Power System Oscillations & ESAMS

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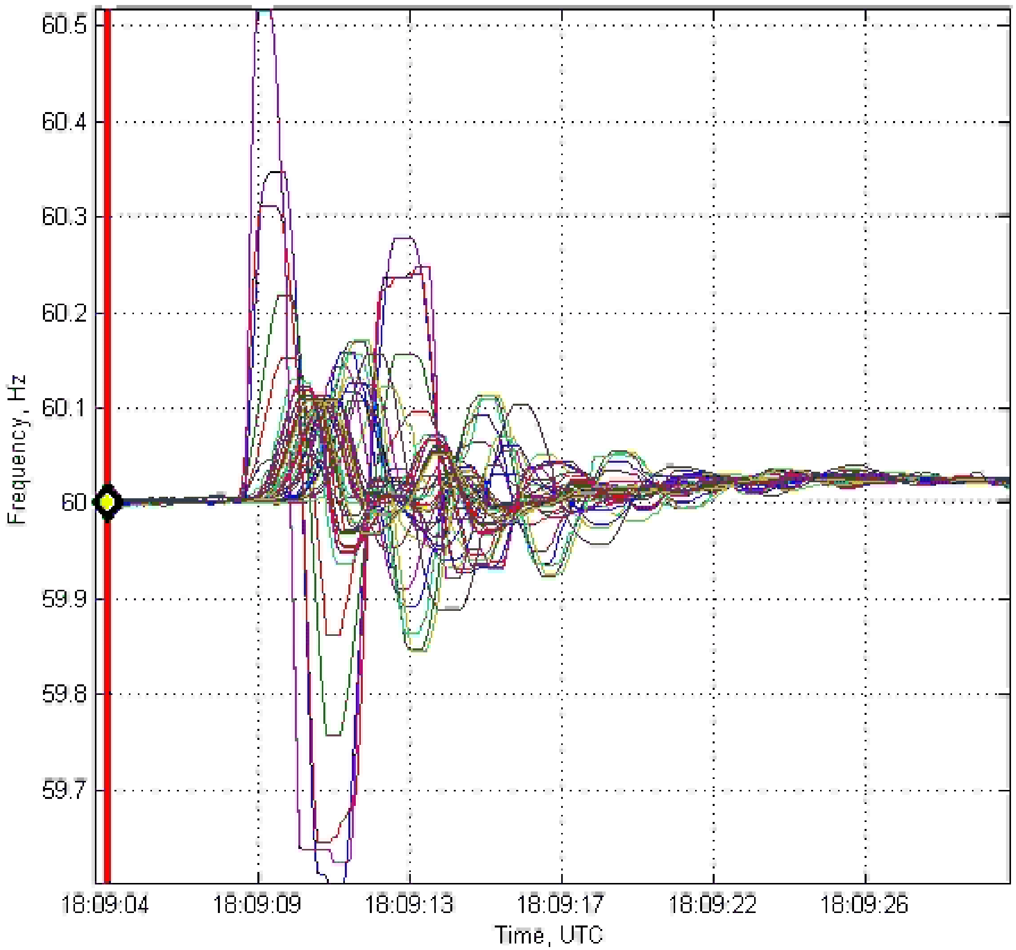
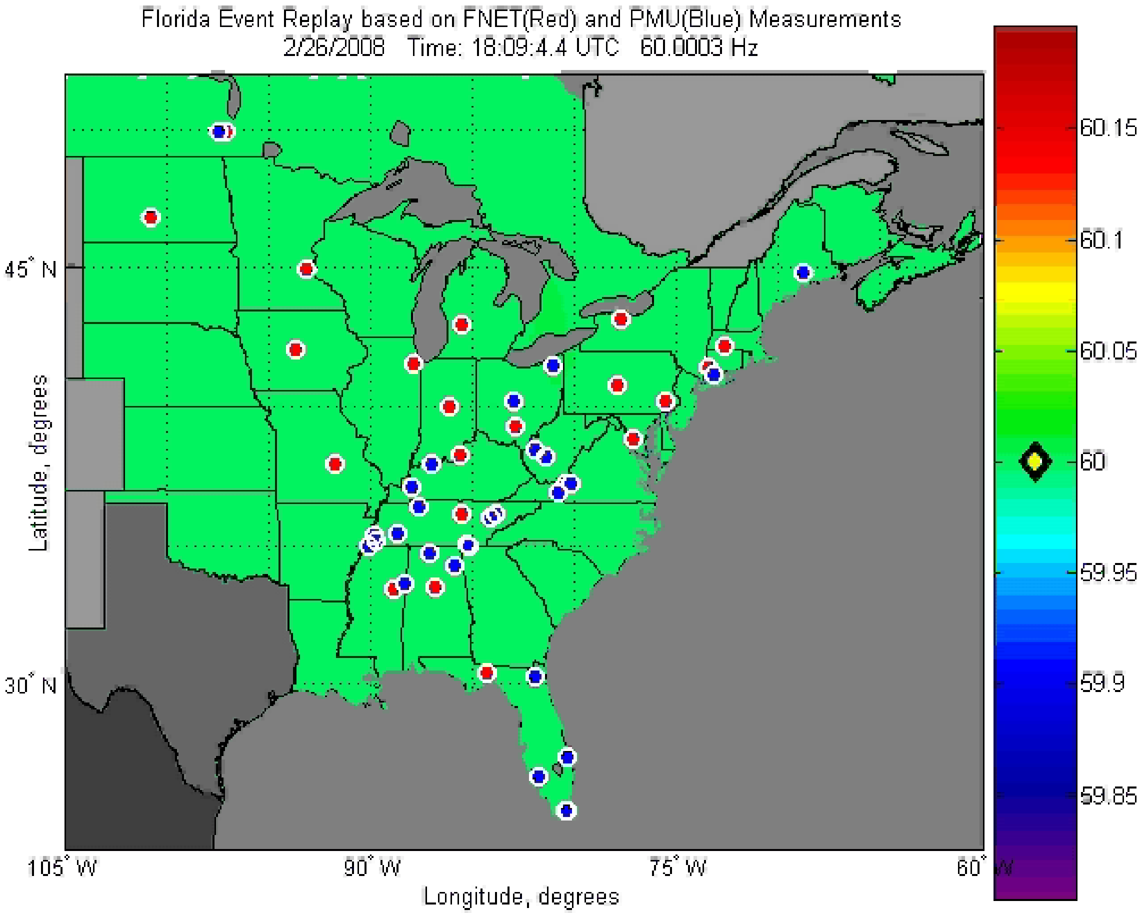
Agenda

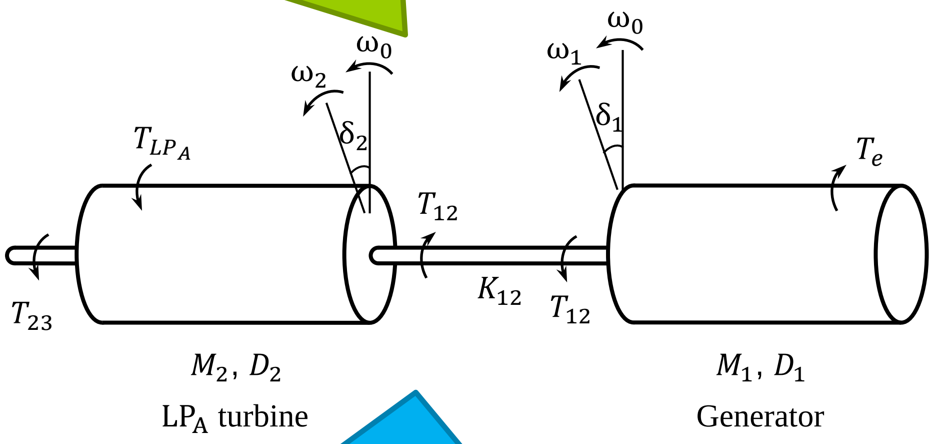
1. Introduction
2. Oscillation Detection
3. ESAMS
4. Conclusion & Final Remarks

The Largest Machine





Electromechanical oscillations: interaction of rotating masses



Complex function of: system strength, inertia, load, controllers, etc.

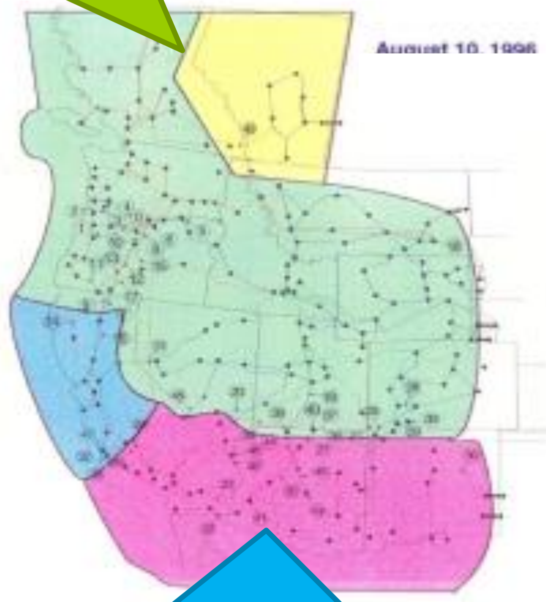
Diagnosis using PMUs

Oscillation Mode

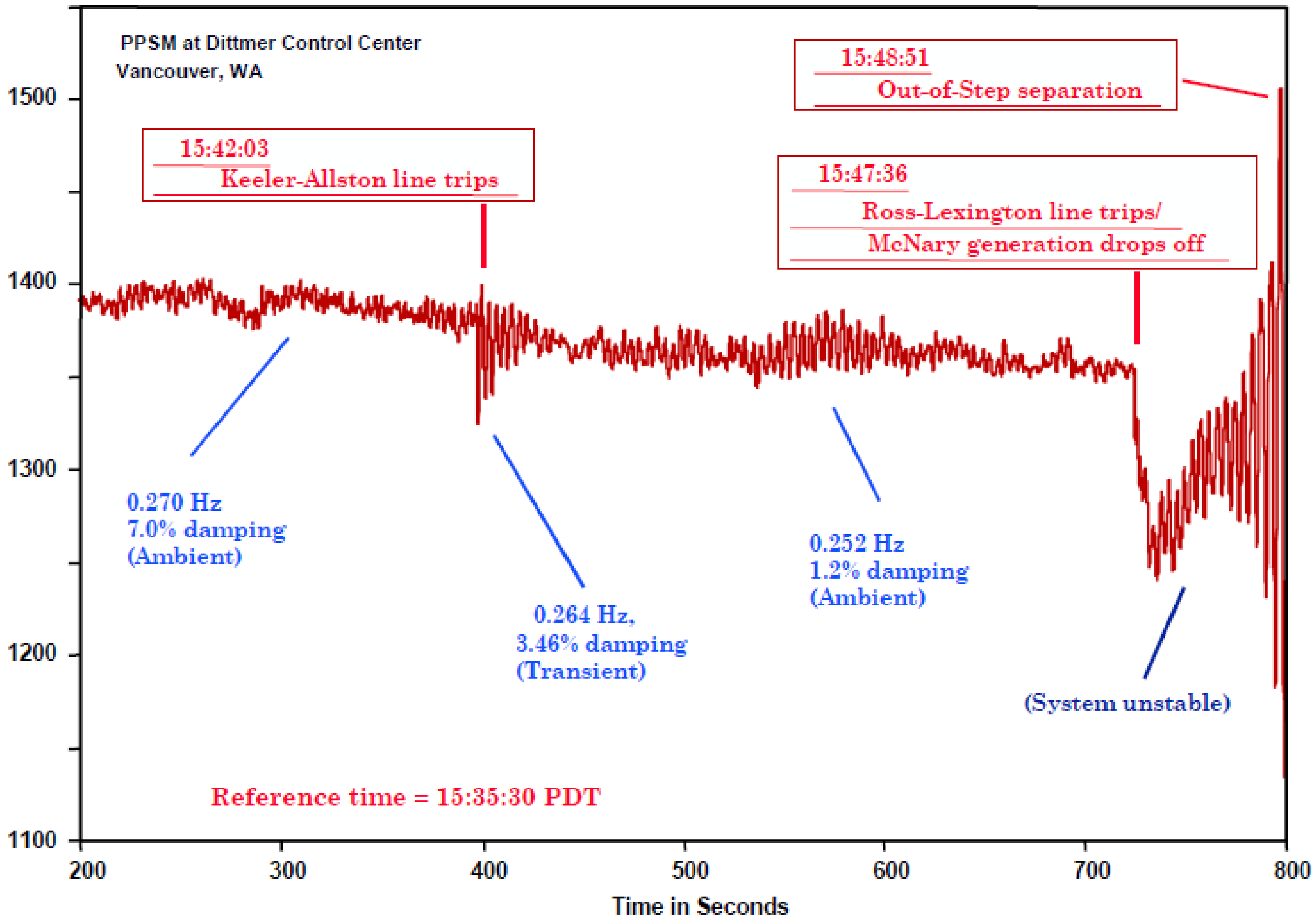
Amplitude	**Frequency**
Damping	**Shape**

WECC 1996

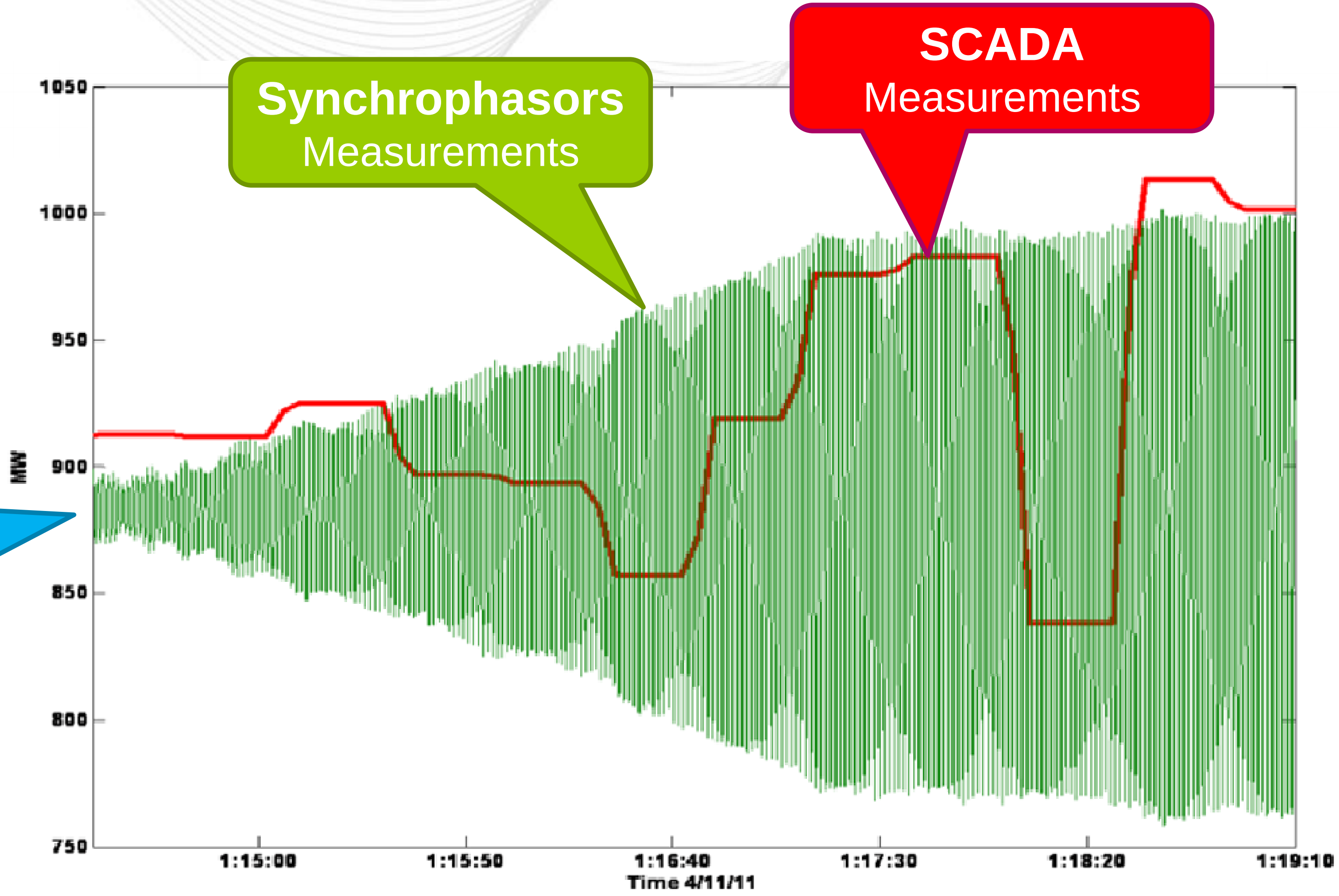
WSCC Split in 4 Islands
- 30 GW Load Loss
- 7.5 Million Customers



System Conditions:
- High north-south flows
- Two forced 500kV line outages.
- Scheduled maintenance at SVC.



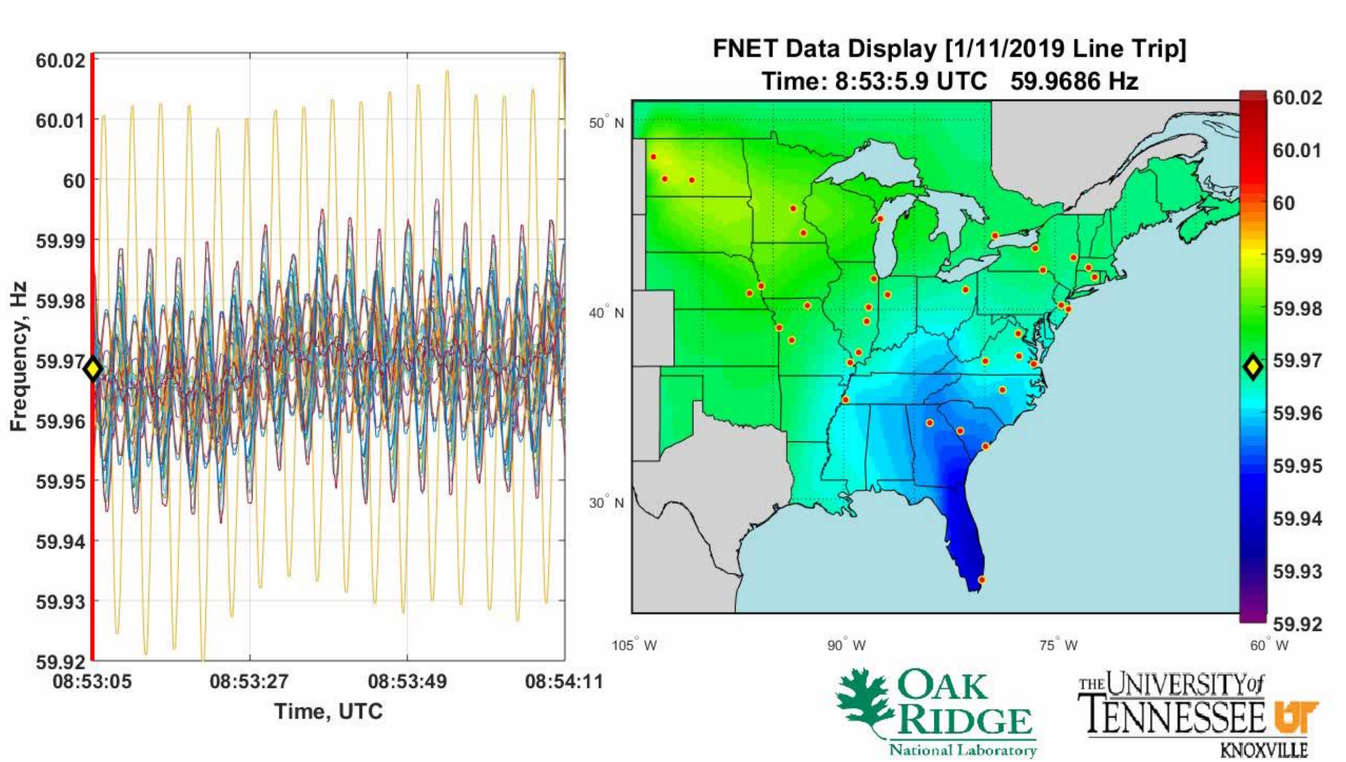
Surry Oscillation 2011



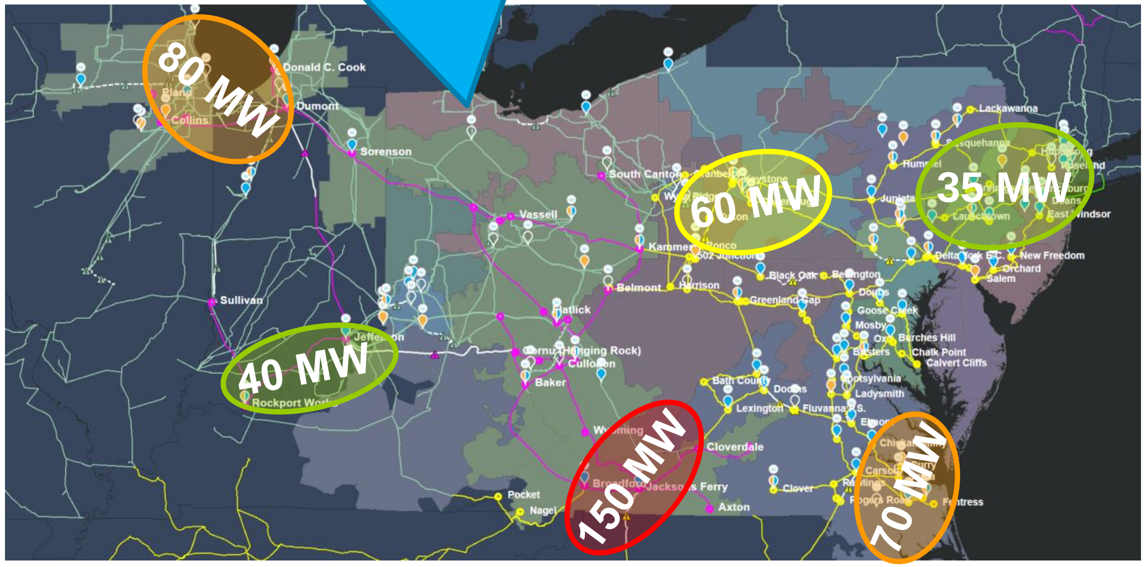
System Conditions

- Multiple maintenance outages.
- High-voltage.
- Under-excited generator.

Forced Inter-Area Oscillation



0.25 Hz (Inter-Area)
South and North-West of PJM



Oscillation Events

April 2011
Surry Oscillation

August 2016
Susquehanna Oscillation

November 2016
Farley Oscillation

July 2017
Quad City Oscillation

January 2019
FRCC Oscillation

You can only diagnose oscillations with PMUs

Actionable Information

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What is an Oscillation?

- A disturbance or weak system causes one generator or a set of generators to swing with respect to the rest of the generators in an interconnected system.
- These oscillation fluctuations have a frequency.

This is NOT the system frequency of 60 Hz!

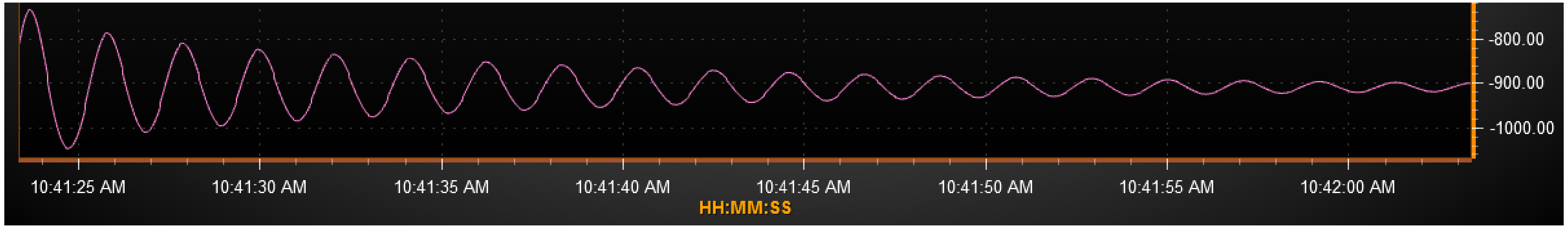
Oscillation terminology:

Mode – describes three of the major characteristics of a system oscillation:

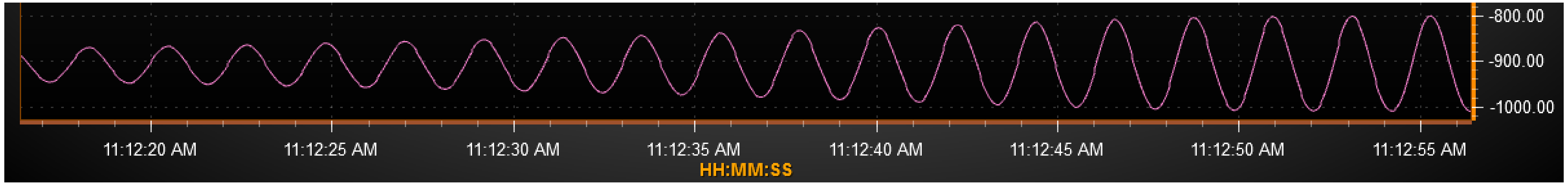
- Energy (Amplitude/Size)
- Frequency
- Damping

Damping: PJM considers anything more than 3% as well damped

Well Damped



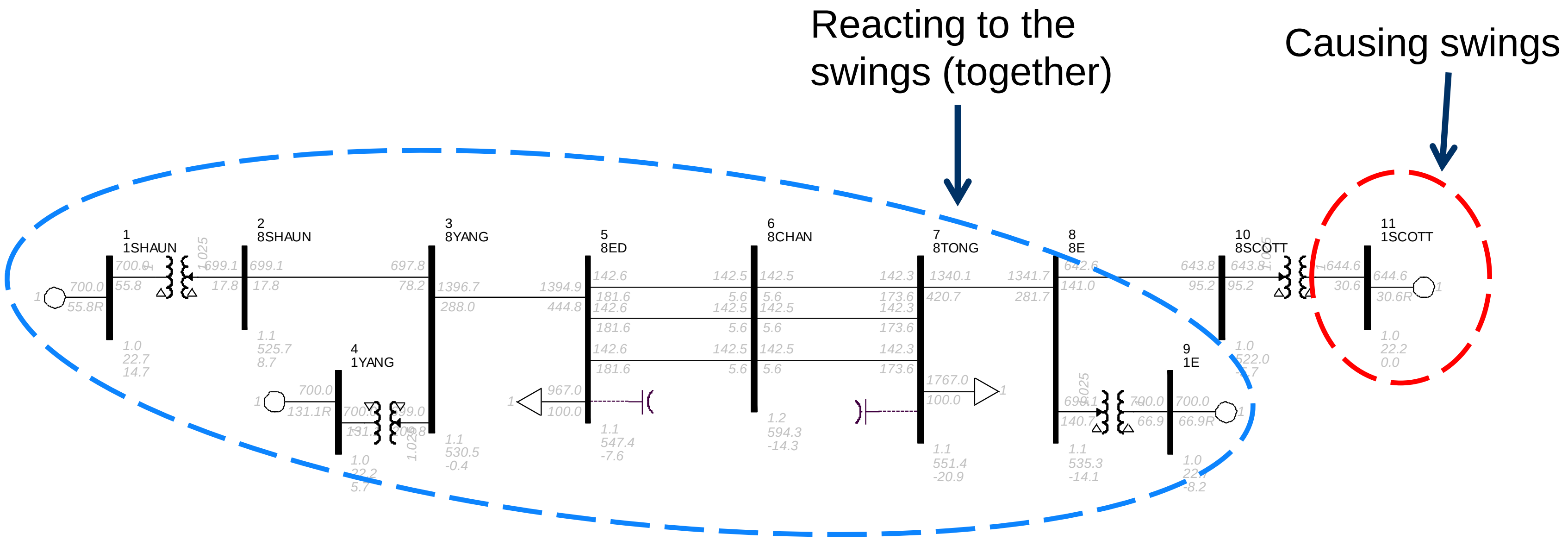
Negative Damping



Oscillation Types

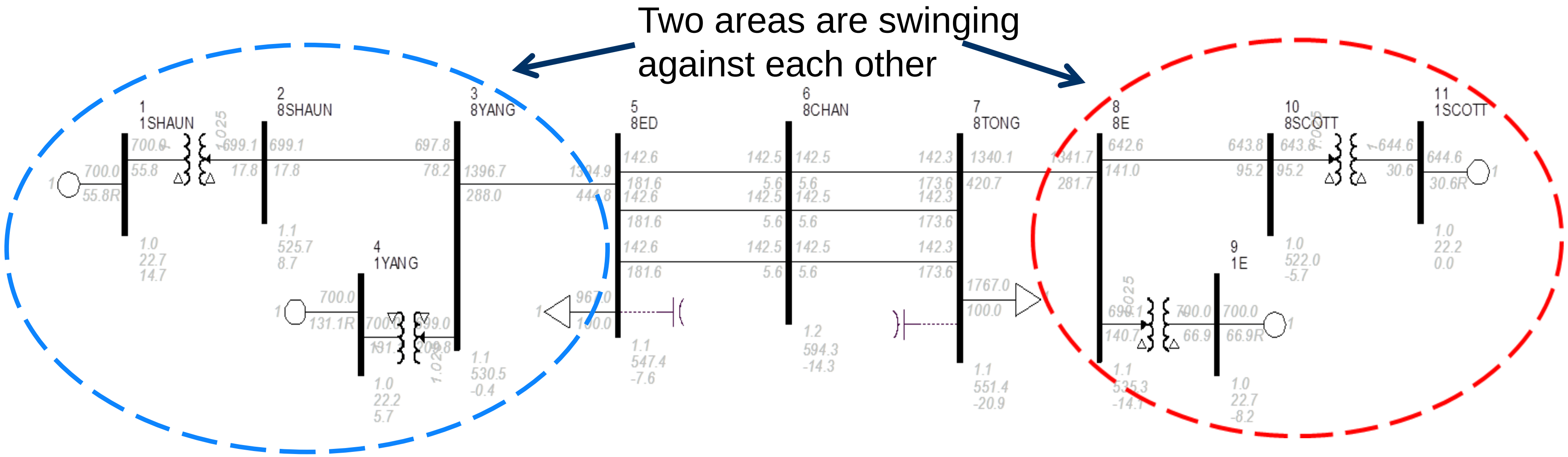
Forced: Occurs when a single generator has a failure in one of its control systems

Oscillation Freq: Less than 15 Hz



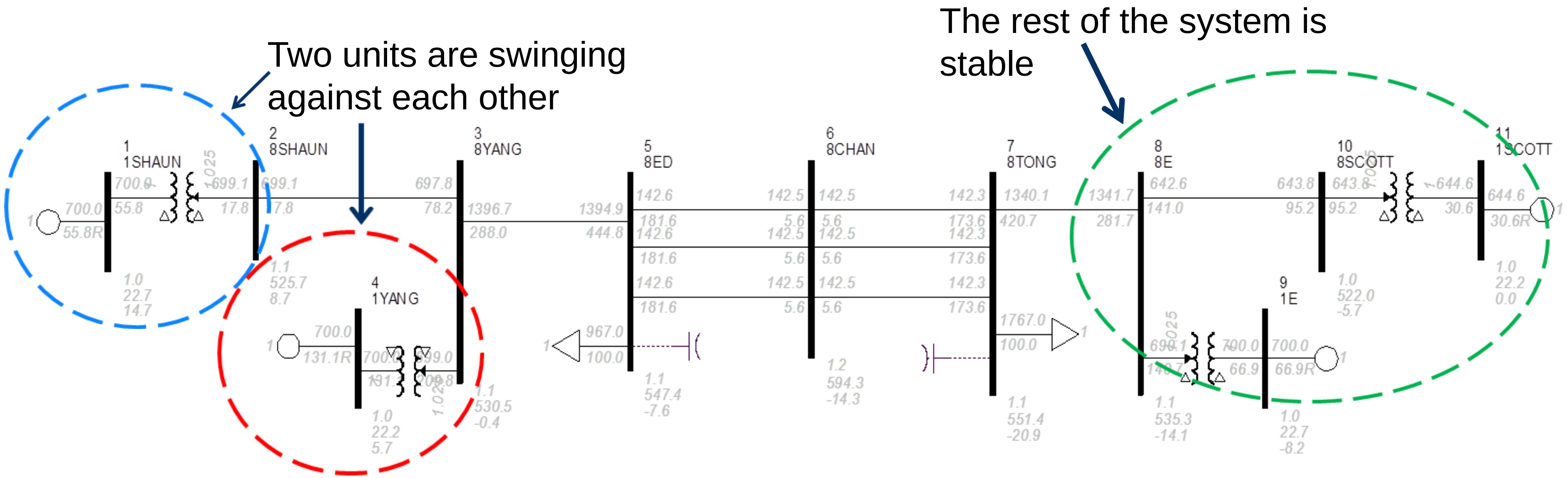
Inter - area : Occurs when a power system is weakened with equipment outages, light load, and large amounts of power are imported across the system

Oscillation Freq: below 0.8 Hz



Local: Similar to inter- area but restricted to a small area of power system

Oscillation Freq: 0.8 – 2.0 Hz



Oscillation Detection in Operations (RTDMS):

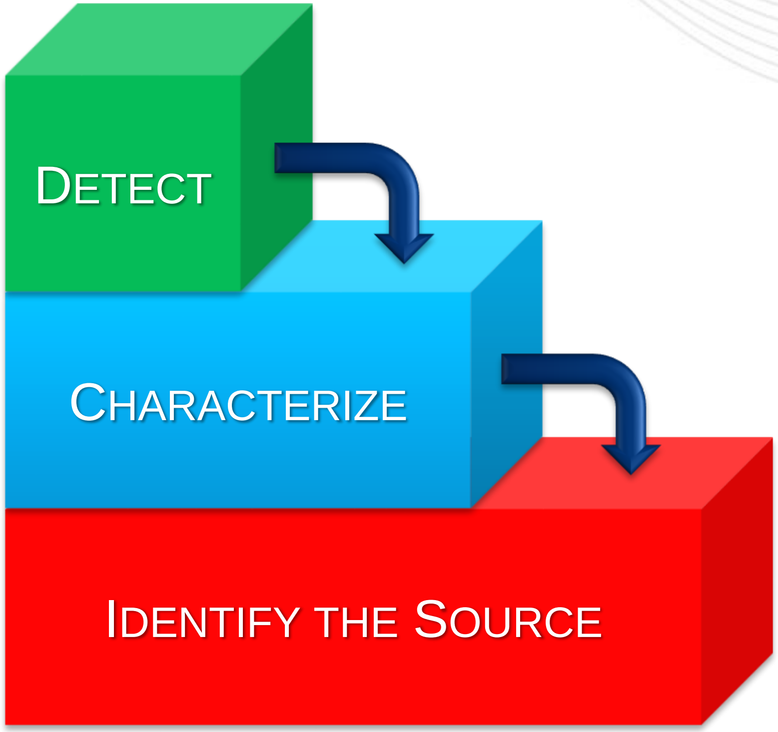
Oscillation detection -

- RTDMS has algorithms to detect major system oscillations and categorize the type (forced, local, and inter-area) based on frequency.
- RTDMS can detect oscillations in system voltage, voltage angle or voltage angle derivative, real and reactive power flow signals.
- Based upon the oscillation frequency, it will detect and categorize the oscillations in 4 bands: Speed Governor, Inter-area, Local Control System, and Torsional Dynamics.

Mode Meter monitoring -

- Monitors known oscillations (natural/system) and can also provide mode shape.

Near Real Time Oscillation Detection



Three main steps in real time oscillation detection.

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Eastern Interconnection Situational Awareness Monitoring System (ESAMS)

DOE Prototype Demonstration Project ESAMS

Overall Project Objective:

*To introduce a common, high-level interconnection-wide view based on synchrophasor information in order to foster discussion within and among Eastern Interconnection operating entities**

Key Elements of the initial high-level view will include:

1. Detect and identify forced and natural oscillations
2. Monitor phase angle pairs and identify when values are outside of normal operating ranges
3. Detect atypical behavior from an ensemble of measurements and identify which ones are contributing to the atypicality

Information Delivery Methods (by subscription):

1. Near real-time text message
2. Emailed reports (daily, weekly, monthly)

**The prototype will not duplicate functionalities currently provided by FNet*

DOE Prototype Demonstration Project ESAMS

Continuation of CERTS baselining project with:

- LBNL and PNNL
- PJM, NYISO, ISONE and MISO
- EPG

Goal: Create a prototype oscillation detection and baselining tool for a large portion of the Eastern Interconnection

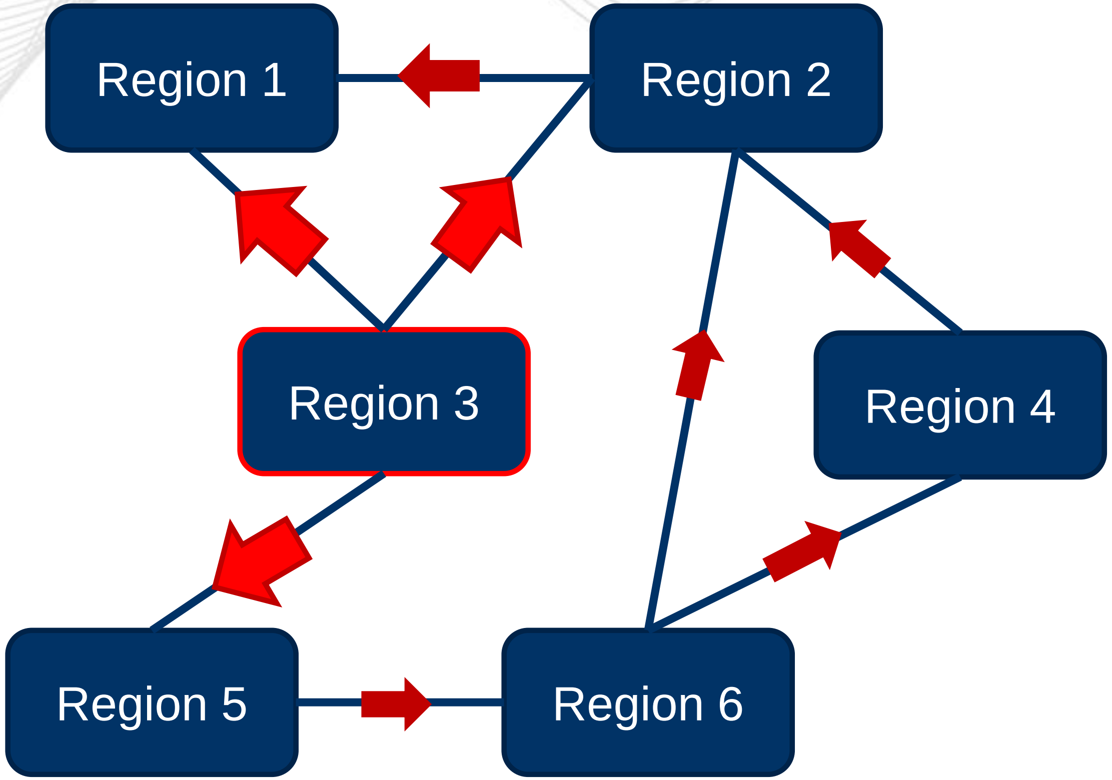
Focus on information sharing

Challenges in Wide-Area Localization

- Direct extension of existing methods would require:
  - Streaming data for every PMU-monitored generation plant
  - Analyzing data for every PMU-monitored generation plant
  - Centralized one-line diagrams
- Severely limited in regions with low penetration of PMUs

Approach

- Divide problem between system- and regional-levels
- Apply Dissipating Energy Flow (DEF) method[1] to major tie lines between utilities
- Localize to a region, then the local utility identifies the source
- Concept is in place at ISO-NE, but without neighbors' data[2]



[1] L. Chen, Y. Min and W. Hu, "An energy-based method for location of power system oscillation source," in *IEEE Transactions on Power Systems*, vol. 28, no. 2, pp. 828-836, May 2013.
[2] S. Maslennikov, B. Wang and E. Litvinov, "Locating the source of sustained oscillations by using PMU measurements," 2017 IEEE Power & Energy Society General Meeting, Chicago, IL, 2017, pp. 1-5.

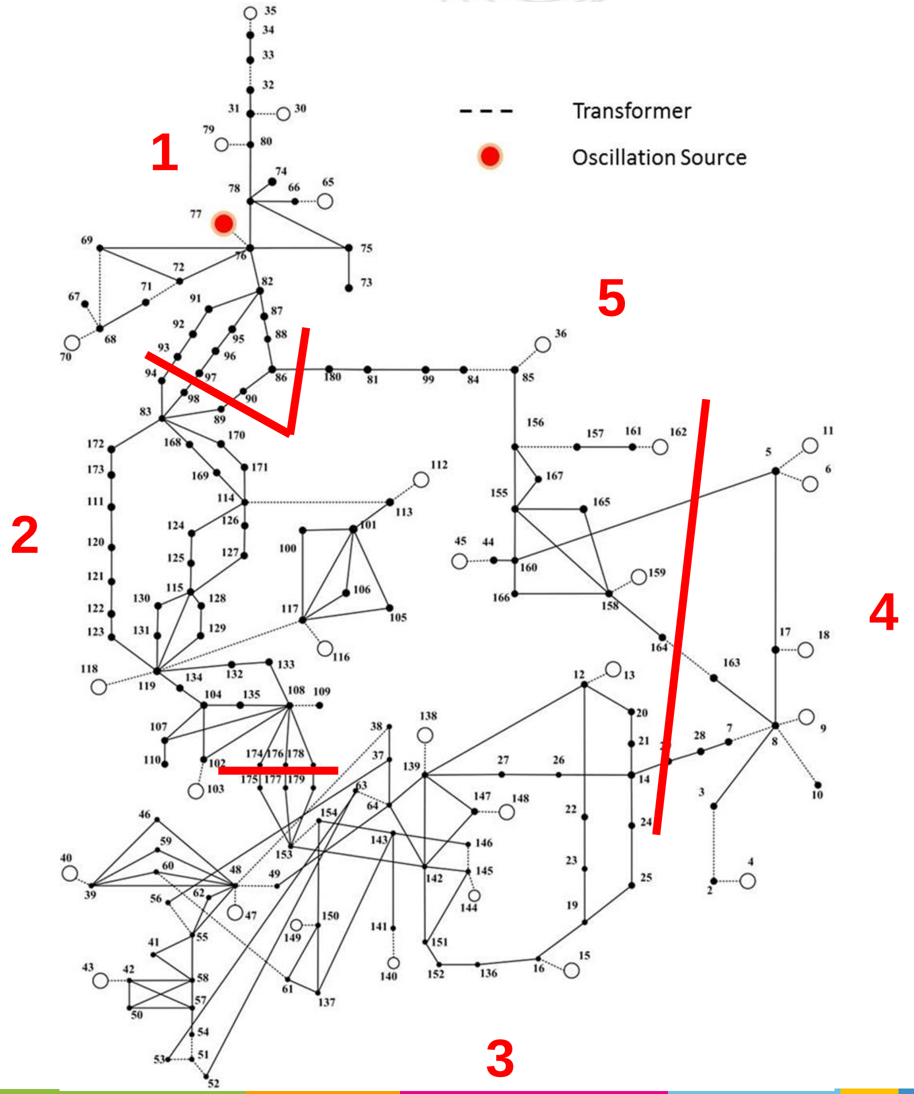
DEF Calculation

- Implemented using cross-spectral density
- Update to existing method[1]
- Pros
  - Avoids filtering required by time-domain implementation
  - Reported values are meaningful – scaling unnecessary
- Con: not well-suited to natural oscillations with varying amplitudes

[1]R. Xie and D. J. Trudnowski, "Tracking the Damping Contribution of a Power System Component Under Ambient Conditions," in *IEEE Transactions on Power Systems*, vol. 33, no. 1, pp. 1116-1117, Jan. 2018.

Localization

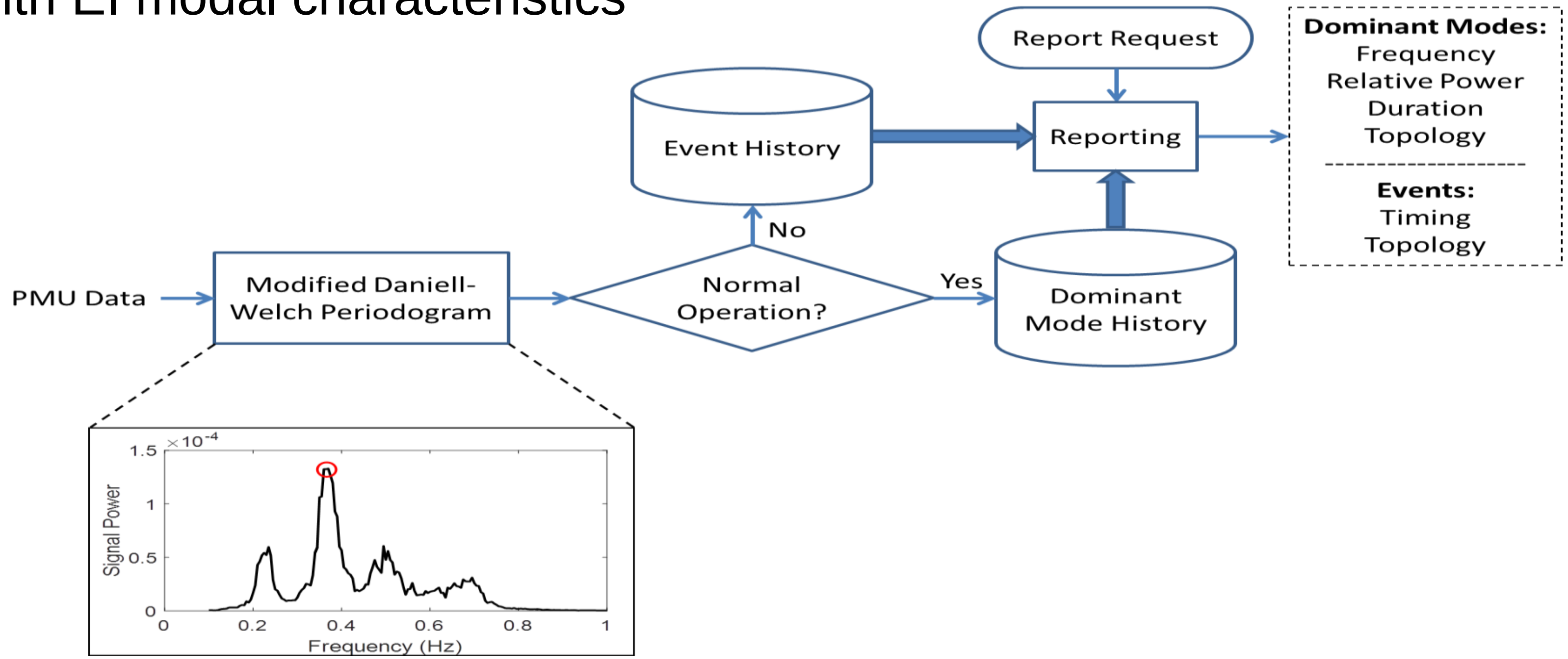
- Power system divided into regions
- DEF calculated for each tie connecting regions
- DEF flow pattern determines source region



Key Element #1: Oscillatory Event Detection

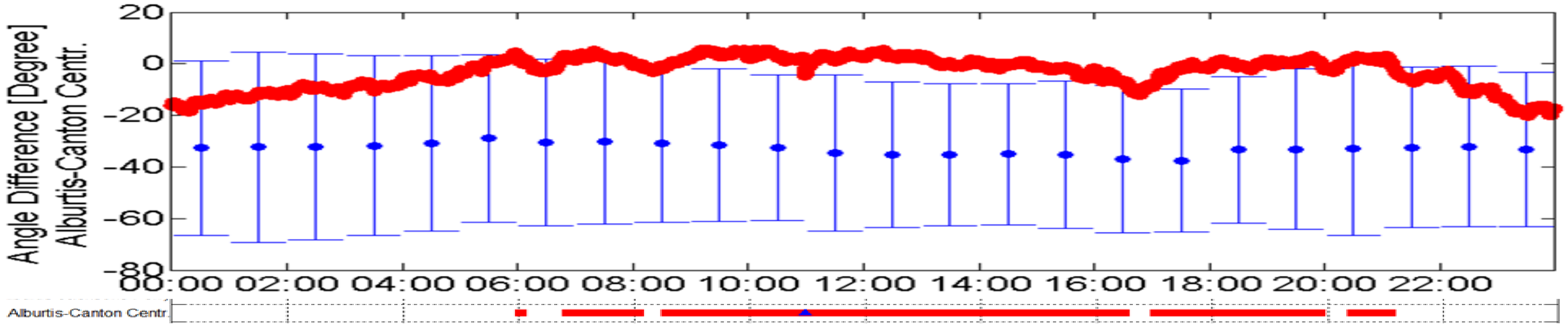
Event: Changes in low-level natural oscillations

- Oscillations between the areas defined by angle pairs
- Increase familiarity with EI modal characteristics

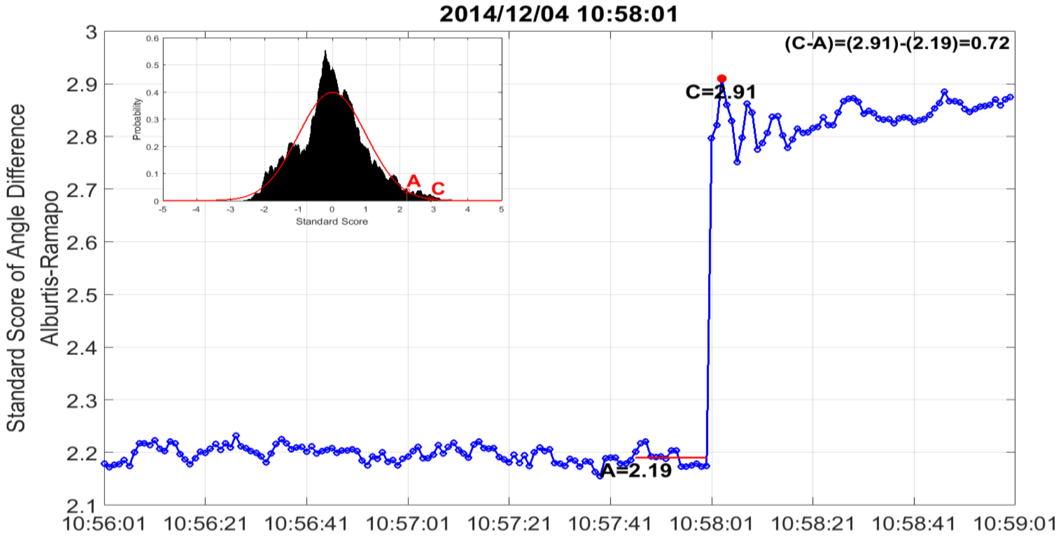


Key Element #2: Monitor Phase Angle Pairs

- Identify when phase angle pair differences are outside of historically observed normal operating ranges

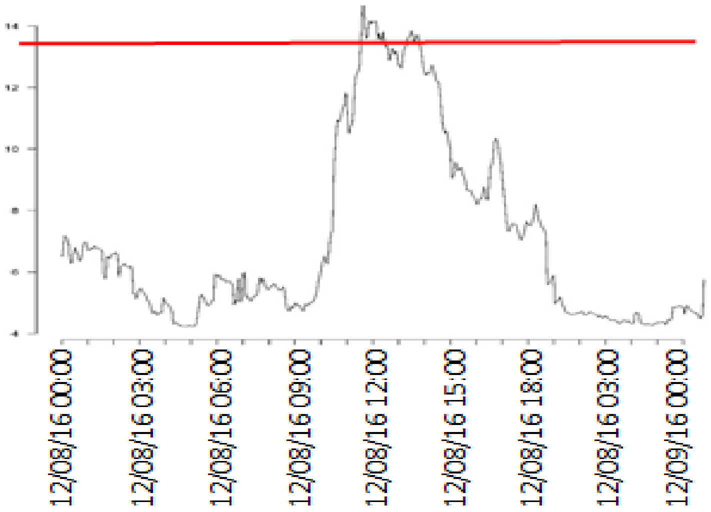


- Apply control chart methodology to detect significant changes in angle pairs

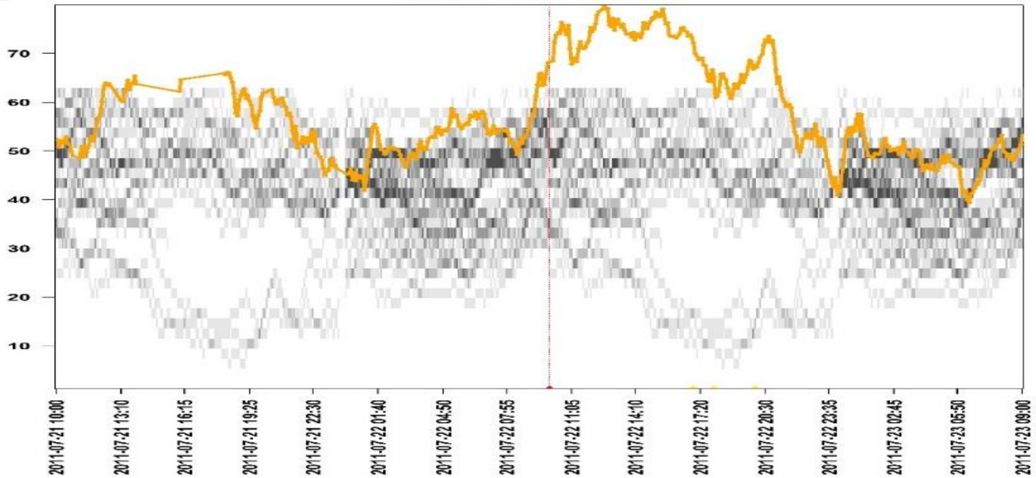


Key Element #3: Detect Atypical Behavior

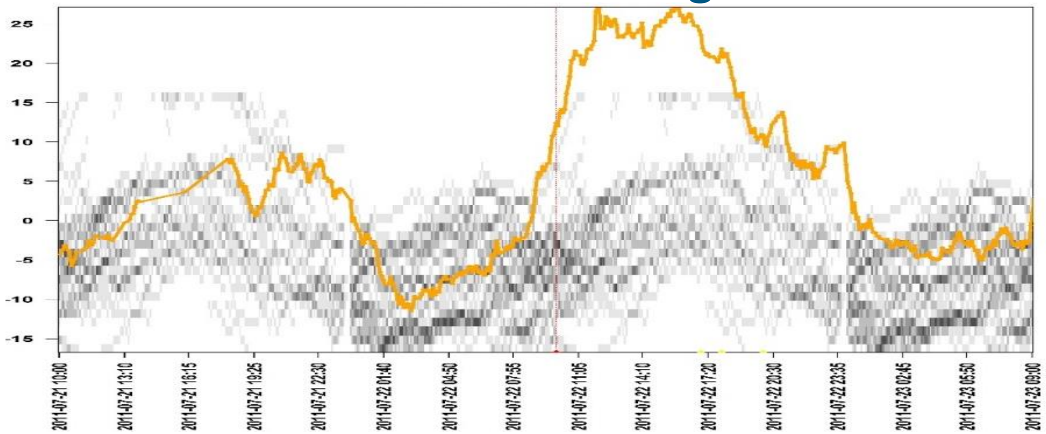
- Use multivariate statistical algorithms and past data to define a baseline of normal, observed behavior
- Compare current data to the baseline to determine when and where atypical behavior is observed



Jackson – Alburtis Angle Pair



Monroe – Hanna Angle Pair



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Conclusion

Situational Awareness

Actionable Information

Tools (Data-Hungry)