ELECTRIC POWER GROUP
WEBINAR SERIES

Operationalizing Phasor Technology

Electric Power Group

Operationalizing Phasor Technology

System Events- Deciphering the Heartbeat of the Power Grid

July 16, 2013

Webinar

John W. Ballance

Electric Power Group

Webinar Outline

- **What is SynchroPhasor Technology?**
- **What can we decipher from System Events Using Synchrophasors to improve planning and operations?**
- **System Events – Case Studies to Illustrate Use of Synchrophasors**
- **Methodology and Tools for Deciphering System Events**
- **Deciphering System Events**
  - **Where is the problem?**
  - **What is the problem?**
  - **What actions do I need to take?**
  - **Did my system behave as expected?**

What is Synchrophasor Technology?

- **A phasor is the amplitude and phase angle representation of a sinusoidal signal**
- **Measurements include magnitude and angle of voltages and currents as well as frequencies**
- **Synchrophasor refers to a phasor referenced to a cosine at nominal frequency synchronized to UTC time**
- **Phasors provide high resolution 30-60 samples per second compared to 1 sample every 2-4 seconds for SCADA**
- **Synchrophasor technology delivers:**
  - ***Wide Area View* - Real time visualization and situational awareness of interconnection or sub-region**
  - ***High Resolution* - improved observability and event diagnostics**
  - ***Grid Dynamics* – measurement based phase angles, oscillations, voltage and angle sensitivities**

What Can We Decipher from System Events?

- **Phase Angle Differences – did they change, are they diverging and is the divergence increasing over time which may indicate stressed conditions and vulnerability?**
- **Frequency Response – how does it compare with frequency bias?**
- **Oscillation – is it local or inter-area; is there a control system problem and if so, where and what needs to be done?**
- **What happened - event signatures**
  - **Line Trip**
  - **Generation Trip**
  - **Lightning Strike**
- **Where did the event happen**
  - **Location and proximity to my system**

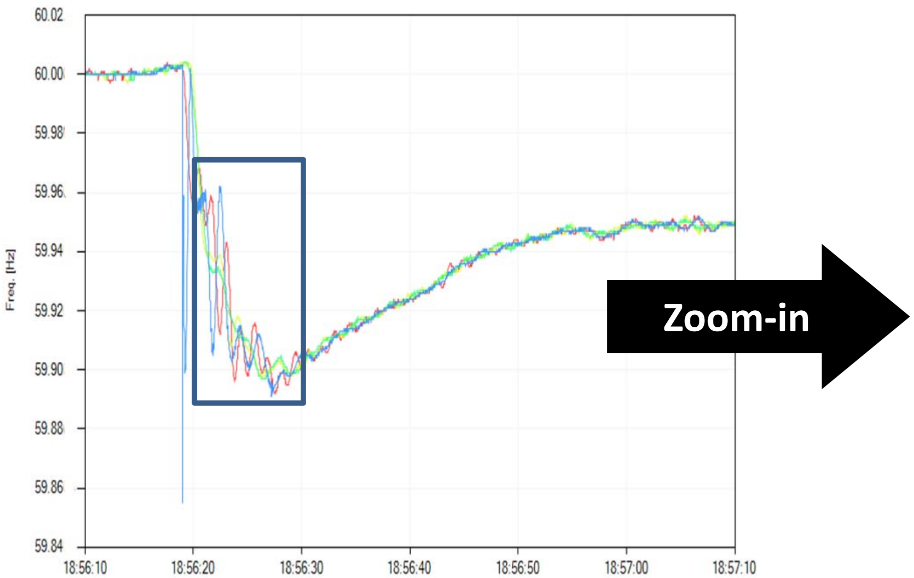
Event Analysis – Guidance for Operations

- This first webinar focuses on the use of event analysis to provide operators with the insights and guidance to make full use of synchrophasor technology in real-time operations
- Analysis of phasor data captured during grid events provides:
  - Ability to investigate the entire grid response based on measurements rather than models
  - Ability to determine where alarms should be set to inform operators of emerging issues
  - Ability to identify events for which operator interaction could improve performance, and to provide guidelines for that intervention
- Operationalizing synchrophasor technology
  - Wide Area View: visualization of grid metrics (e.g., Voltage, Angles, Frequency)
  - Resolution: Improved resolution of events occurring on the grid
  - Grid Dynamics: early detection of unwanted interactions and oscillations

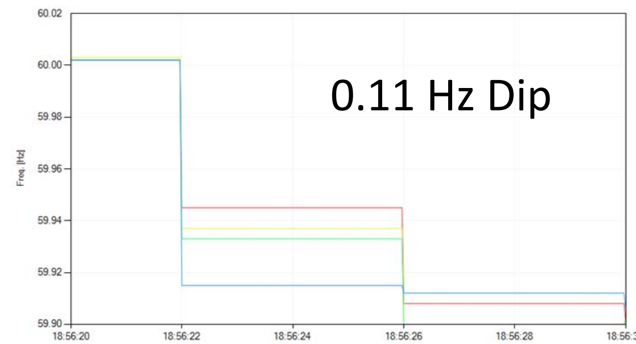
Observability – SCADA Vs. PMUs

QUESTION: Detection of Frequency Differences Across the Interconnection

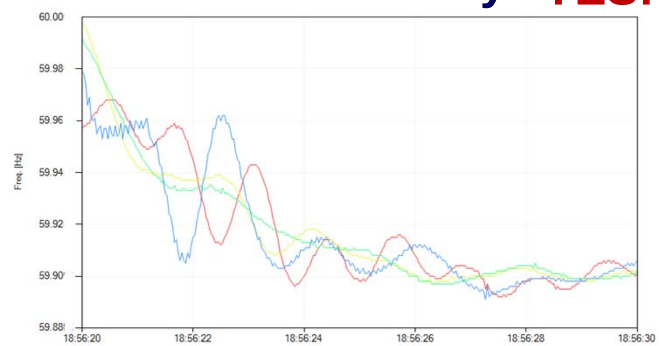
Observability



SCADA Observability **NO!**



PMU Observability **YES!**



ANSWER: SCADA - Frequency appears to be similar at all locations – no oscillations
PMU's - Frequency measurements from different locations show variations – indicates inter-area dynamics or oscillations

Electric Power Group

System Events – Case Studies to Illustrate Uses

1. Western Line Trip
   - Power delivery unchanged following first line outage
   - Phase Angle Change indicates greater grid vulnerability
2. Tornado near Browns Ferry – what happened?
   - Generation Trip
   - Frequency Response
   - Lightning Strike
3. Florida Blackout – Turkey Point Trip – 4million customers impacted
   - Is the problem contained or is my system vulnerable?
4. ERCOT – Wind Plant Oscillations and Generator Outage
   - Sustained Oscillations
   - Oscillations driven by generator control system malfunction

1. Western Line Trip

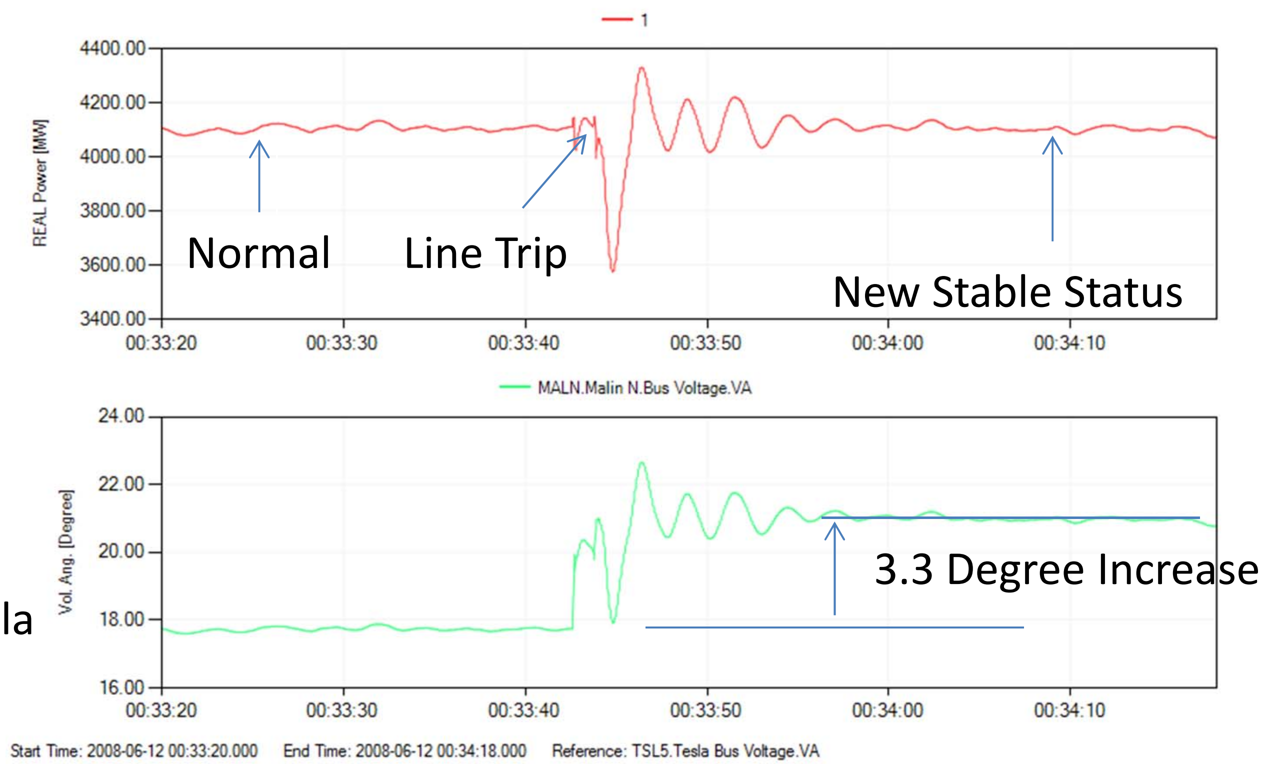
- **What happened?**
  - One of the three Pacific Intertie 500 kV lines in northern California tripped during a fire
- **What was observed?**
  - Power delivery from Oregon to California remains unchanged at 4100 MW, but indications of an event
  - Voltage angle from southern Oregon to central California increased by 3.3 degrees – indicator of increased grid stress
  - No frequency step change hence conclusion that there was no generation loss
- **Key questions**
  - Is voltage support adequate?
  - Increase in grid stress – does it make my system vulnerable?

1. Western Line Trip – First Event

One of three 500 kV Pacific Intertie lines in northern California trips due to fire under line. Power delivery from Oregon to California remains unchanged at 4100 MW. Voltage angle between Malin and Tesla increases 3.3 degrees

Power on COI

Angle – Malin to Tesla



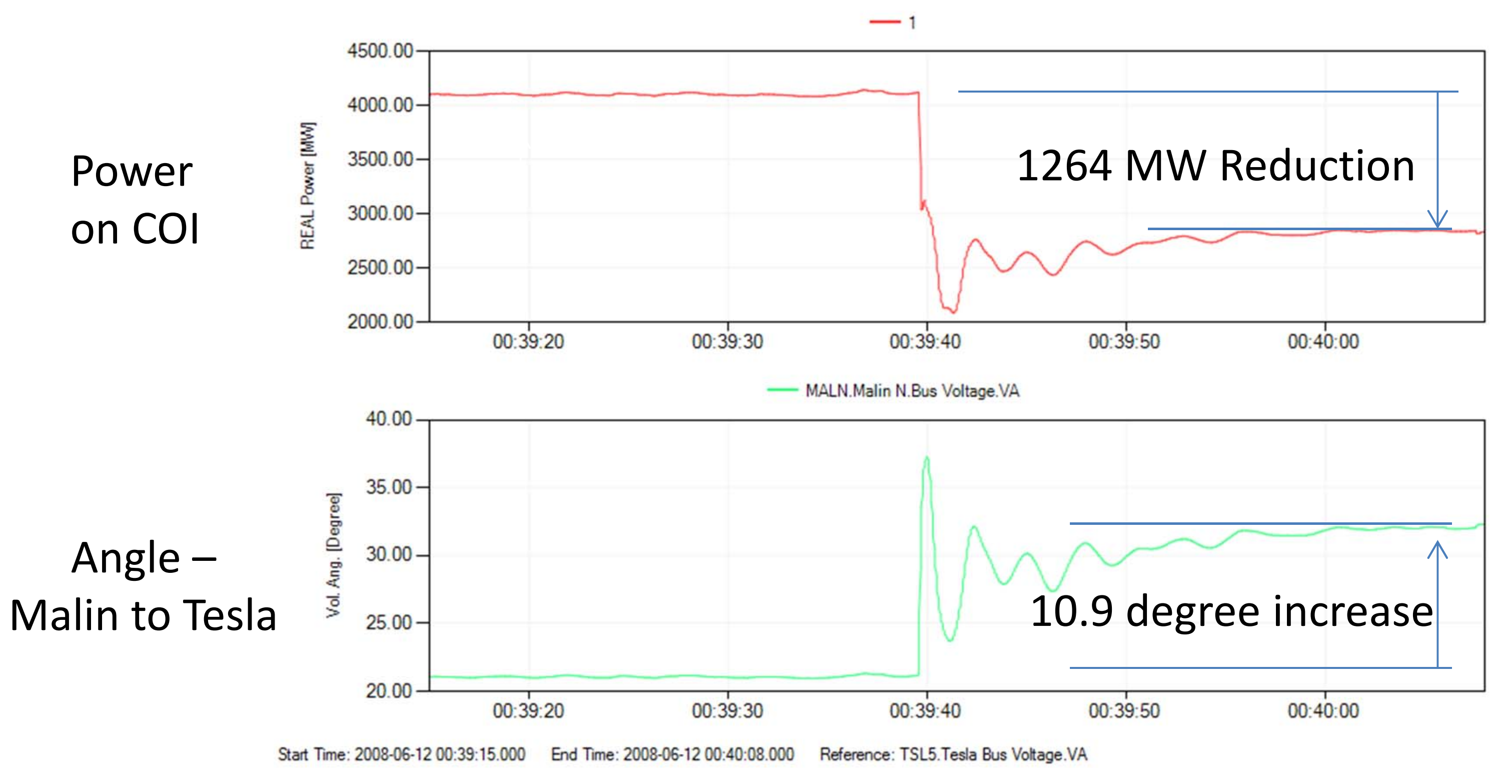
No Power change – Did stress change?

Increased angle means increased stress

Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

1. Western Line Trip – Second Event
Power flow and angle changes

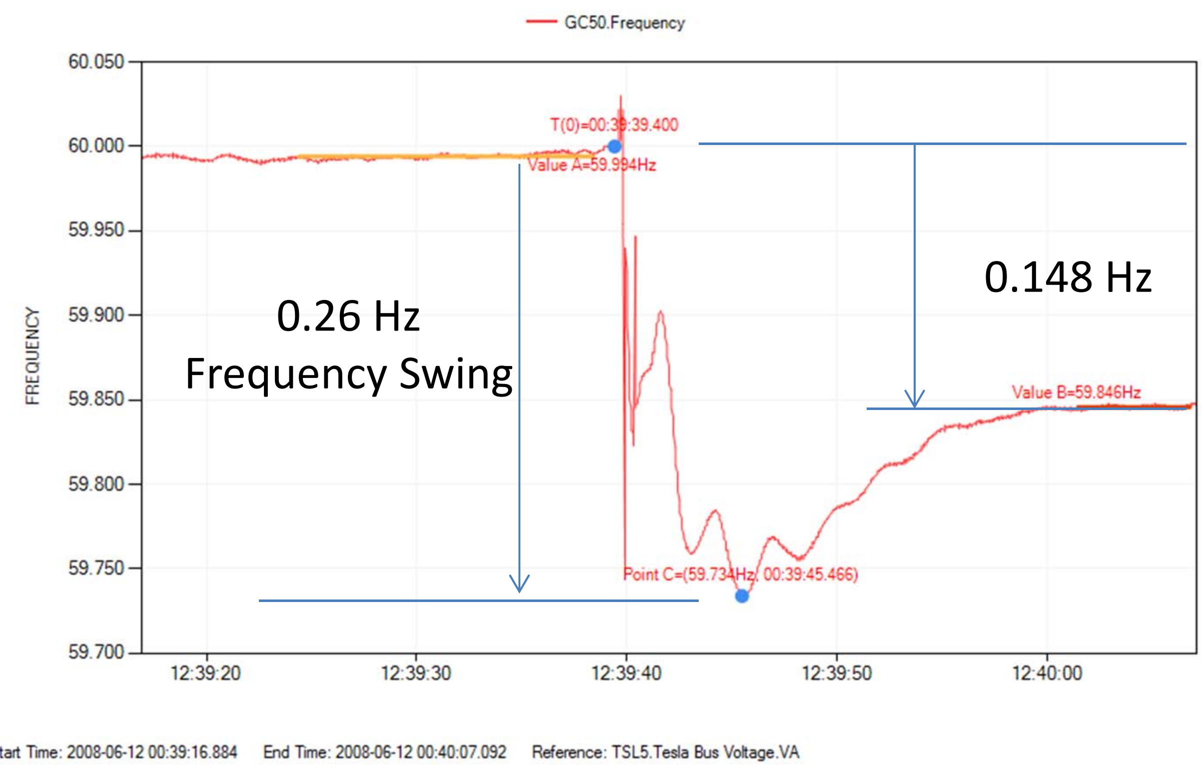
Second 500 kV Pacific Intertie line trips due to fire. 2644 MW of generation tripped automatically. Third line remains in operation.



Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

1. Western Line Trip – Second Event
Frequency swing

Second 500 kV Pacific Intertie line trips due to fire. 2644 MW of generation tripped automatically. Third line remains in operation.



Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

Electric Power Group

1. Western Line Trip

- **What does it mean for my system?**
  - The transmission grid has lost some elements
  - Power flows have been reduced, but
  - Phase angles indicate increasing stress

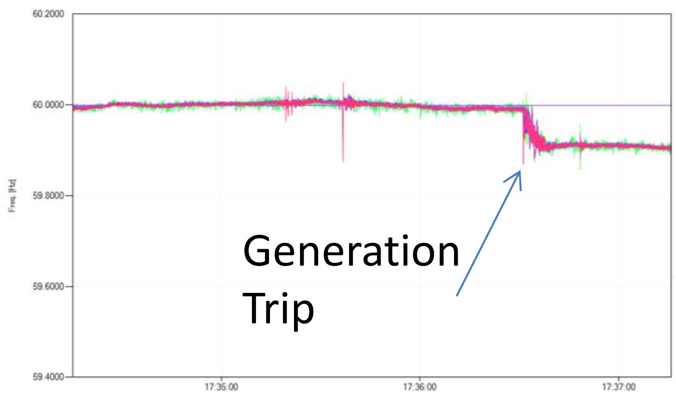
- **What should I do?**
  - Validate that my system is still in secure state
  - Can my system withstand the next contingency?
  - Validate frequency bias against measured frequency response

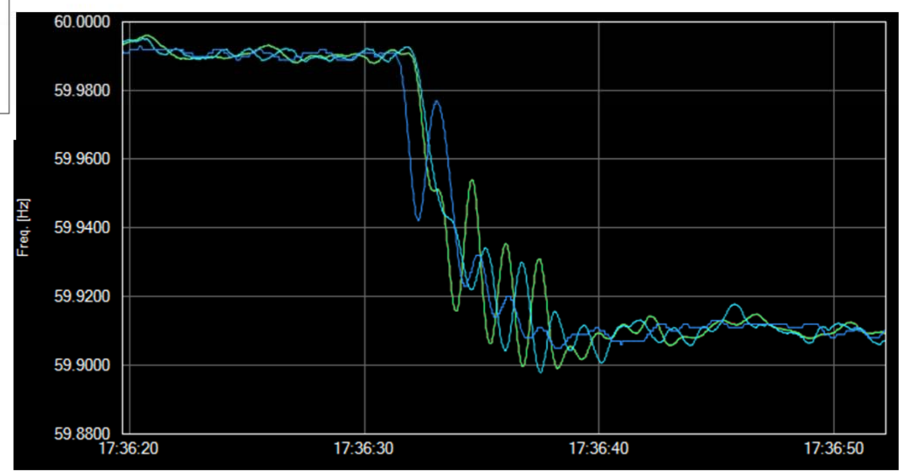
2. Tornado and Browns Ferry Trip

- **What happened?**
  - On 4/27/2011, all three Browns Ferry reactors tripped.
  - 2500 MW of generation lost
- **What was observed?**
  - Frequency dropped from 59.992 Hz to 59.908 Hz
  - Frequency plot shows transients – indicating that there were several lightning strikes/flashovers prior to the generation trip – potentially providing early warning for the operators
- **Key Questions**
  - What was the frequency response for this event?
  - How does this compare with frequency bias?

2. Tornado and Browns Ferry Trip

- **Frequency drop from Browns Ferry trip – from 59.992 to 59.908**
- **Stabilized within 15 seconds**

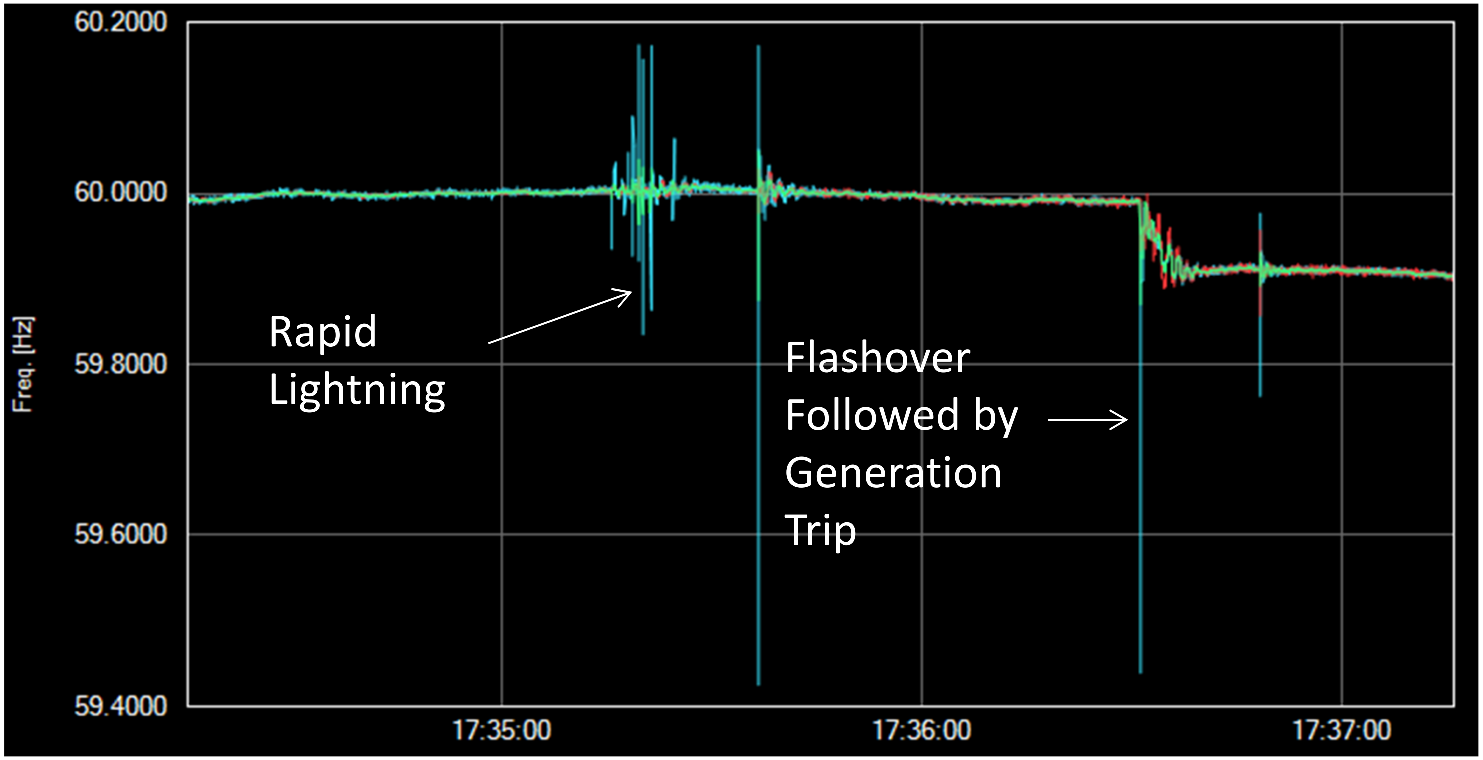




Screenshots of PGDA (Phasor Grid Dynamics Analyzer)

2. Tornado and Browns Ferry Trip

- **Frequency transients – likely caused by lightning, preceded the generator trip**

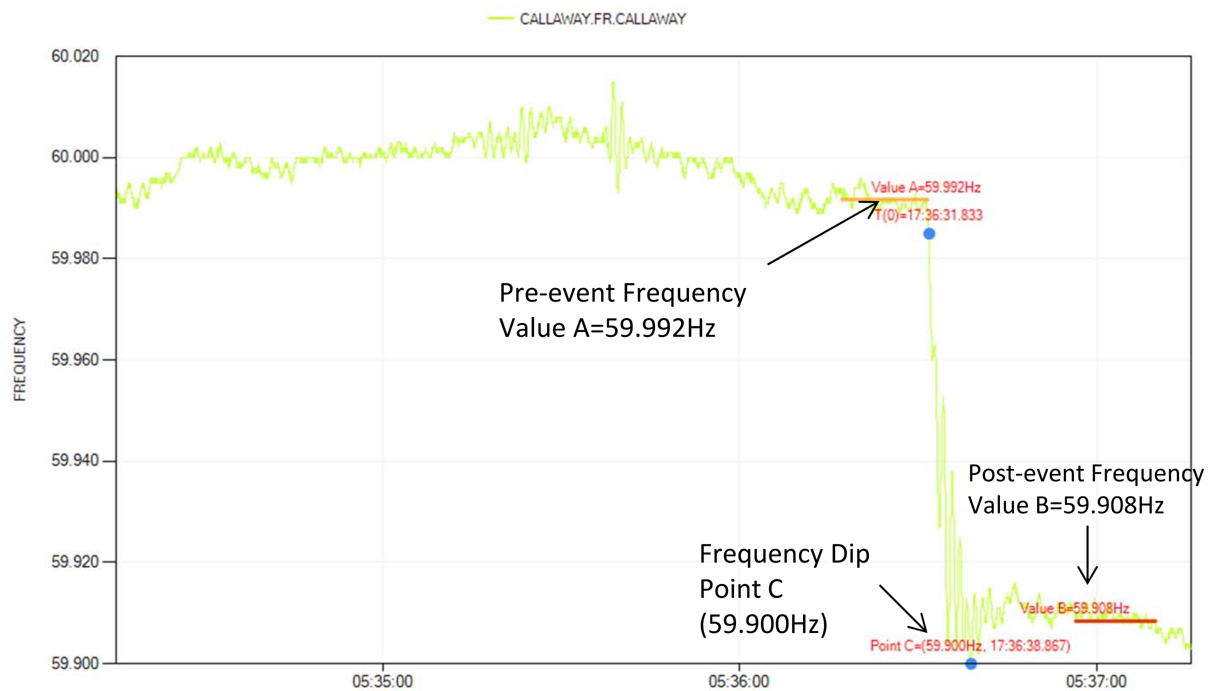


Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

2. Tornado and Browns Ferry Trip

- **Frequency Response**
  - **Loss of Generation: 2500 MW**
  - **Frequency Dip 59.992-59.908=0.084Hz**
  - **Frequency Response=2500/0.084*0.1=2980MW/0.1Hz**

- **Validate or adjust Frequency Bias**



Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

2. Tornado and Browns Ferry Trip

- **What does it mean for my system?**
  - The frequency signal provided early warning of storm activity impacting transmission
  - Has the frequency stabilized?
  - What transmission did I lose during the storm?

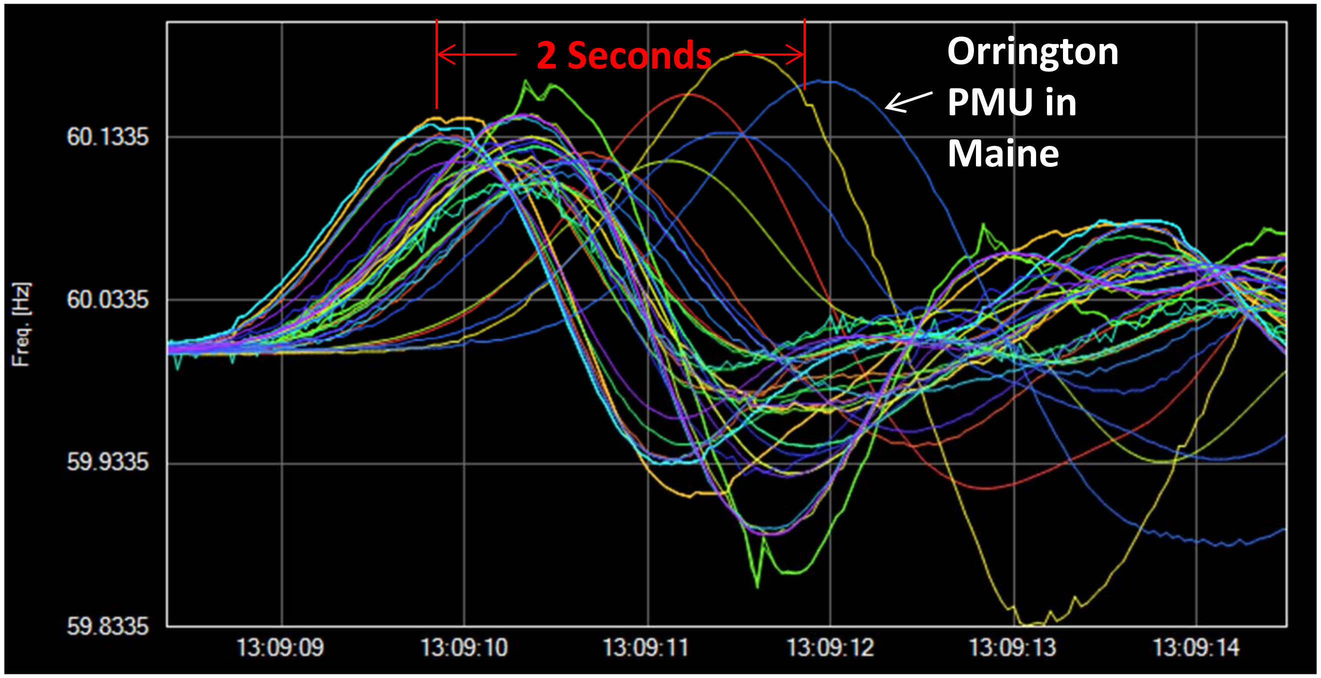
- **What should I do?**
  - Validate that my system is still in secure state
  - Validate frequency bias against measured frequency response

3. Florida Turkey Point Trip - 2008

- **What happened?**
  - On 2/26/2008, a failed switch and fire at an electrical substation outside Miami triggered widespread blackouts in parts of Florida
  - The nuclear reactors at Turkey Point power plant tripped
  - Four million people were affected
- **What was observed?**
  - Frequency swing was felt as far as Canada Border after about 2 seconds
  - SCADA does not have the ability to see what happens within 1~2 seconds
  - SCADA does not offer wide area visibility to what is happening outside the footprint
- **Key Questions**
  - Wide area situational awareness – what happened? Where?
  - Is my system the cause? Is my system vulnerable?
  - Actions? Pinpointing cause and assessment of current wide-area situation helps determine what actions if any are needed to mitigate this event or prepare for the next event

3. Florida Turkey Point Trip - 2008

- **Wide-area Monitoring - PMUs traces shown include Florida, Canada, Ohio, and Maine**
  - **Frequency wave propagation can be seen by the time delay in frequency change at PMUs across the grid.**
  - **Frequency swing observed near Canadian Border after 2 seconds**
- **What does it mean for my system?**
  - **Am I leading or following the oscillation?**
  - **Is my system behaving as expected?**



Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

3. Florida Turkey Point Trip - 2008

- **What does it mean for my system?**
  - The frequency signal indicates loss of generation
  - Has the frequency stabilized?
  - Where was the event, and how far was it from my system?

- **What should I do?**
  - Validate that my system is still in secure state
  - Validate frequency bias against measured frequency response

4. ERCOT – Voltage Oscillations Driven by a Wind Plant

- **What happened?**
  - A wind generator tripped
  - Previously, two other lines had tripped and reclosed
  - Customers complained of flickering lights beginning the previous evening
- **What was observed?**
  - The nearest PMU to the wind generator that tripped was about 50 miles away
  - Voltage oscillations at about 2 Hz were detected beginning late on the evening prior to the trip
  - At about 20:35, the 2 Hz oscillation magnitude sharply increased, and continued until the wind farm tripped
  - The oscillations started suddenly (they did not ramp up, they appeared at full magnitude when they begin) and ended suddenly, concurrent with the trip of the wind generator
- **Key Question**
  - What do these oscillations mean for my system?

4.ERCOT – Voltage Oscillations Observed by a Nearby PMU

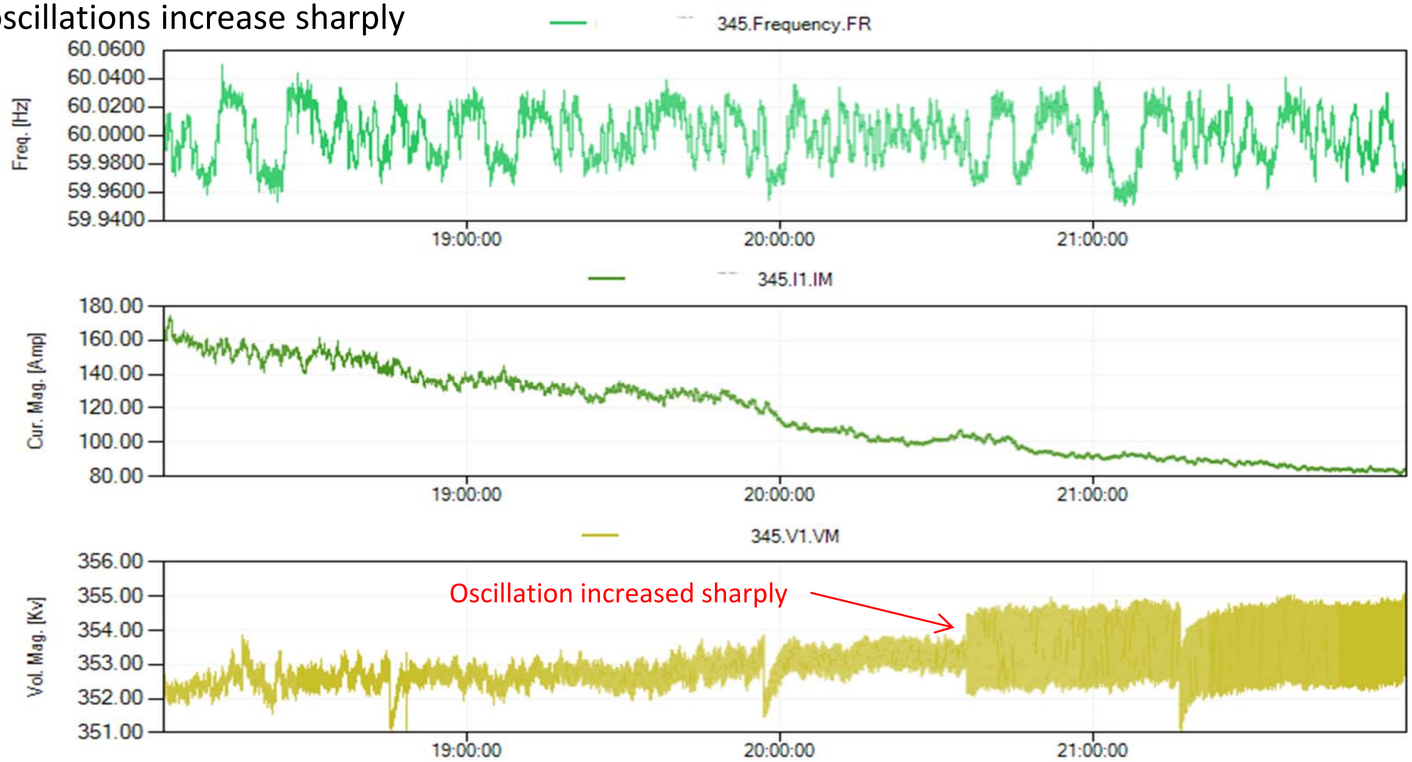
Pre-event

This plot of the Frequency, Current Magnitude, and Voltage Magnitude phasors, observed by a nearby PMU illustrate the presence of a 2 Hz voltage oscillation as early as 18:00, growing slowly until about 20:35, when the oscillations increase sharply

Frequency

Current

Voltage

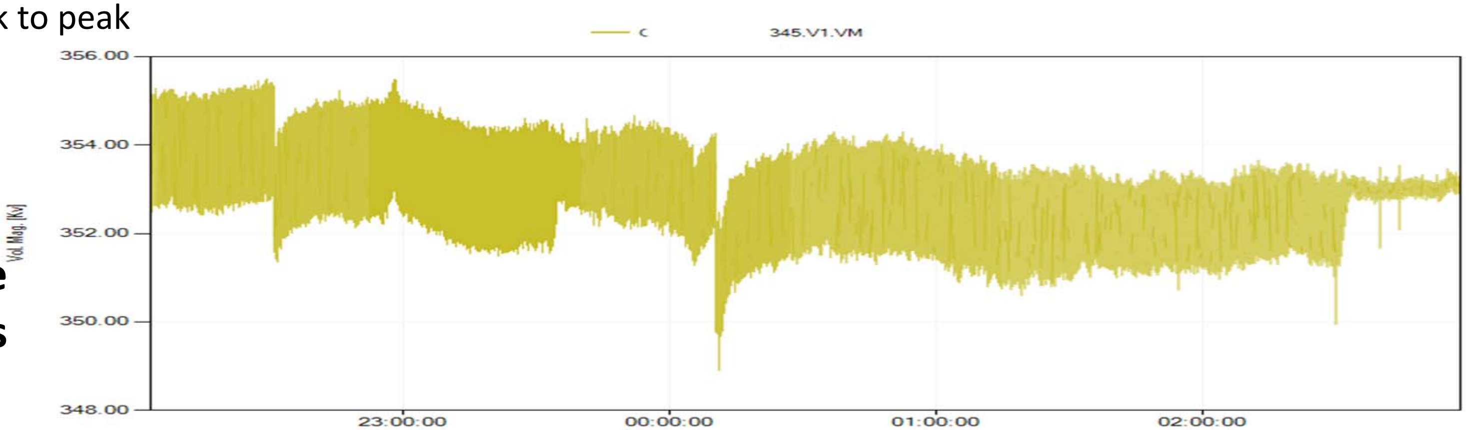


Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

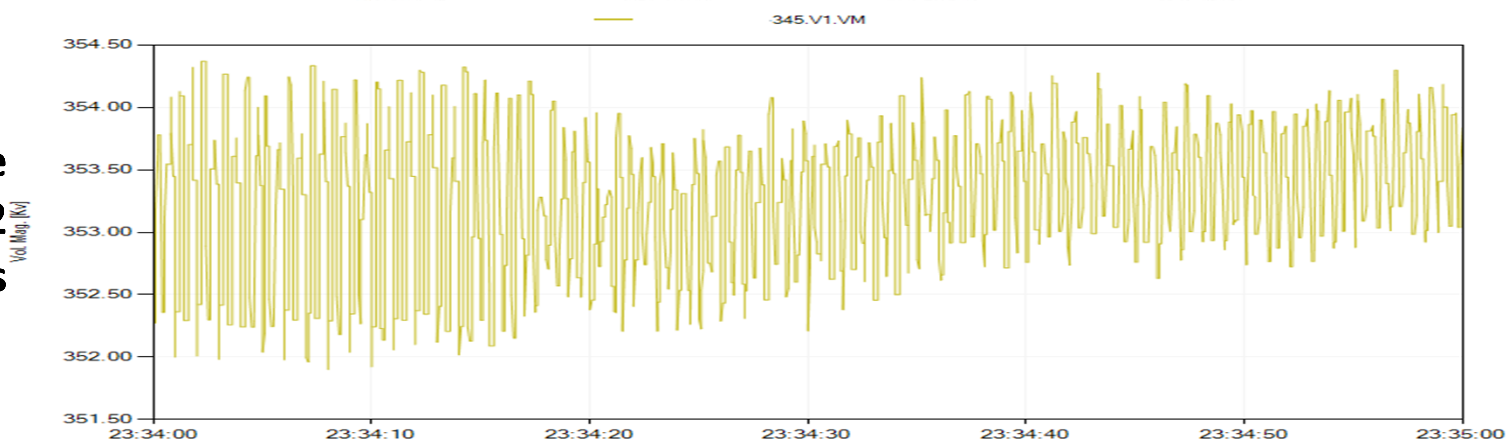
4. ERCOT – Wind Plant Voltage Oscillations Observed

Plot of voltage magnitudes over four plus hours prior to generator trip. Bottom plot shows oscillation on expanded scale. Note that while several external events cause step changes in average voltage (likely generation turning on and off), the magnitude of oscillations are unaffected. Oscillations are about 2 kV peak to peak

Voltage Over 5 hours



Voltage Over 2 Minutes



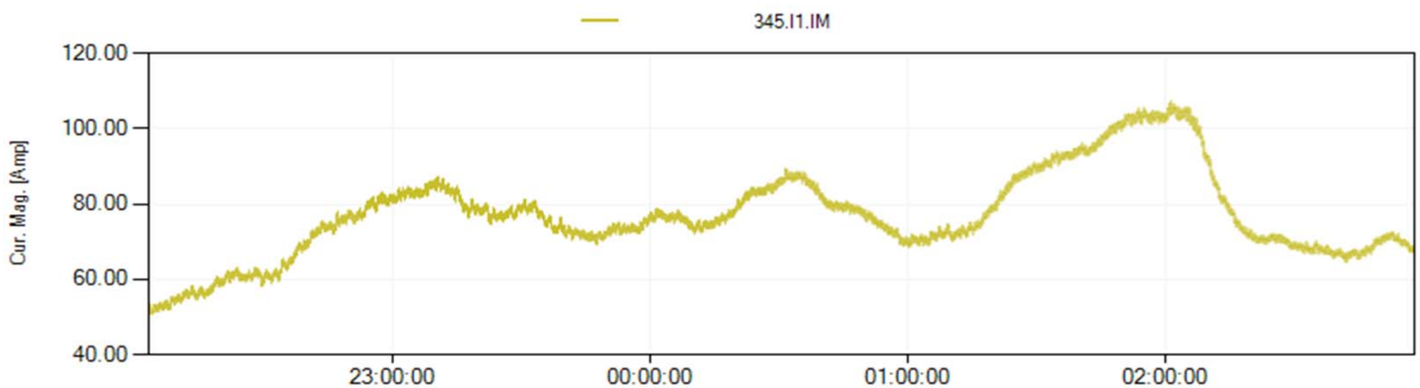
Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

4. ERCOT – Wind Plant Voltage Oscillations Observed

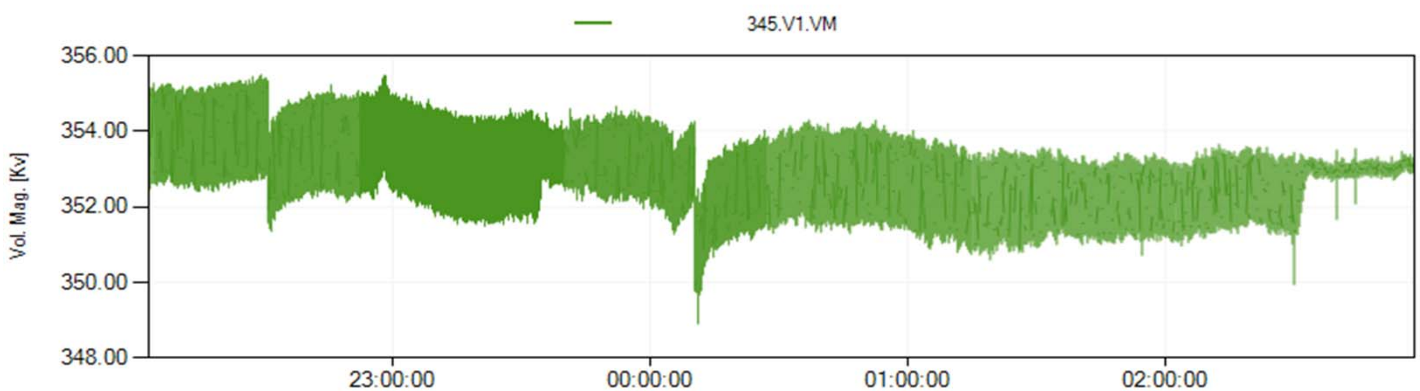
Event

Plot of current and voltage magnitudes at nearby PMU for entire five hour data extract. Note that there is no significant oscillation in the current magnitude, while the voltage signal shows voltage oscillations. This suggests that the generators nearest this PMU were not the source of the oscillations.

Current



Voltage

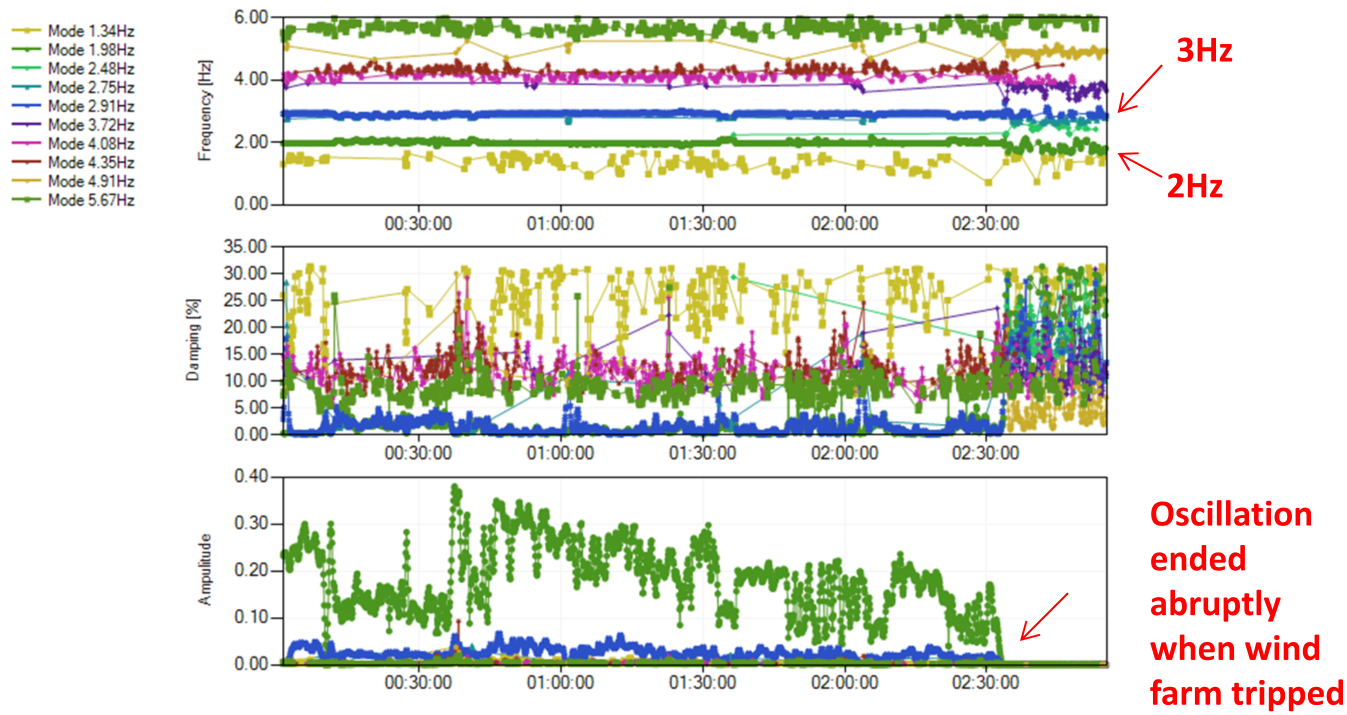


Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

4. ERCOT – Wind Plant Voltage Oscillations

Event

This plot illustrates the modal analysis of the voltage signal from midnight to 3:00 AM. Note the strong frequency oscillation at 1.98 Hz (essentially 2 Hz), which ended abruptly at about 2:30 AM, following the trip of the wind farm.



Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

4. ERCOT – Wind Plant-Driven Voltage Oscillations

- **What does it mean for my system?**
  - The 2 Hz oscillation is being caused by some device/generator, and is most likely a controller (e.g., generator voltage regulator) with a bad setting
  - Because the oscillations start suddenly (they do not ramp up, they appear at full magnitude when they begin) and end suddenly, a control device is suspected
  - Because the monitored current signal does not reflect the 2 Hz oscillation, it is unlikely that the generation nearest the monitoring PMU is the cause of the oscillation
- **What should I do?**
  - Check with the generation owner of the plant that tripped to determine if the plant was doing anything unusual during the event, such as changing controller settings
  - Validate that the wind generator models used for grid planning match those provided by the generation owners

Tools for Deciphering Events

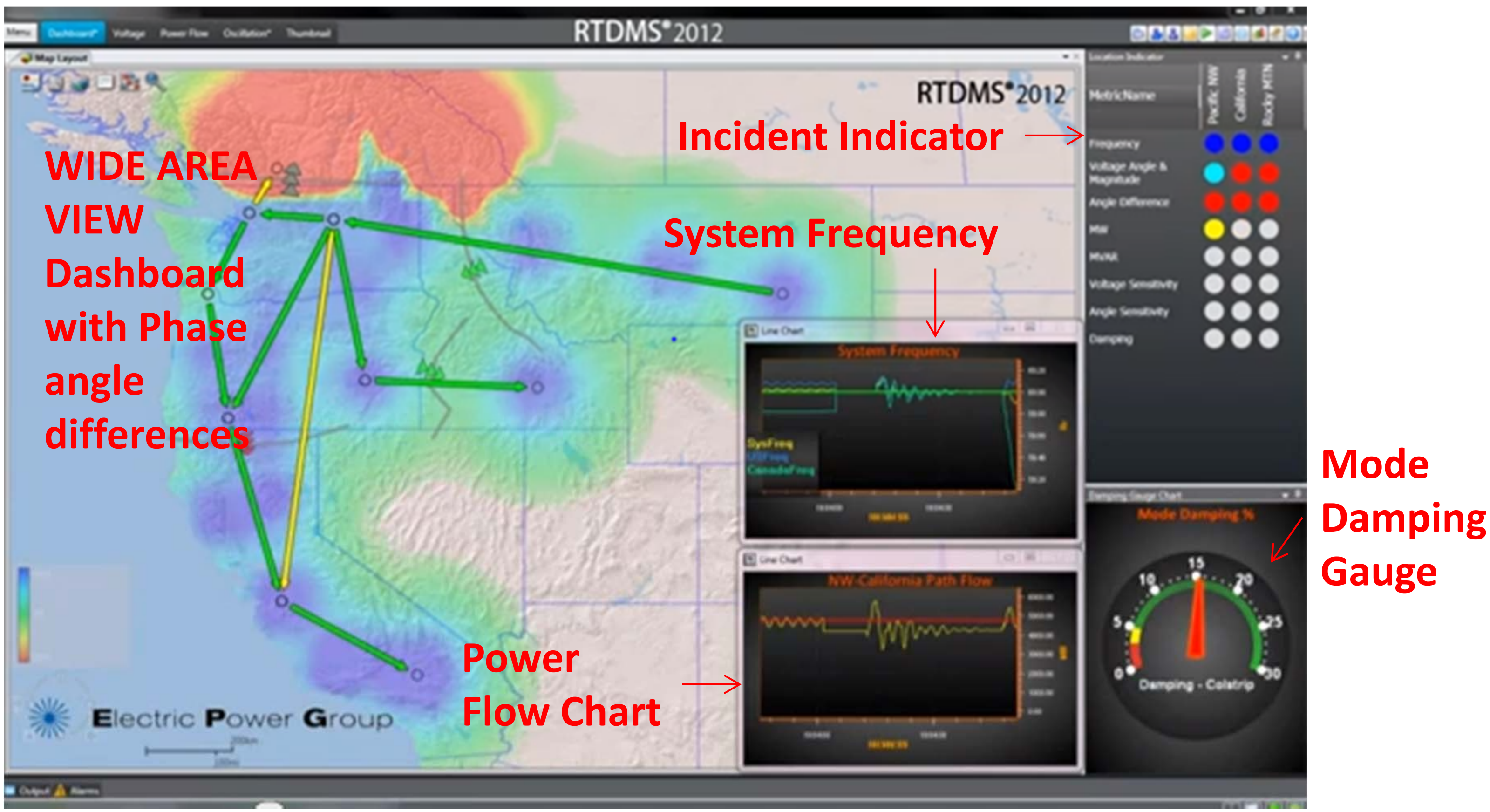
Real Time Dynamics Monitoring System® - Used by Operators in Control Rooms

Phasor Grid Dynamics Analyzer - Offline Analysis Tool for Engineers and Planners

®Electric Power Group. Built upon GRID-3P platform, US Patent 7,233,843, US Patent 8,060259, and US Patent 8,401,710. All rights reserved.

Wide Area View

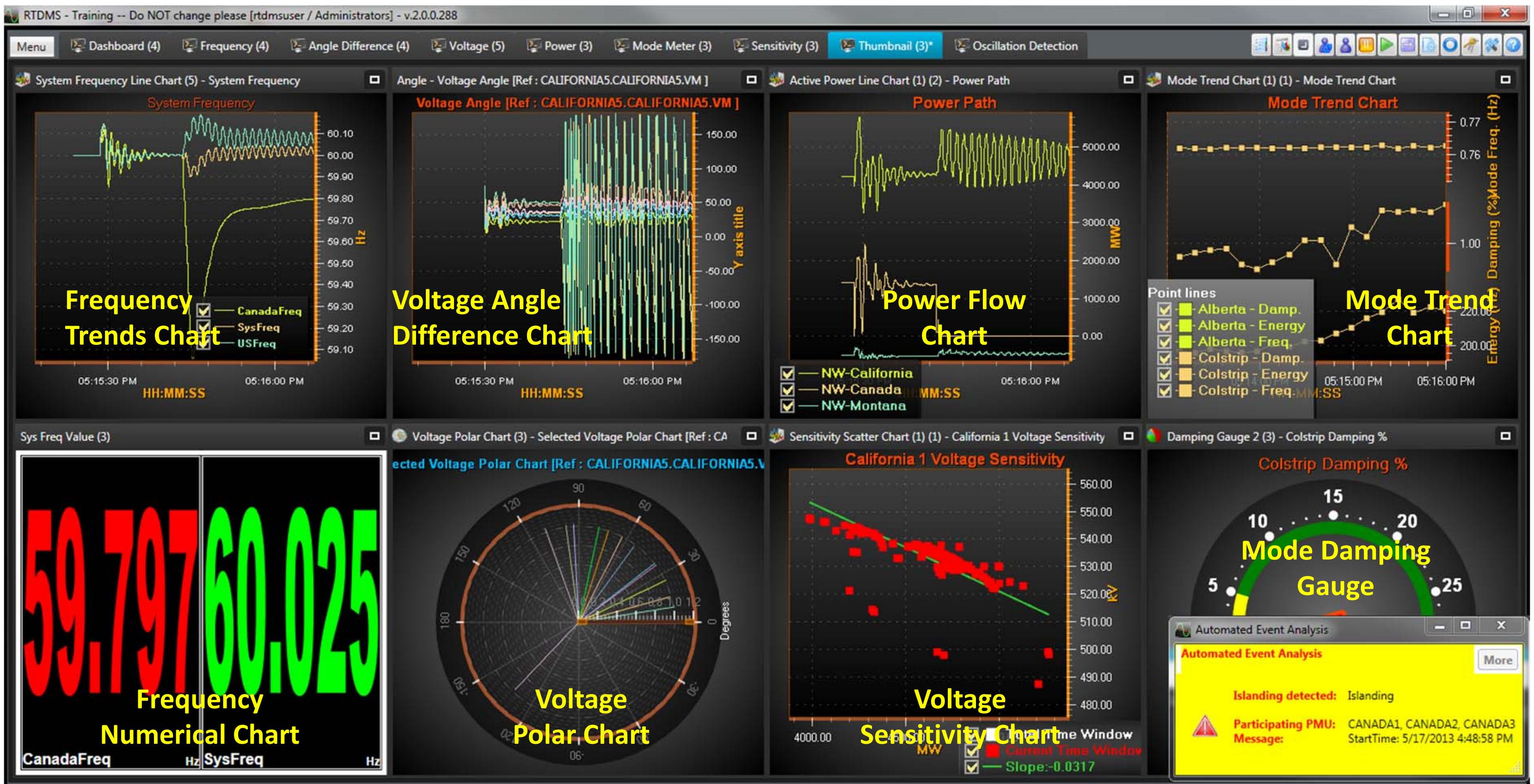
- **RTDMS – Real Time Dynamics Monitoring System - Used in Control Rooms at ISOs and Utilities**



Screenshot of RTDMS – Real Time Dynamics Monitoring System

Grid Dynamics- High Resolution in Real Time

- **RTDMS – Real Time Dynamics Monitoring System - Used in Control Rooms at ISOs and Utilities**



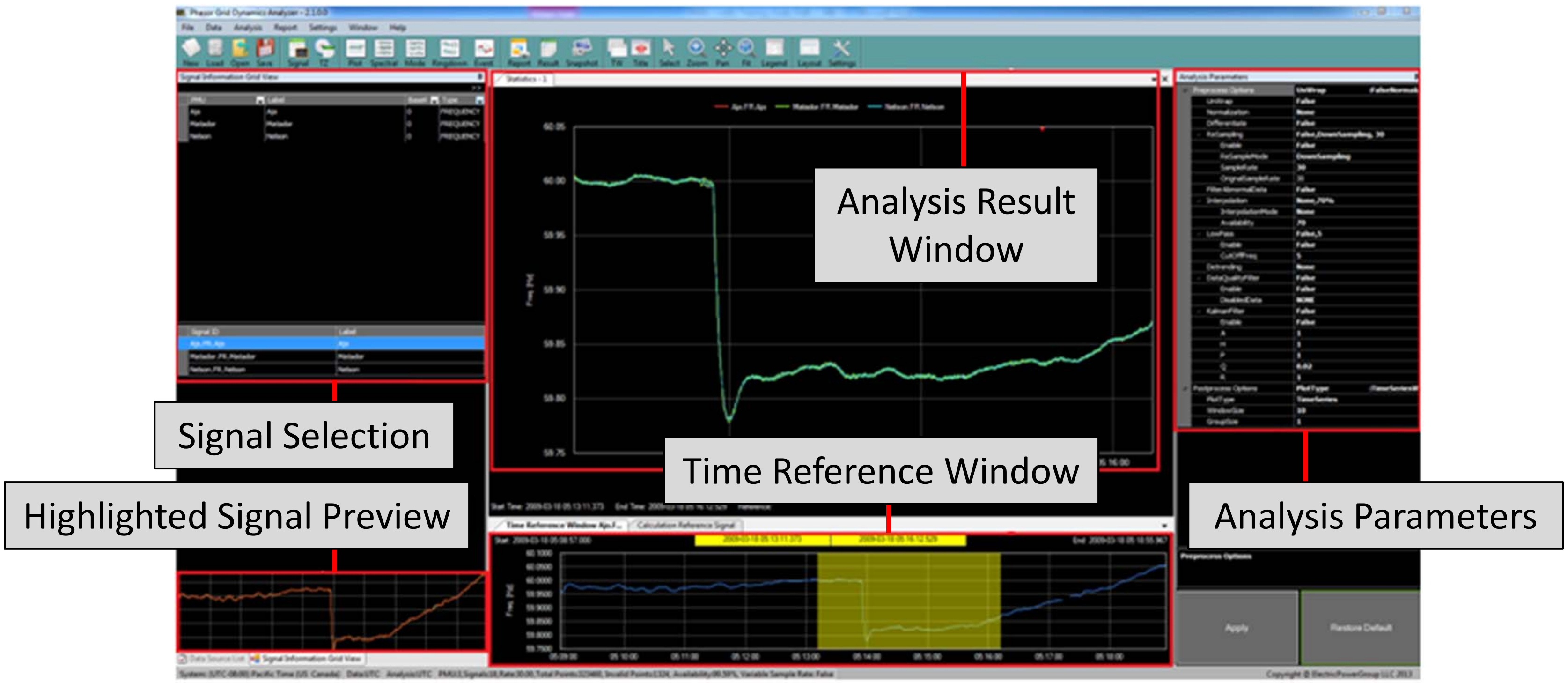
Screenshot of RTDMS – Real Time Dynamics Monitoring System

Islanding Detected

Electric Power Group

Detailed Offline Analysis Toolkit

- **PGDA – Phasor Grid Dynamics Analyzer - Offline Analysis Tool for Engineers and Planners**



Screenshot of PGDA (Phasor Grid Dynamics Analyzer)

Operationalizing Synchrophasor Technology – Key Steps

- **System Events – operating engineers should analyze significant events and use results to improve operations**
  - Frequency Response
  - Voltage Sensitivities
  - Validate models
  - State Estimator Calibration
- **Oscillations – diagnose root cause to determine source of problem e.g., faulty controller**
- **Wide Area Events – diverging phase angles, oscillations – determine current system condition. Are you in a secure state?**

EPG WEBINAR SERIES

Webinars are planned monthly, on the third Tuesday of each month from 11 a.m. to 12 Noon Pacific. The initial webinar topic list includes:

- **System Events - Deciphering the Heartbeat of the Power Grid** (Jul 16)
- **Using Synchrophasor Technology For Real-Time Operation and Reliability Management** (Aug 20)
- **Phase Angle Differences – what they mean and how to use them for operations** (Sep 17)
- **Data Diagnostics** (Oct 15)
- **Generator Parameter Validation** (Nov 19)
- **Using Synchrophasor Technology to identify Control System Problems** (Dec 17)
- **Establishing Alarm Limits For Use in Operations** (Jan 21, 2014)
- **Model Validation** (Feb 18, 2014)

Your feedback and suggestions
are important – PLEASE do let us know…

Frank Carrera
carrera@ElectricPowerGroup.com

Or if you prefer, call and
tell us directly
626-685-2015

Q&A

Thank you!

Electric Power Group
201 S. Lake Ave., Ste. 400
Pasadena, CA 91101
626-685-2015
www.ElectricPowerGroup.com

PGDA State-of-the-Art Algorithms

Datasets

- Filtering selection of various metrics
- Apply status flag to repair data and interpolate missing data

Statistical Analysis

- Uses Pre-Processing Techniques like Interpolation, Low Pass Filtering, Detrending, Normalization and Pseudo Signals
- Uses Post-Processing Techniques to plot Mean and Standard deviation chart and Moving range charts

Ring down Analysis

- Uses Pre-Processing Techniques like Interpolation, Detrending, Low Pass filtering, re-sampling and Normalization
- Uses Ring-down modal estimation algorithms like Prony, HTLS (Hankel-Total least Squares) and Matrix Pencil.
- Uses Post-processing options to change plot settings like frequency range, display and discard mode characteristics

Spectral Analysis

- Uses Pre-Processing Techniques like Interpolation, Detrending, Low Pass filtering and re-sampling
- Applies windowing functions like Hann, Bartlett, modified Barlett-hanning, Blackmann, Blackman-harris, Bohman, Chebyshev, Flat Top, Gaussian, Hamming, Kaiser, Nutall, Parzen, Rectangular, Tukey and Triangular
- Uses Post-processing options to change plot settings such as spectrum scaling, normalization and frequency range

Ambient Modal Analysis

- Uses Pre-Processing Techniques like Interpolation, Detrending and Re-sampling
- Uses Ambient-data mode estimation algorithms like Yule Walker, Yule Walker Spectral and Sub-Space System identification (N4SID)
- Applies windowing functions such as Hann, Bartlett, modified Barlett-hanning, Blackmann, Blackman-harris, Bohman, Chebyshev, Flat Top, Gaussian, Hamming, Kaiser, Nutall, Parzen, Rectangular, Tukey and Triangular
- Uses post-processing options to change plot settings such as frequency range, display and discard mode characteristics

Event Analysis

- Automatic calculation of Estimated Inertial Frequency Response using identified NERC frequency response points A, B and C
- Automatic calculation of Voltage magnitude, Voltage Angle and Power swing and deviation