Analysis of Eastern Interconnection Modes and Oscillations using SEL Archived PMU Data

Mani V. Venkatasubramanian
Tianying Wu
Washington State University

Jared Bestebreur,   Ellery Blood
Greg Zweigle
Schweitzer Engineering Labs

WSU Project Objectives

- **Oscillation Monitoring System for WECC, Entergy, and Southern Company**

- **Monitoring hundreds of PMUs simultaneously**

- **Damping Monitor Engine – ambient data analysis – track inter-area modes and oscillations**

- **Event Analysis Engine – detection and analysis of ringdowns and oscillations**

- **Real-time engines and off-line engines**

FFDD Mode Estimation Results

- **Fast Frequency Domain Decomposition (FFDD) for Ambient Modal Analysis**

- For each mode:

    - Mode frequency

    - Mode damping ratio

    - Mode energy

    - Mode shape

    - Estimation confidence level

SEL Synchrophasor Network

- **Wall outlet PMUs located at SEL field offices**

- **60 Hz Sampling Rate**

- **VPN connection to SEL HQ in Pullman WA**

- **8 PMUs in Western, 9 in Eastern, and 2 in Texas**

- **TCP connections: Data quality is excellent**

- **In place since 2003**

- **Data archived and used for live demo of SEL Synchrowave software**

- **Why not do ambient modal analysis?**

SEL Synchrophasor Network
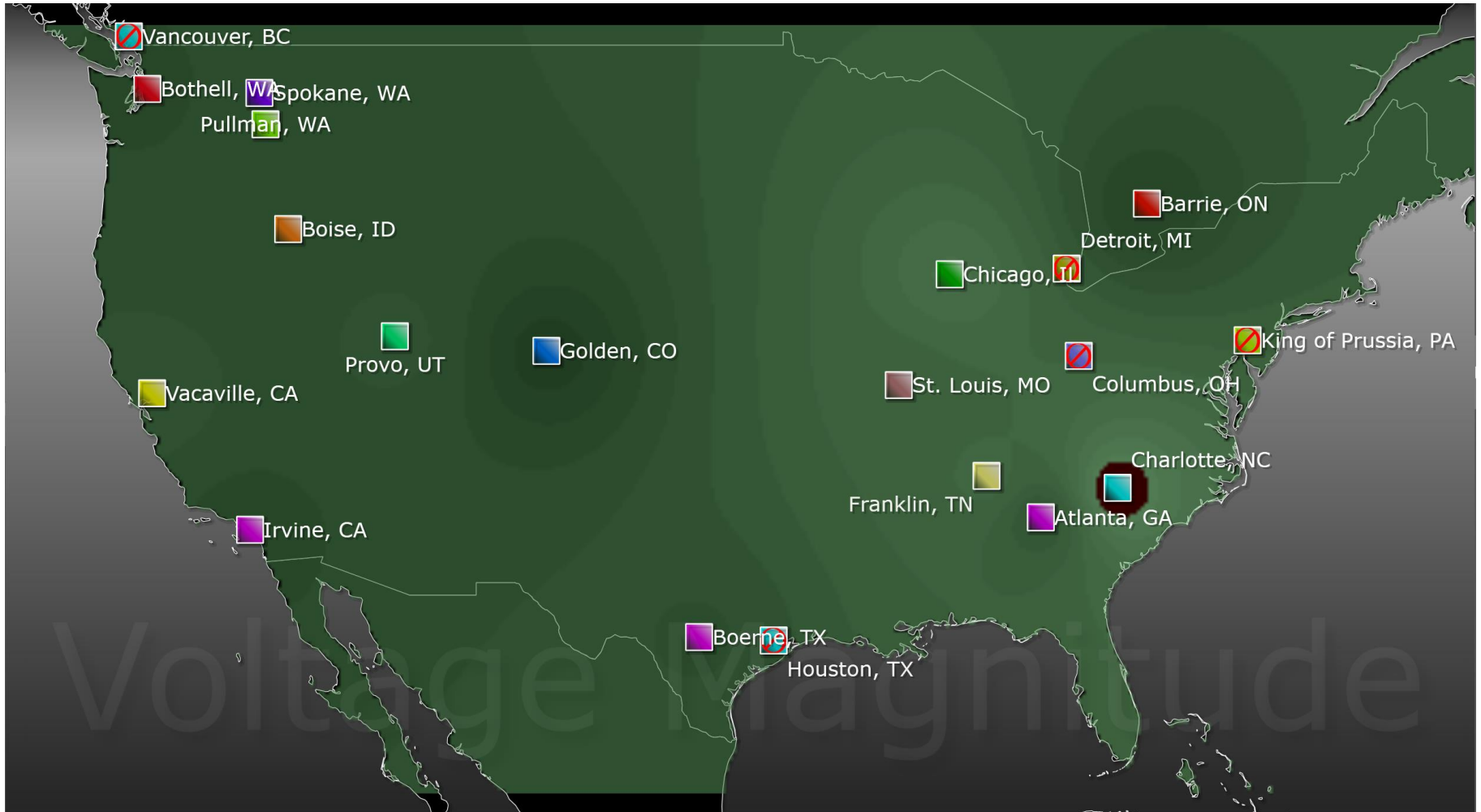
Capture from SEL Synchrowave website live demo
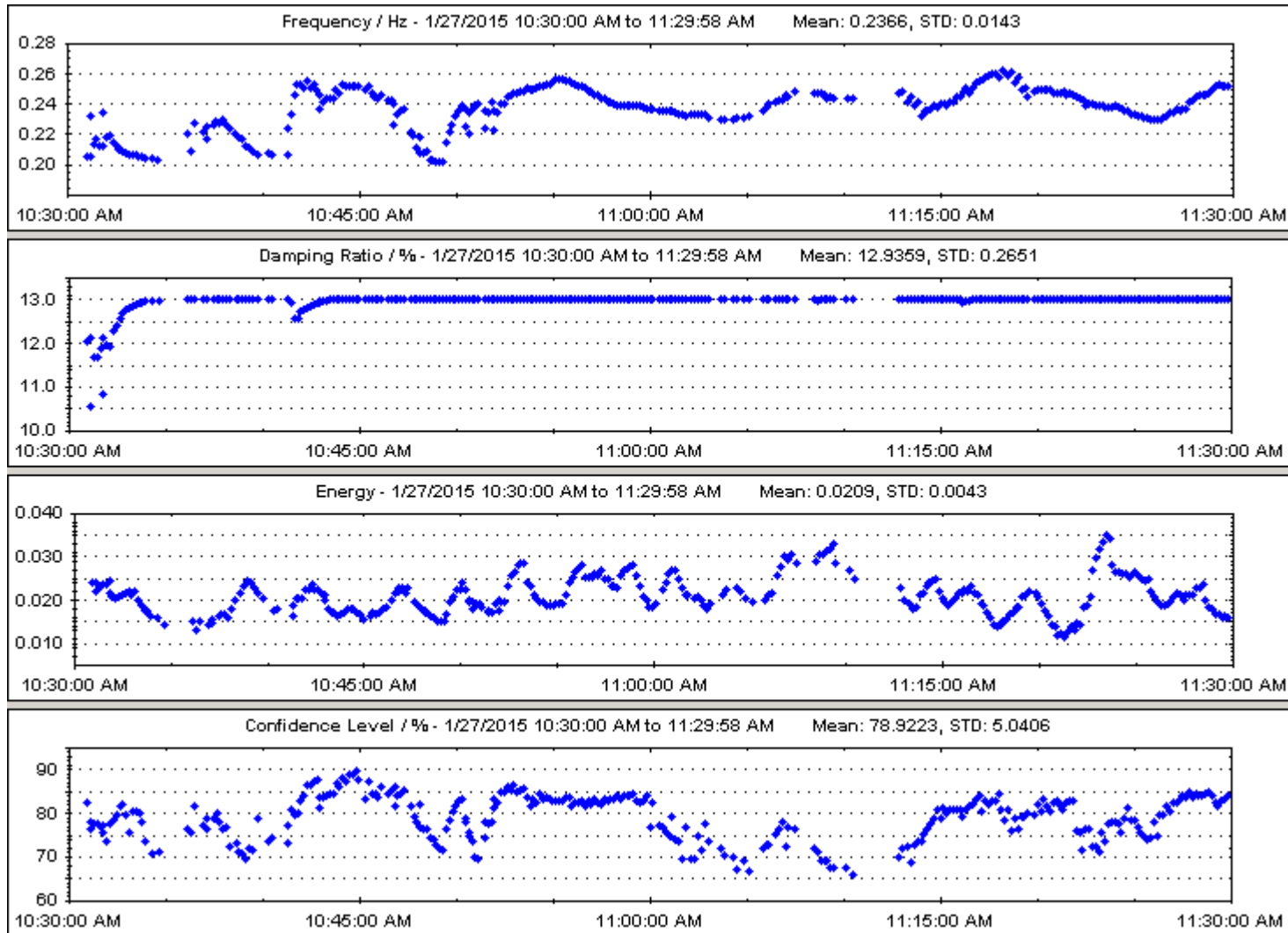
Validation using WECC PMU Data

– **Compare results from WECC PMUs versus SEL PMUs for the western system**

– **One hour of data from 200 WECC PMUs (30 Hz) and 8 SEL PMUs (60 Hz)**

– **Only Bus Voltage Phase Angle and Bus Frequency usable from SEL PMUs**

– **Vancouver, BC; Bothell, WA; Pullman, WA; Spokane, WA; Golden, CO; Boise, ID; Vacaville, CA; Irvine, CA**

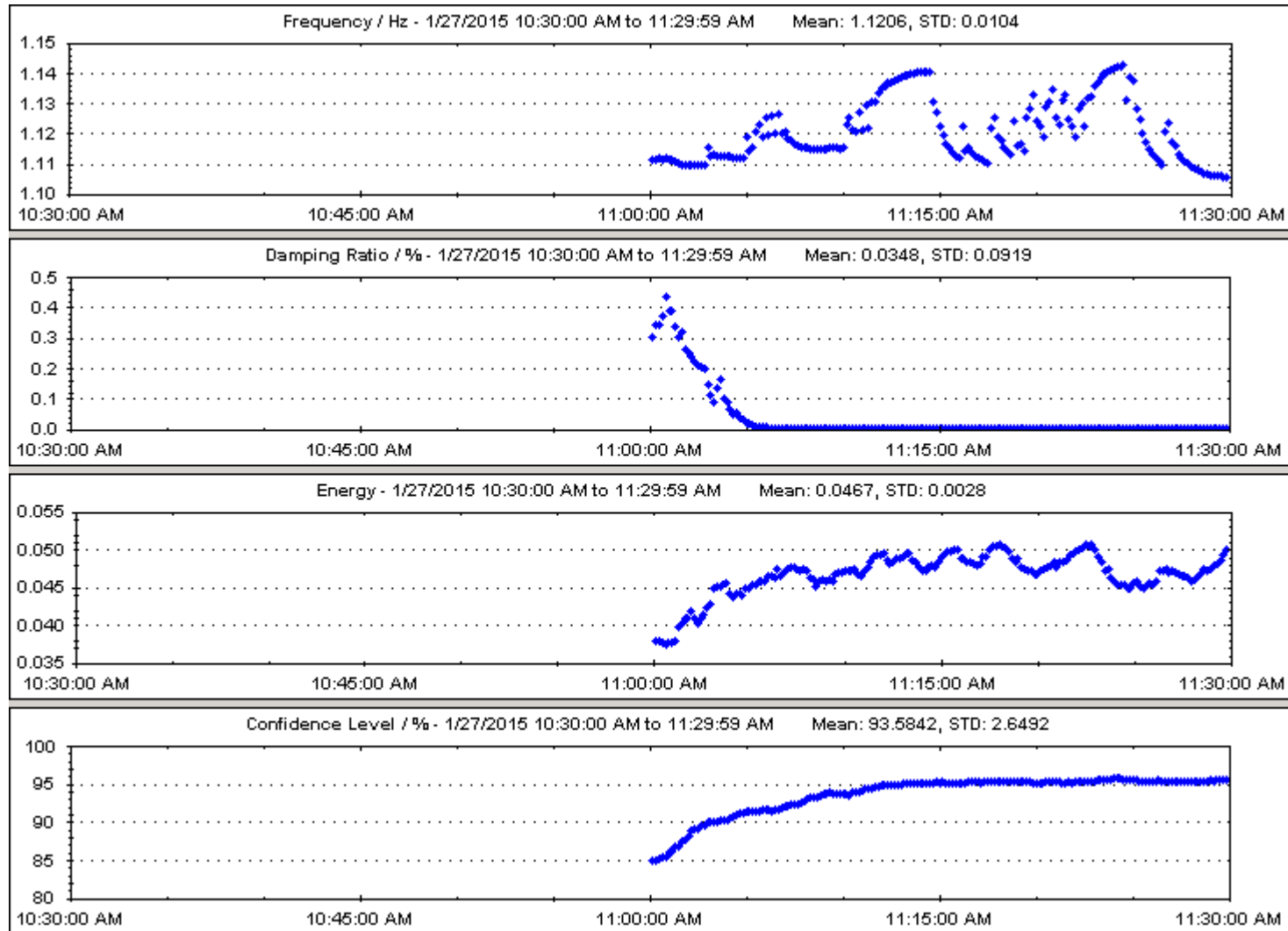– **Reasonable coverage**

0.25 Hz Mode using WECC PMU Data
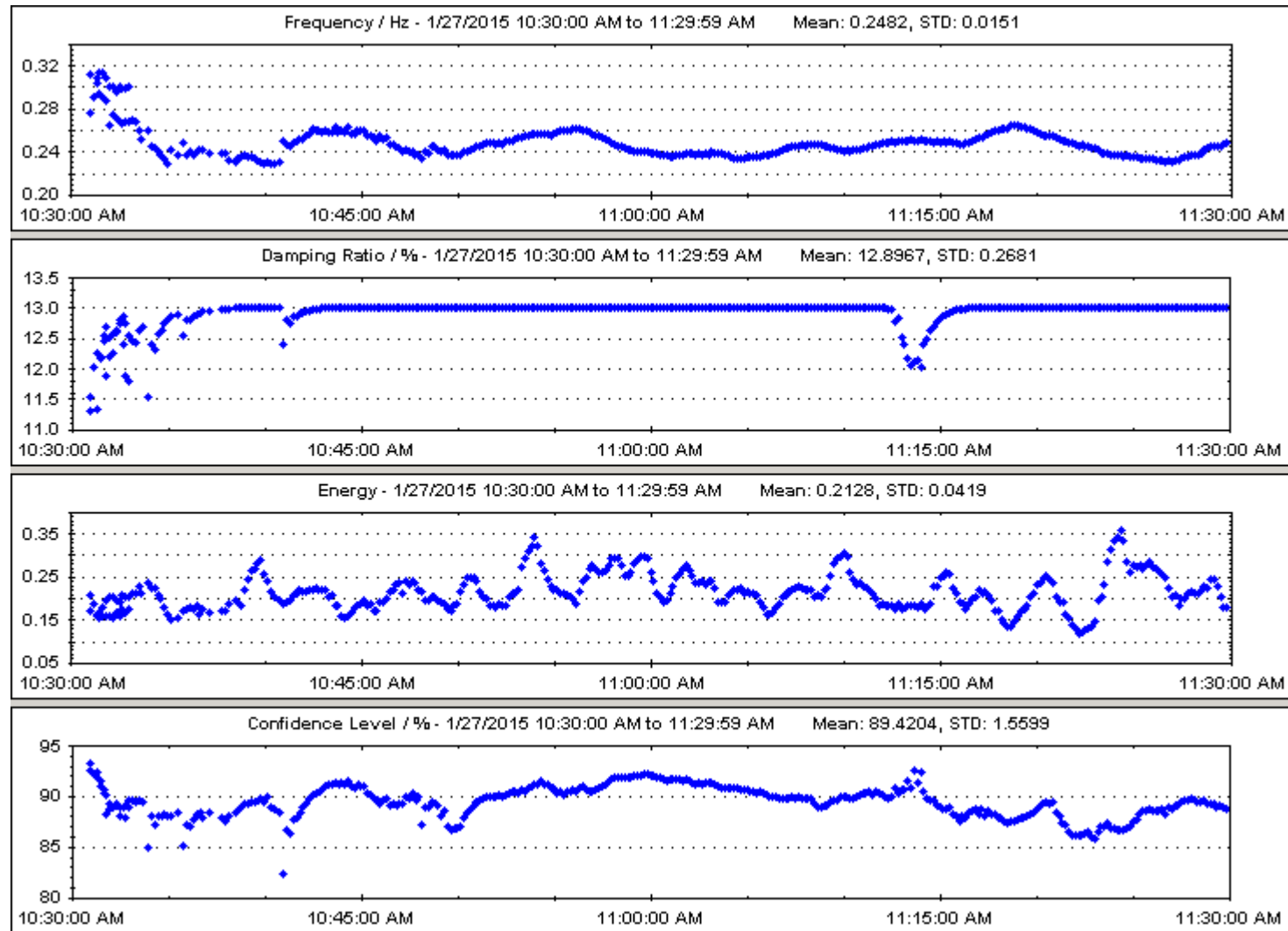
0.25 Hz mode well-damped. Estimation confidence very high 90%.

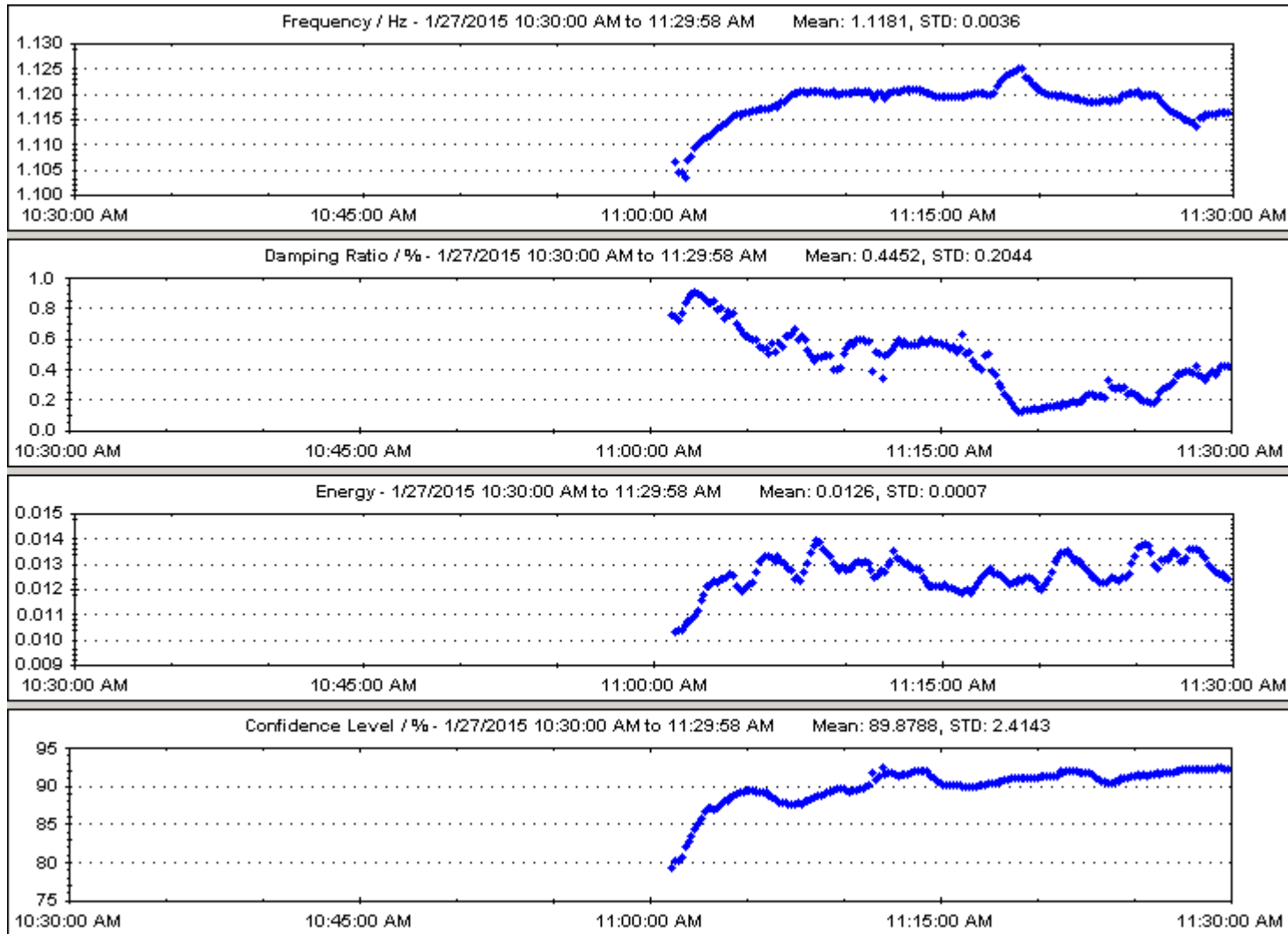# 0.25 Hz Mode using SEL PMU Data

0.24 Hz mode well-damped. Estimation confidence high 80%.
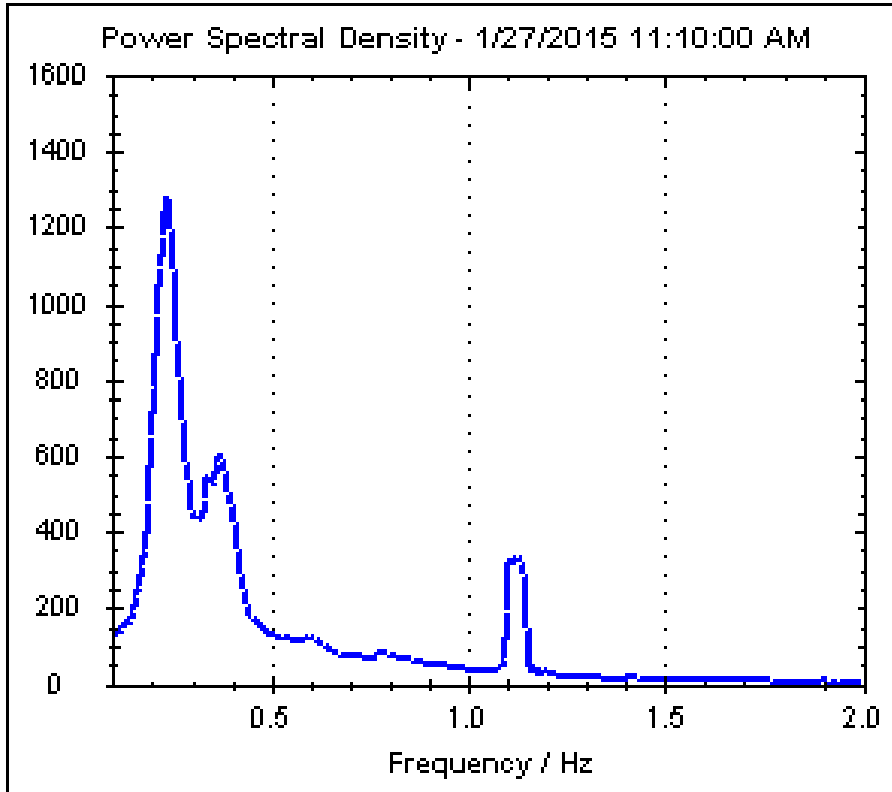
1.12 Hz Osc using WECC PMU Data

1.12 Hz "mode"at zero damping. Estimation confidence very high 95%.
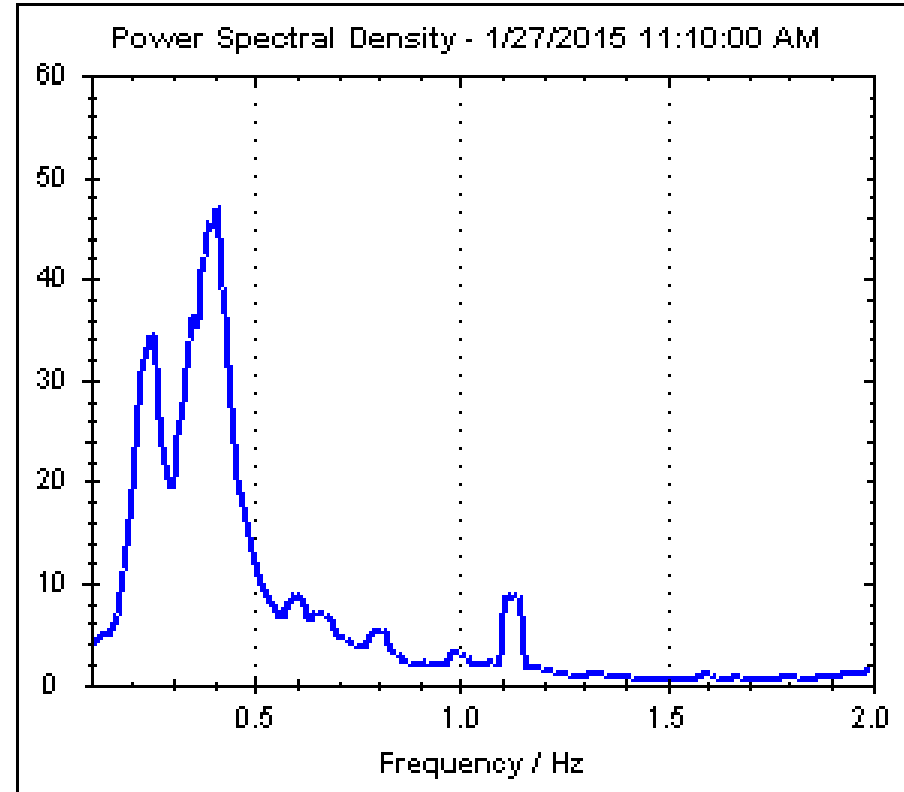
1.12 Hz Osc using SEL PMU Data

1.12 Hz "mode"at near zero damping. Estimation confidence very high 90%.

PSD Comparison


193 WECC PMUs
(0.25 Hz mode emphasized)

8 SEL PMUs
(0.4 Hz mode emphasized)

Eastern Interconnection Modes

- Atlanta, GA; Charlotte, SC; Detroit, MI; King of Prussia, PA; Barrie, ON; Chicago, IL; St.Louis, MO; Franklin, TN; Columbus, OH.

- Reasonable coverage

- Several weeks of data from 2015 received from SEL

- January, April, July, and October 2015
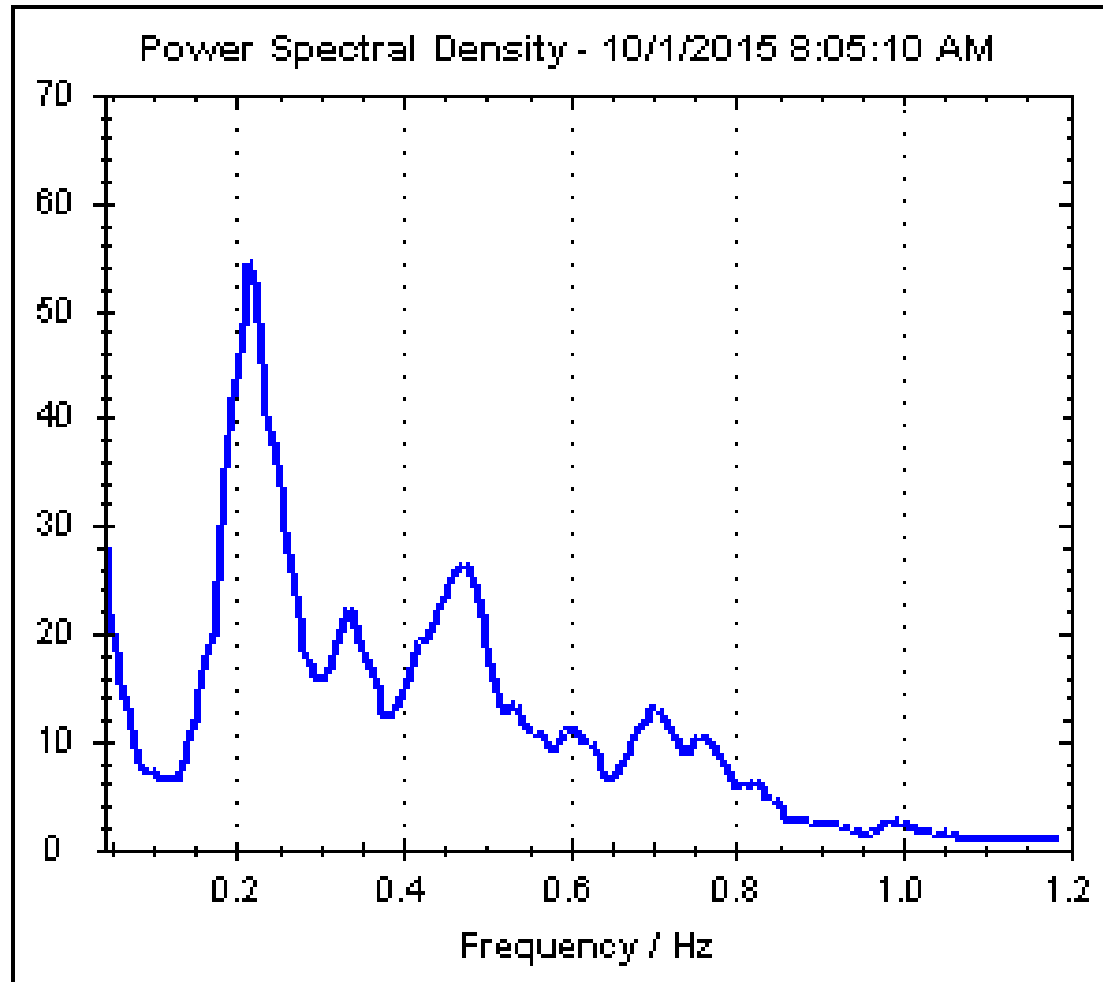
- Dominant modes? Observability? Forced Oscillations?

Off-Peak Conditions PSD Example

Power Spectral Density - 10/1/2015 12:09:35 AM
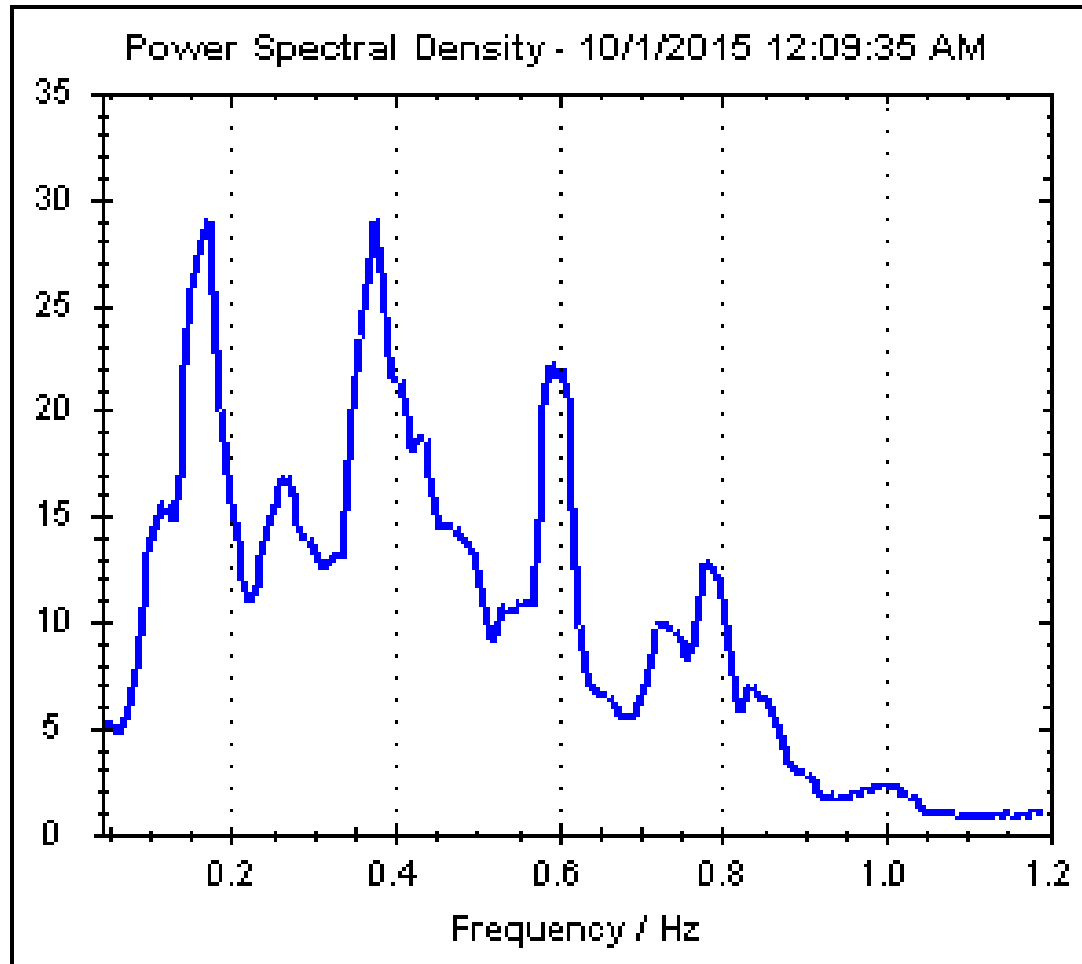
3 AM Eastern Time on October 1 2015

Modes at 0.18 Hz, 0.25 Hz, 0.38 Hz, 0.6 Hz, 0.8 Hz

Peak Conditions PSD Example

Power Spectral Density - 10/1/2015 8:05:10 AM
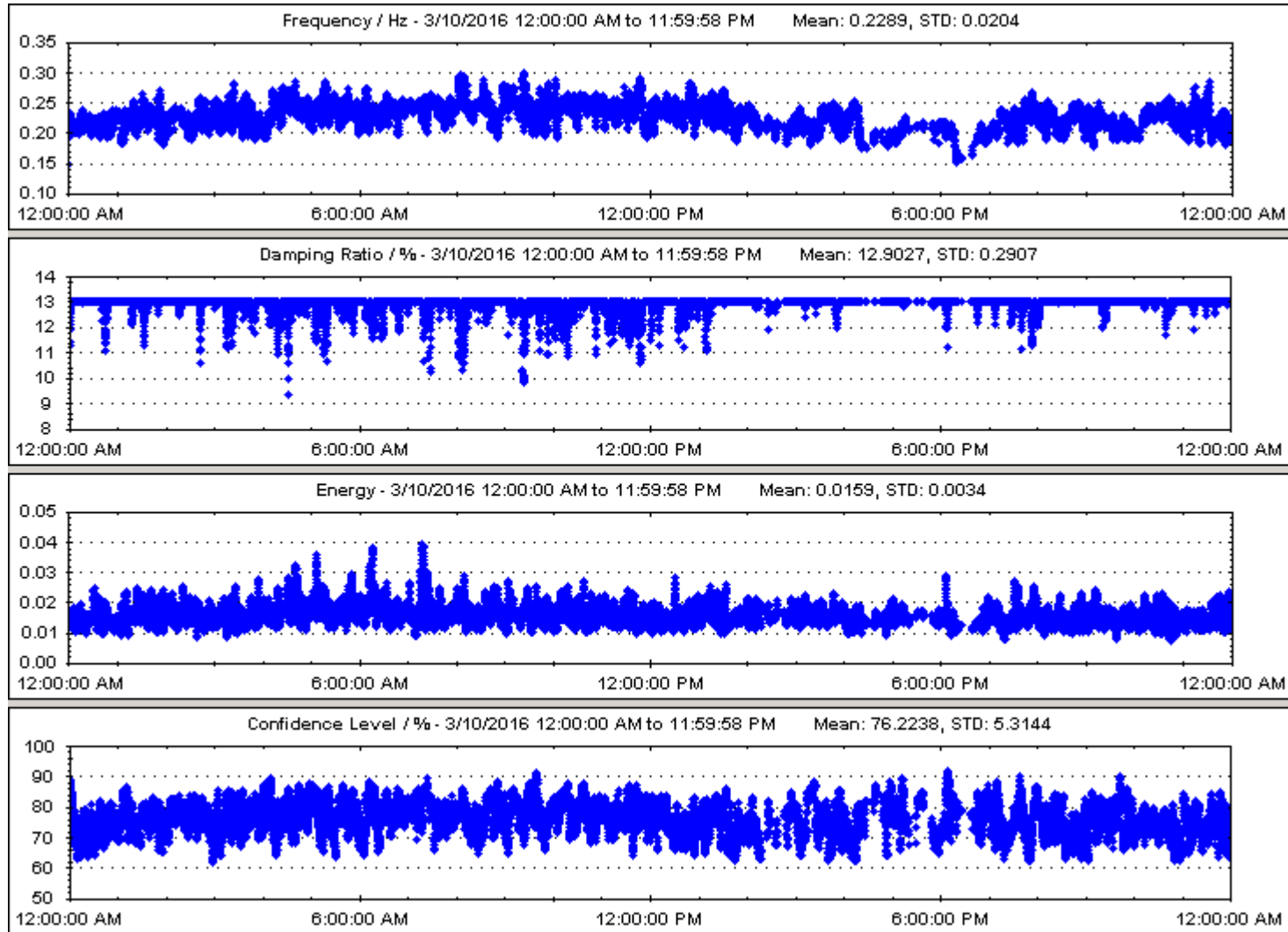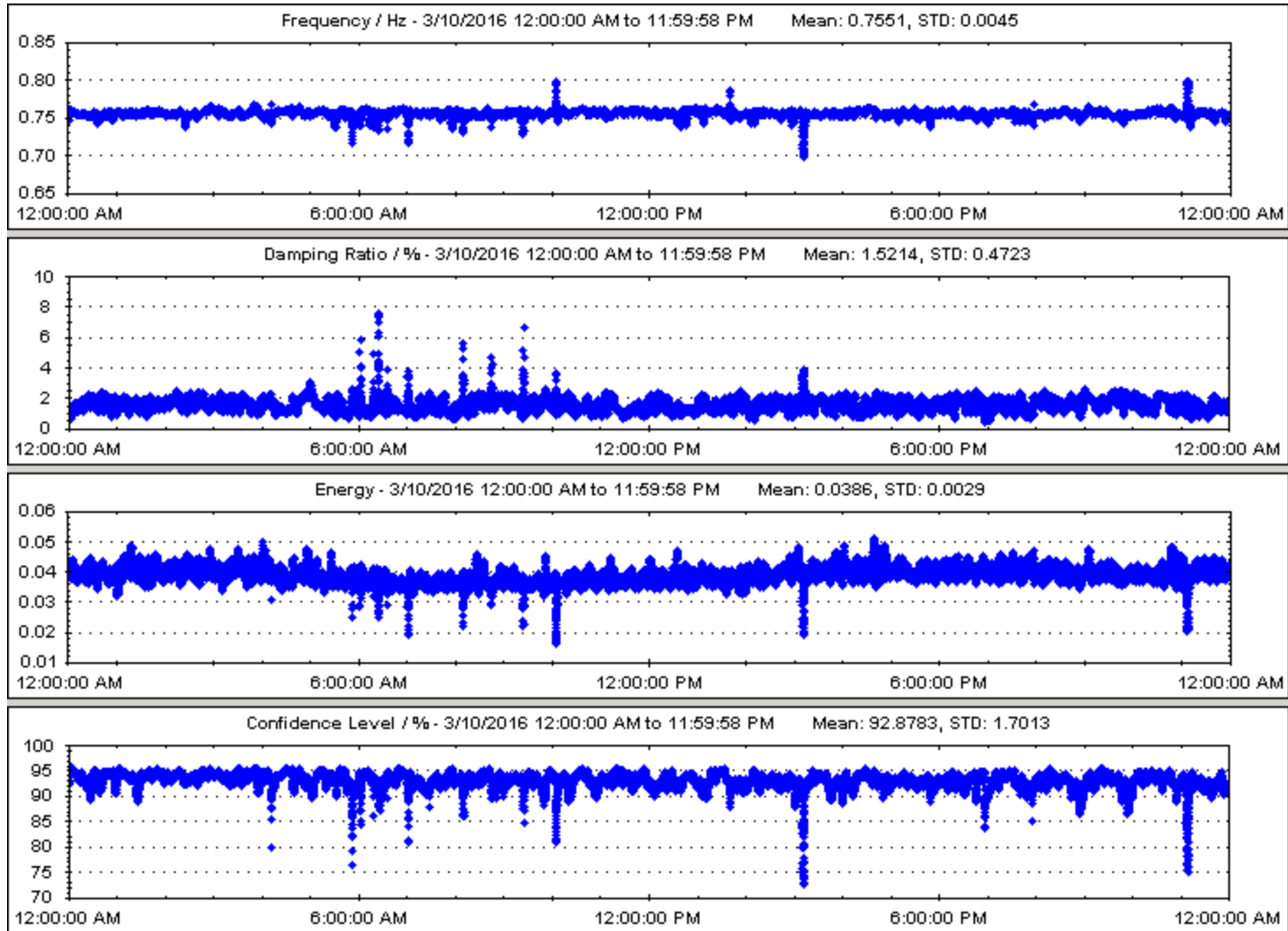
11 AM Eastern Time October 1 2015

Modes at 0.22 Hz, 0.32 Hz, 0.45 Hz, 0.6 Hz, 0.7 Hz

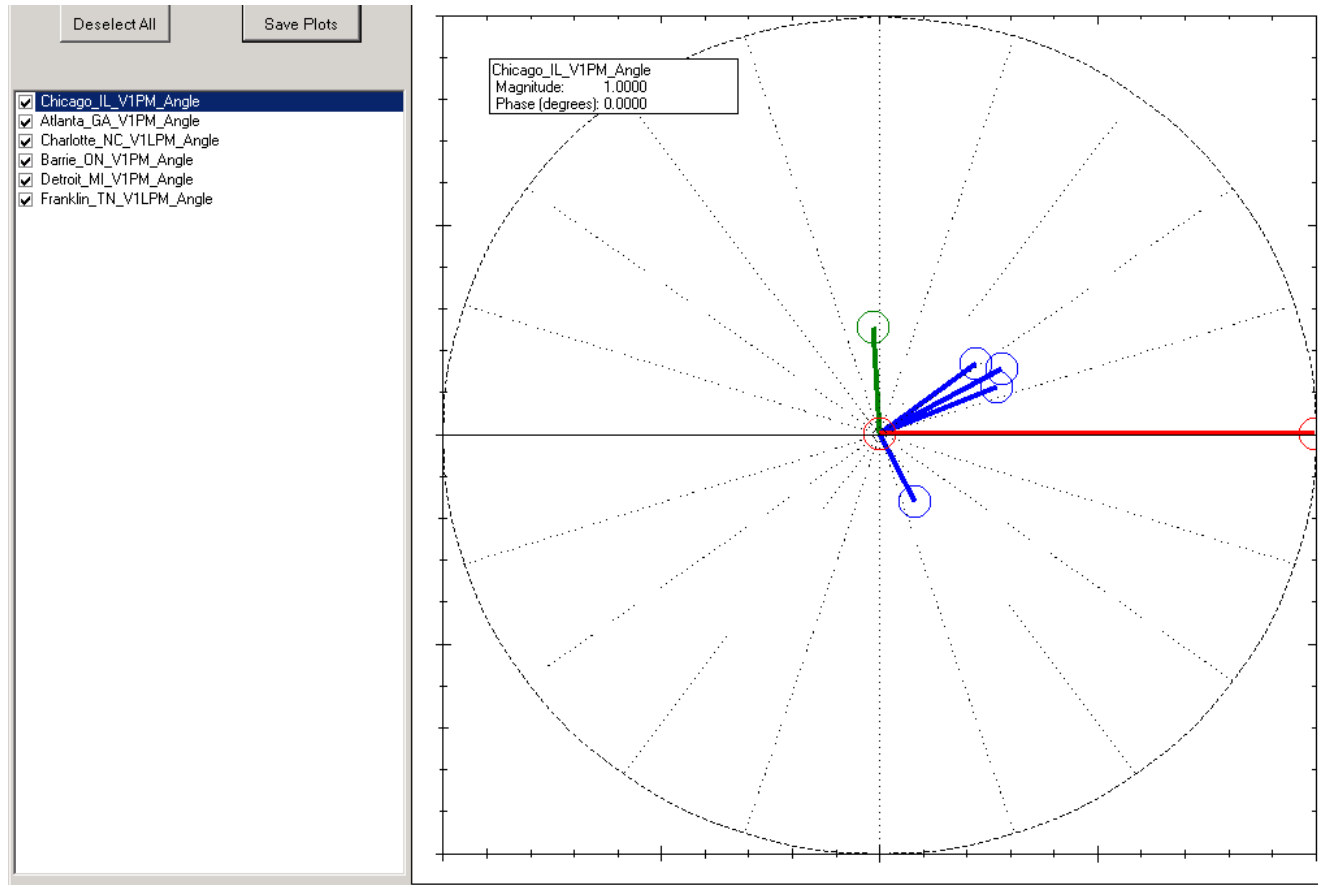# Jan 1 2015 0.23 Hz Mode Results

0.23 Hz Mode Well-damped. Confidence 75%.
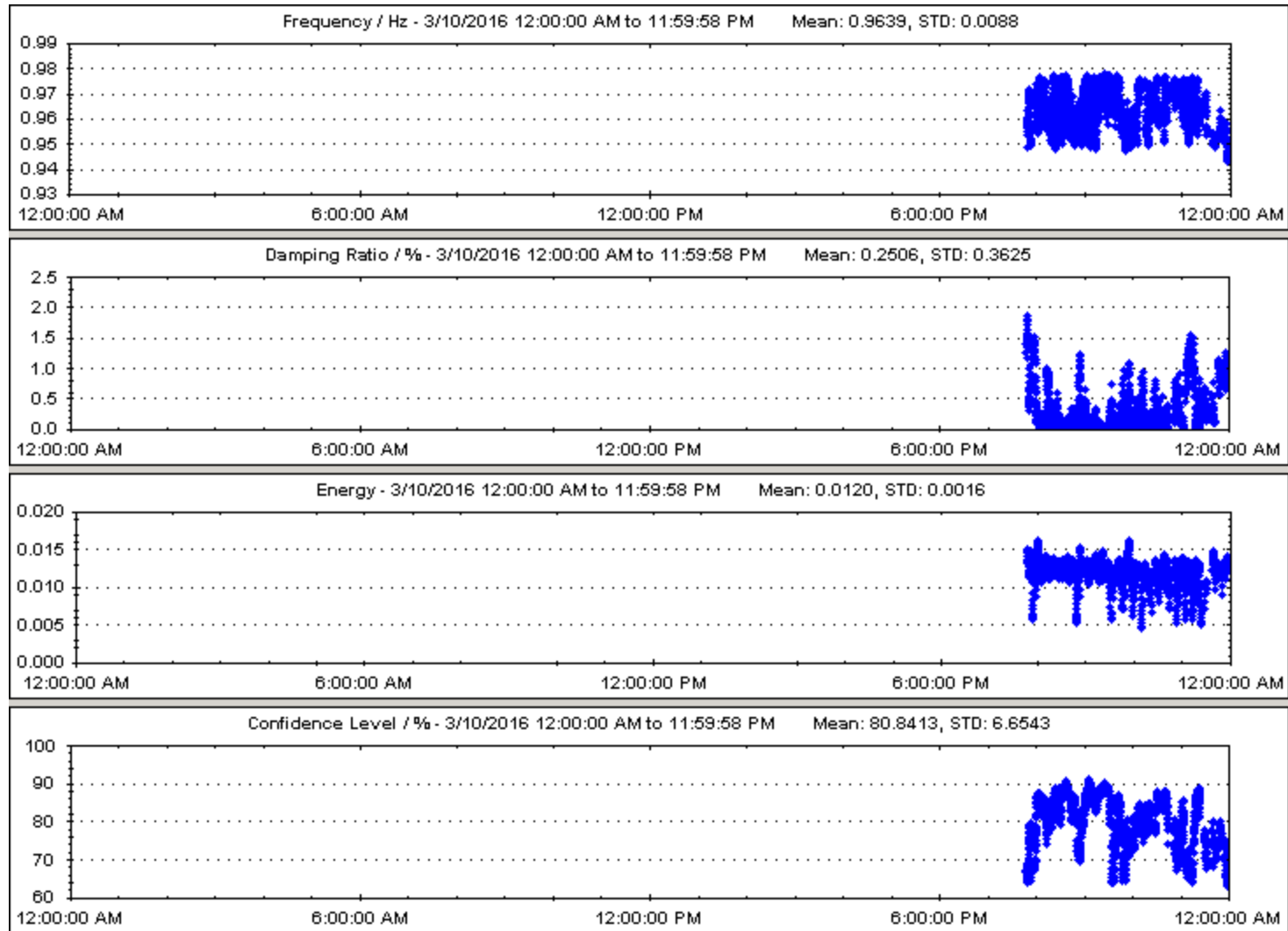
Jan 1 2015 0.75 Hz Mode Results

0.75 Hz Mode Low Damping. Confidence 93%.
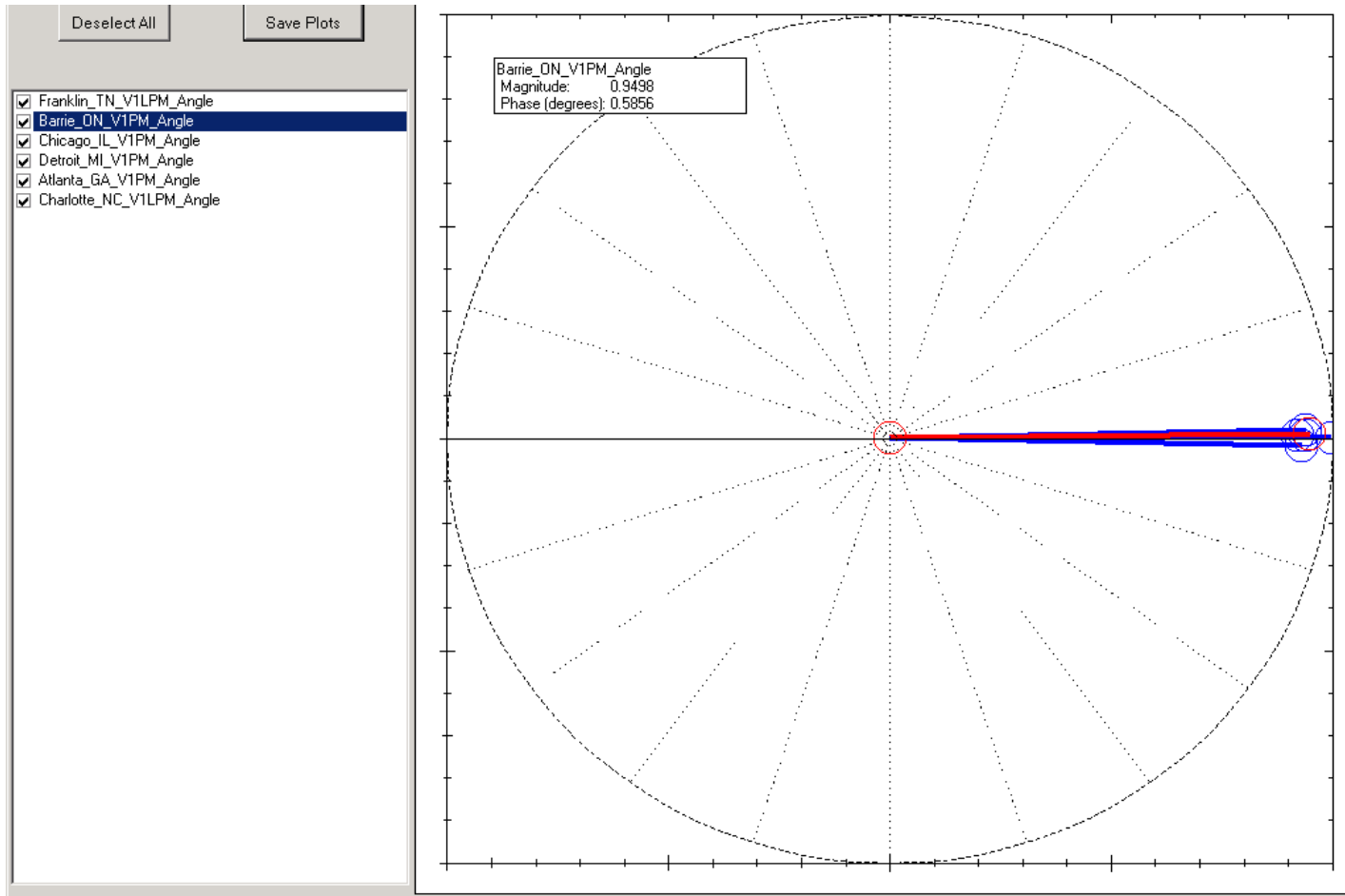
Jan 1 2015 0.75 Hz Mode Shape

Chicago Clearly Dominant in Mode Shape.
0.75 Hz Oscillation Source Likely Near Chicago.
Oscillation stopped on July 4, 2015 at 5 AM PDT?

Jan 1 2015 0.96 Hz Mode Results

Frequency / Hz - 3/10/2016 12:00:00 AM to 11:59:58 PM   Mean: 0.9639, STD: 0.0088

Damping Ratio / % - 3/10/2016 12:00:00 AM to 11:59:58 PM   Mean: 0.2506, STD: 0.3625

Energy - 3/10/2016 12:00:00 AM to 11:59:58 PM   Mean: 0.0120, STD: 0.0016

Confidence Level / % - 3/10/2016 12:00:00 AM to 11:59:58 PM   Mean: 80.8413, STD: 6.6543

0.96 Hz Mode Low Damping. Confidence 80%.

Jan 1 2015 0.96 Hz Mode Shape

No Clear Dominant Signal in Mode Shape.
Forced Oscillation Source Unknown.

Conclusions

- **Inter-Area Modes and Forced Oscillations can be monitored from Wall Outlet Phase Angles**

- **Many oscillatory modes present in the eastern interconnection (0.2 Hz, 0.4 Hz, 0.5 Hz, 0.6 Hz, 0.7 Hz, 0.8 Hz, …)**

- **0.2 Hz mode well-observed in SEL PMU data**

- **Many other modes with limited observability**

- **Can detect start/end times of forced oscillations**

- **Source location possible with more PMUs**

- **Real-time Ambient Modal Analysis of PMUs from Wall Outlet PMUs Recommended.**