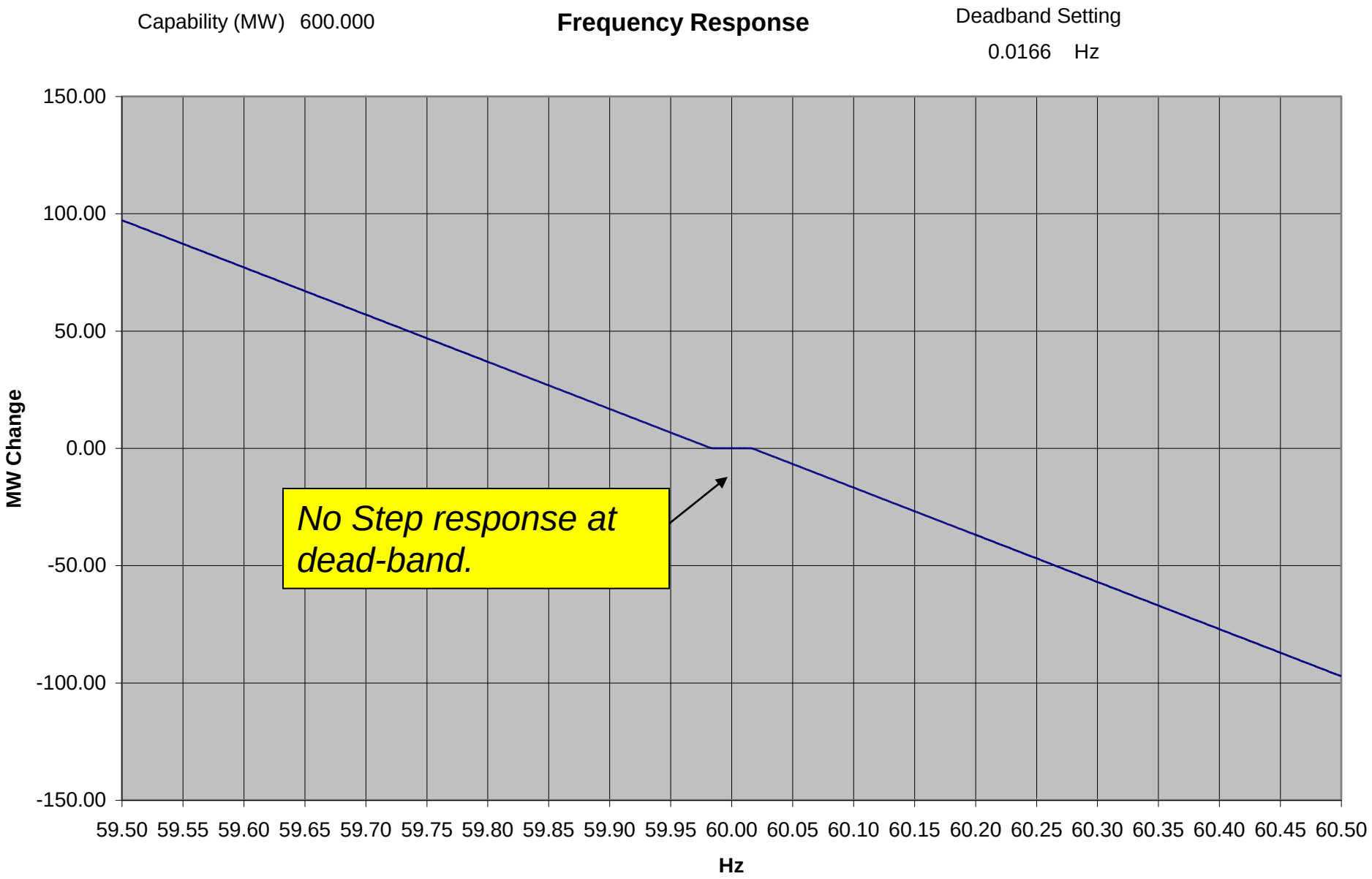
- Moving to ±16.67 mHz deadbands (1 rpm on a 3,600 rpm machine)
- Continuous response (no step) at deadband

- Results in a improved frequency response for small disturbances
- Results in generators responding more often in smaller increments
  - Saves wear and tear on turbines
- Results in more stable operation when near boundary conditions of deadbands

±0.036 Hz Vs ±0.016 Hz Deadband



± 16.6 mHz Deadband – No Step Response



Questions?