Notes on Frequency Response for FERC Conference on September 23, 2010

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1. Background

At a very basic level, the system frequency is governed by the Newton law of motion

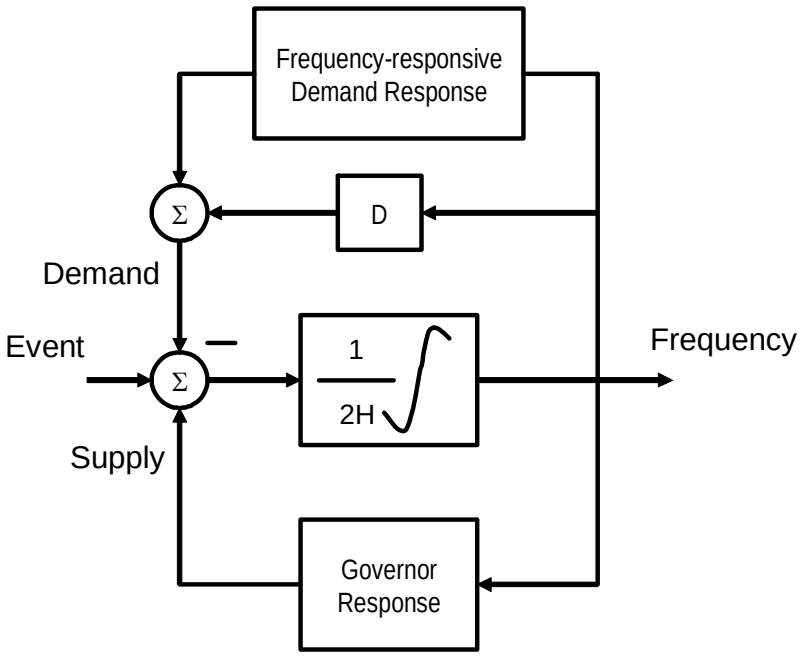


Figure 1: basic representation of the system frequency governing

"Supply = Demand" means that the system frequency is constant (does not have to be at 60 Hz)

"Supply < Demand" means that the system frequency is declining
"Supply > Demand" means that the system frequency is rising

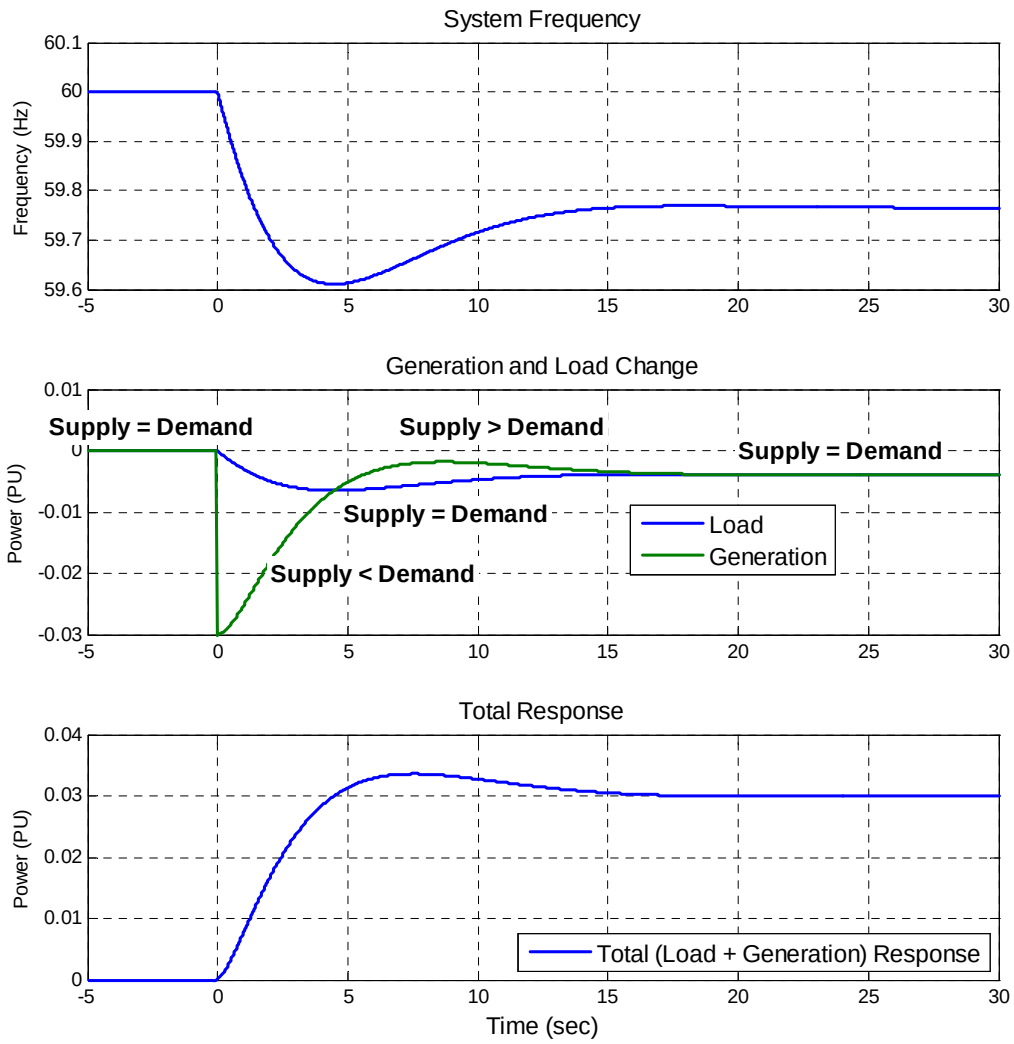


Figure 2: illustration of frequency response for a 3% generation loss

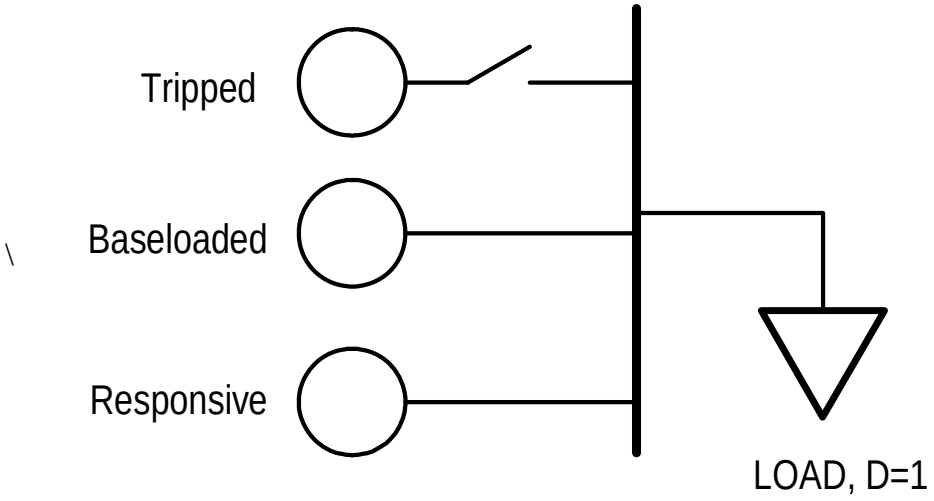
System factors that affect the nadir frequency:

- system inertia, H=4 seconds is often mentioned
    - gas-turbine generators 5 to 6.5 seconds
    - steam-turbine generators 2.5 to 5 seconds
    - hydro-turbine generators 2.5 to 6 seconds
    - air-derivative gas turbines 2 – 2.5 seconds
    - electronically connected generation 0
    - fans, propeller type, 0.5 to 1 second
    - air-conditioner compressor 0.05 to 0.1 seconds
- load damping, D=1 is often mentioned
    - fan motor D=3
    - compressor D=1
    - electronic loads D=0
- system size
    - Eastern Interconnection
    - Western Interconnection on-peak load as high as 161 GW, off-peak load is as low as 73 MW
    - ERCOT
- size of the disturbance event relative to the system size

2. Frequency Response Characteristics

Very often, the frequency response discussion focuses on the “amount” of response requirement. “Amount” is only one of the attributes of response, there are other response factors that will have great influence on the nadir frequency.

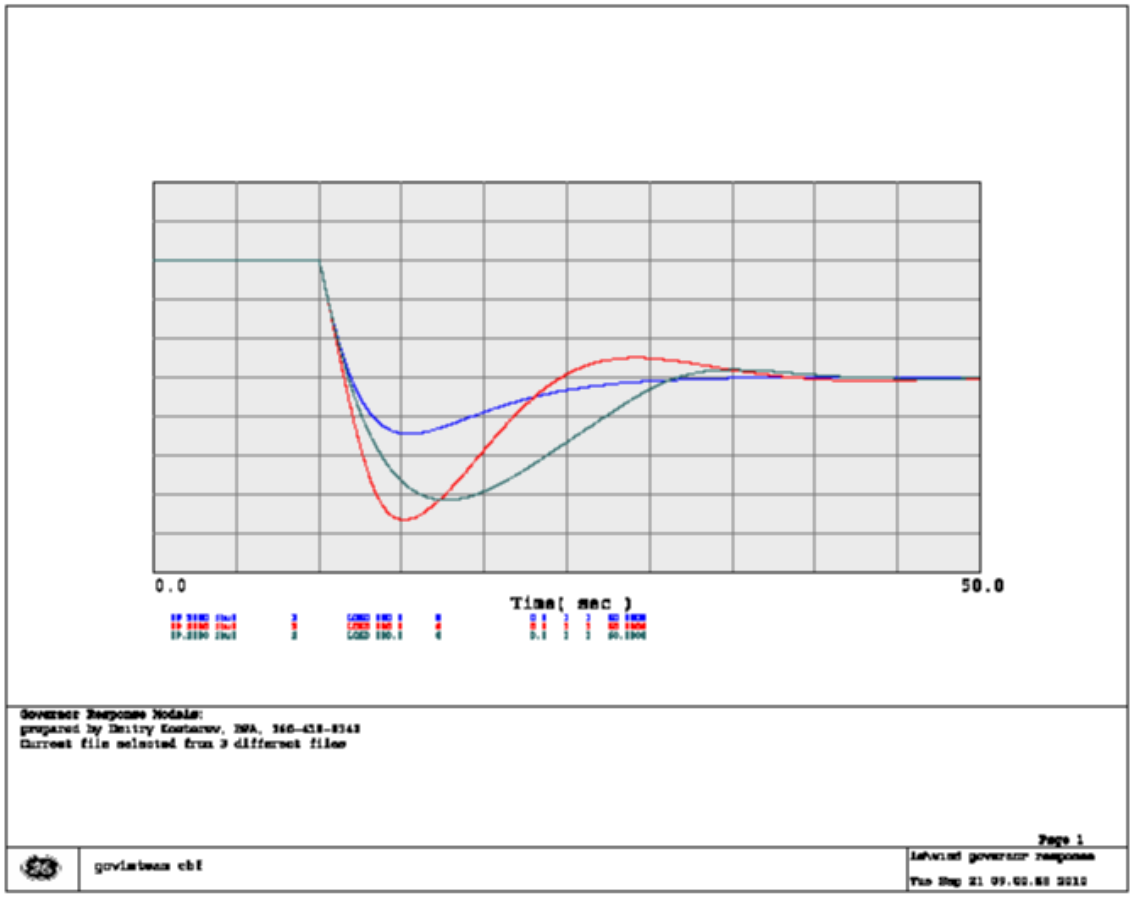
Simple test system to illustrate the point



System size is 100 GW
3 GW of generation tripped
All generators have inertia of 4 seconds
Load damping D=1
Baseloaded generation does not response to frequency, produces the same MWs
Responsive generation has droop setting of 5% and head room of 3GW

Case 1: different speed of response of “responsive” units

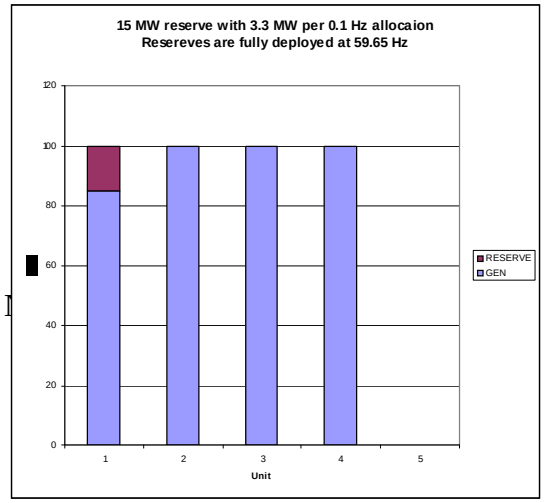
Blue = gas-turbine unit on governor control
Red = (fast) hydro-power unit on governor control
Green = (ideal) steam-turbine unit on governor control

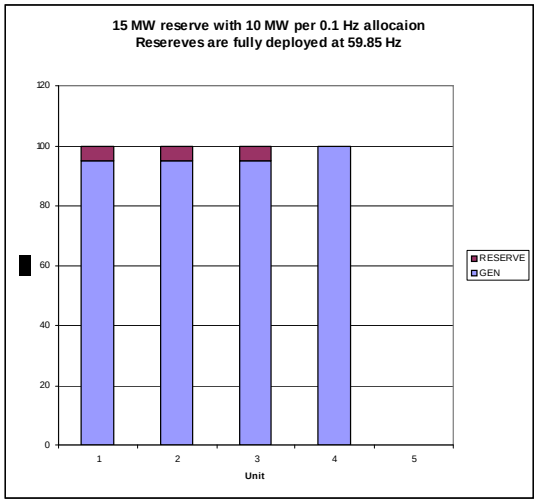


Case 2: different deployment rate

Given the same MW amount of head room and speed, the nadir frequency will greatly depend on how the reserves are allocated.

On the left side, all the reserves are put on a single unit. On the right, the reserves are spread among three units. With the same droop setting, the frequency drop for the case on the left case will be three times the frequency drop for the case on the right side.





The following are inter-related (for a given required frequency response amount)

- Deployment Frequency = the frequency by which the required frequency response amount must be fully deployed
- Deployment rate (MW / 0.1 Hz) = Required frequency response amount divided by the Deployment Frequency
- Responsive Capacity = amount of synchronous capacity that is carrying the frequency responsive reserves
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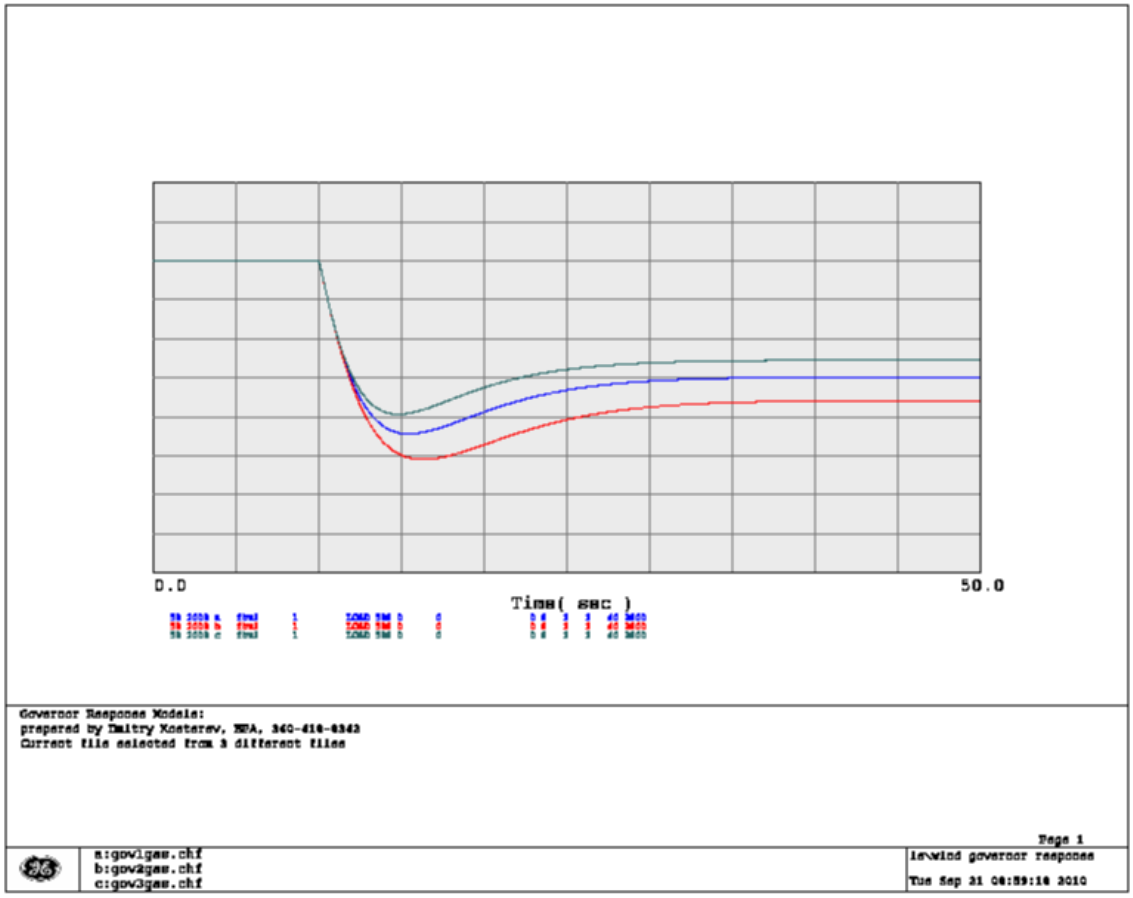
Simulations are done on the test system above to confirm the importance of the deployment ratet:
3GW of frequency response are distributed among:

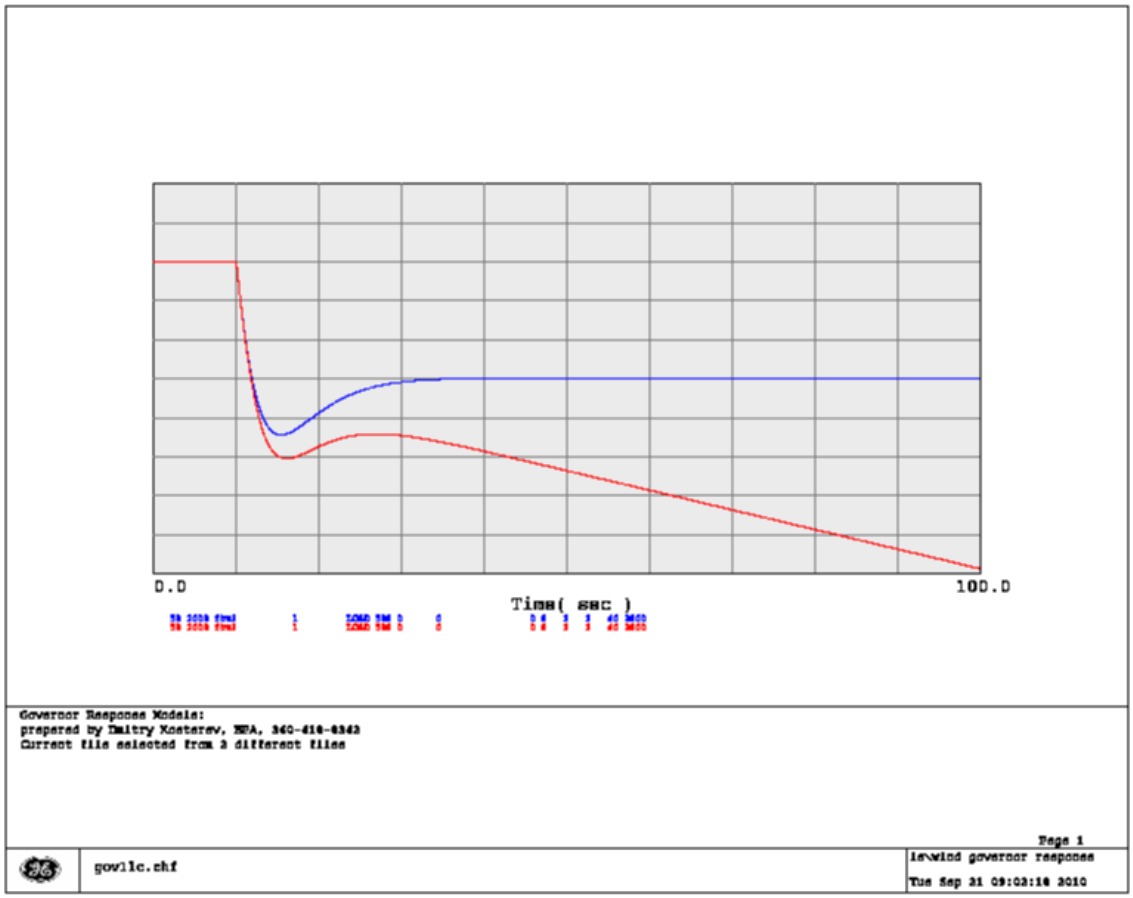
- 20 GW of generating capacity (red)
- 25 GW of generating capacity (blue)
- 30 GW if generating capacity (green)



Case 3: Frequency response sustainability.

3GW of frequency response are distributed among the generators with the same governor control:

- Blue = frequency response is sustained
- Red = generator has a “slow” load controller returning to MW set-point



CONCLUSION

The frequency response requirement needs to be characterized by the following properties:

- Response amount (MW)
- Deployment frequency (Hz) or Deployment Rate (MW/0.1Hz)
- Response time
- Sustainability

3. Questions related to the primary frequency response.

Question 1:

What is the frequency control objective?

1. What is the "design" event we are protection for?
2. What is the frequency performance for the "design" event?
3. Does the same performance need to be maintained under all system conditions?
4. How does the historic performance of the interconnection compare to the frequency control objective?

Question 2:

Should be the requirement be expressed as Total System Response or as a Controllable Response?

Total System Response = "Governor Response" + "Frequency-Responsive Demand Response" + "Natural Load Response (to Voltage and Frequency)" – "Incremental Transmission Losses"

"Controllable Response" = "Governor Response" + "Frequency-Responsive Demand Response"

For example, WECC studies show that for a 2,800 MW generation outage, the 2,800 MW of total primary response is needed, from which 2,400 MW needs to come from governor response and 400 MW comes from natural load response minus incremental transmission losses.

The implications of this decision:

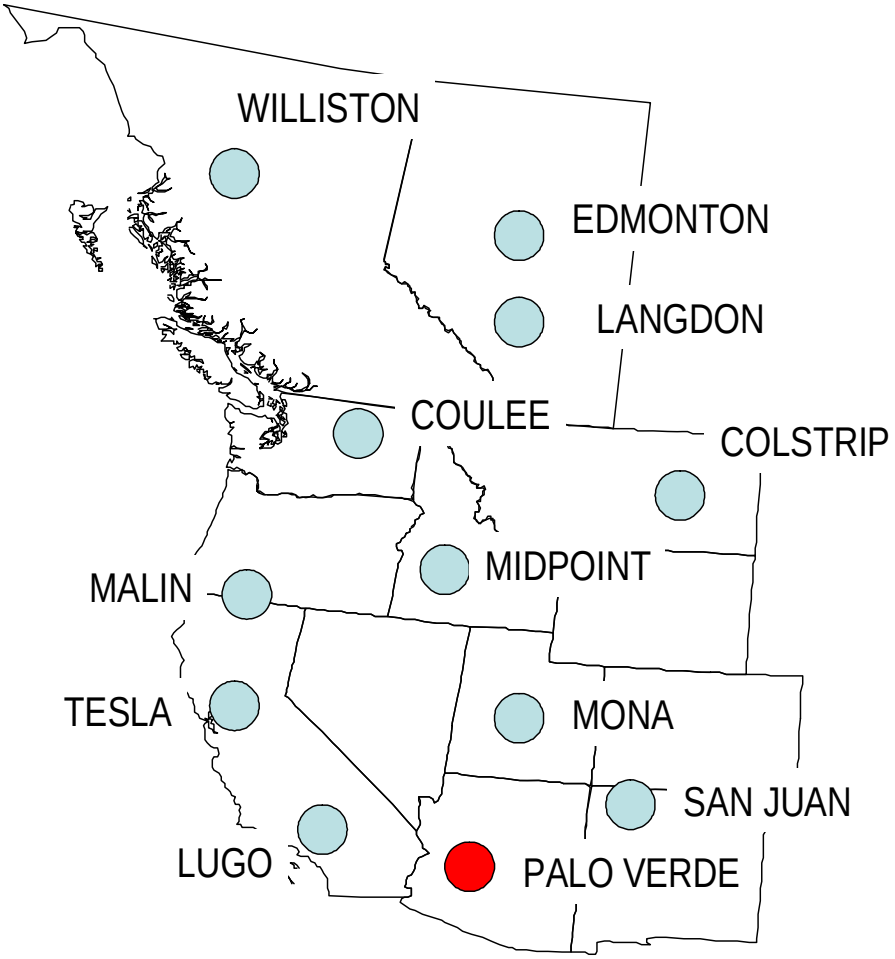
- if the requirement is expressed as "total" response, the requirement needs to be assigned to individual BAs and measured at BA boundaries
- if the requirement is expressed as "resource" response, the requirement needs to be assigned to individual generators

4. Transmission system impact on Governor Response Requirements

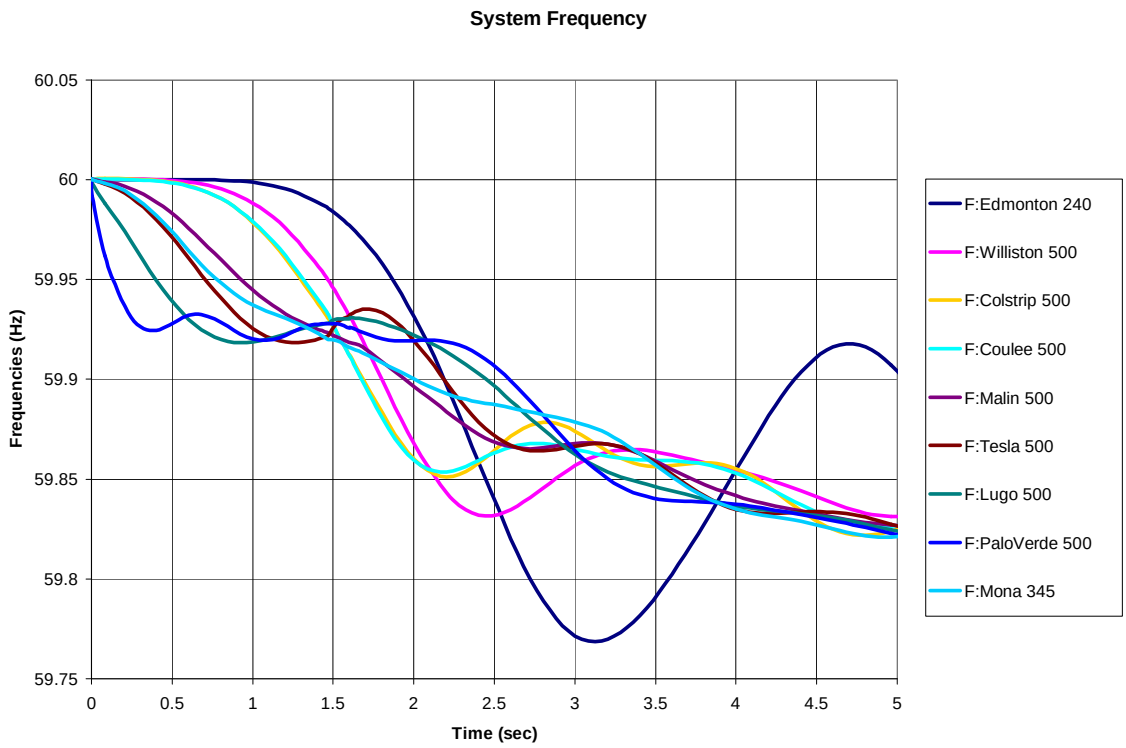
WECC FRR studies indicated that the following two factors also play a significant role in arresting the system frequency decline:

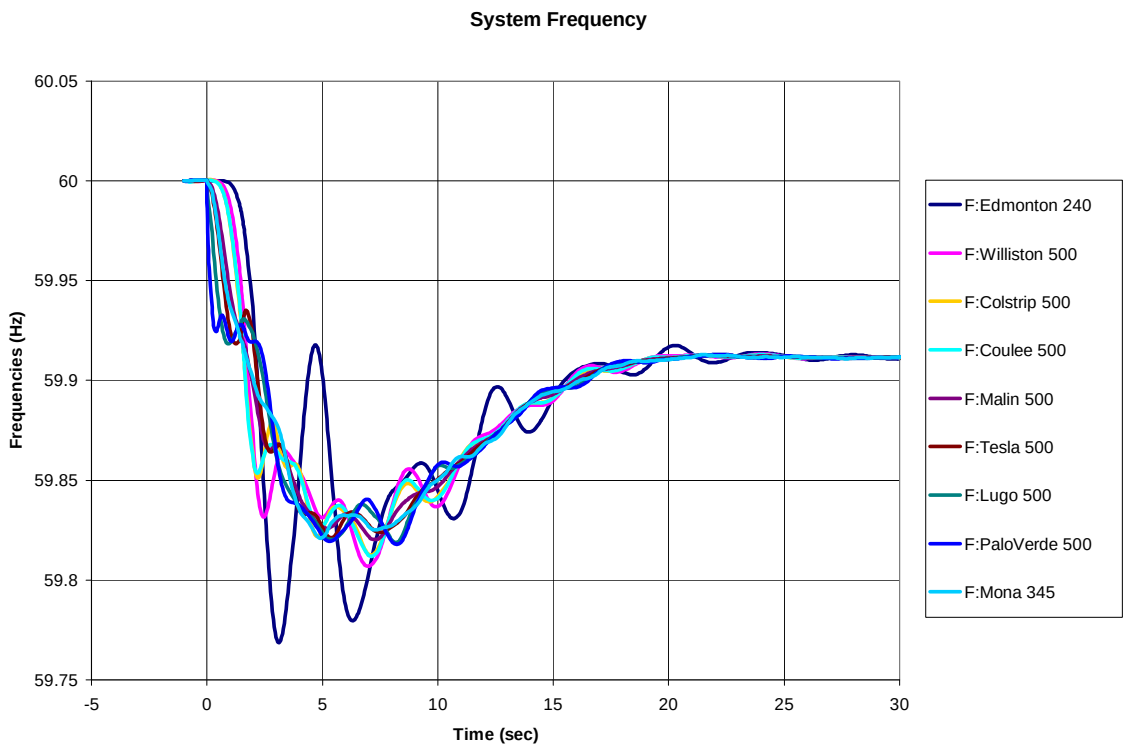
- voltage sensitivity of loads, as the load voltages can change significantly during the initial disturbance transient
- incremental power losses due to re-distribution of power flows

Simulation of 2 Palo Verde (Arizona) outage in Western Interconnection

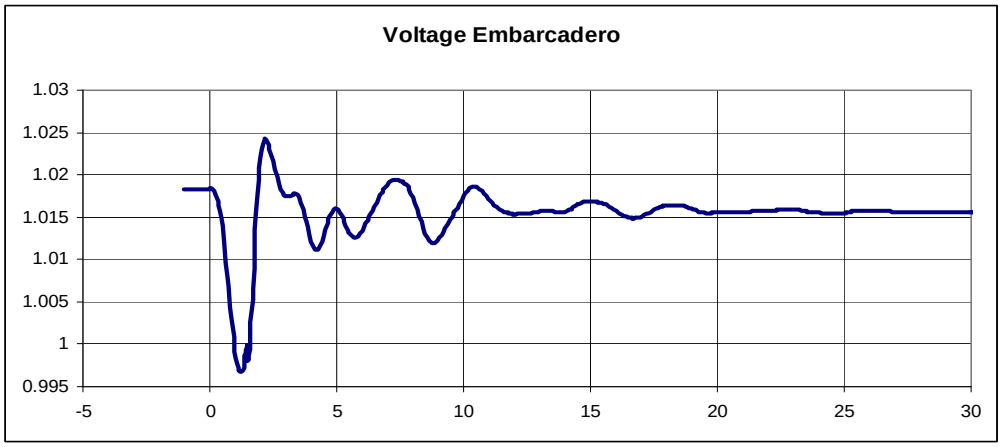


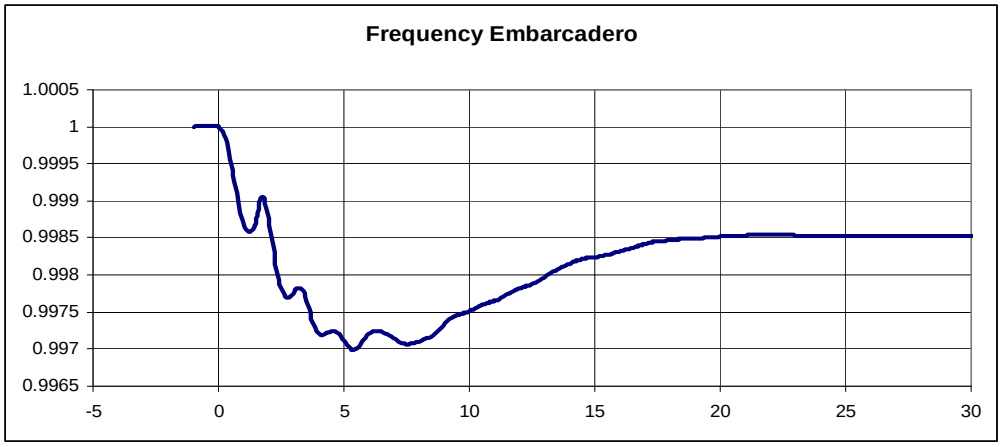
Frequencies across the Western Interconnection

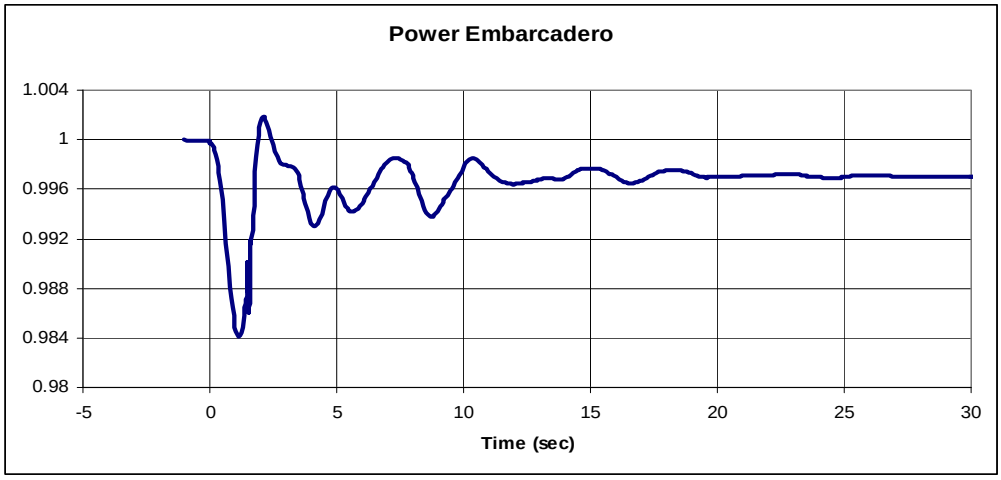




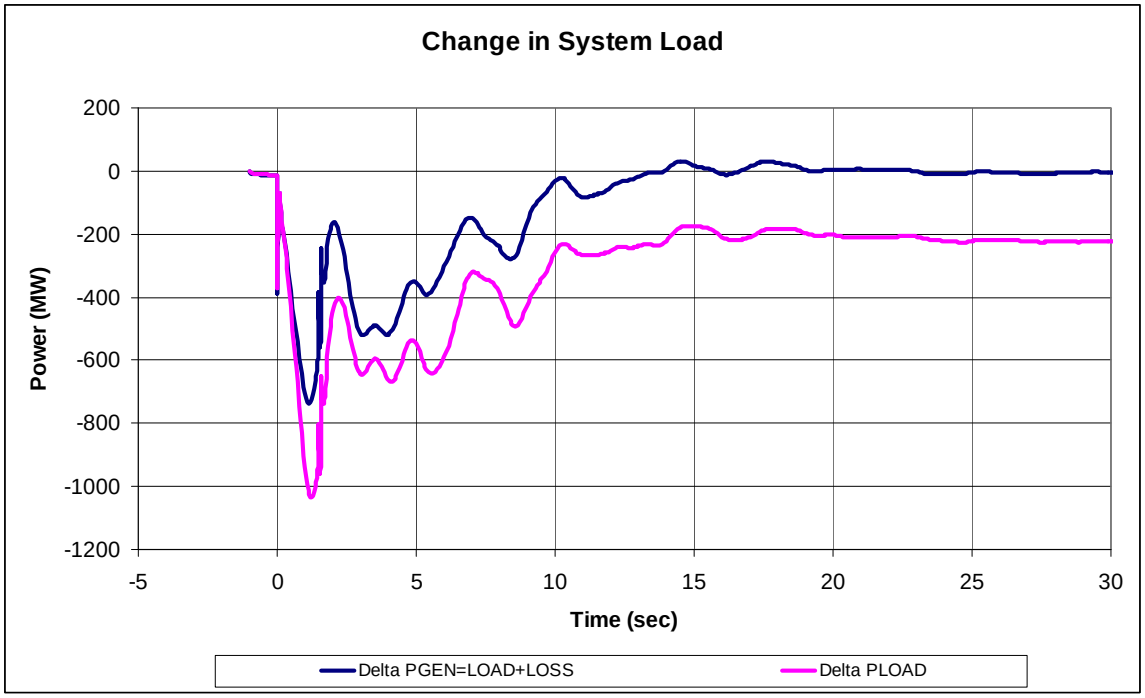
Generation outage creates a system transient affecting both, bus frequencies and voltages in the system. Voltage changes will be largest in the middle of the system. Embarcadero (downtown San Francisco) bus voltage, frequency and load following a two-unit Palo Verde outage







Change in the total system load during a disturbance:
- red (lower) line – change in total load in an interconnection
- blue (higher) line – change in total load minus incremental transmission losses



5. "Design Event" and Frequency Performance in the Western Interconnection

WECC Reliability Criteria:

Category	Events	Controlled loss of load permitted?	Minimum frequency
B:	N-1	NO	59.6 Hz, 6 cycles
C:	N-2, N-1-1	YES	59.0 Hz, 6 cycles

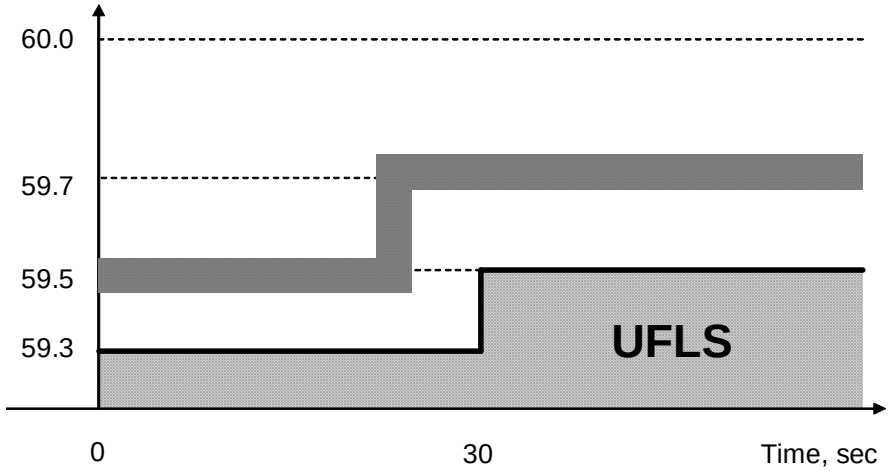
WECC largest N-2 is 2,800 MW corresponding to simultaneous outage of 2 Palo Verde generators. There are also several SPS schemes that will trip about 2,800 MW for N-2 transmission line outages under certain conditions.

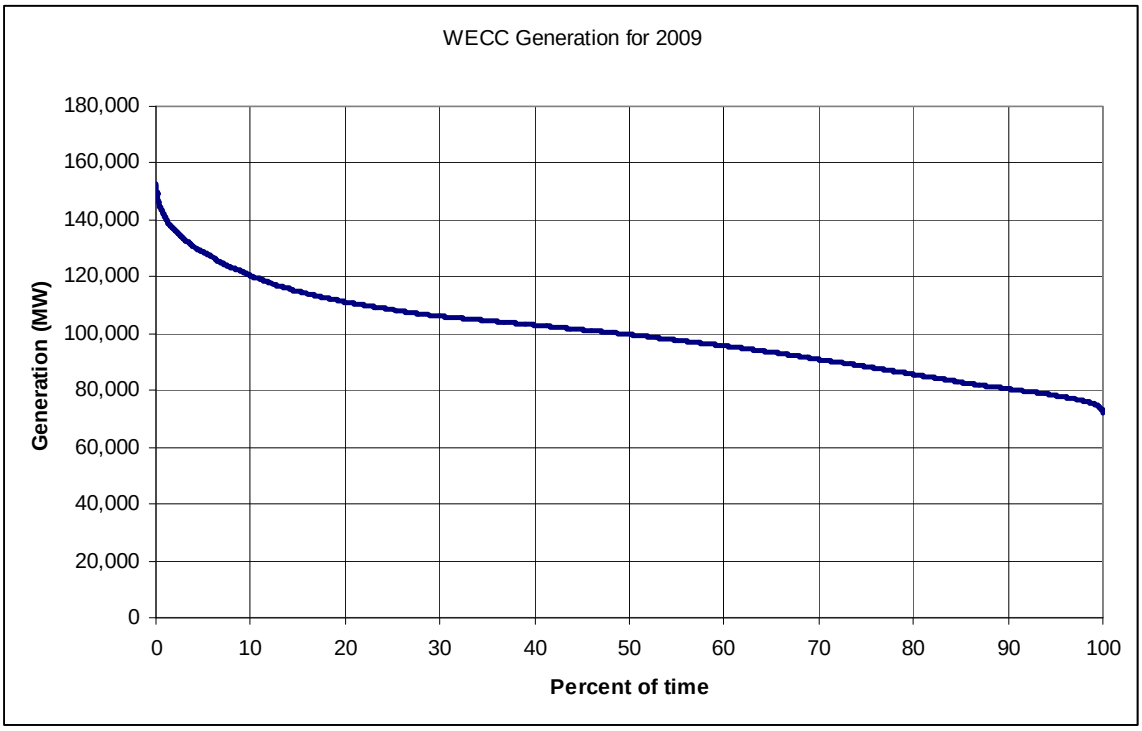
System Operating Limits of many major paths are set by N-2 outages.
N-2 outages are stability-limiting, we do not want to be dependent on UFLS operation to keep the interconnection in synch.
Generation outages of ~2,800 MW do occur.

The consensus is that 2,800 MW is the "design" event for Western Interconnection, for which there will be no Under-Frequency Load Shedding.

WECC coordinated UFLS program:
- a block of load at 59.5 Hz with 30 second delay
- a large block of load at 59.3 Hz with almost no delay

Our conclusion:
The nadir frequency needs to stay above 59.3 Hz (with some margin to account for oscillations) for an instantaneous outage of 2,800 MW of generation.
What the settling frequency needs to be? Above 59.5 Hz (with some margin).



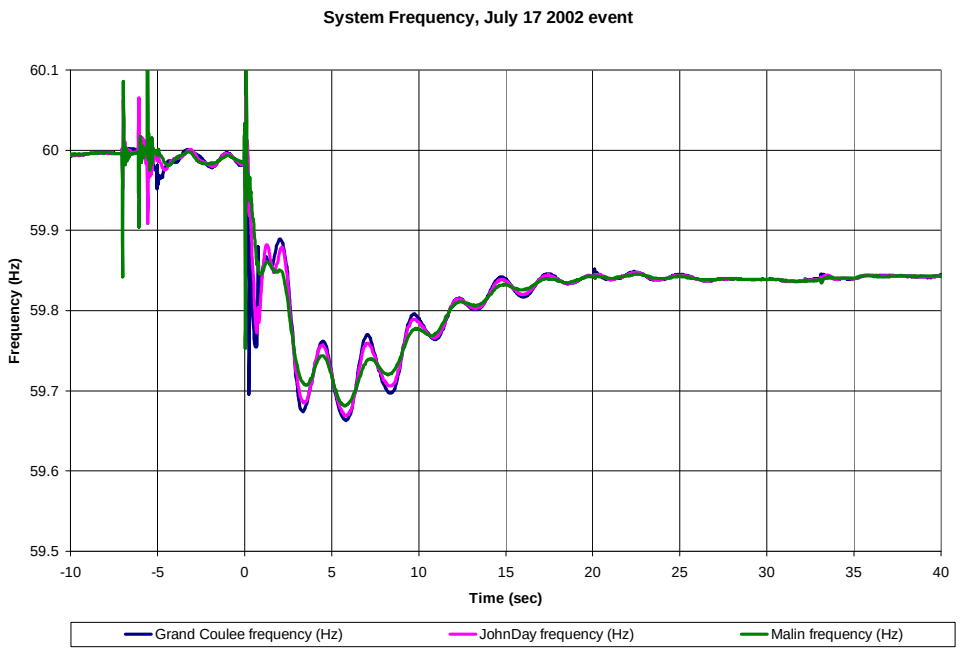


WECC total generation peak > 150GW, off-peak about ~ 75 GW

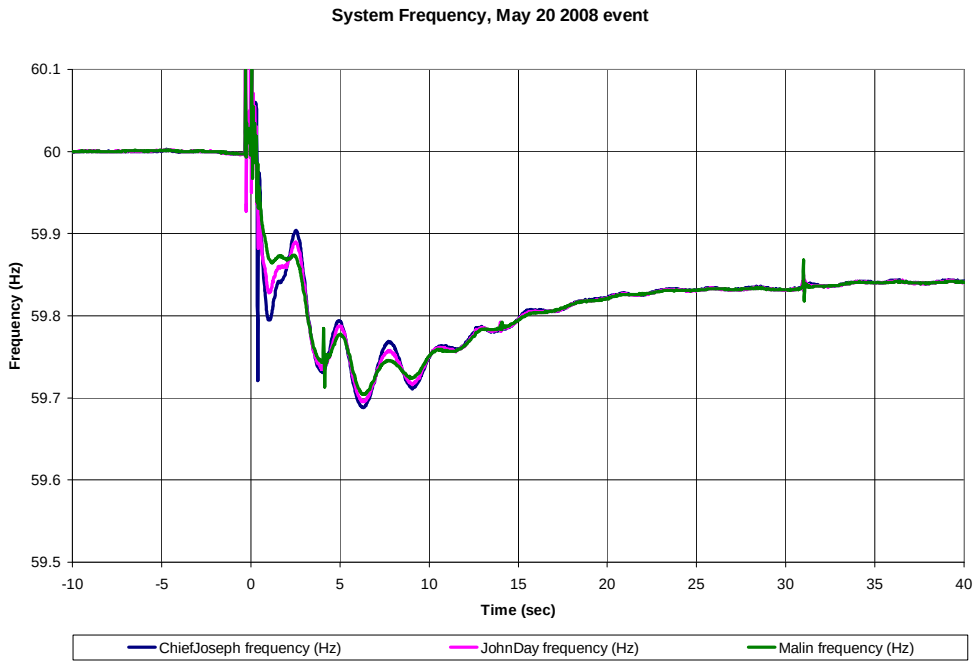
2,800 MW generation loss represents less than 2% of system capacity on-peak and 3.7% of system capacity off-peak.

6. Historic Performance of Western Interconnection

2,812 MW RAS event on June 17, 2002

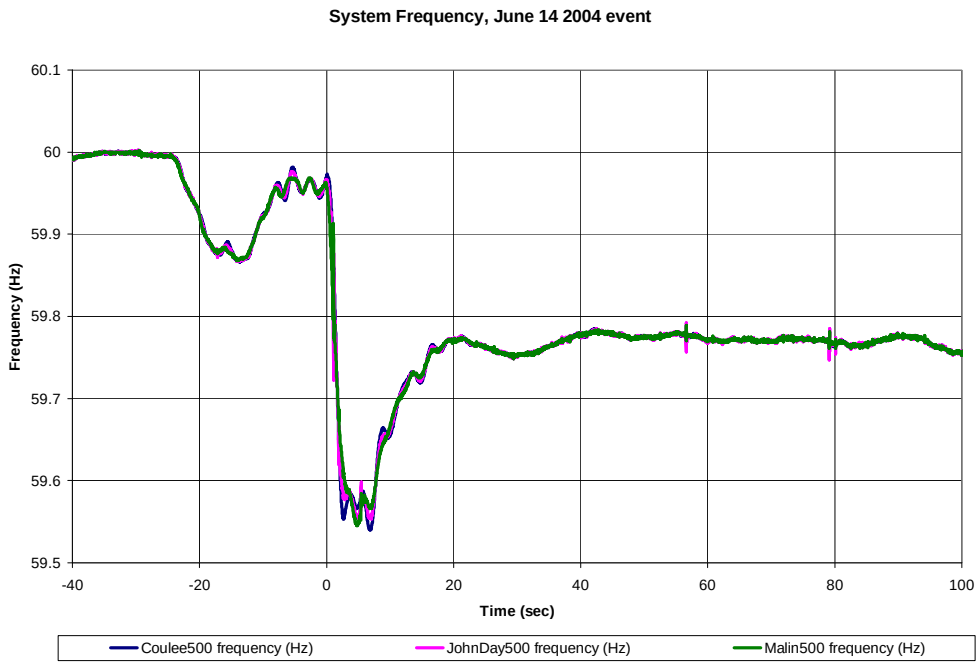


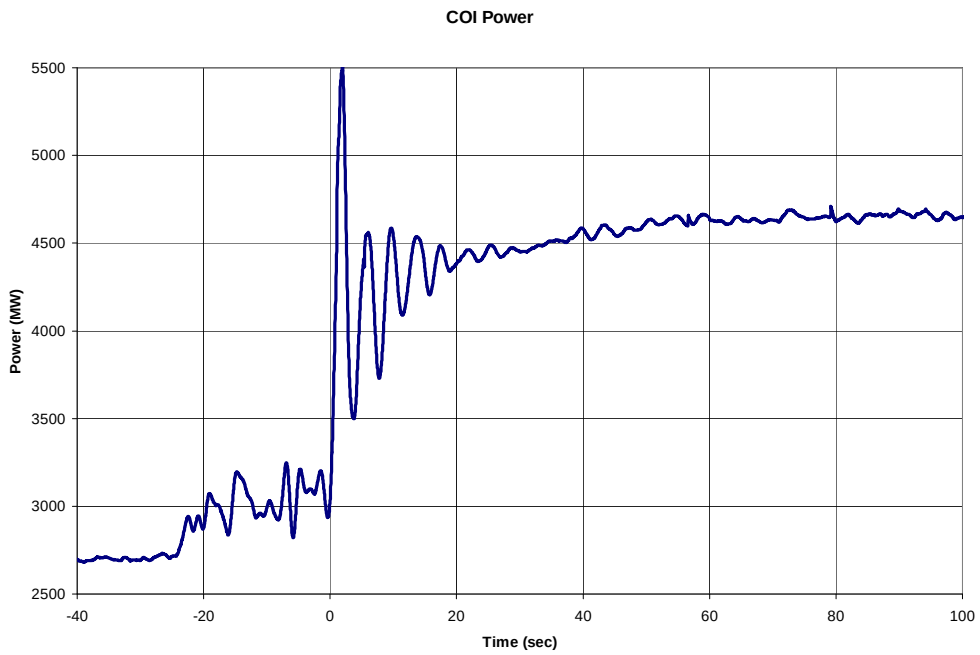
2,815 MW RAS event on May 20, 2008



West Wing fault in Arizona on June 14, 2004:

- 3,900 MW lost at 0 seconds on plot scale





Captain – Jack – Olinda 500-kV line was out of service during the disturbance

7. Primary Frequency Response Requirements in the Western Interconnection

A. If the requirement to be expressed as a "total" response

Measured at BA boundaries

Requirement at 10 seconds (nadir)
Amount: 2,800 MW = design event
Deployment frequency = 0.5 Hz (deployment rate = 560 MW / 0.1 Hz)

Requirement at 30 seconds (settle)
Amount: 2,800 MW = design event
Deployment frequency = 0.25 Hz (deployment rate = 1120 MW / 0.1 Hz)

B. If the requirement to be expressed as a "controllable resource" response

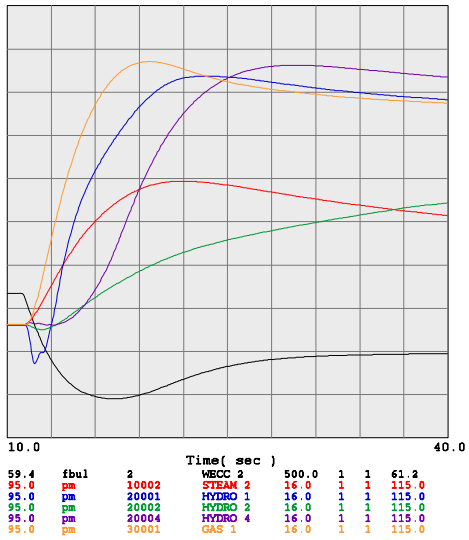
Measured at generators and loads part of the frequency-responsive demand response

Requirement at 10 seconds (nadir):
Amount: 2,400 MW = generation portion of the total response
Deployment frequency = 0.5 Hz (deployment rate = 480 MW / 0.1 Hz)

Requirement at 30 seconds (settle):
Amount: 2,800 MW
Deployment frequency = 0.25 Hz (deployment rate = 1120 MW / 0.1 Hz)

8. Simulated typical responses of various types of generators under governor control

9.



Governor Response Models:
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governor response - pslf
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Comparison
30-second plot

- Frequency

-Steam Turbine on Governor Control

-Francis Turbine with Fast Governor

-Francis Turbine with Slow Governor

-Kaplan Turbine with Fast Governor

-Gas Turbine on Governor Control

Other points

1. While the current focus is on the primary frequency control, the entire duration of frequency response issues must be thought through first to ensure that there is an agreement between the primary, secondary and tertiary frequency control requirements.

2. Frequency response allocation mechanisms must be established.

3. Frequency response measurement can be a major challenge.
    a. Likely to require transducers that measure generator active power and frequency at rate of 10 time per second
    b. If allocated to BA, will require time-synchronized transducers that measure BA frequency at multiple locations and BA interchange flows

4. How to measure response for multiple sequential unit outages?