Special Reliability Assessment on Oscillatory Modes in North American Interconnections

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NERC
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Special Reliability Assessment

We thank all the reliability coordinators for providing PMU data.

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Objectives

- Analyze PMU event data from Eastern, Western, and Texas interconnections
- Inter-Area Modes: what modes, damping levels, mode shapes, energy…
- Seasonal properties
- Interactions with forced oscillations
- PMU data for 8 events in each interconnection collected
- Compare with model based simulations

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Report Outline

- Inter-Area Oscillations Fundamentals
- Analysis Techniques
- Event Analysis Results: Eastern, Western and Texas Interconnections
- Findings, Conclusions and Recommendations
- Appendices: Analysis methods

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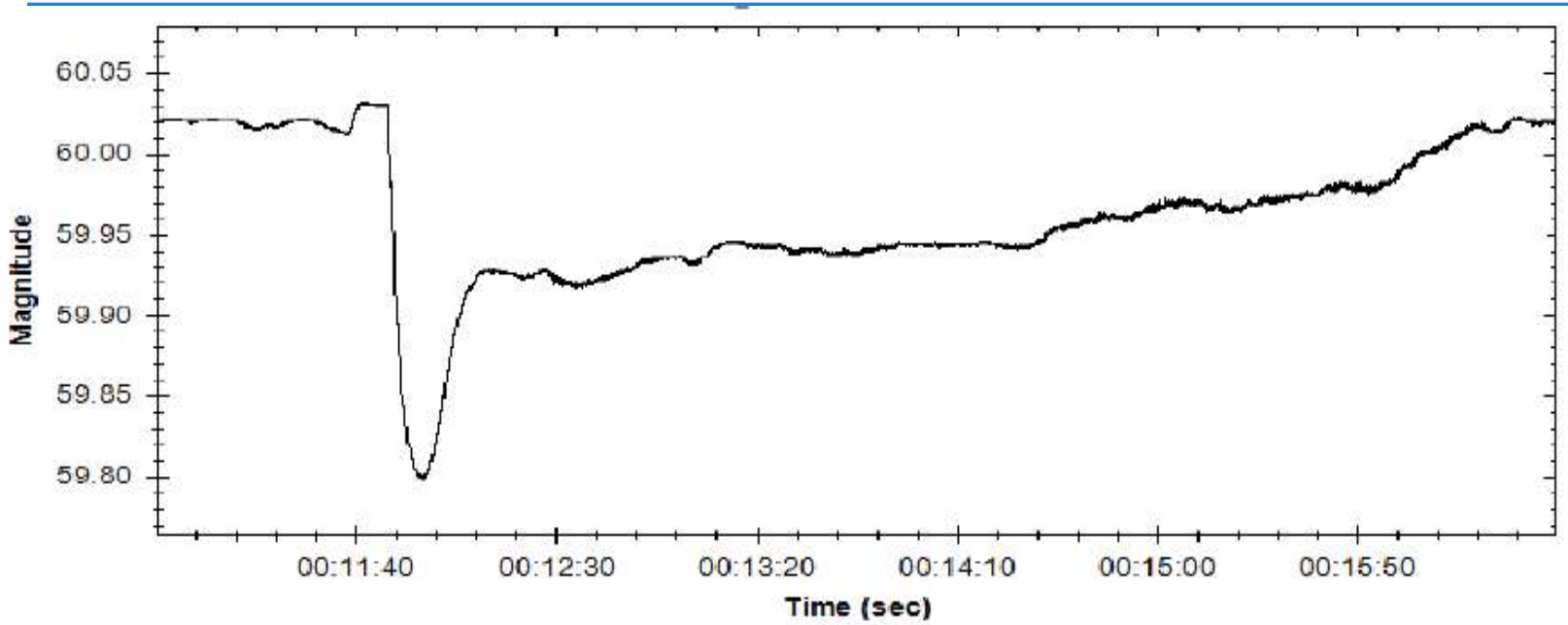
Texas Interconnection Event 5



Generator outage event at 00:11:48

Frequency hits minimum 59.80 Hz at 00:11:51

Recovers to 60 Hz by 00:16:09

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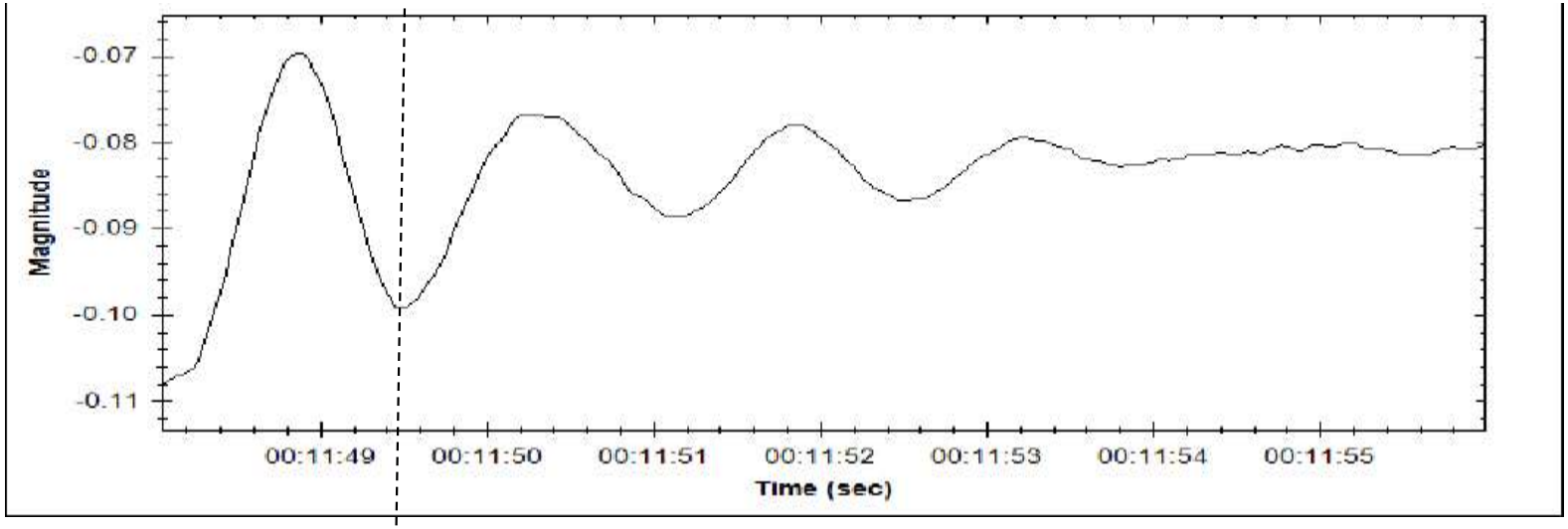
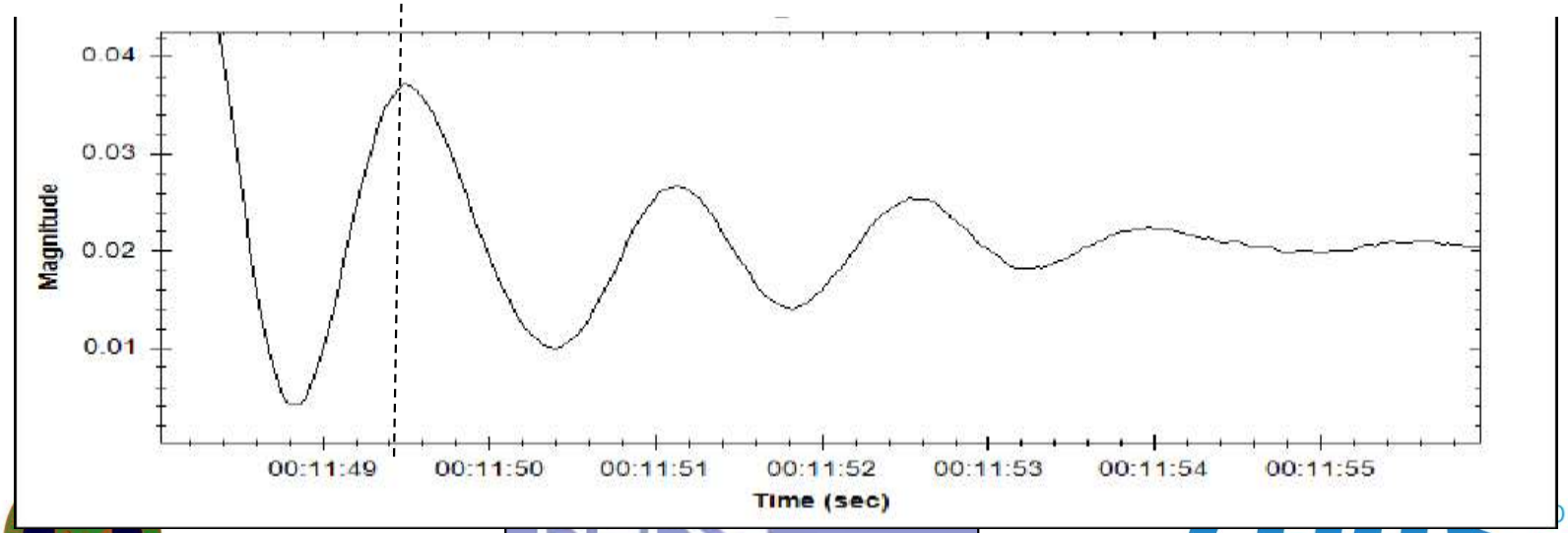
Phase Angles Relative to Center



South Texas



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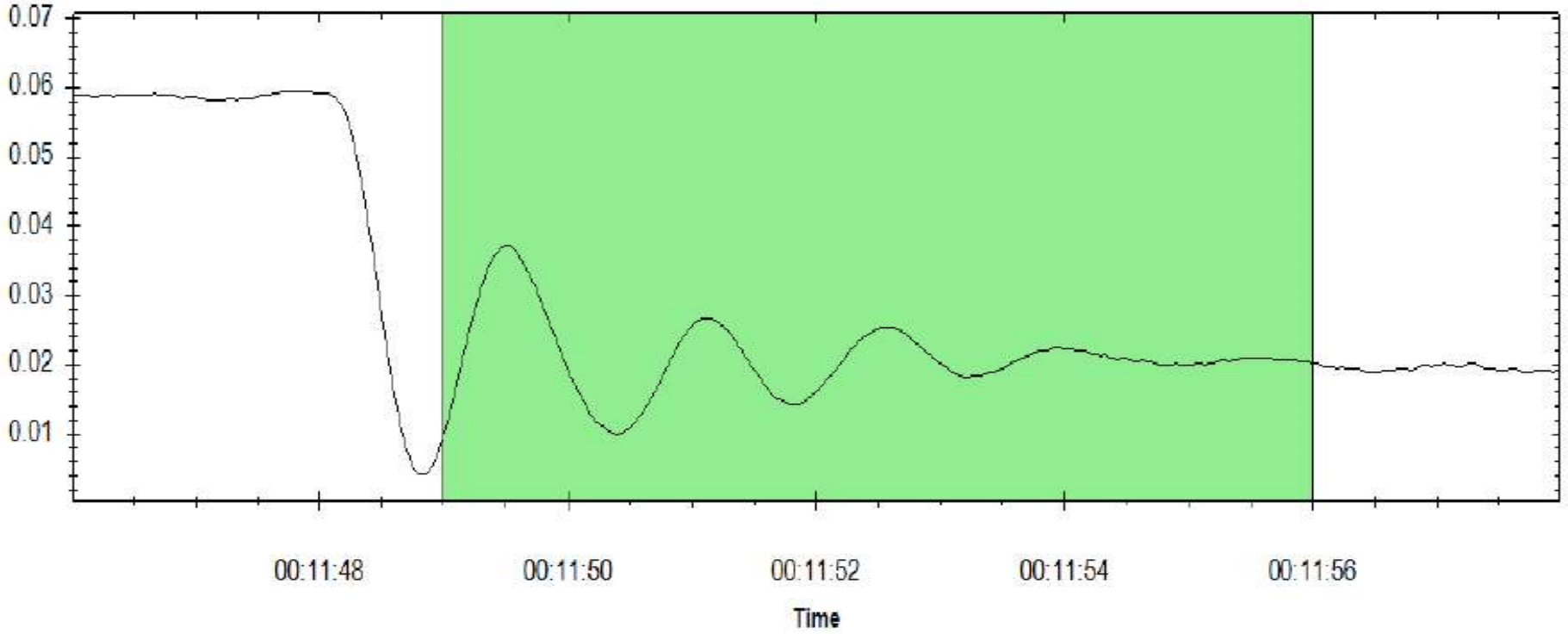
Analysis using Relative Bus Phase Angles (wrt Center)



Ringdown Analysis window from 00:11:49 to 00:11:56

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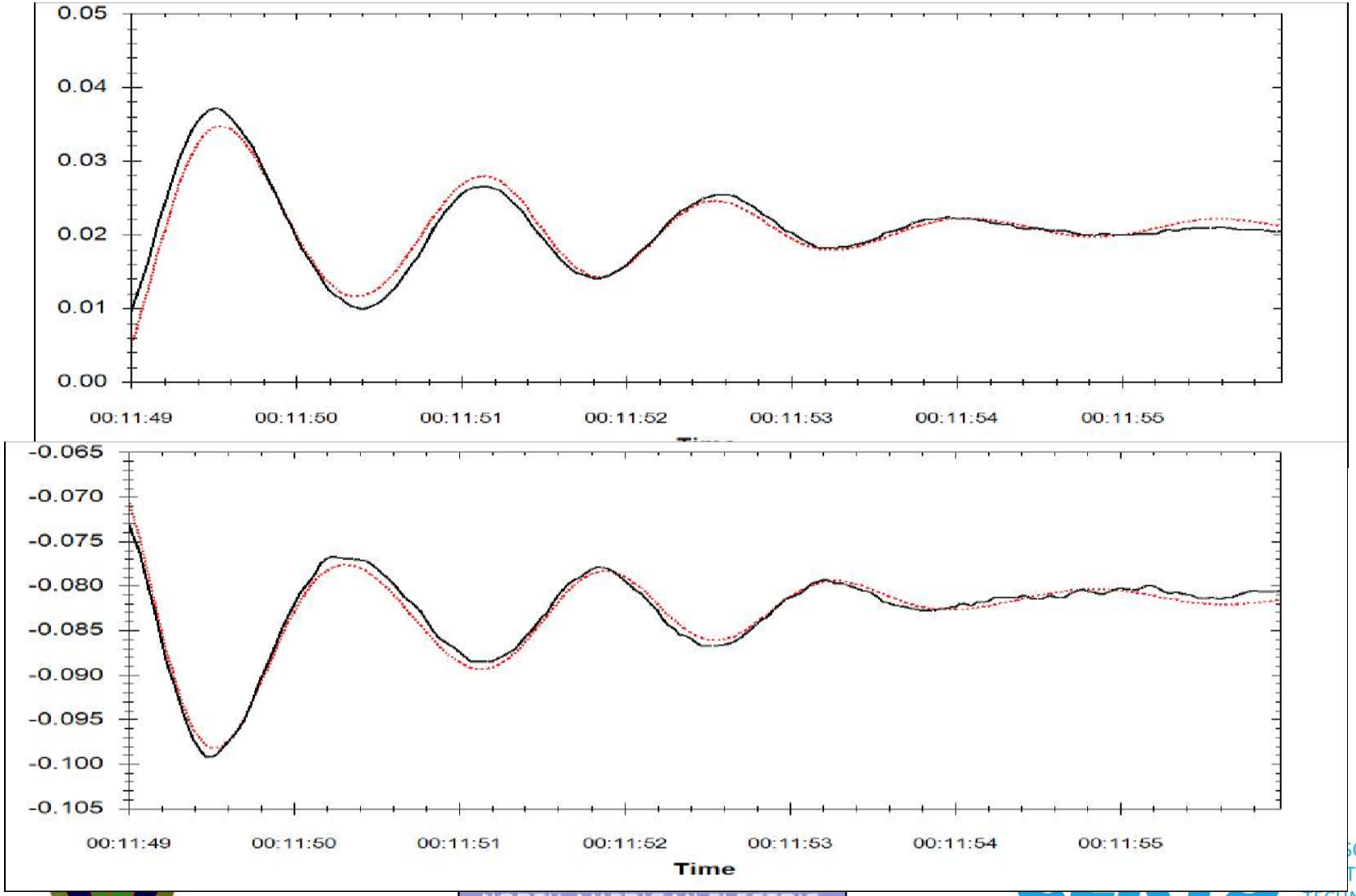
Ringdown Analysis and Reconstructed Signals



South Texas

North Texas

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Ringdown Analysis using ERA

Mode Frequency (Hz)	Damping Ratio (%)	Relative Energy
0.67	11	95

- Modes with relative energy less than 10% are not shown.
- 13 Relative bus voltage phase angle signals used.
- HTLS, ERA, Matrix Pencil and Prony agree for the main 0.67 Hz mode.
- 7 second Analysis window.

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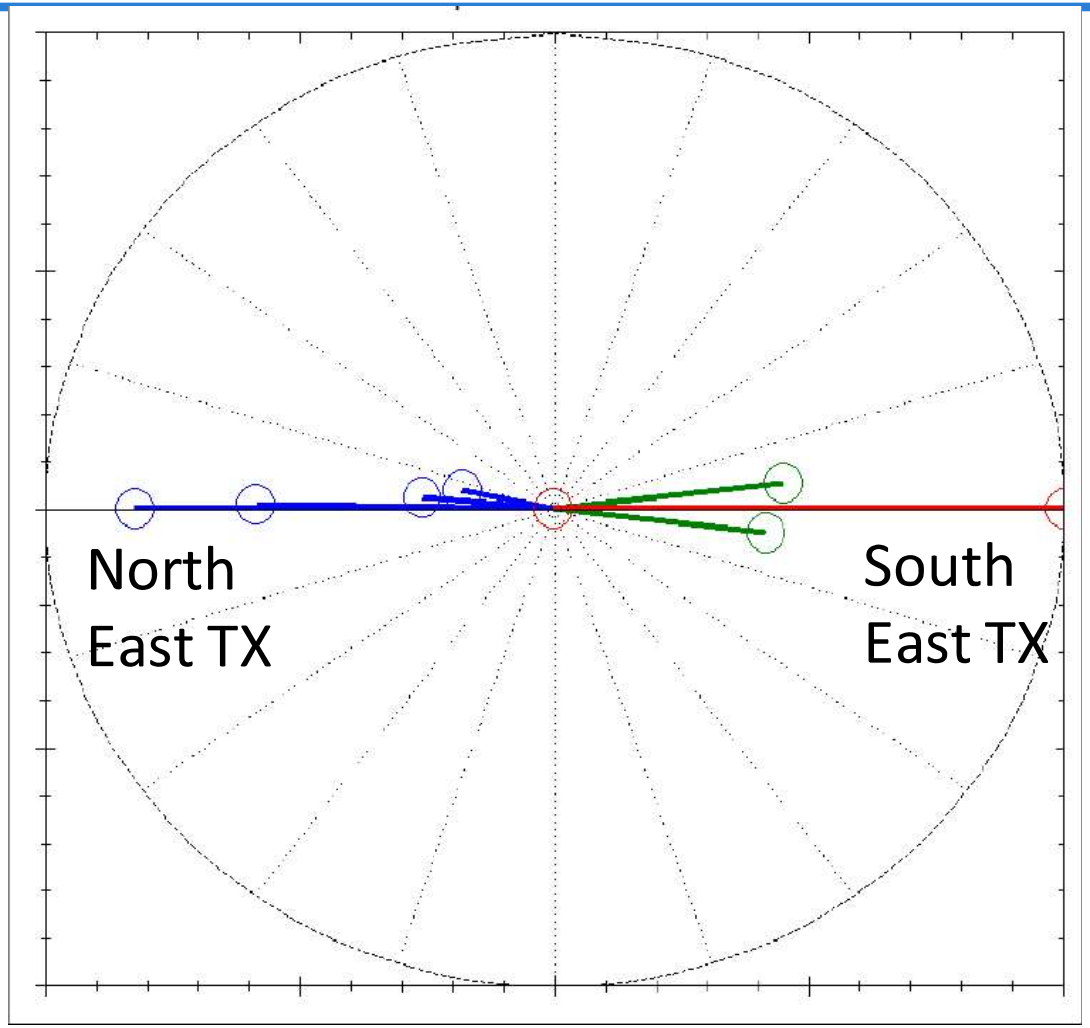
Mode Shape of the Dominant Mode



0.67 Hz at around 11% damping ratio

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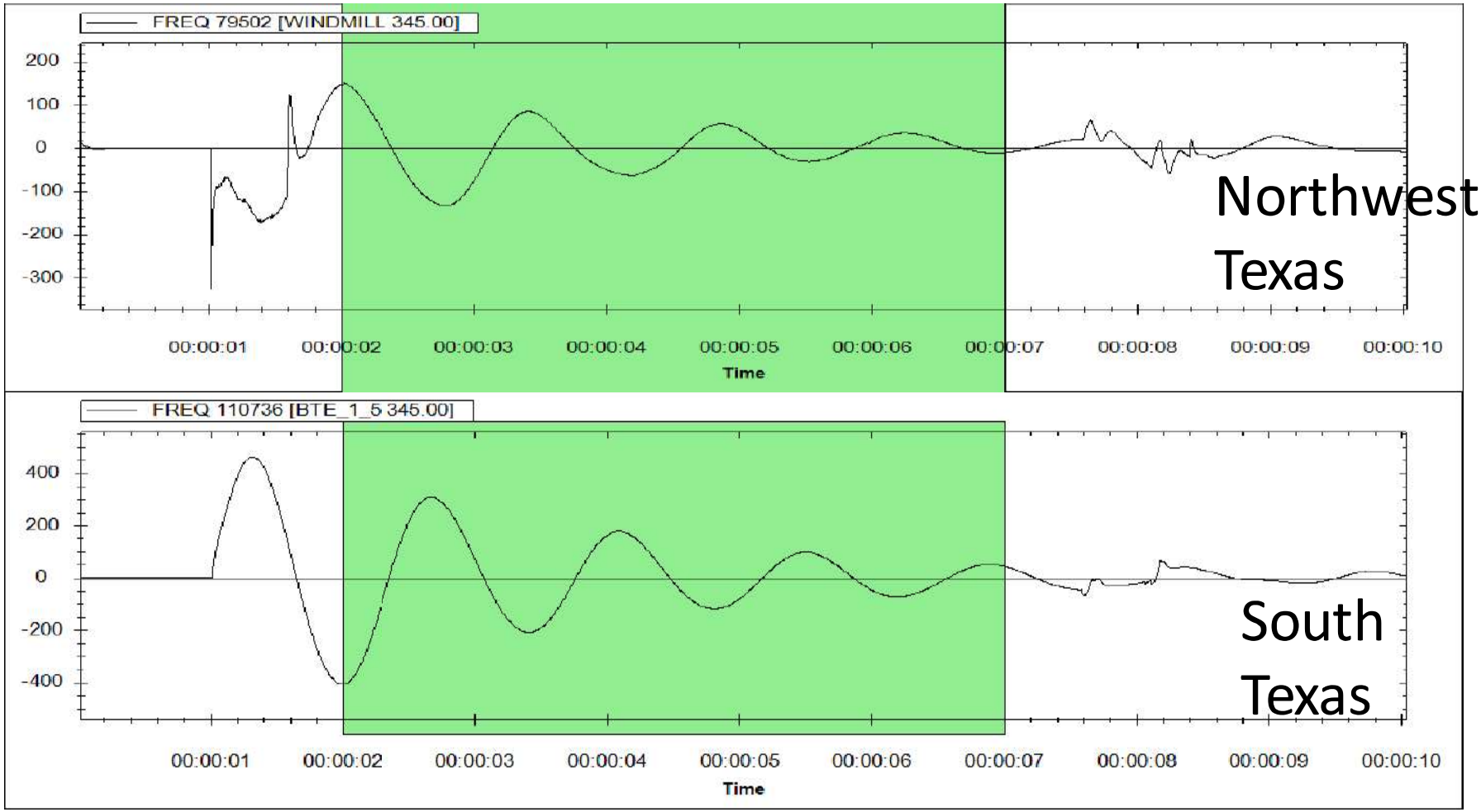
Simulated Case 1 Frequencies wrt Panda



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Ringdown Analysis Results for Window 2 to 7 sec

Method	Prony	Matrix Pencil	HTLS	ERA
Mode 1 Freq	0.713	0.713	0.713	0.713
Mode 1 Damp Ratio	9.16	8.67	8.67	8.67
Mode 1 Energy (%)	96.71	99.10	99.10	99.10

- 51 Bus Frequencies (Panda 345 bus freq used as reference)
- Analysis window 2 to 7 seconds
- NORTHDC7_345 and EDISON7A_345 dropped from analysis

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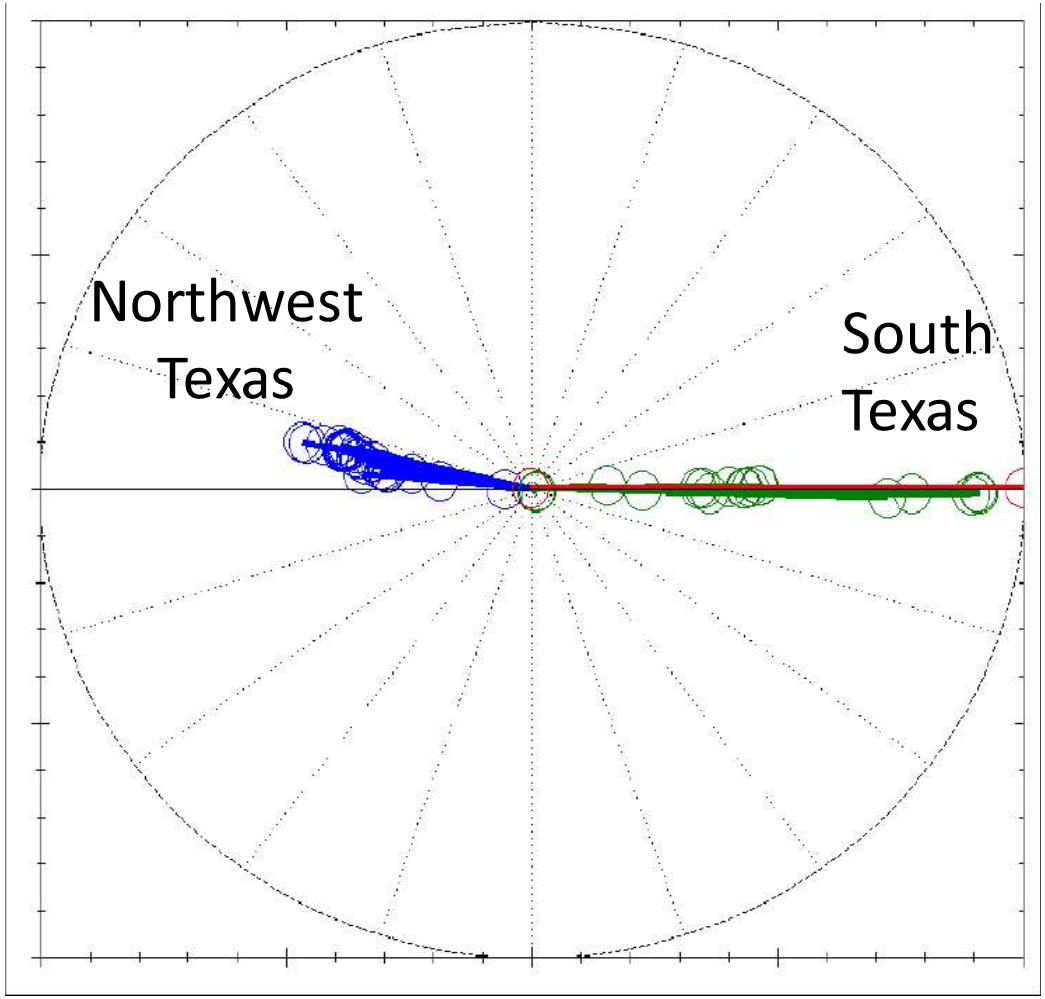
HTLS Mode Shape of 0.71 Hz Mode



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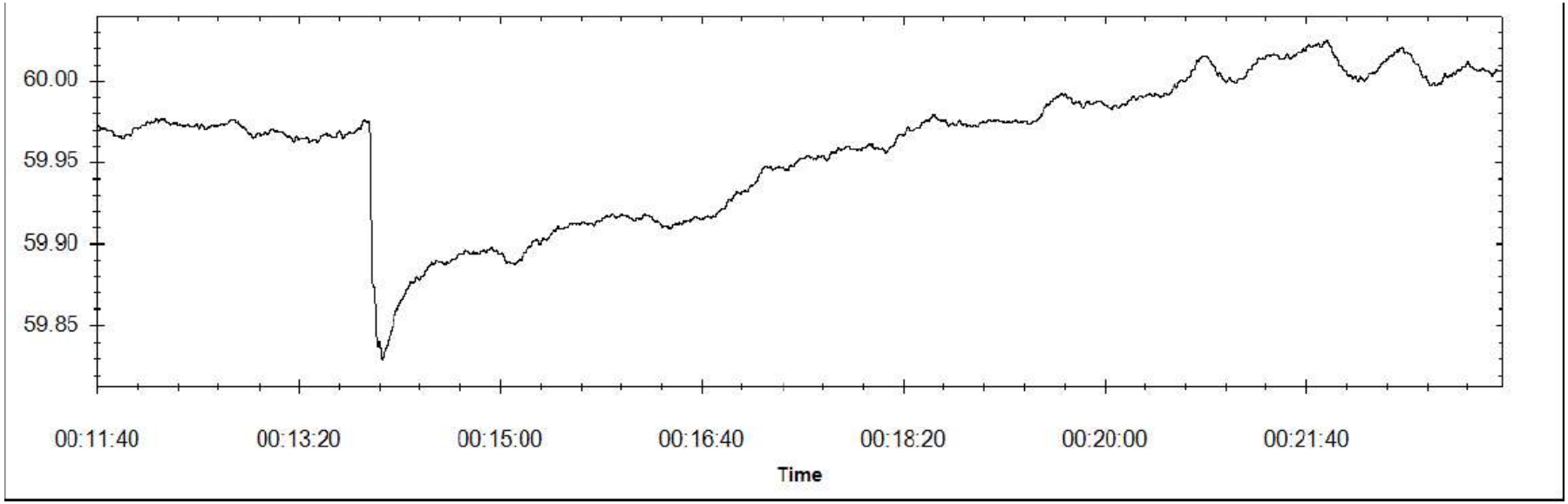
WECC Case 1 Arizona Bus Frequency



Colorado generator outage event at 00:13:55

Frequency hits minimum 59.83 Hz at 00:14:01

Recovers to 60 Hz by 00:20:39.

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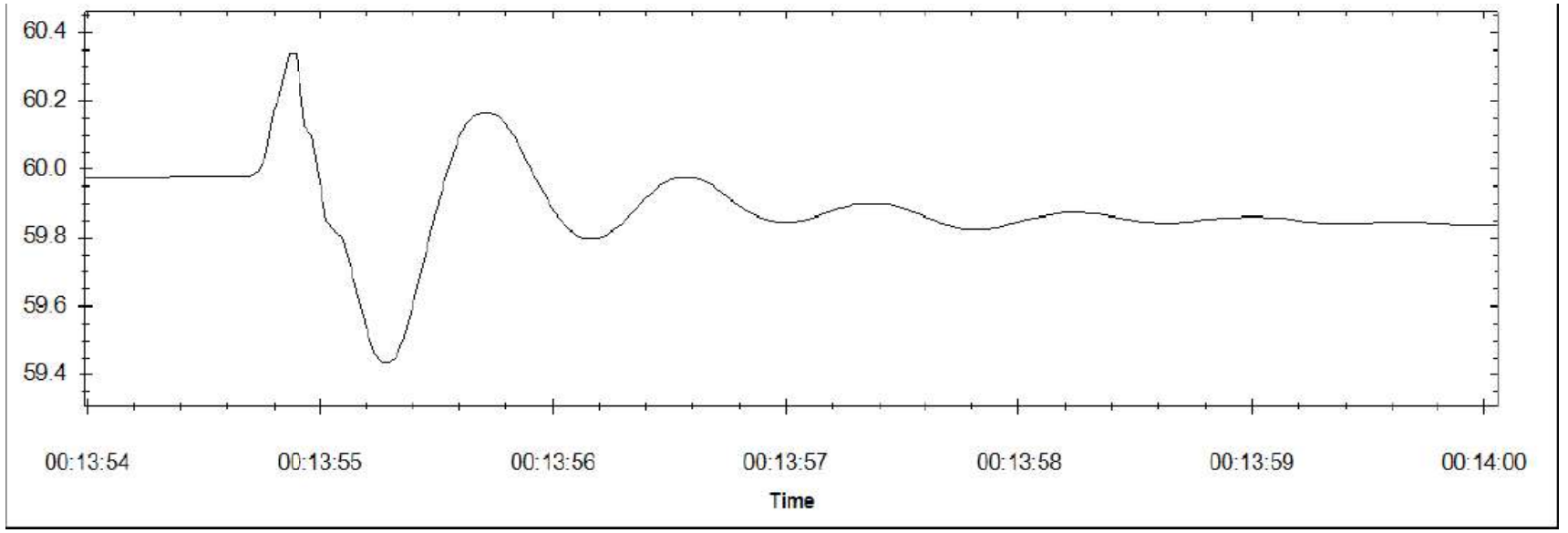
Montana Bus Frequency



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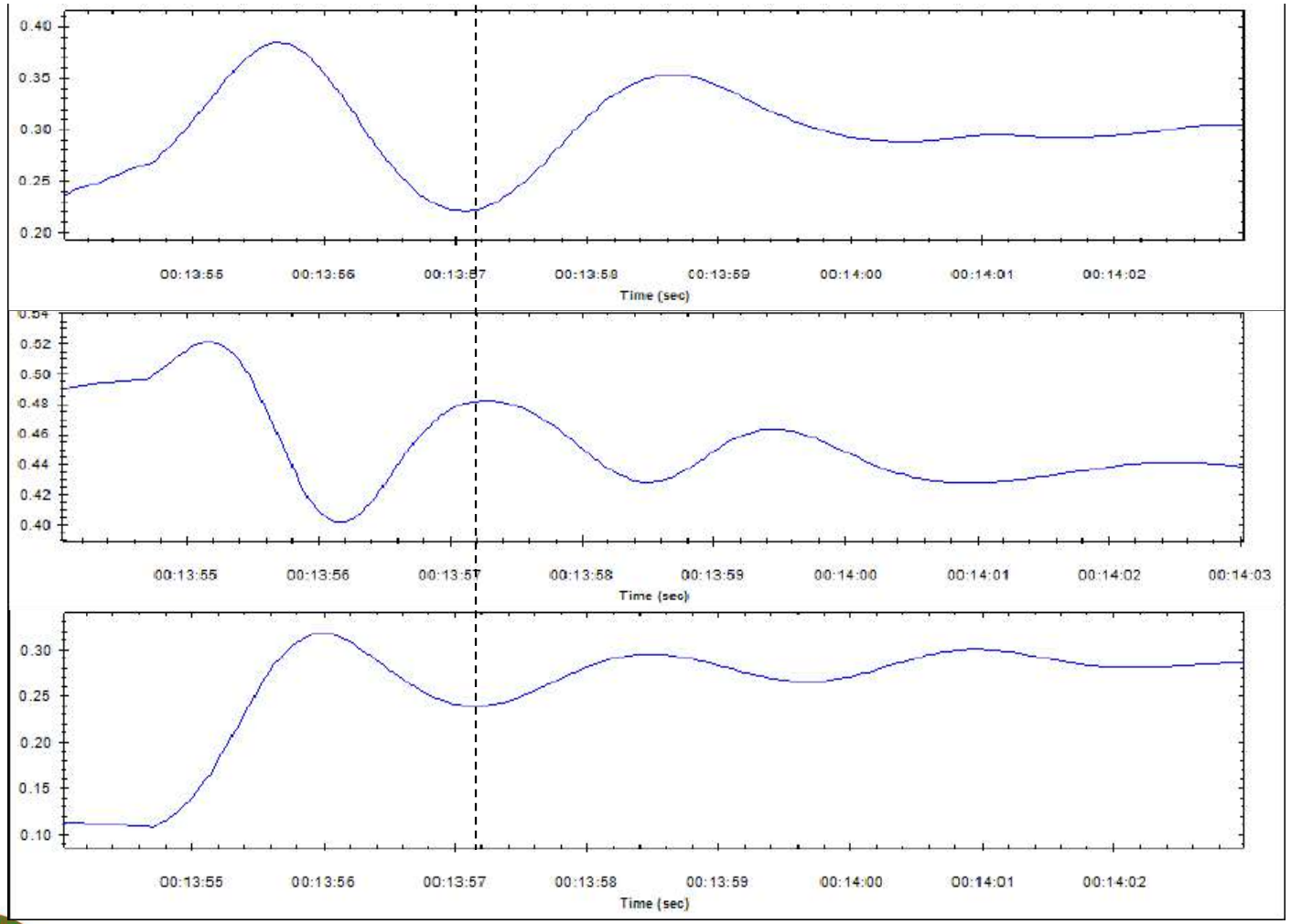
Phase Angles Relative to COI bus



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British Columbia

Arizona

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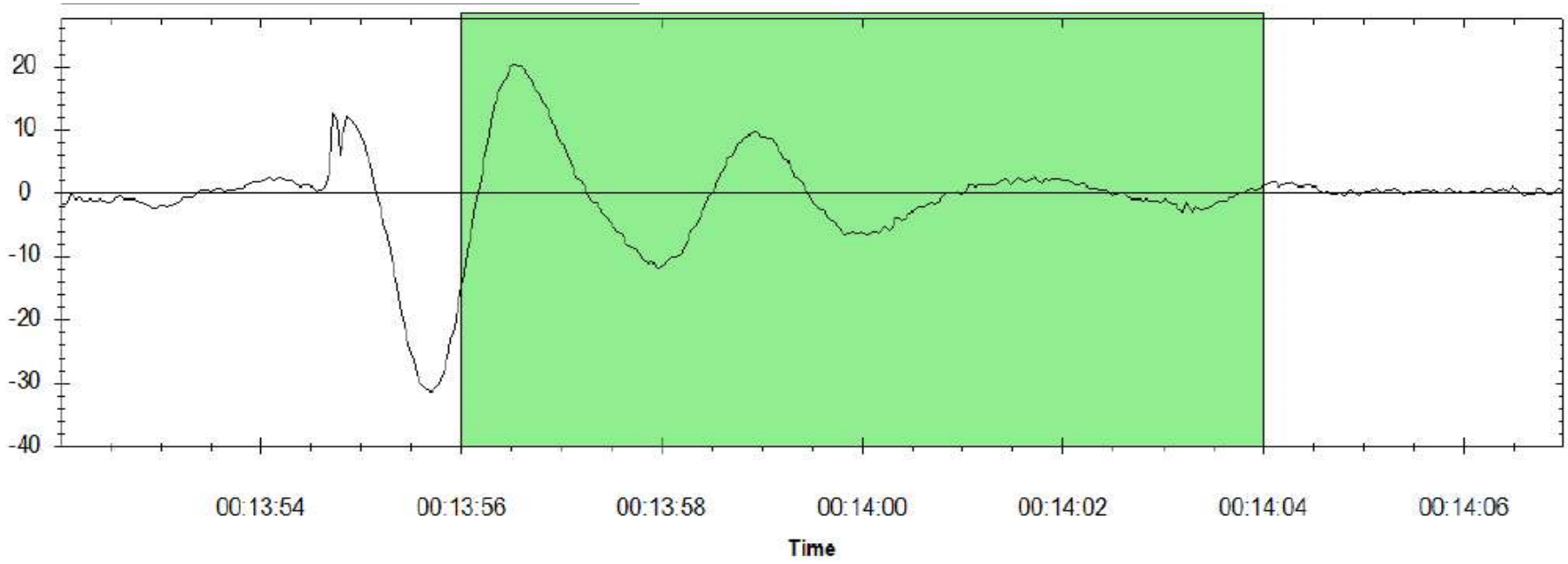
Analysis using Relative Bus Frequencies (wrt COI bus)



Ringdown Analysis window from 00:13:56 to 00:14:04

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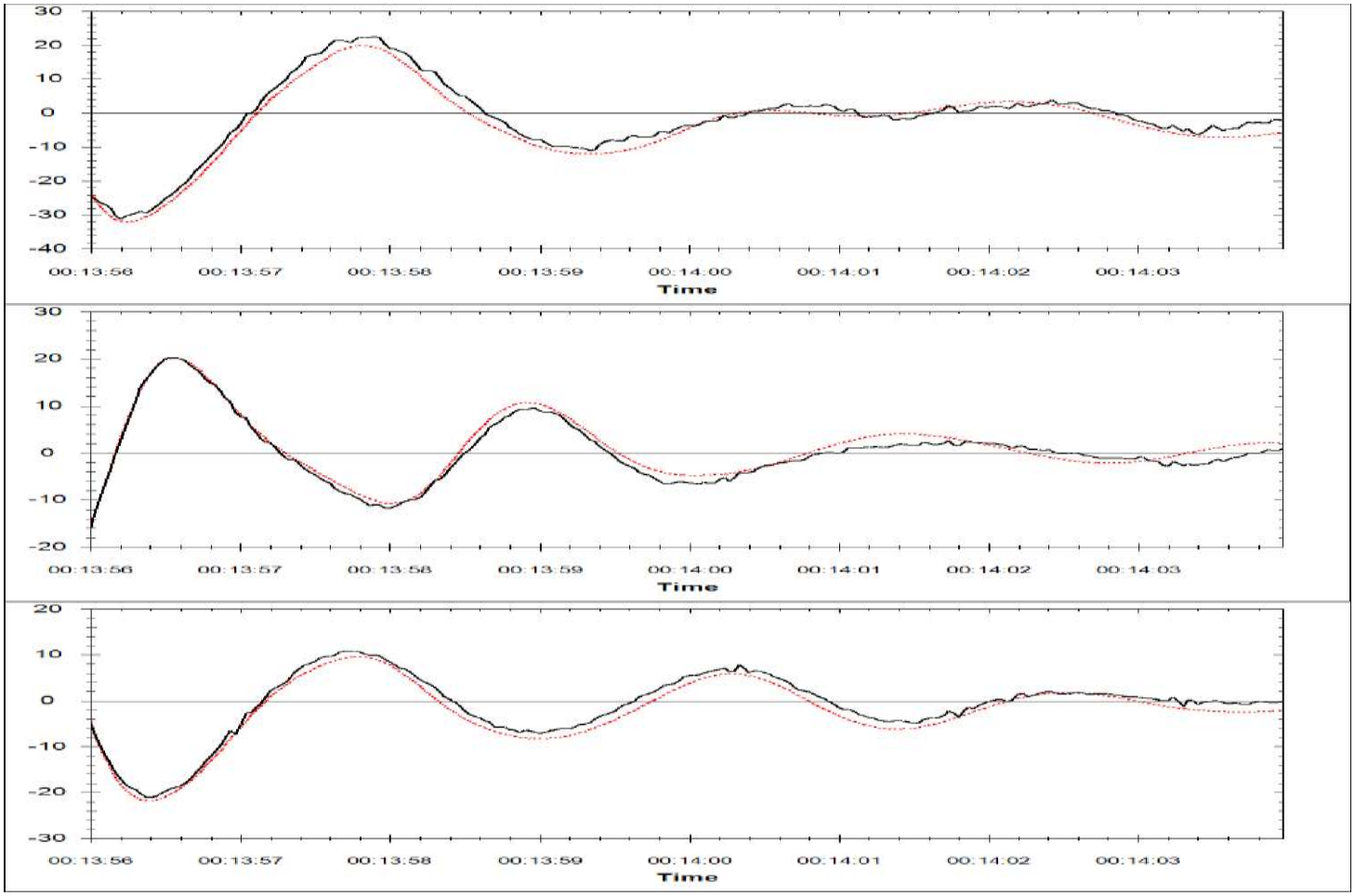
Ringdown Analysis and Reconstructed Signals



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Arizona

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Ringdown Analysis using HTLS

Mode Frequency (Hz)	Damping Ratio (%)	Relative Energy (%)
0.42	12	51
1.29	8	31

- Modes with relative energy less than 10% are not shown.
- 128 Relative bus frequency signals used.
- HTLS, ERA, Matrix Pencil and Prony agree for the main 0.42 Hz mode.
- 8 second Analysis window.

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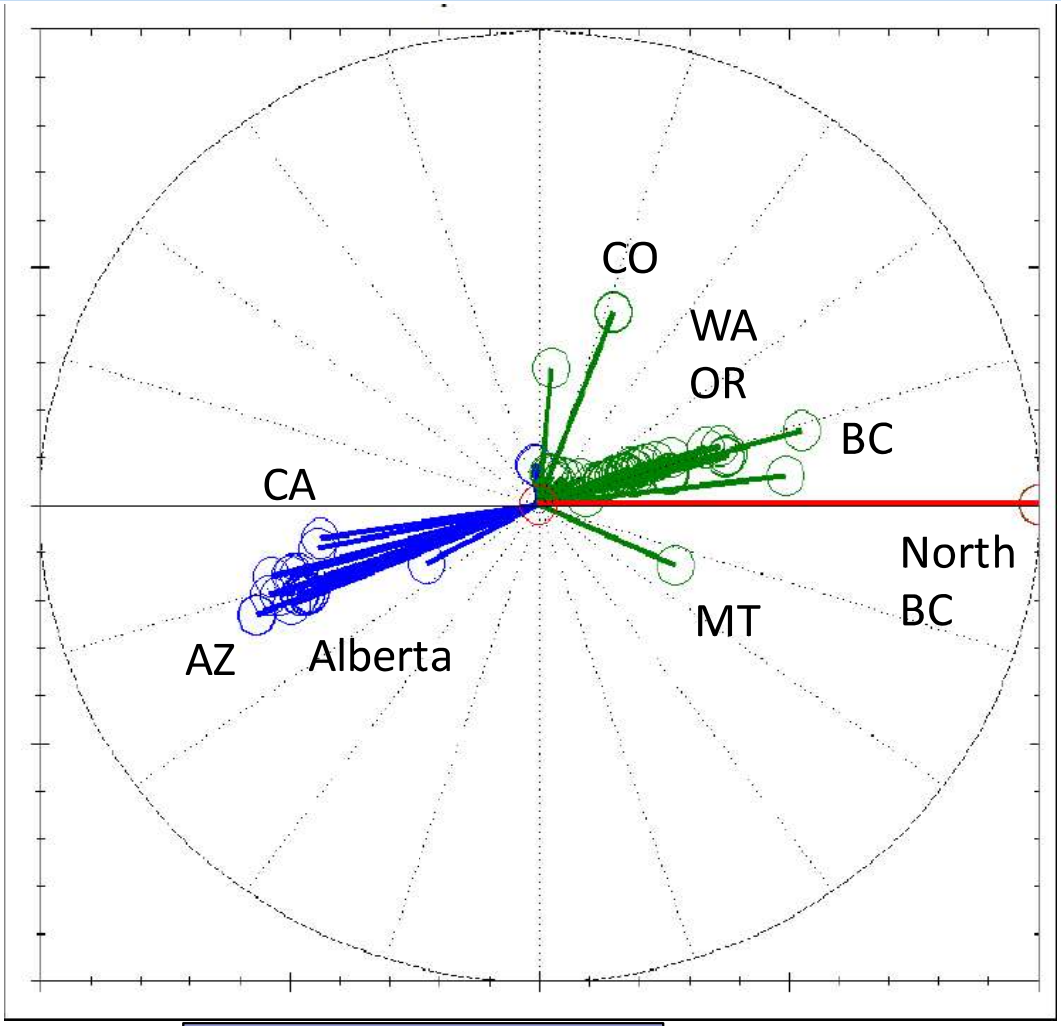
Mode Shape of the 0.42 Hz Mode



0.42 Hz mode at around 12% damping ratio

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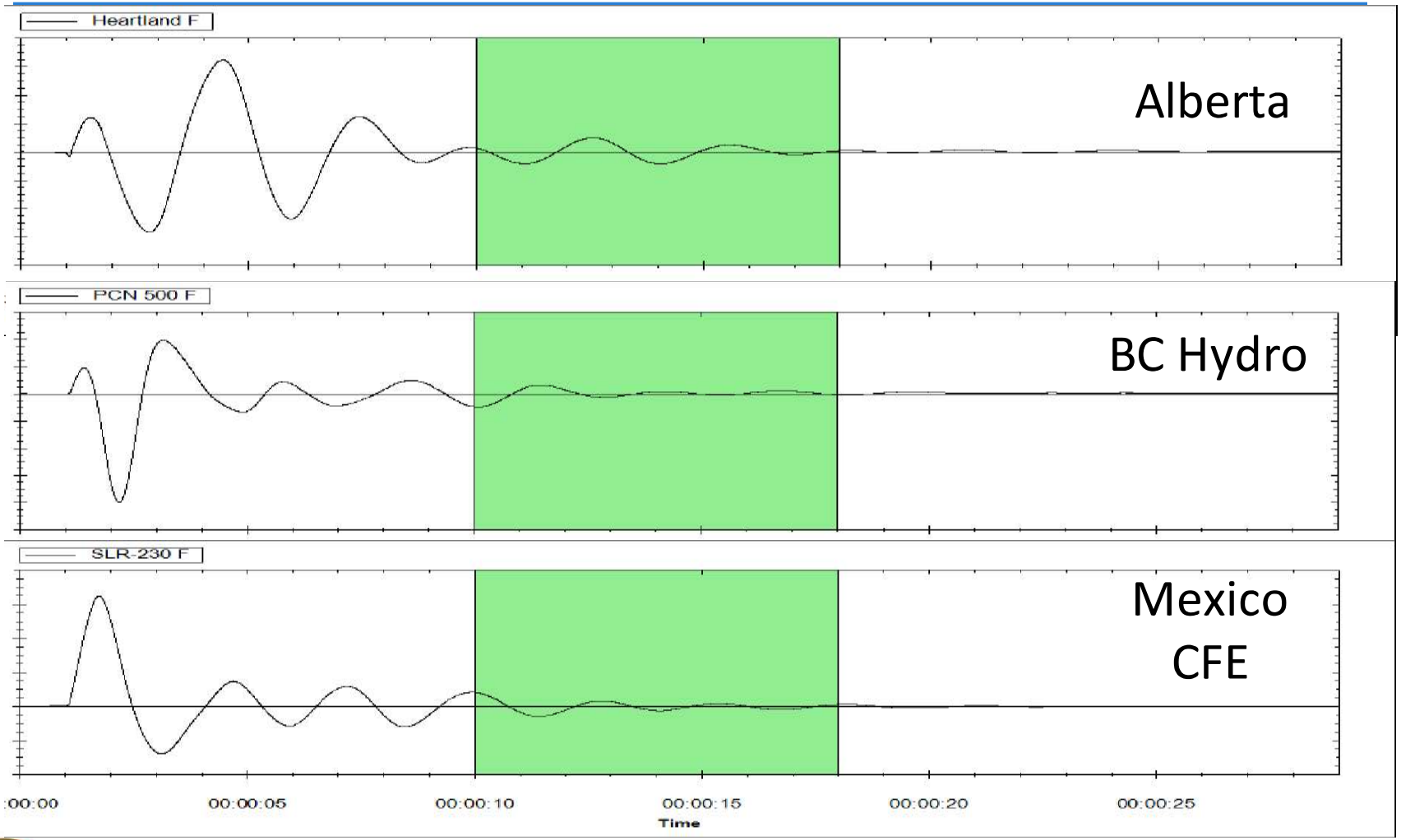
Simulated WECC Case 1 Frequencies wrt Malin



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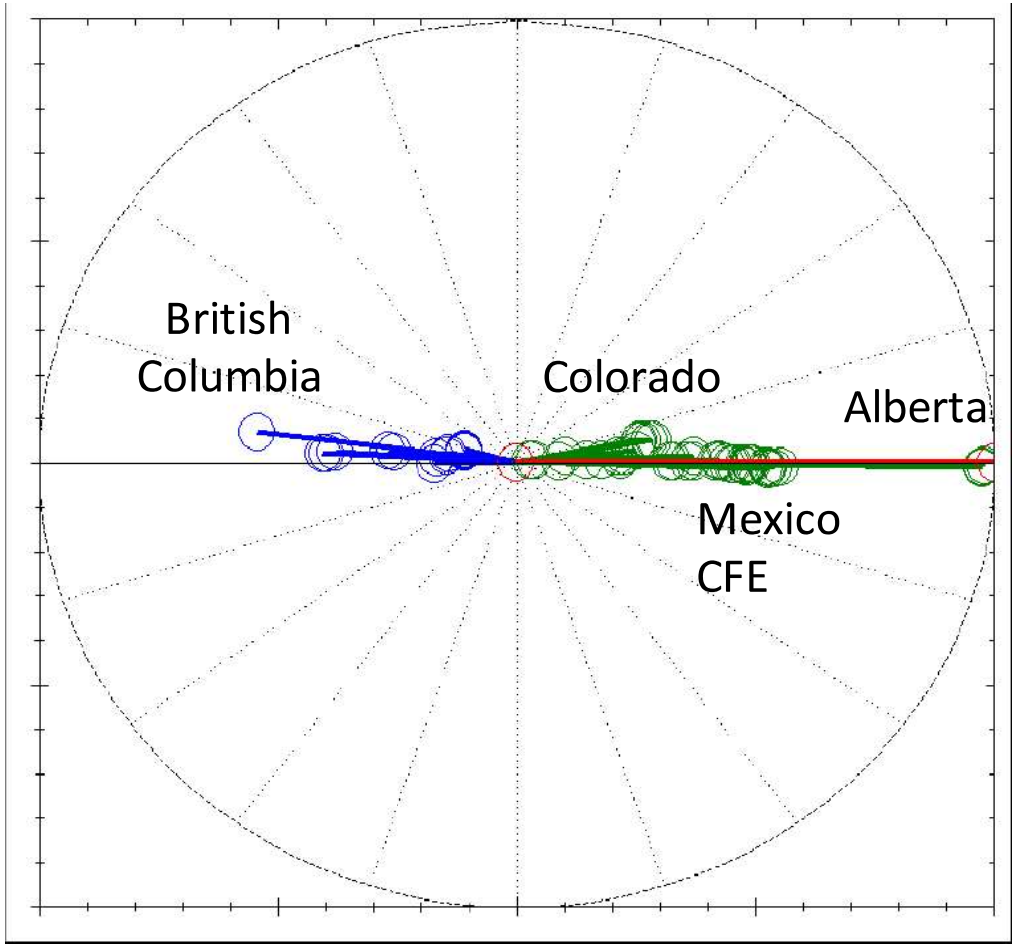
Prony Mode Shape of 0.37 Hz Mode



0.37 Hz mode at around 9% damping ratio

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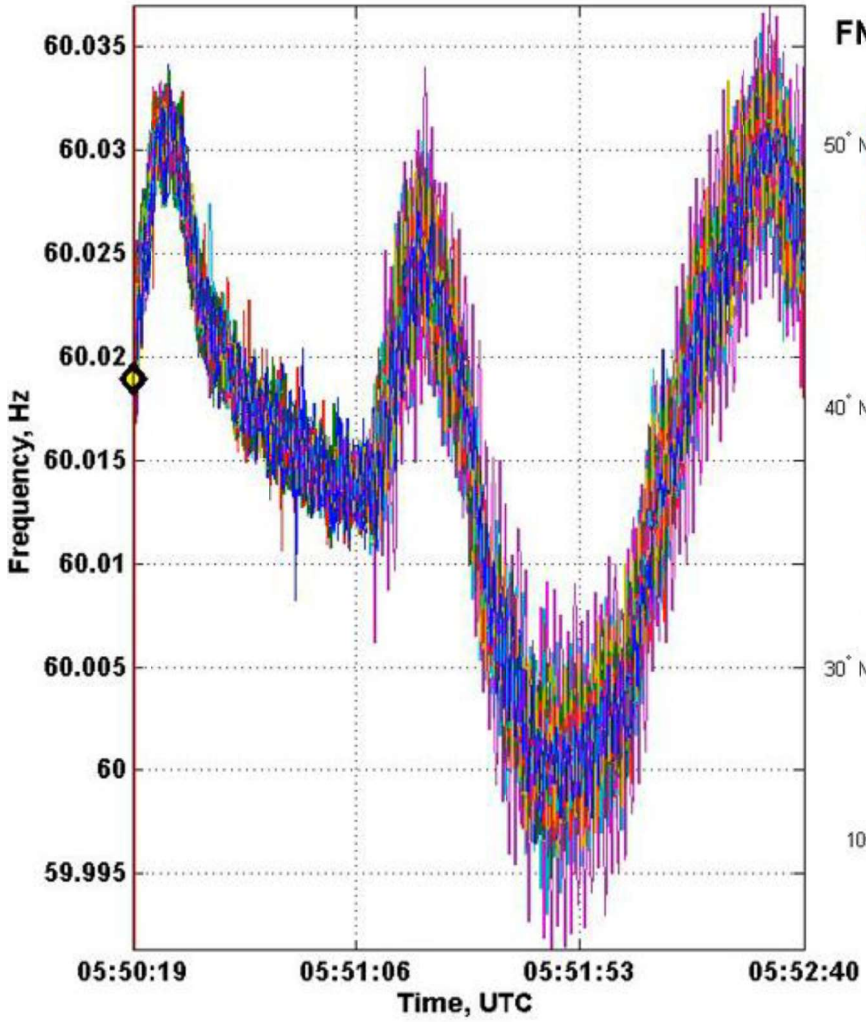
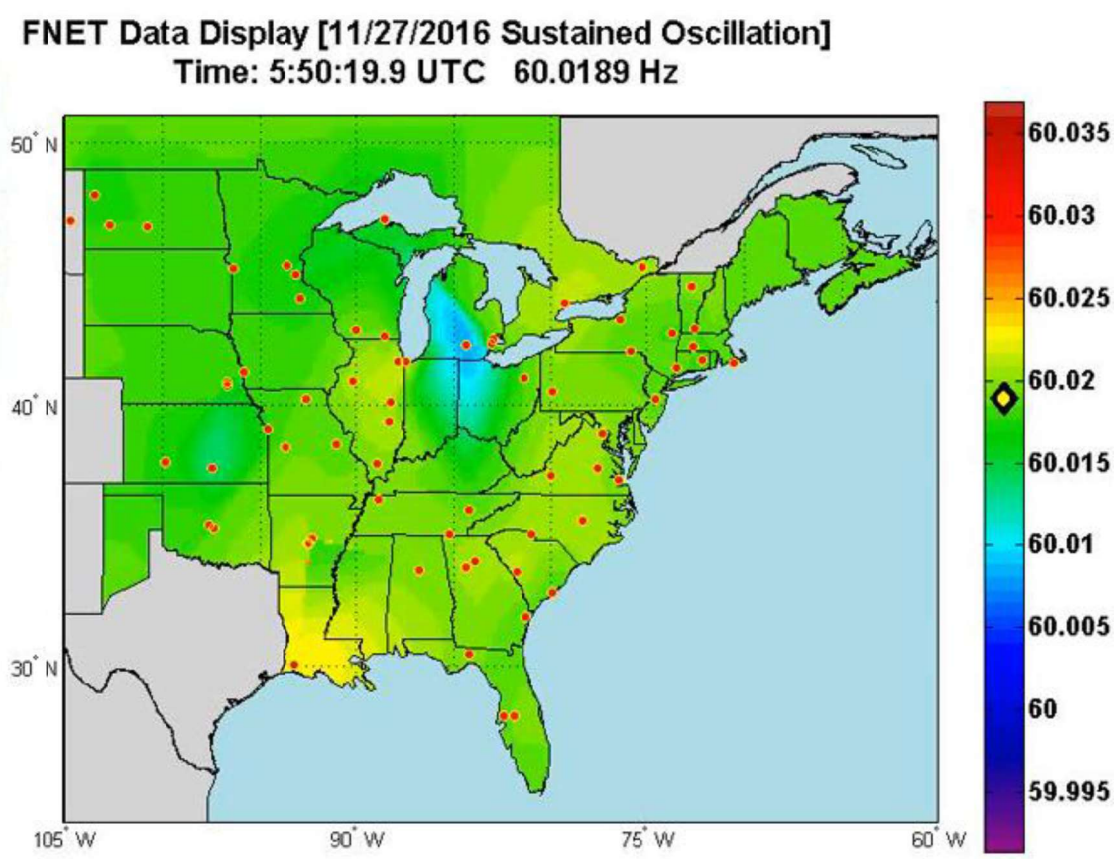
November 27 2016 Eastern Event





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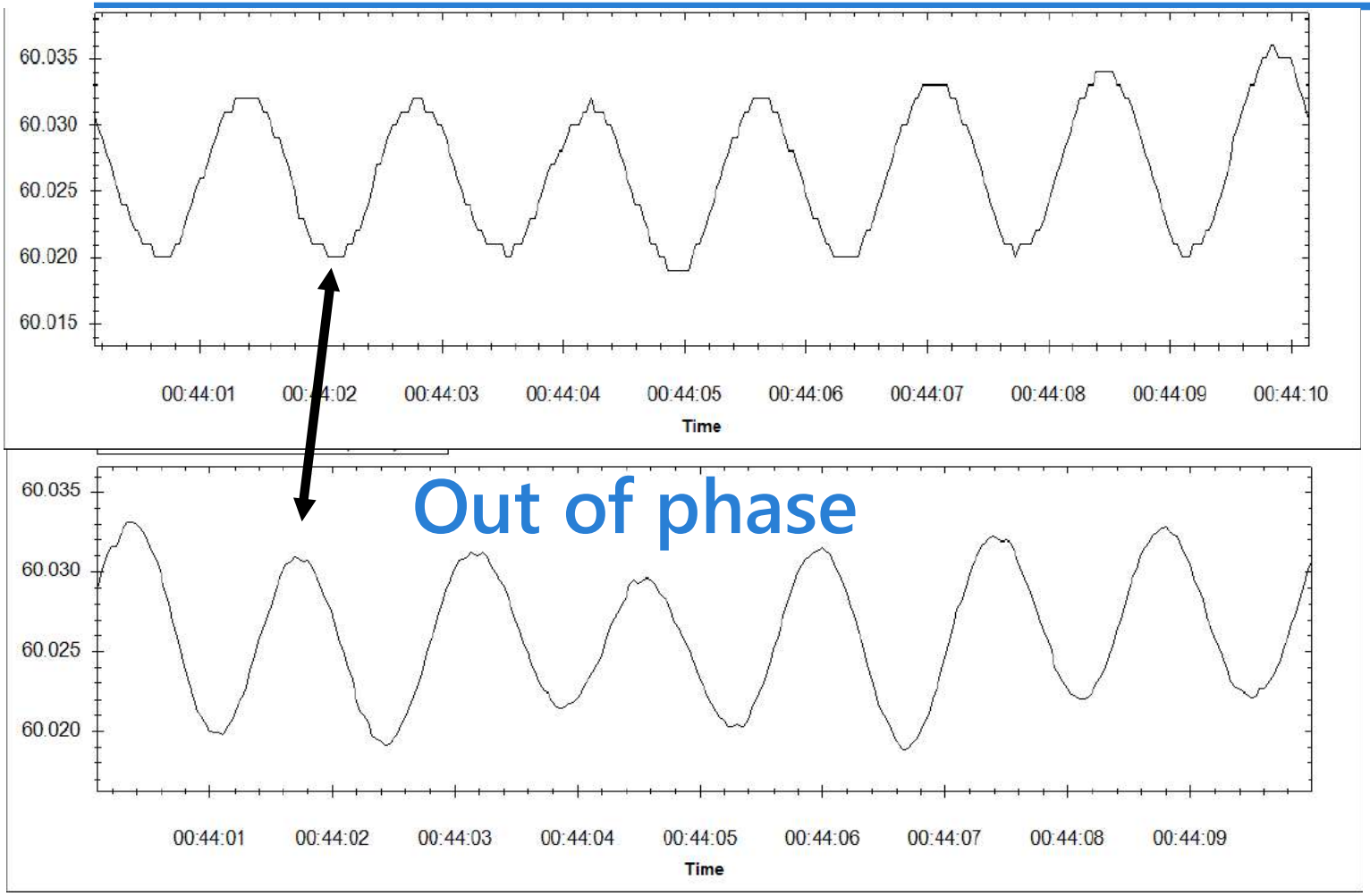
November 27 2016 Bus Frequency Time Plots



Alabama

New Jersey

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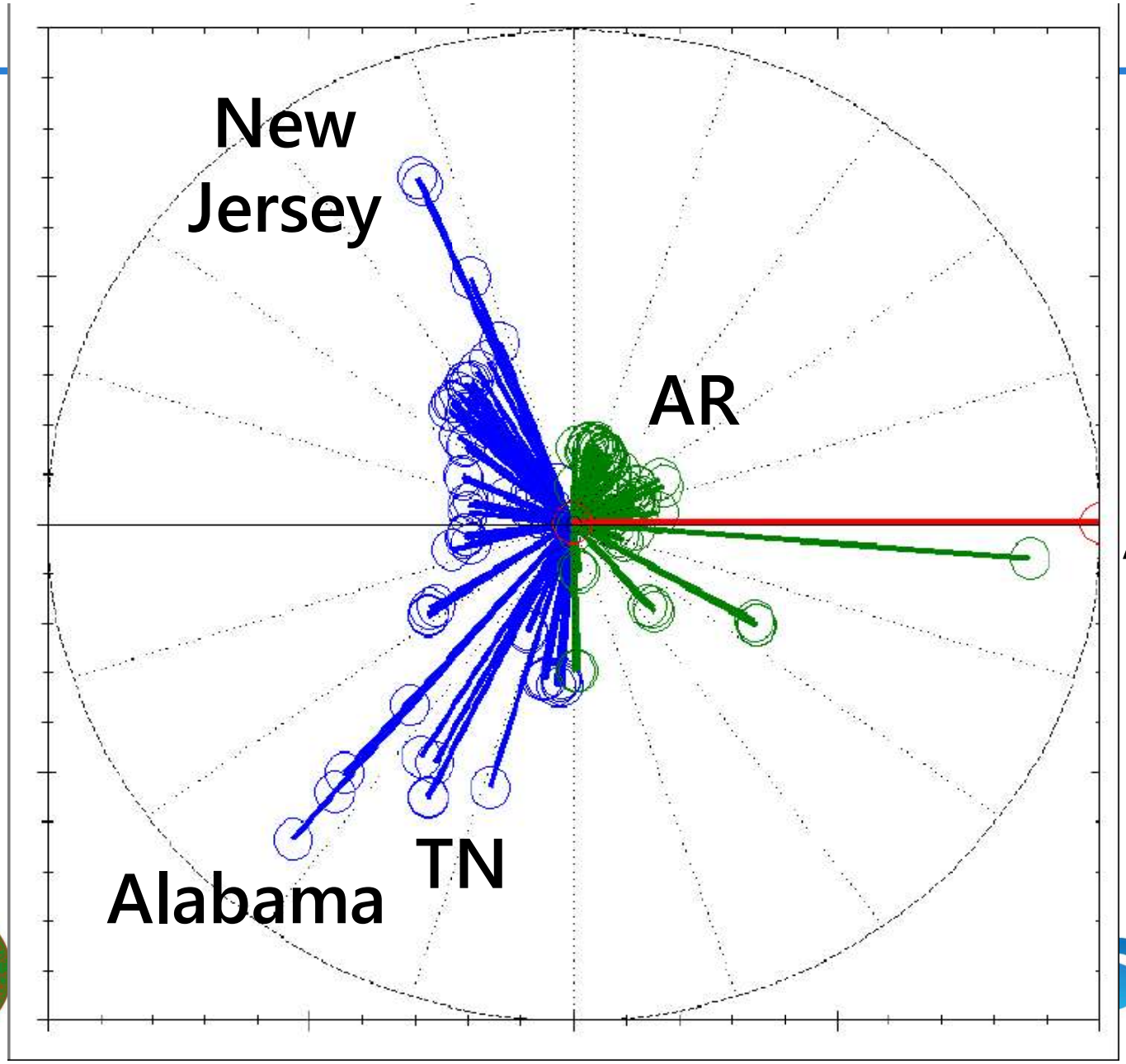
0.7 Hz Oscillation Mode Shape



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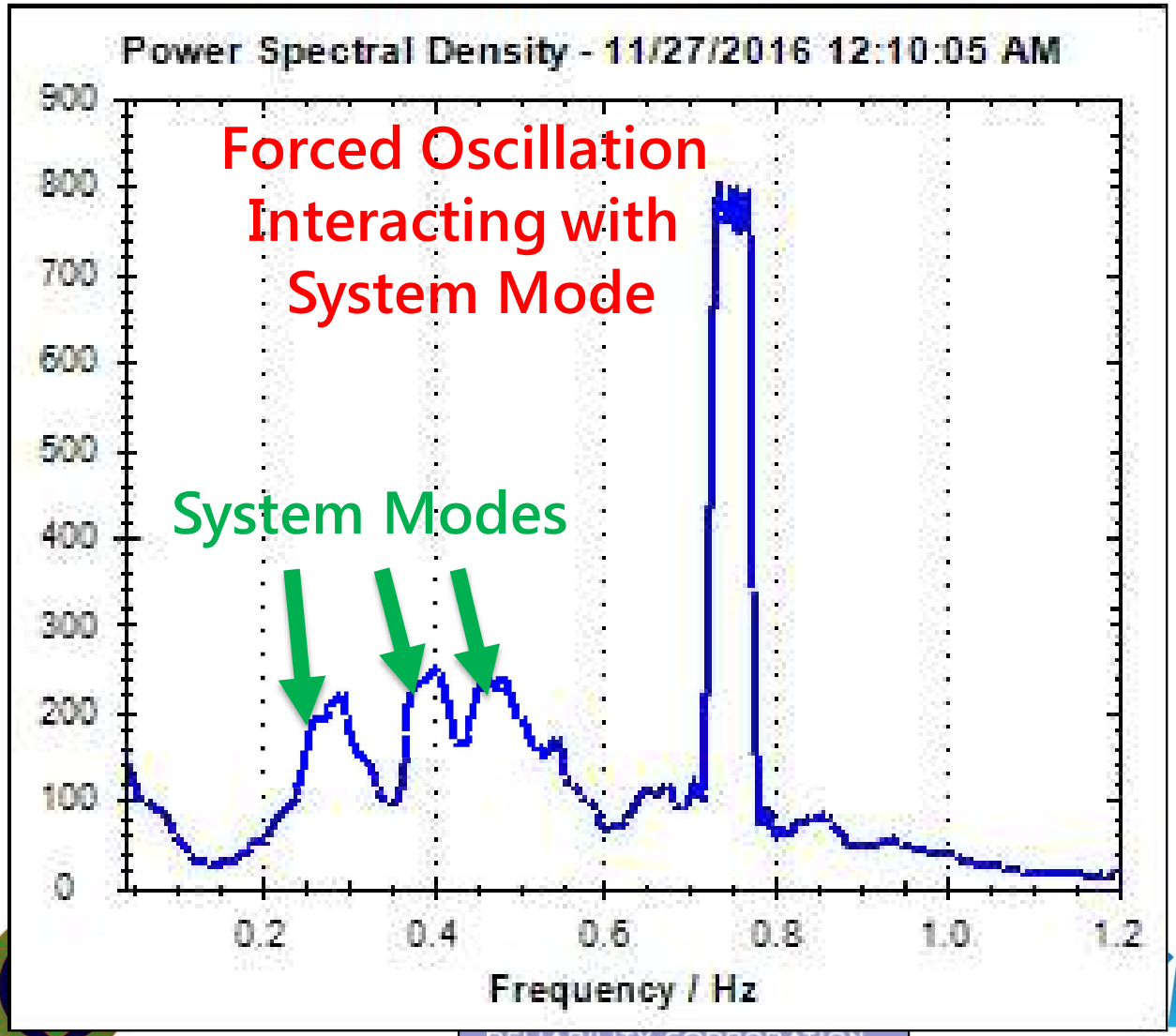
FFDD Power Spectrum@12:10AM (Before)



Main modes

0.25 Hz

0.4 Hz

0.5 Hz

0.75 Hz

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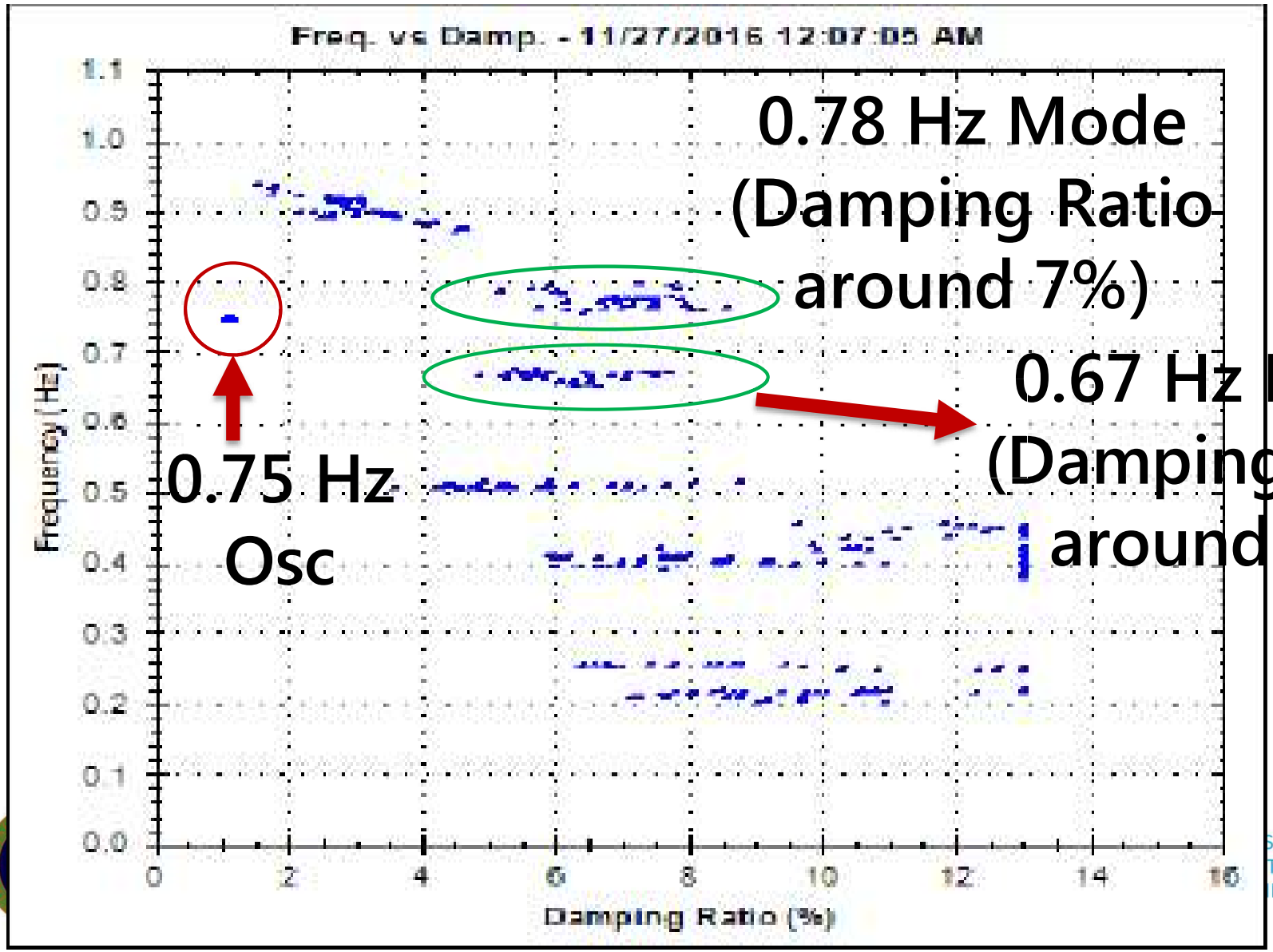
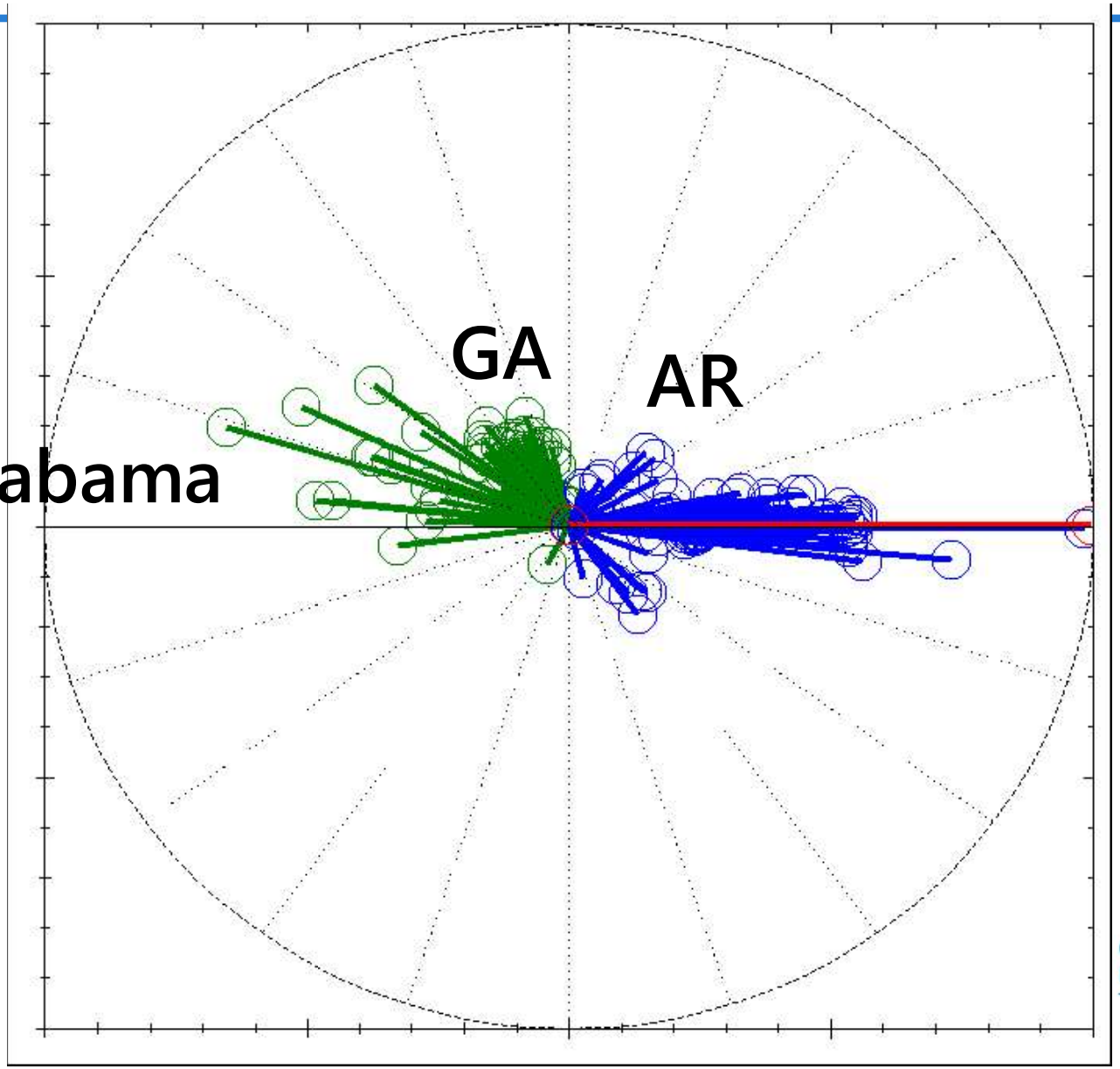
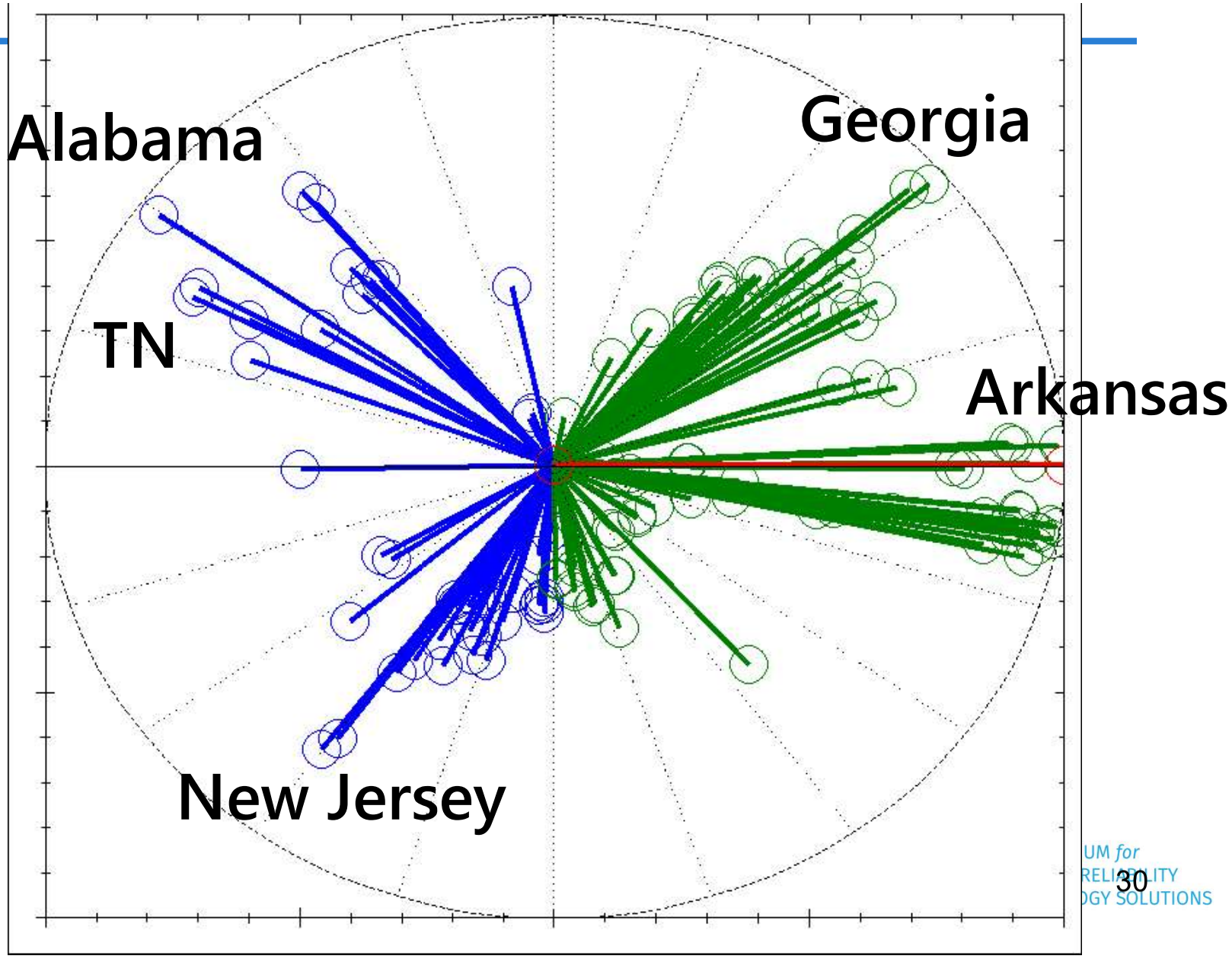
FSSI Estimates Before GA Osc Event



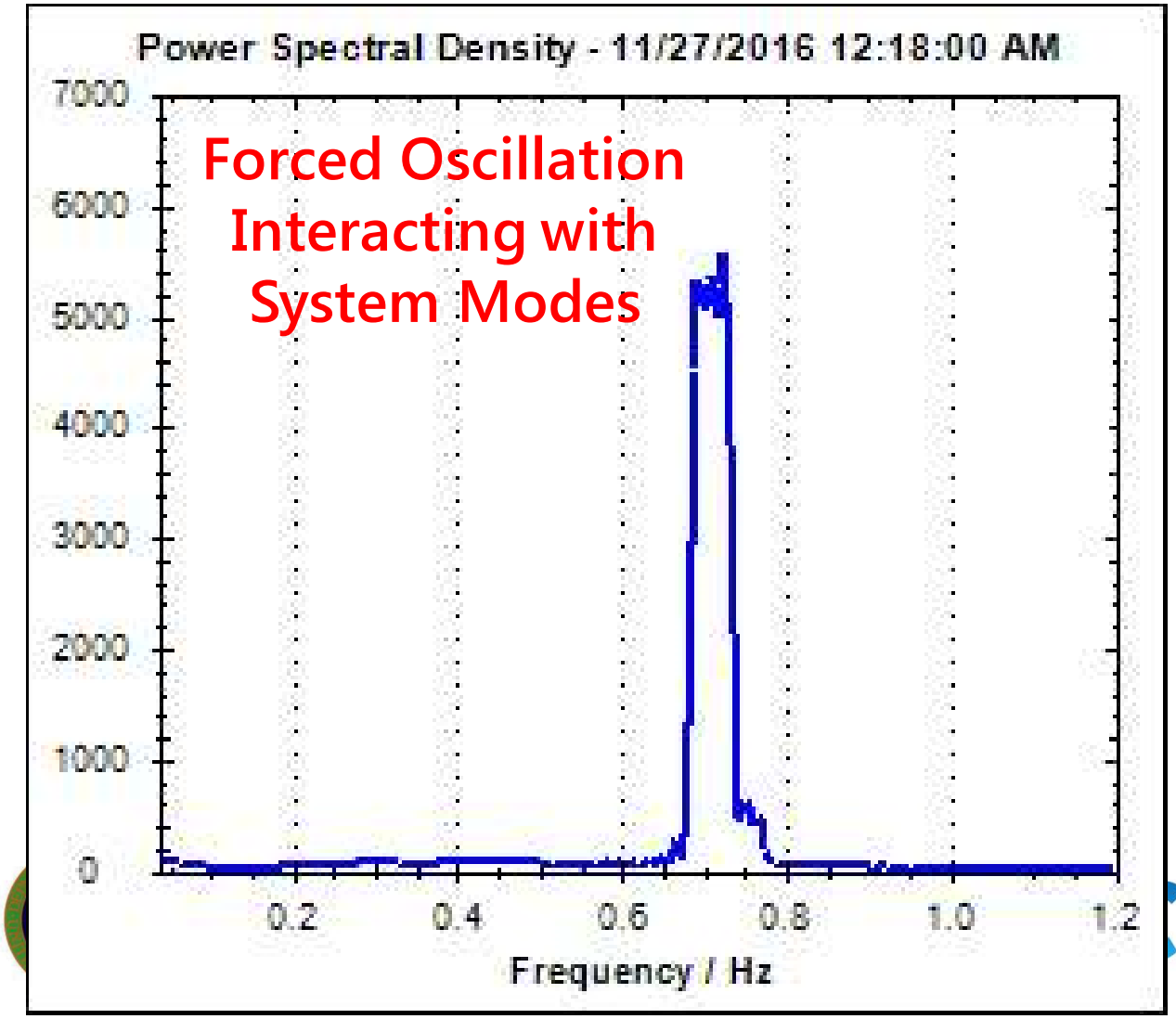
0.67 Hz System Mode Shape from FSSI



0.78 Hz System Mode Shape from FSSI



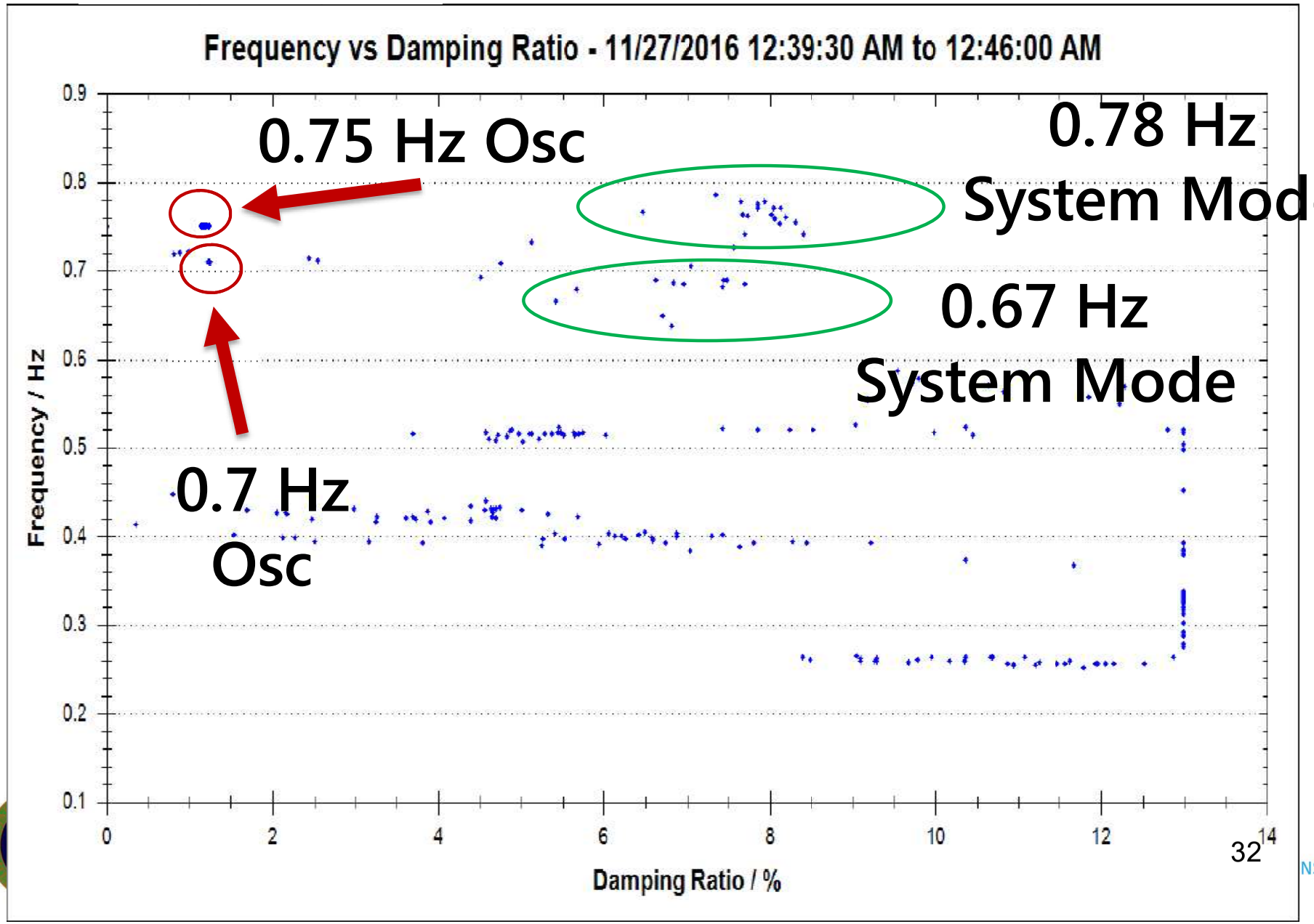
Power Spectrum @ 3:15 AM (During)



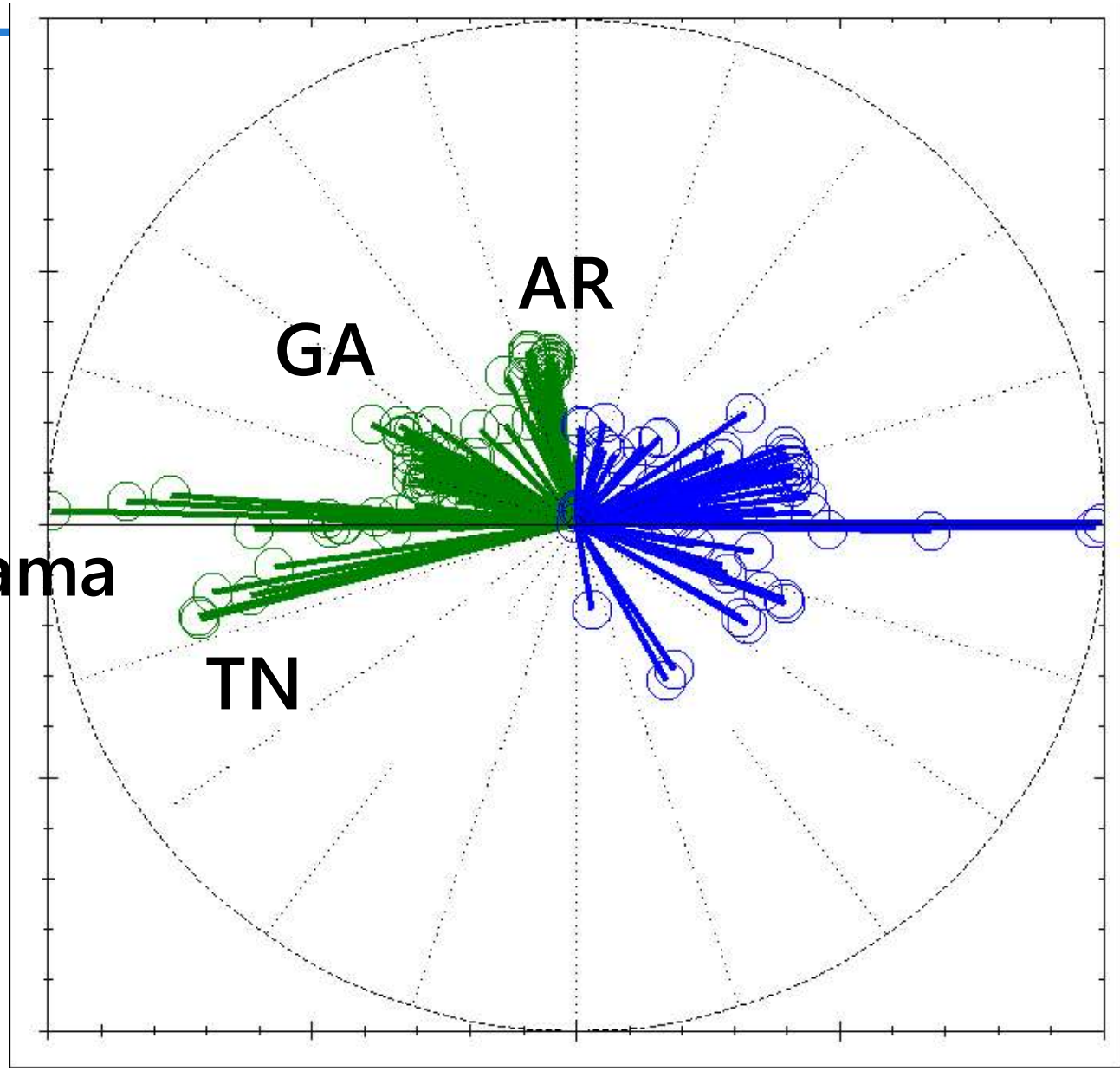
Main mode

0.75 Hz

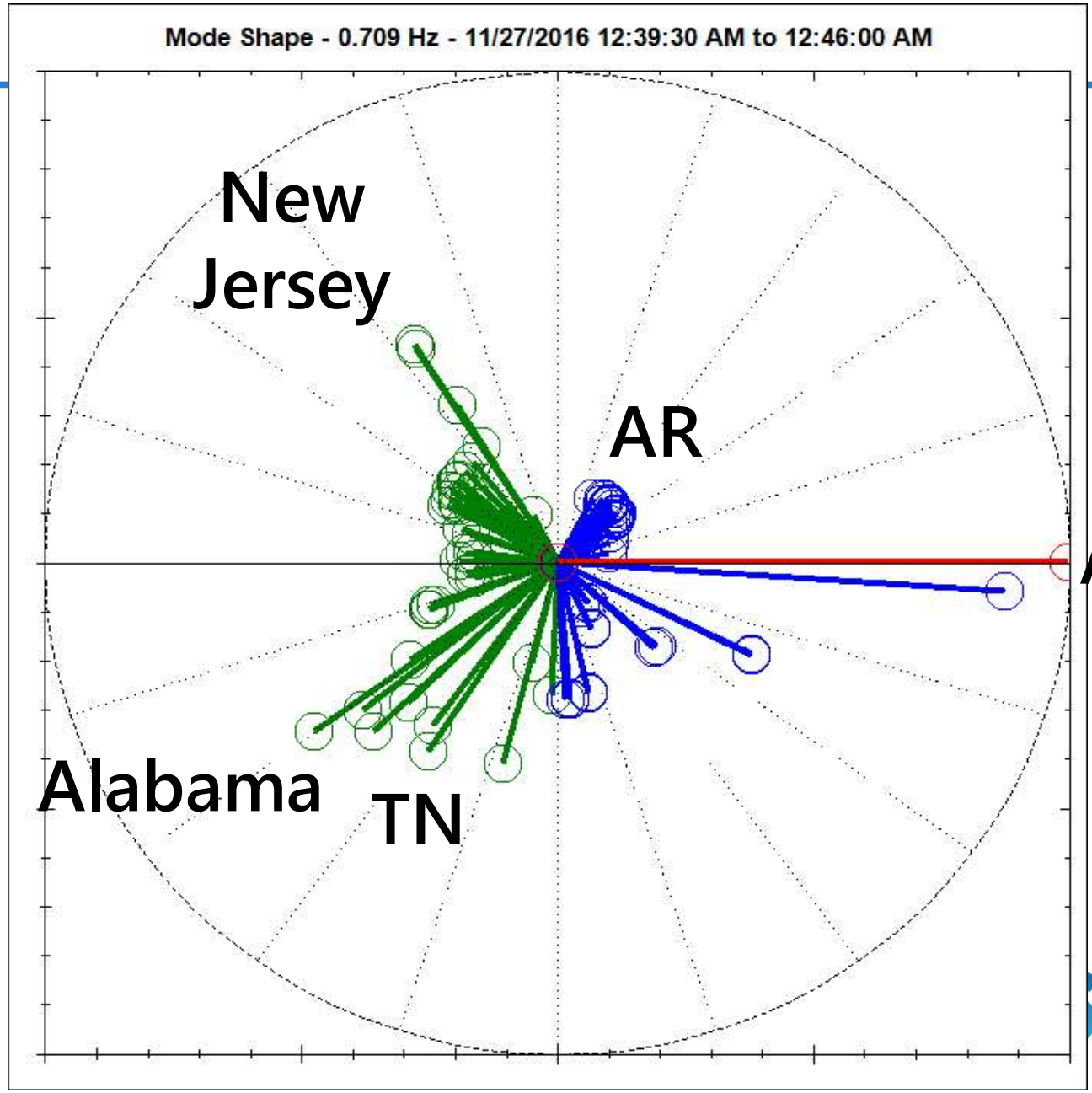
FSSI Estimates During GA Osc Event



0.69 Hz System Mode Shape from FSSI



0.7 Hz Oscillation Mode Shape from FSSI



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Resonance Conditions for 0.7 Hz Georgia Oscillation

(R1) Forced Osc freq near System Mode freq **(close)**

- **0.7 Hz Oscillation versus 0.67 Hz System Mode**

(R2) System Mode poorly damped **(invalid)**

- **0.67 Hz Well-damped (6% Damping Ratio)**

(R3) Forced Osc location near the two distant ends (strong participation) of the System Mode **(not true)**

- **GA Location 22% Relative Energy for the Mode**
- **Interaction with 0.78 Hz mode?**

Only 1+ conditions valid: Resonance effect small.

Special Reliability Assessment Summary

- **Many inter-area modes in North American interconnections**
- **Mode shapes appear to be consistent in general across different events**
- **Damping levels have been from 6% to 10+%**
- **Many forced oscillations are present that are exciting inter-area modes**
- **Mode shapes comparison between model based simulation and system PMU capture very useful.**
- **Report full draft by end May 2018**

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November 27, 2016 Event Analysis

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