Wide-Area Oscillation Resonance Event in the Western Interconnection on September 5 2015

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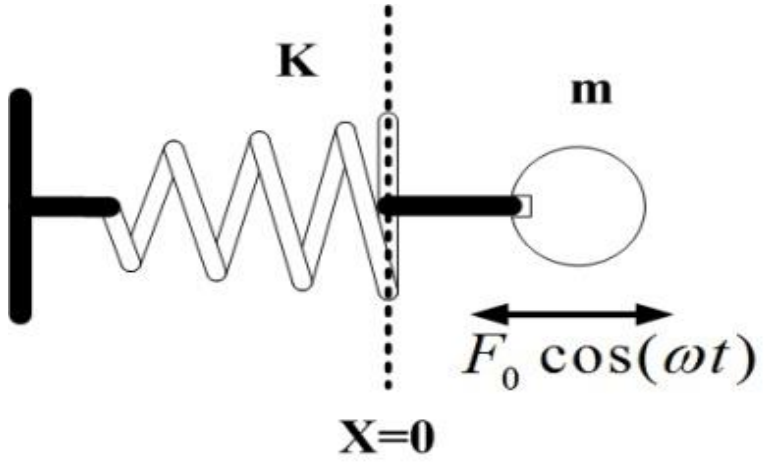
Definitions

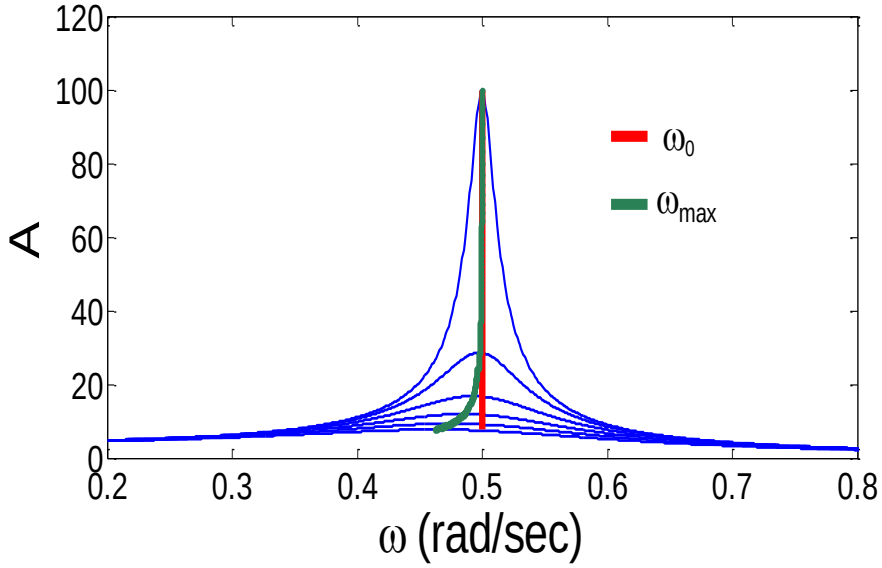
- **System Mode – Inter-area Modes and Local Modes**
- **Natural/System oscillations – Oscillations from sources internal to the system**
- **Forced oscillations - Oscillations from sources external to the system**

Resonance in Physics

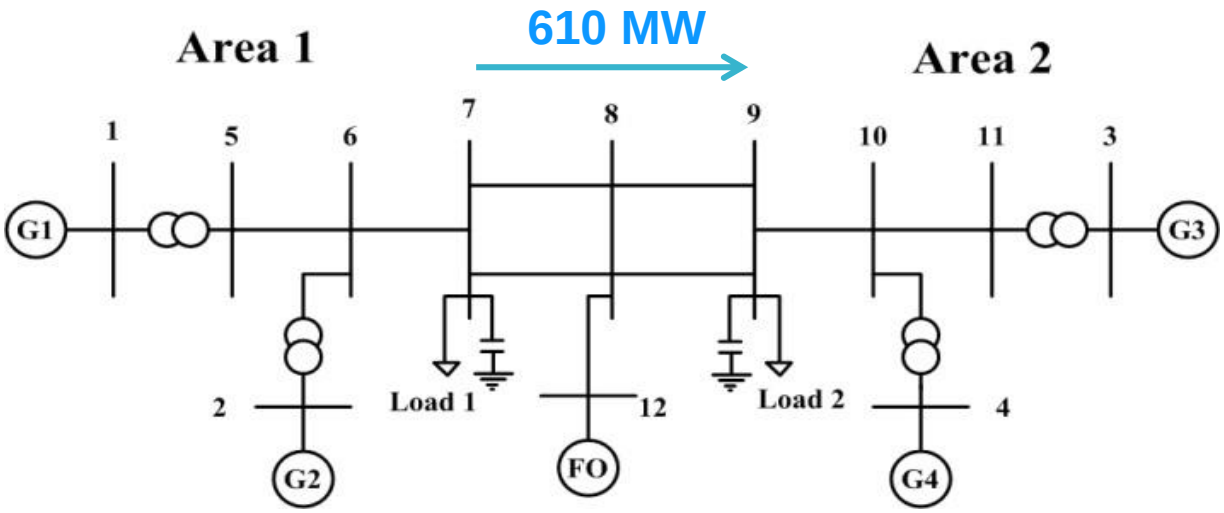


$$\begin{cases} A = \dfrac{F_0/m}{\sqrt{(\omega_0^2 - \omega^2)^2 + (\omega\gamma)^2}} \\ \tan\delta = \dfrac{\omega\gamma}{\omega_0^2 - \omega^2} \end{cases}$$

High resonance effect when forced oscillation frequency close to system mode frequency and when system mode poorly damped.

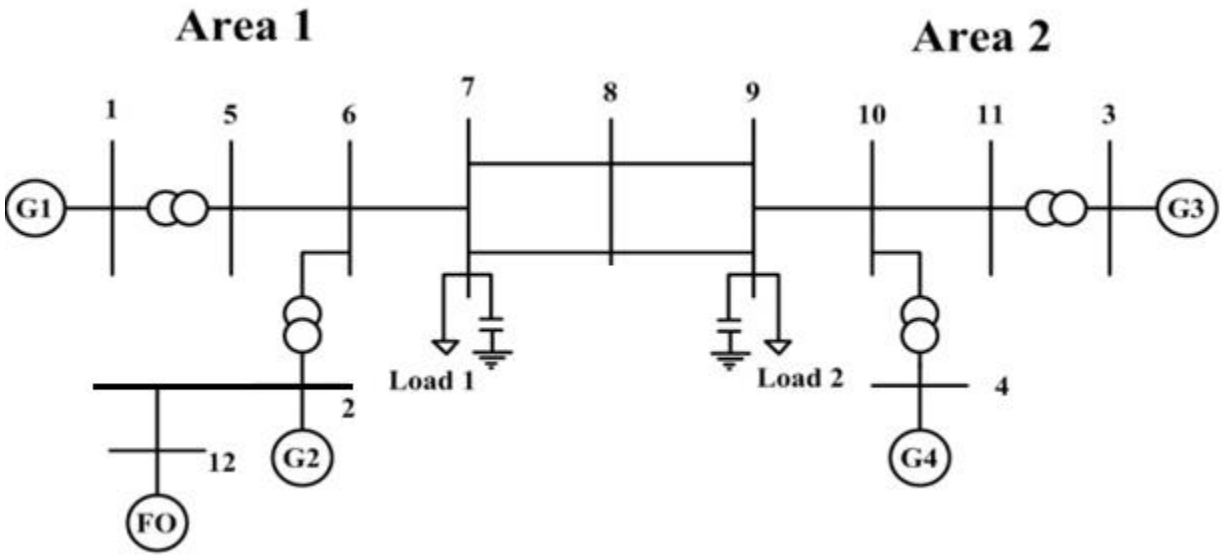


Resonance in Kundur Test System



- When does resonance occur?
- When is resonance severe versus mild?
- Sensitivity to forced oscillation frequency, location, system mode damping, and local versus inter-area mode.
- Recent paper in IEEE Trans. Power Systems

High Resonance Case



35 MW Forced Oscillation (FO) can lead to 400 MW Tie-line oscillations when FO freq close to system mode freq and system mode at 2% damping ratio.

Tie-line oscillations can be 500 MW if FO near the receiving end near bus 3 or 4.

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Resonance with Inter-area Mode

Resonance effect high when:

(R1) Forced Oscillation freq near System Mode freq

(R2) System Mode poorly damped

(R3) Forced Oscillation location near the two distant ends (strong participation) of the System Mode

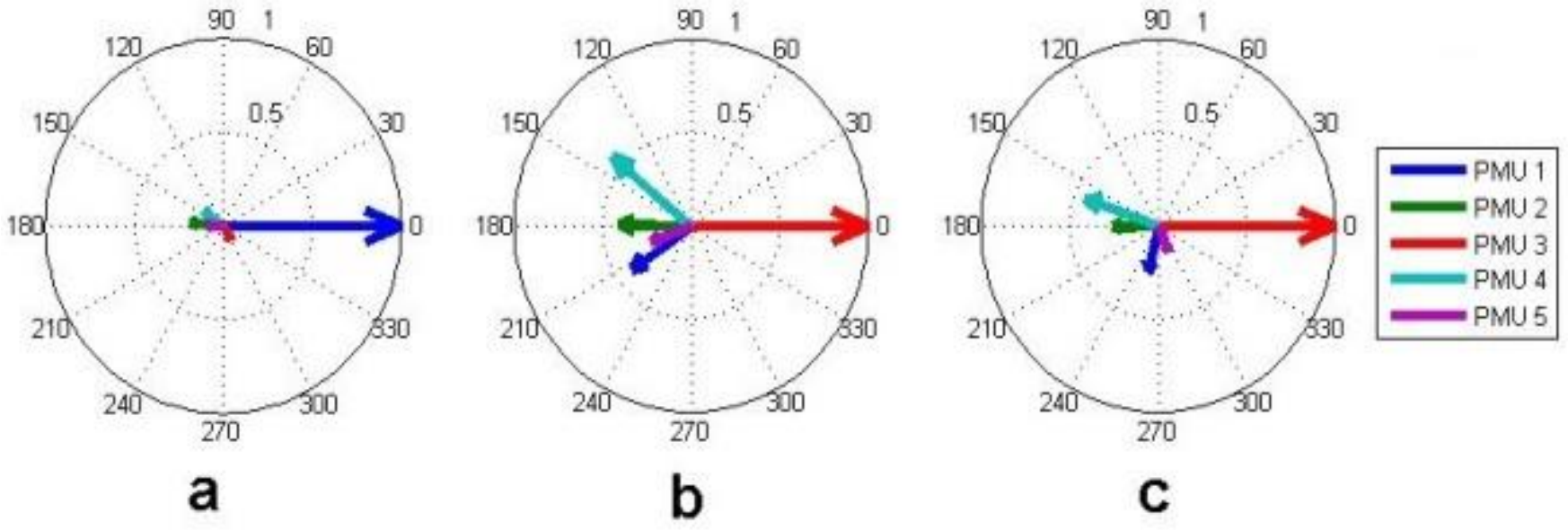
Resonance effect medium when:

- Some conditions hold

Resonance effect small when:

- None of the conditions holds

No resonance on June 13, 2013 event



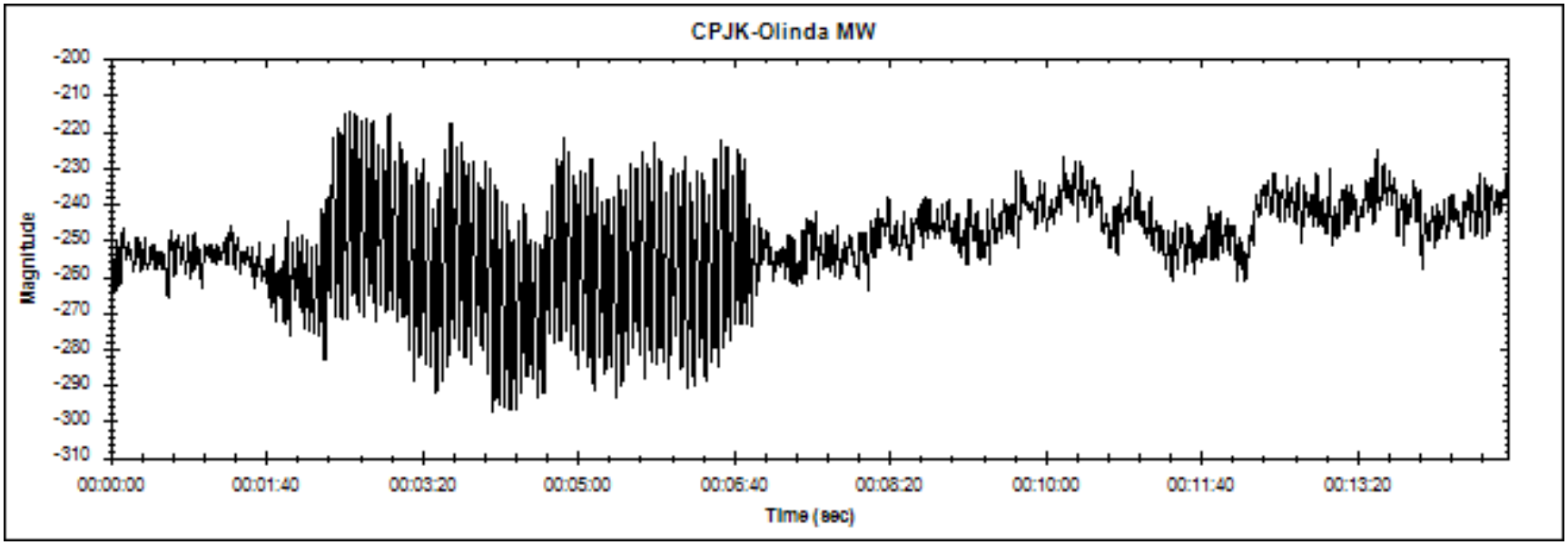
Case 1
0.37 Hz
Forced Oscillation

Case 1
0.4 Hz at
15% Damping Ratio

Case 2
0.4 Hz at
14% Damping Ratio

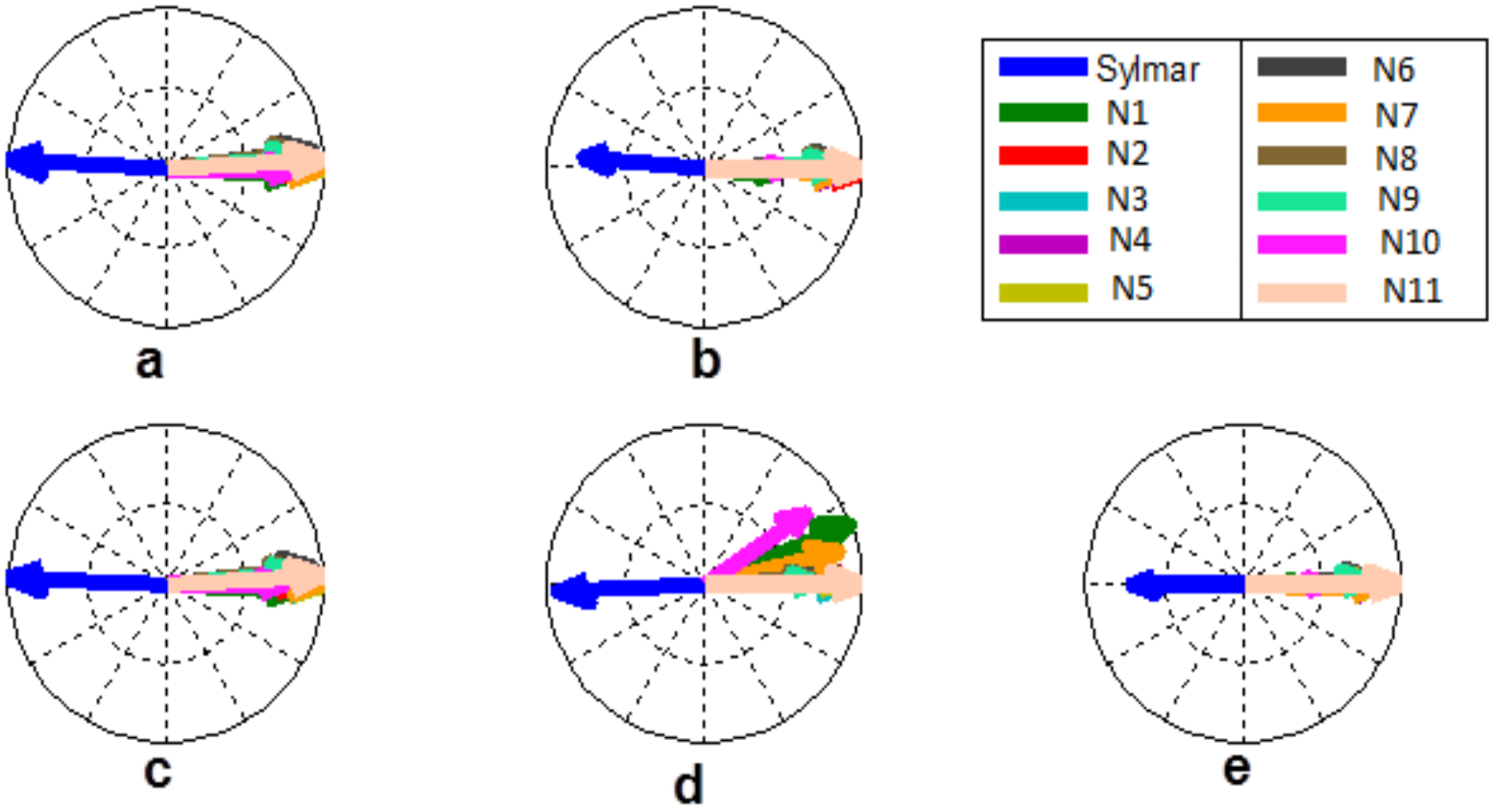
Resonance effect low because system mode well-damped and FO location near the center of the mode. Only (R1) holds. No tie-line oscillations from 10 MW forced oscillation.

Medium Resonance on November 29, 2005



- System mode 0.26 Hz and Forced Ocillation at 0.27 Hz
- Forced Oscillation source near Sending End
- System Mode Well-damped at 7%
- (R1) and (R3) valid.
- Two out of three conditions were true.
- Resonance Amplification Factor = 10.
- Warning for the future.

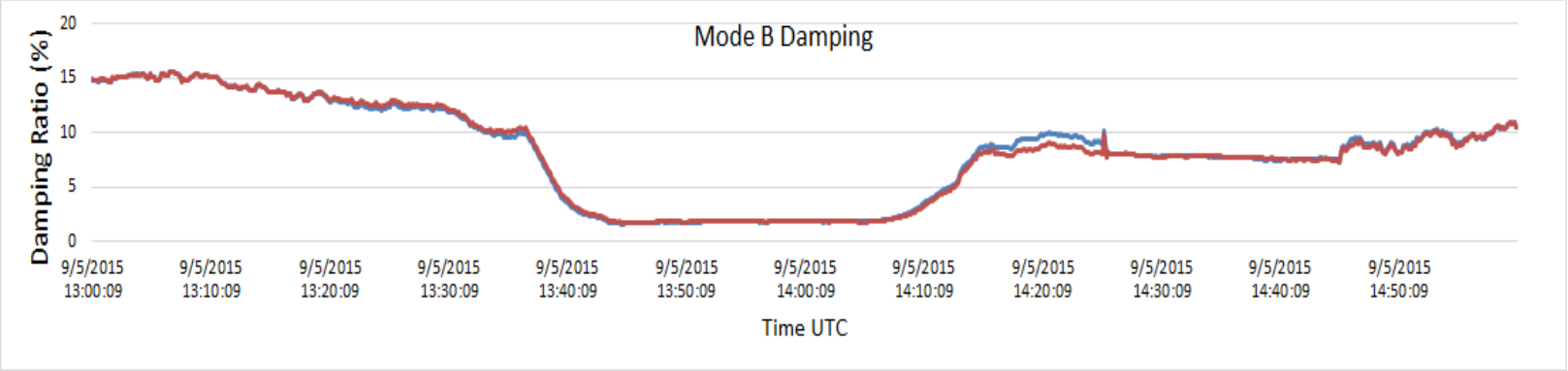
Medium resonance on November 29, 2005



Resonance effect medium because system mode well-damped (7%) and FO location near one end of the mode. 200 MW tie-line oscillations from 20 MW forced oscillation. (Recent IEEE Trans. Paper)

Sept 5 2015 Event

- On Sept 5th, 2015, the MAS Engine (Montana Tech) detected very low damping on the N-S ‘B’ Mode
- No topology changes (sudden)
- No gen/load/tie line flows drops (slow)



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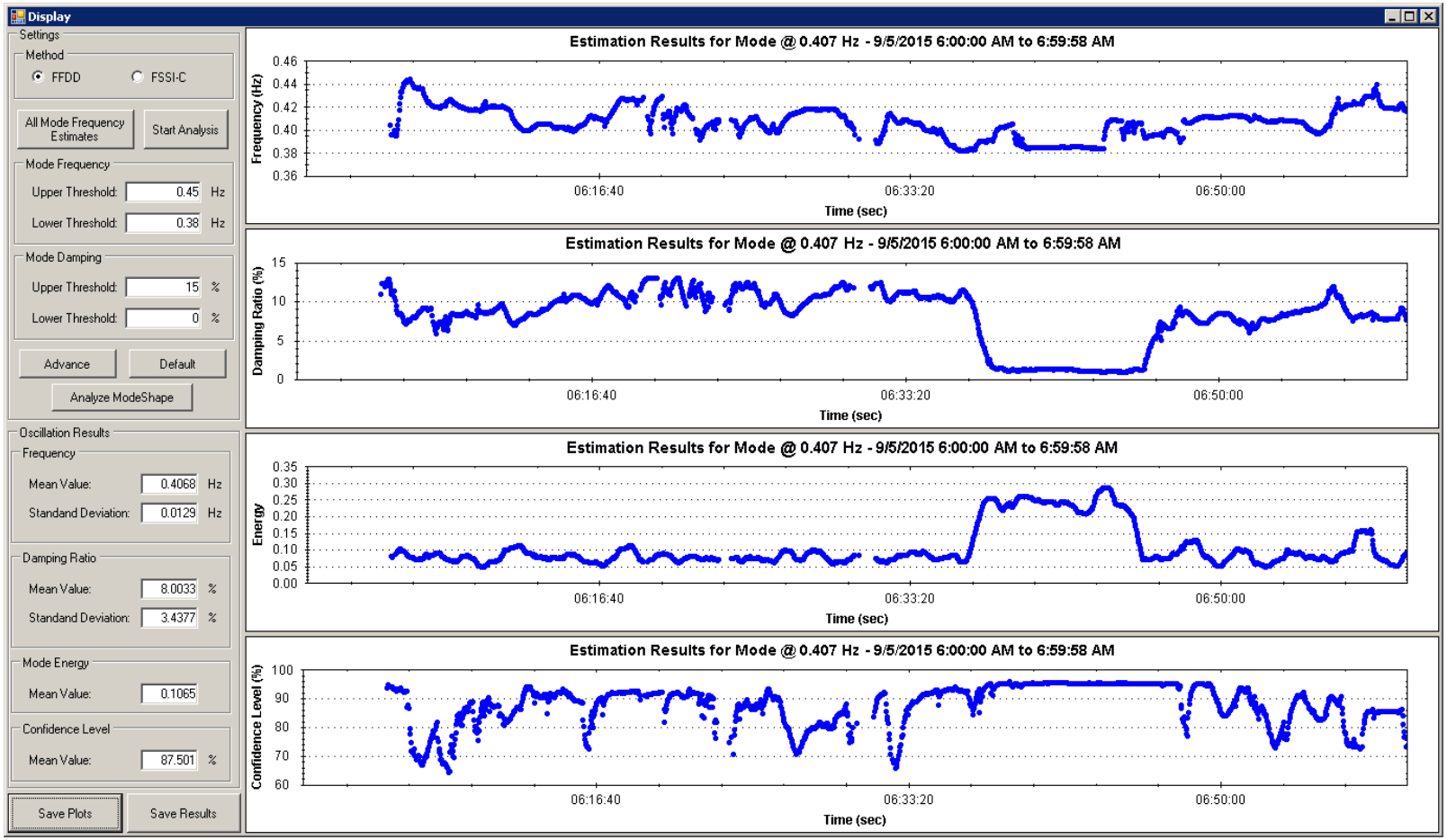
FFDD Analysis of Sept 5 2015



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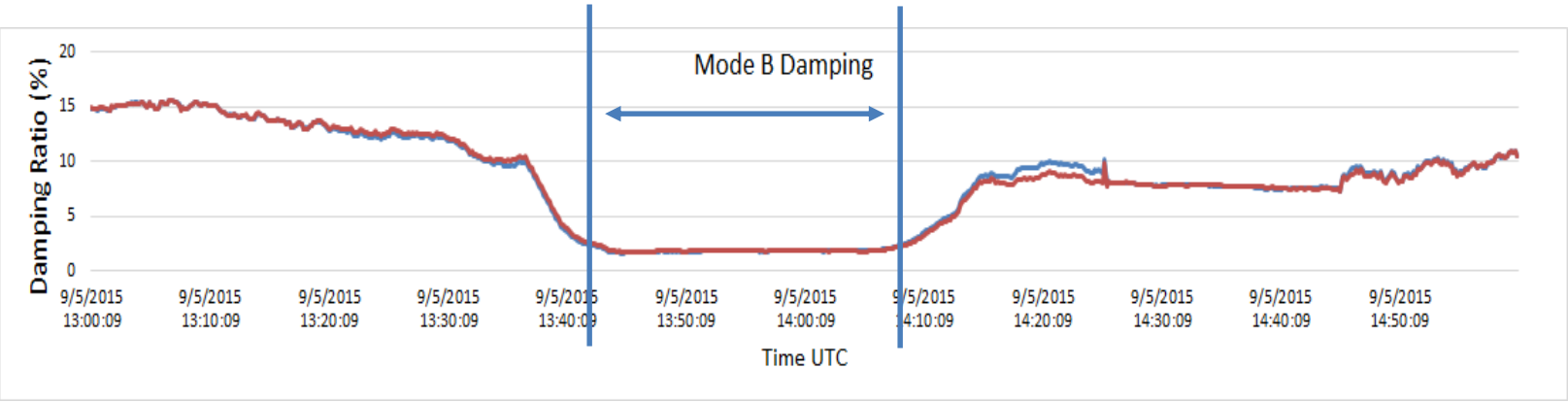
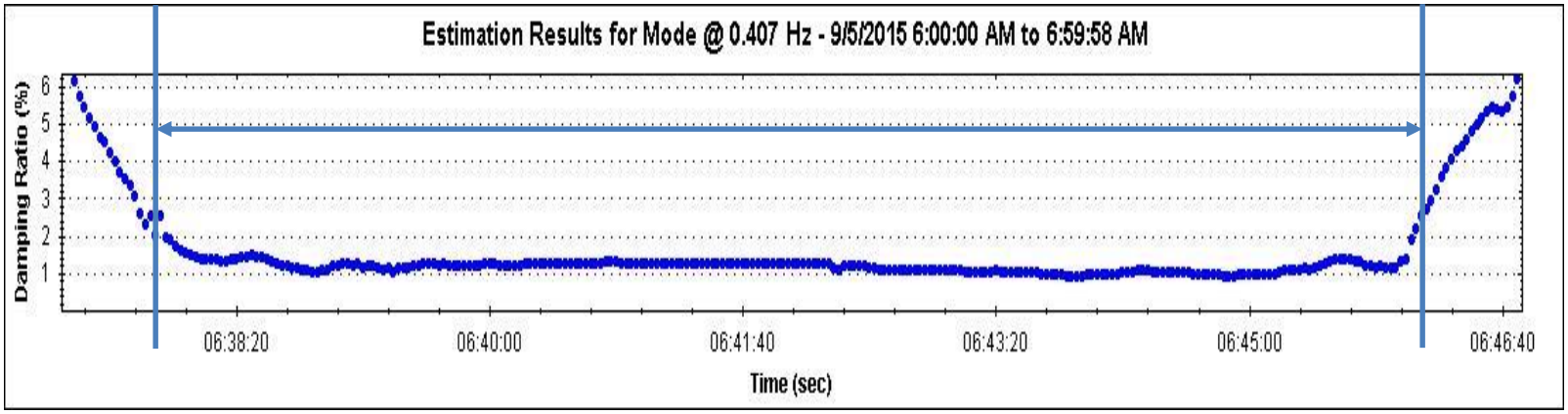
Low Damping Start/End Times



MAS

6.42 to 7.07



FFDD

6.37 to 6.46

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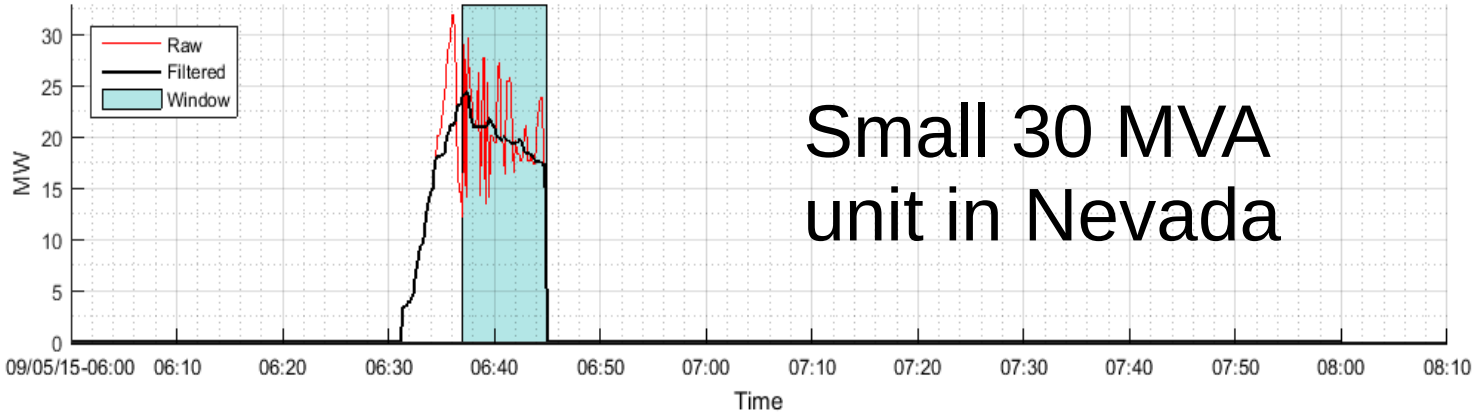
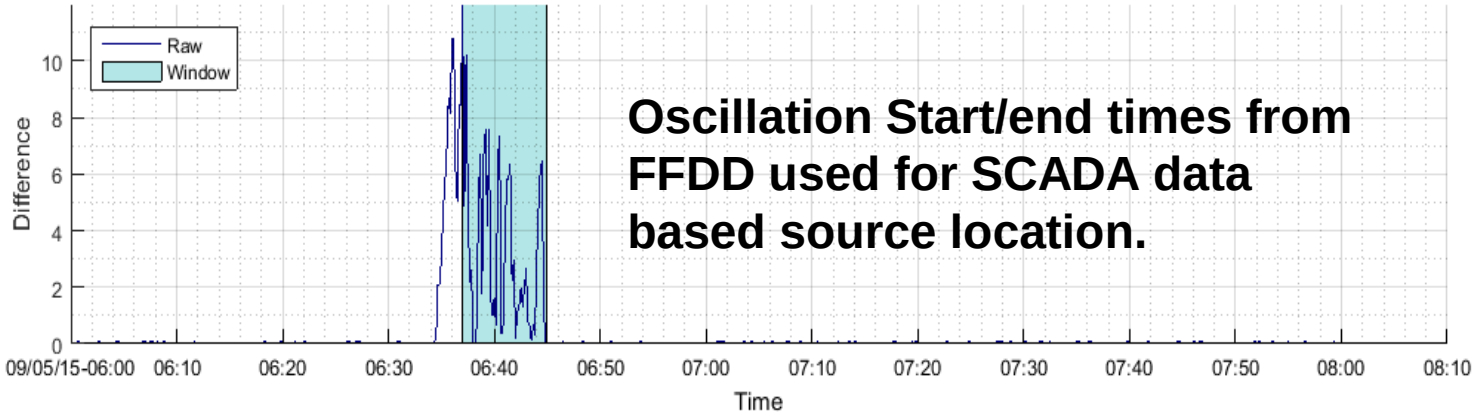
Highest Ranked Generator from SCADA by PMA



Small 30 MVA unit in Nevada

Relative Confidence: 50 %



Oscillation Start/end times from FFDD used for SCADA data based source location.

Plant owner confirmed the oscillation event.

Unit shunt down within ten minutes.

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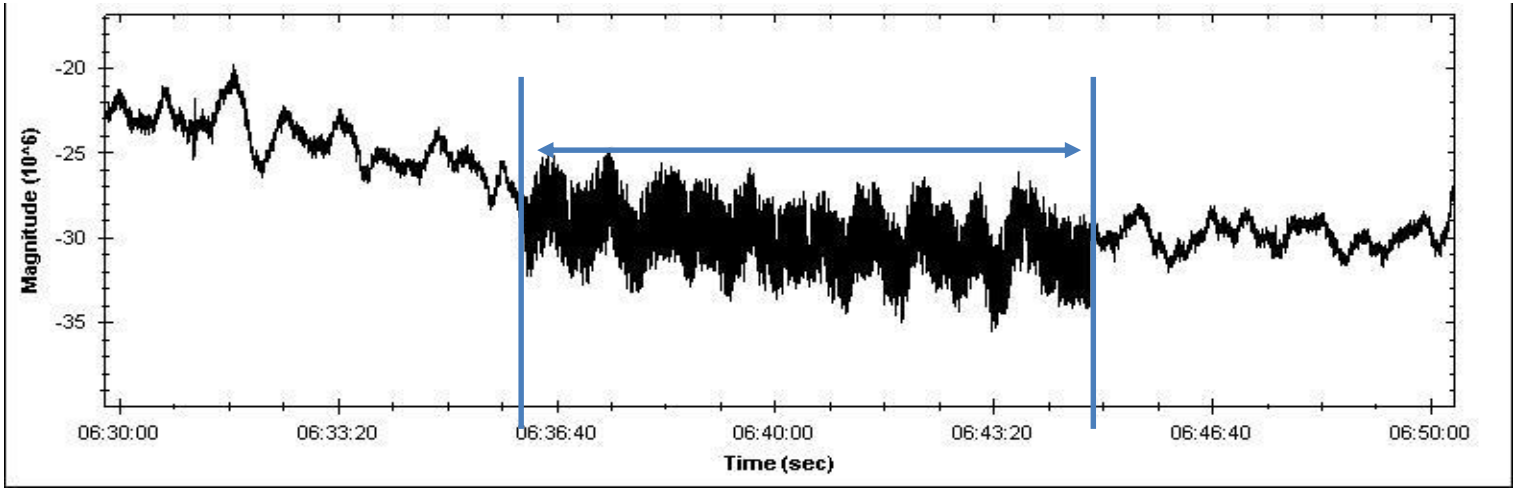
PMU Validation of the Oscillation Source



- MW Flow on a line nearby
- Actual Osc start/end times: 6.35 to 6.45
- FFDD Osc Start/end times: 6.37 to 6.46
- 6 MW Oscillations near the source

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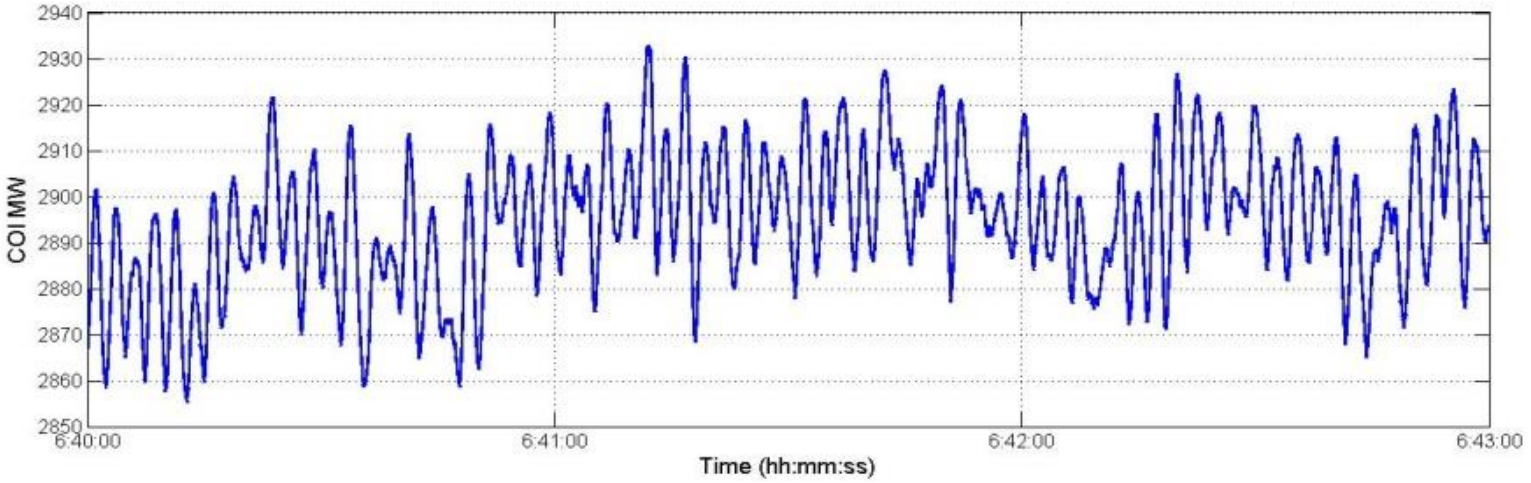
Resonant Oscillations on COI Tie-lines



- 6 MW Oscillations near the source
- 40 MW Oscillations on the Cal-Ore tie-lines
- Inter-area resonance amplified the oscillations
- Instance of medium resonance

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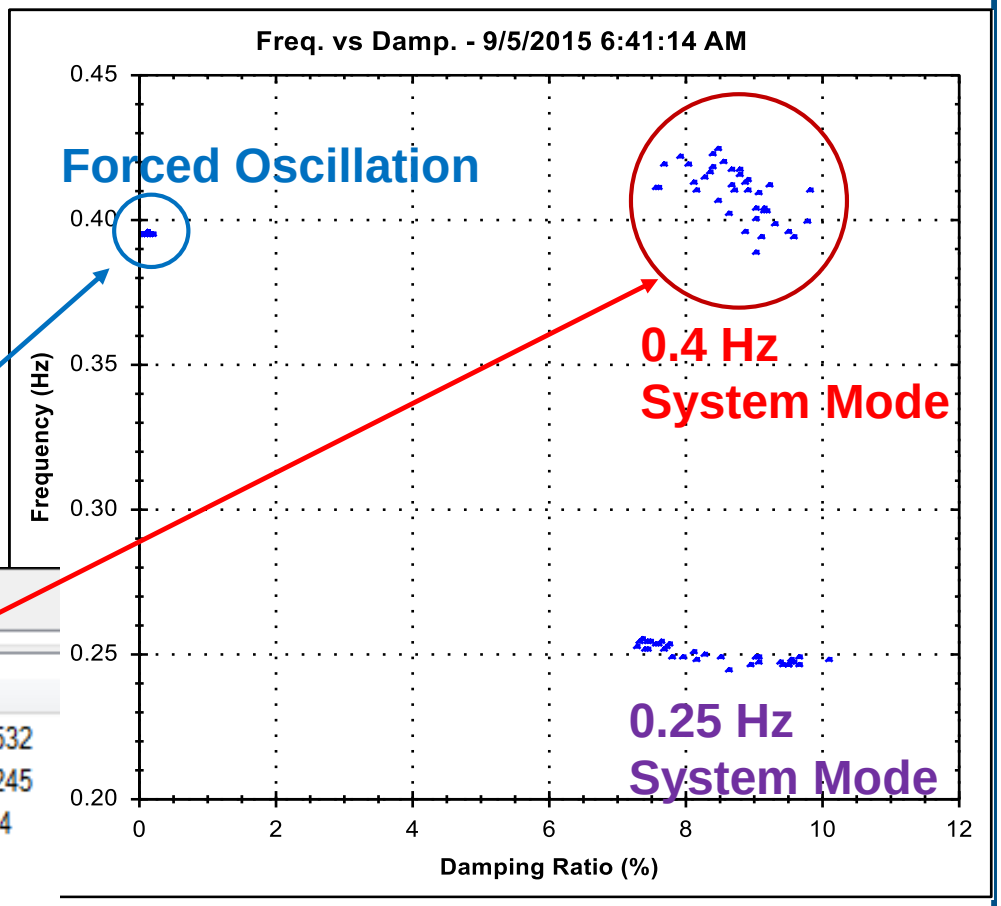
FSSI Confirmation of Resonance

- **Forced Oscillation Freq very close to 0.4 Hz inter-area mode**
- **Source location Nevada sensitive for the mode**
- **Two (R1) and (R3) out of three conditions true => Medium resonance**

FSSI Results



Mode Results | Summary Plot

FFDD / FSSI

Frequency (Hz)	Damping (%)	Confi Level (%)	Energy
0.3952	0.0651	80.0000	3,670,143.5532
0.2474	9.5872	80.0000	1,517,696.5245
0.4034	9.1667	80.0000	939,345.2124

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Summary

- Forced Oscillations are problematic…
- Nov 29, 2005 Alberta event - documented instance of resonance between forced oscillation and (0.25 Hz) inter-area mode.
- Sept 5, 2015 Nevada event – second documented instance of resonance between forced oscillation and (0.4 Hz) inter-area mode.
- June 17, 2016 oscillation event in the east.
- Inter-Area Resonance – potential risk for operational reliability of the grid
- Urgent need to identify oscillation sources (FODSL) and work with those entities