Recent Progress on Forced Oscillation Detection and Source Locating Findings at Peak Reliability

NASPI Work Group Meeting

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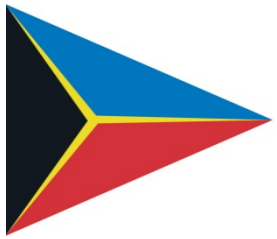

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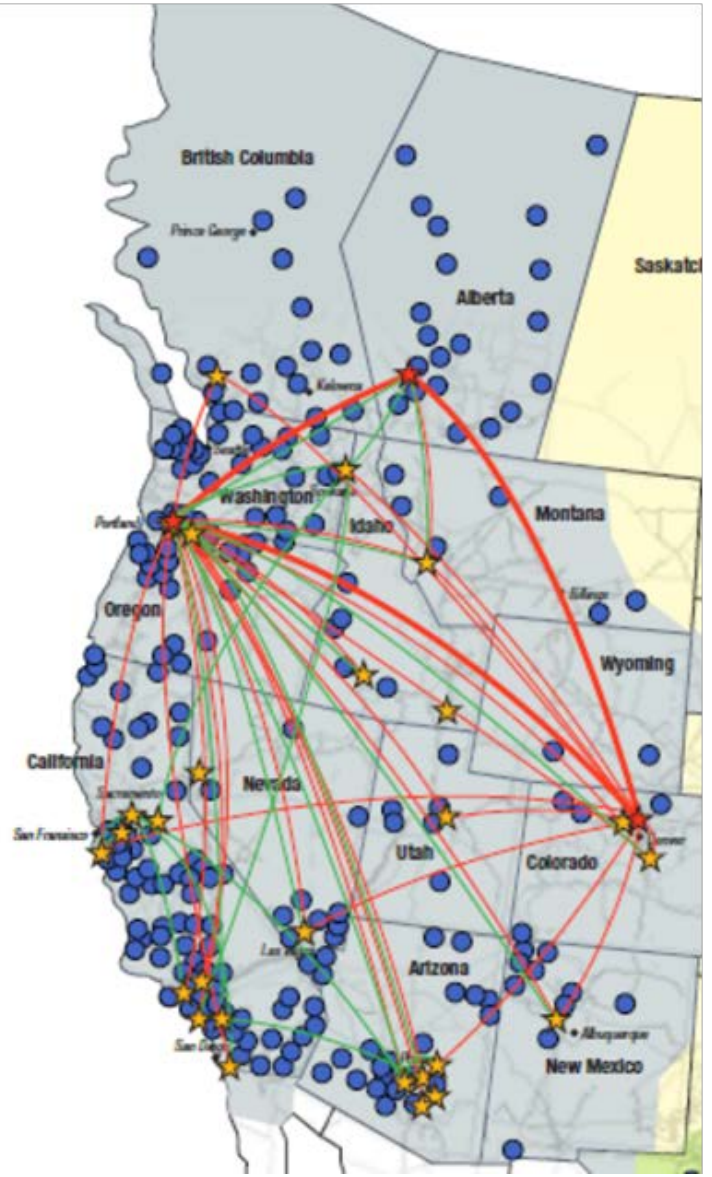
assuring the wide area view

Peak Reliability (formerly WECC RC) Synchrophasor Effort

WISP/PRSP Accomplishments:

- 600+ Phasor Measurement Units
- 70+ Phasor Data Concentrators
- WAN Communication Infrastructure
- Data Center(s) and Information Technology Infrastructure
- Advanced Transmission Software Applications
- Peak is receiving 400+ PMU data from 16 Western Interconnection Entities
- Control Room Solution use case development



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Motivation of Forced Oscillation Analysis

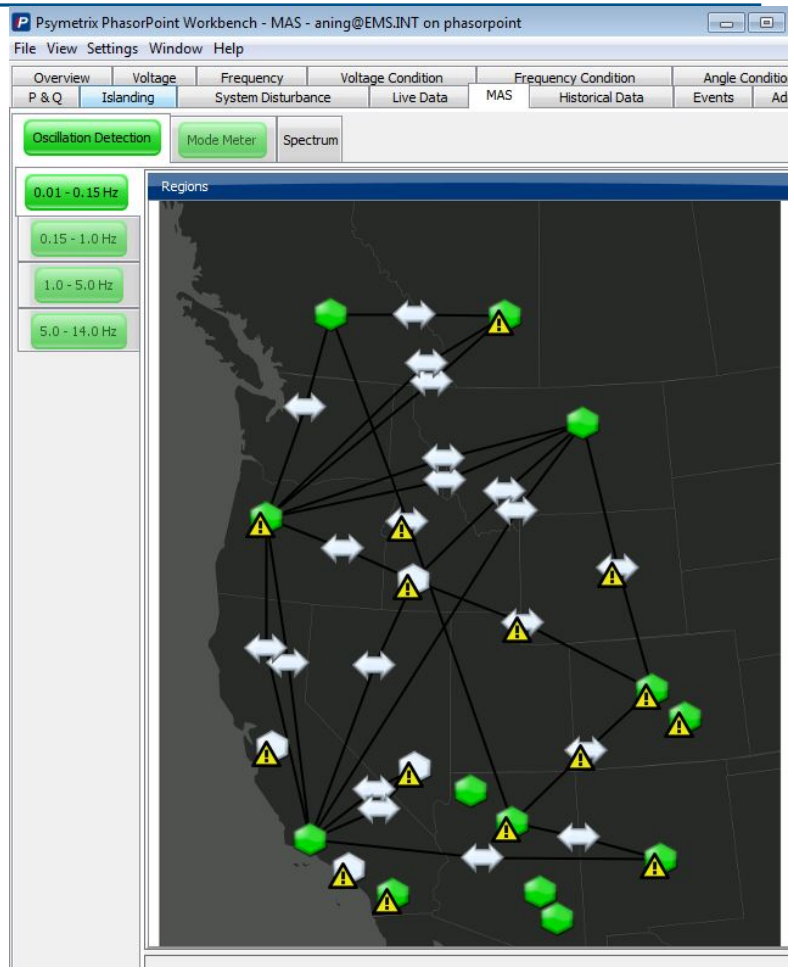
- Forced Oscillation **does** exist in the system (equipment malfunction, poor control designs, and abnormal operating conditions of power plant)
- Forced Oscillation with low oscillation frequency could potentially resonate with system modes to trigger wide area oscillations
- Persistent Forced Oscillations with high oscillation amplitude could cause damage to local power plant

Forced Oscillation Detection

- Characteristics of Forced Oscillations
  - Sustained oscillations until source mechanism mitigated
  - Near zero damping ratio
  - Mostly fixed oscillation frequency
  - High oscillation energy
- Methods of Detection
  - Direct: Montana Tech Modal Analysis Software (MAS) Oscillation Detection Module (ODM)
  - Indirect: Washington State University OMS tool and MAS Mode Meter

MAS Oscillation Detection Module

- Raw PMU data as input
- Four Oscillation Frequency Bands
  - 0.01 Hz,0.15 Hz,1 Hz, 5 Hz,15 Hz
- Time domain RMS energy filter
- Baselining needed for alarming
- Inverse Time Alarm is available for MAS 2.0
- High oscillation energy triggers ODM alarm indicates Forced Oscillation



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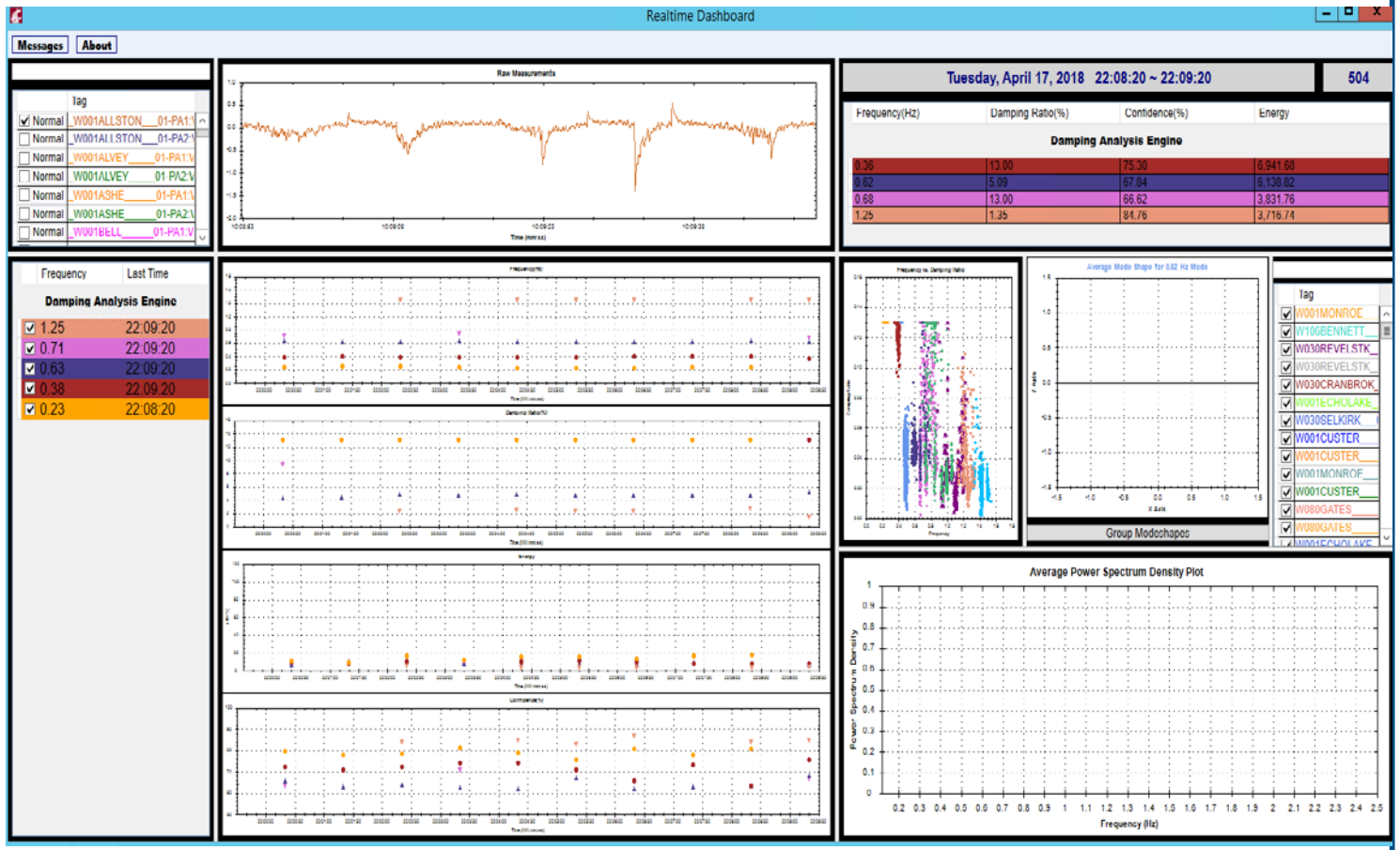
WSU Oscillation Monitoring System

- Use all available PMU Active Power signals as input
- Automatically detected dominant modes (frequency, damping ratio, mode shape, energy, confidence level)
- 1 minute moving window
- Updated every 10 seconds
- Sustained low damping ratio and high energy indicates possible Forced Oscillation



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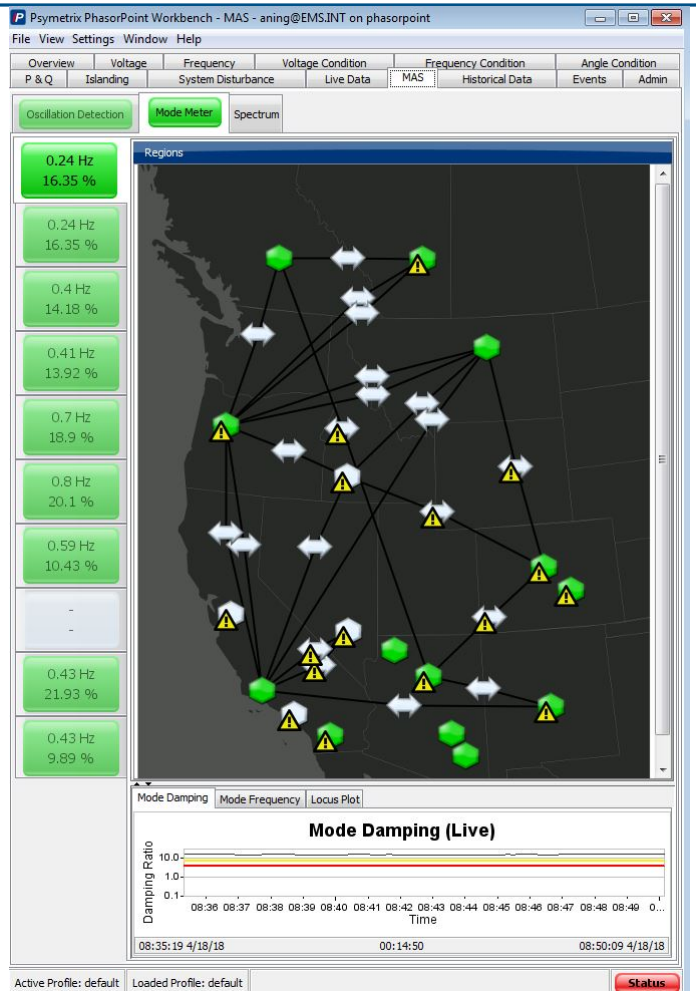
MAS Mode Meter Module

- Predefined voltage angle pairs for monitoring inter-area modes
- Monitoring 5 modes in the western interconnection
- Estimating frequency, damping ratio, energy and mode shape
- 30 minutes moving window (20/40 minutes for MAS 2.0)
- Updated every 10 seconds
- Lower than usual damping ratio indicates possible Forced Oscillation



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Oscillation Source Locating

- PMU data based:
  - Highest oscillation energy (MAS ODM)
  - Largest Mode Shape (WSU OMS and MAS Mode Meter)
  - Simple, direct and Robust
  - Sometimes accurate but not always
  - May not be able to pinpoint to the exact source due to limited PMU data coverage

Oscillation Source Locating

- SCADA data based:
  - Inputs are oscillation start and end times
  - Retrieve all generator (2700+) MW and MVAR SCADA data
  - Finding oscillating generator output by examining numerical difference between oscillation window and ambient window
  - In collaboration with WSU, two algorithms are developed to analyze:
    - PMA* (Pattern Mining Algorithm)
    - MVRA* (Maximal Variance Ratio Algorithm)
  - Larger pool of FO candidates, capable of pinpointing the source
  - Cannot always find the source

*J. O'Brien, T. Wu, V. Venkatasubramanian, H. Zhang, Source Location of Forced Oscillations "Using Synchrophasor and SCADA Data", Proceedings of the 50th Hawaii International Conference on System Sciences, 2017

Peak's Toolsets for Forced Oscillation Analysis

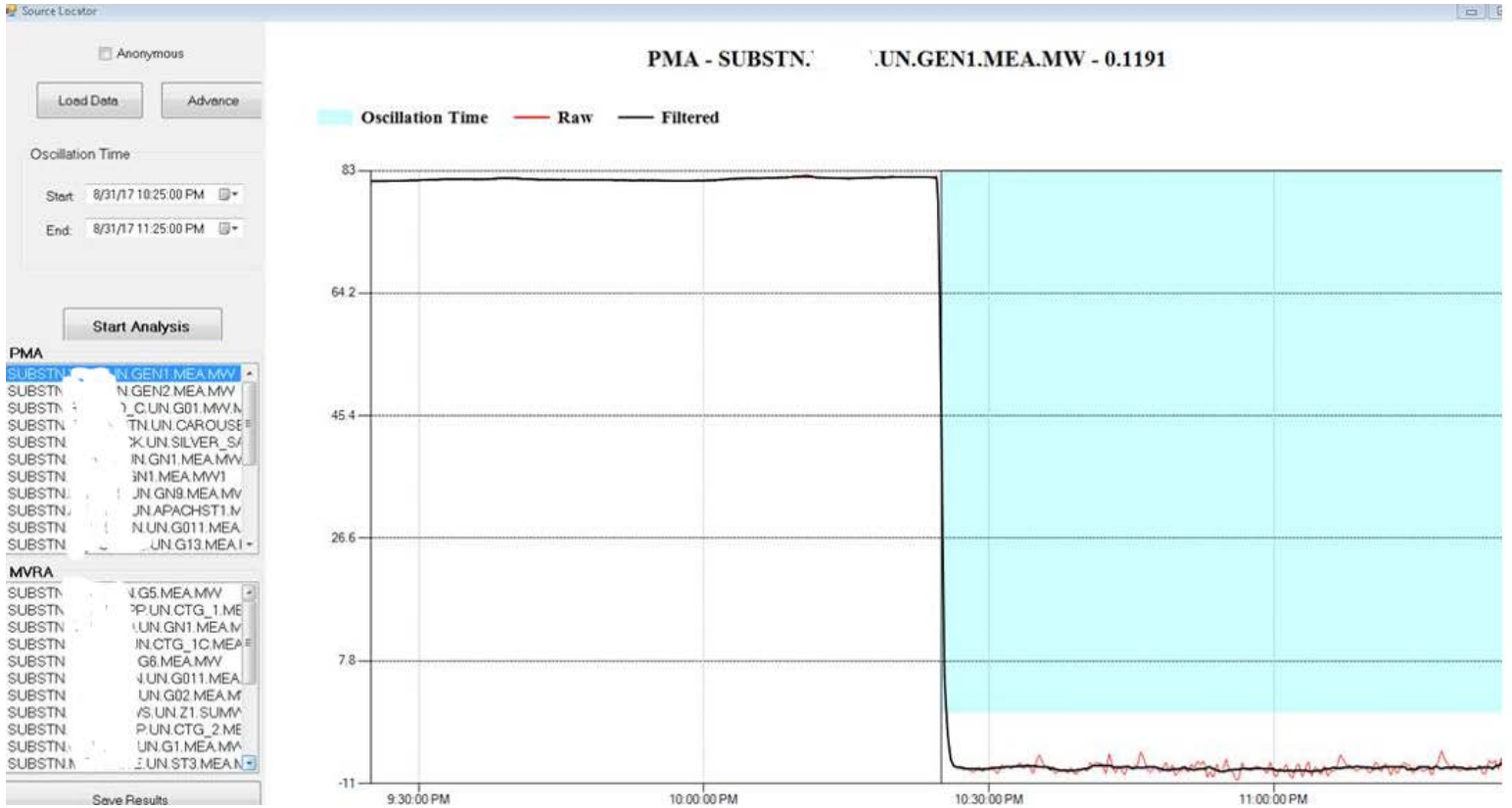
- MAS 1.0 in Production (MAS 2.0 in development)
  - Includes both ODM and Mode Meter
  - Collaborating with BPA on MAS results
- WSU OMS in Development and Testing Environments
- FODSL (Forced Oscillation Detector and Source Locator)
  - Joined efforts between Peak and WSU
  - Using WSU OMS modal results to detect forced oscillation
  - Using all generator SCADA data to locate the oscillation source

Forced Oscillation Event Analysis 1

- 8/31/2017 Forced Oscillation at a Hydro Plant
- Alarmed by both ODM (Band 3) and FODSL
- Offline study confirmed real-time results
- Sustained oscillation during night time

Forced Oscillation Event Analysis 1

- FODSL Offline Results



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Forced Oscillation Event Analysis 1

- SCADA PI Trend on that Generator

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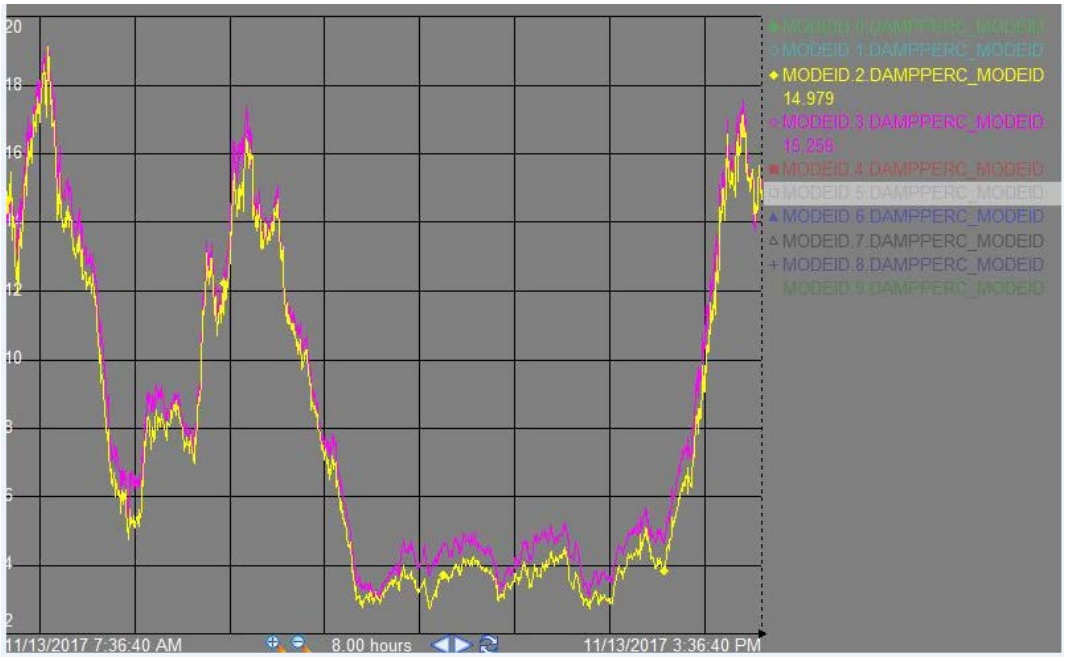
Forced Oscillation Event Analysis 1

- Plant was operating the unit in the motoring mode
- Tail water was not depressed due to equipment failure
- Luckily, no resonance has been created mainly attributed to its high oscillation frequency (1.23Hz)
- Power Plant owner is cooperative and appreciative, fixed the issue after notified
- “Extreme turbulence and cavitation occurring during the flooded motoring combined with the PSS operation at the same time”
- “We are unable to determine oscillations of this frequency at the plant using our PI data system”
- “This is certainly a most powerful tool”

Forced Oscillation Event Analysis 2

- 11/13/2017 Forced Oscillation at a Hydro Plant
- Alarmed by ODM (Band 2) and Mode Meter (N-S Mode B)
- Damping ratio of N-S Mode B has dropped dramatically during the event while no significant system operation change



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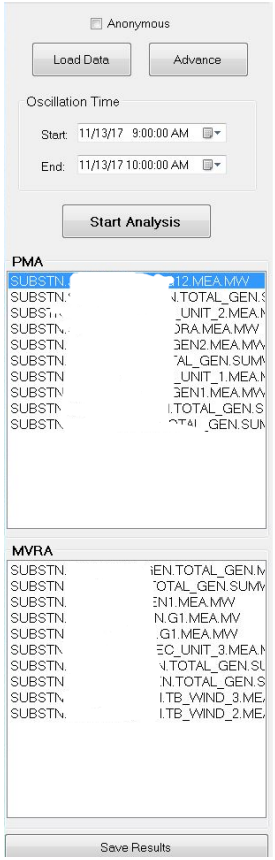
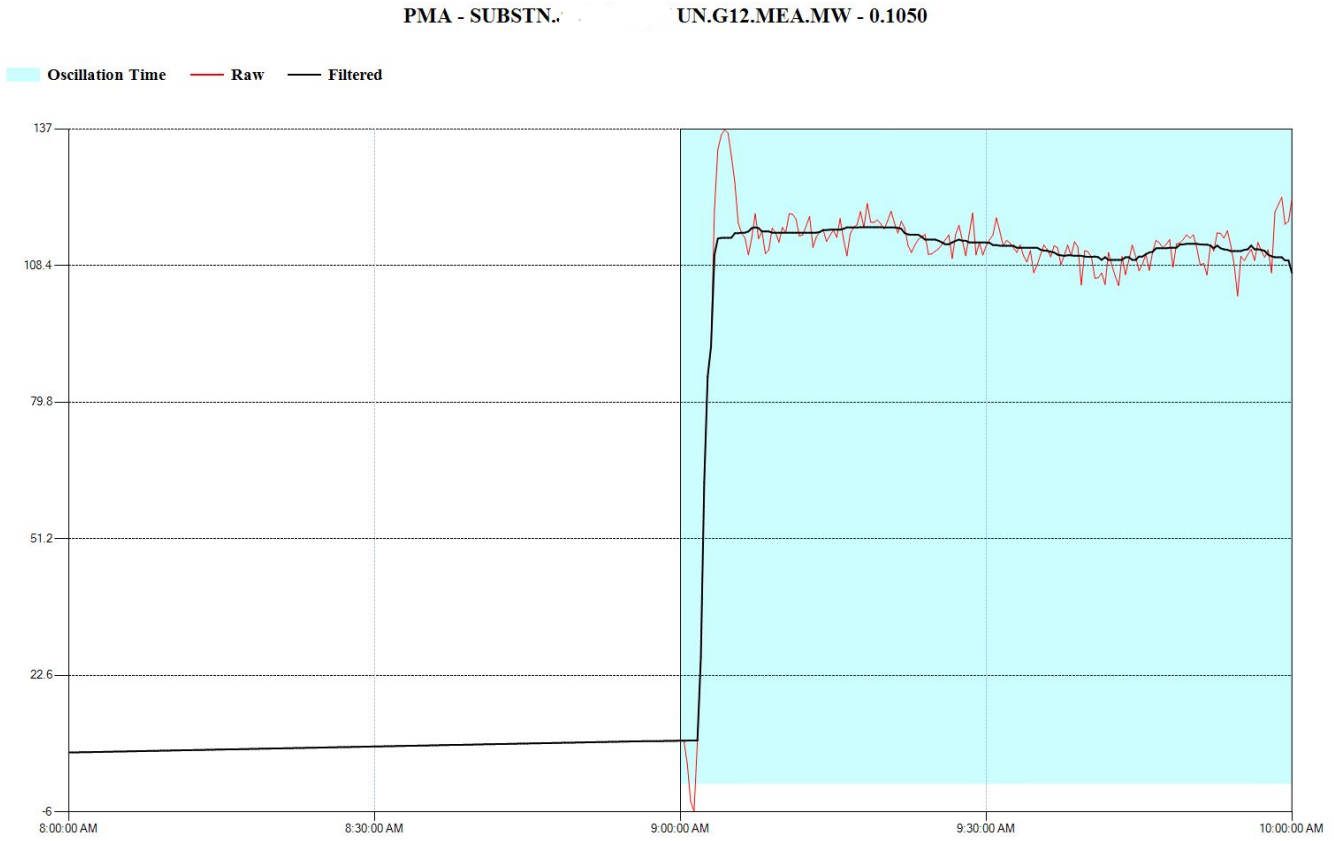
Forced Oscillation Event Analysis 2

- FODSL offline tool found the source of the oscillation as a hydro unit





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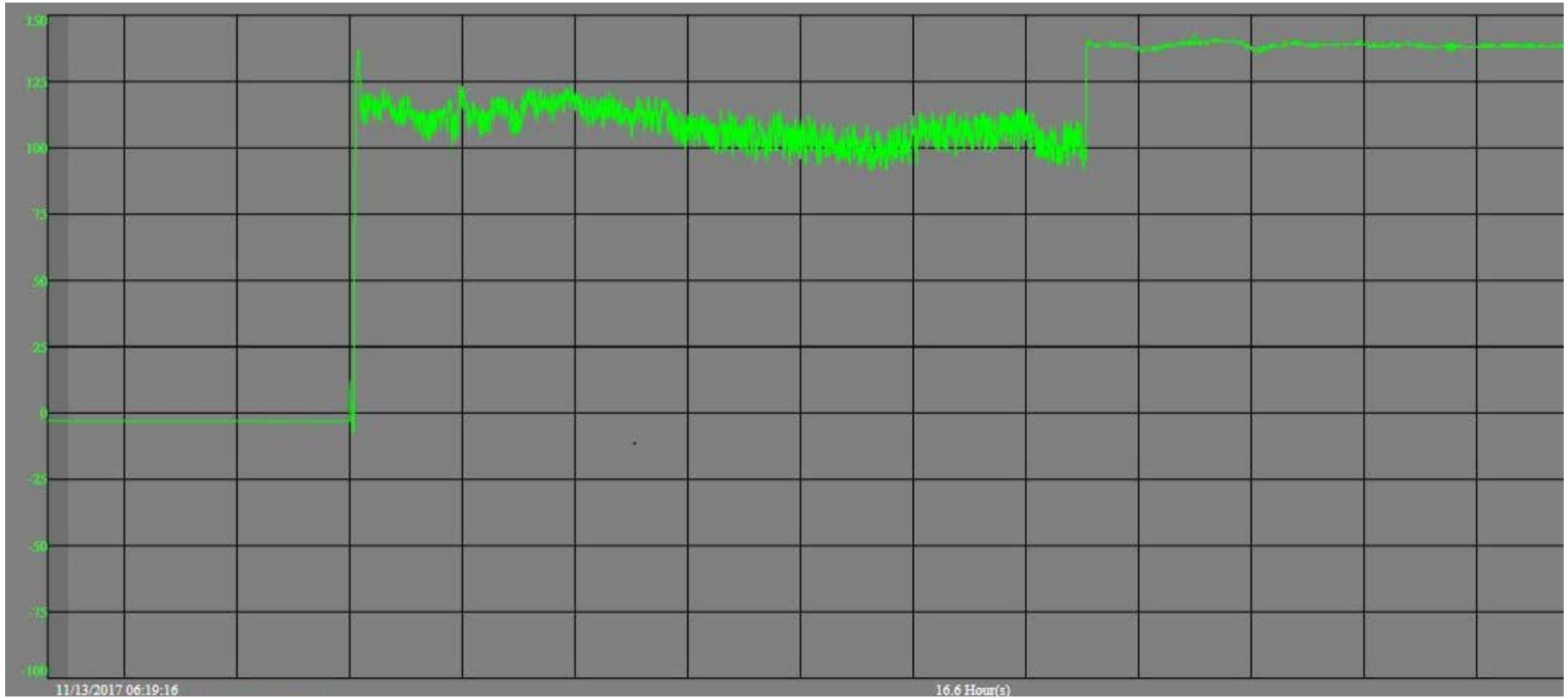
Forced Oscillation Event Analysis 2

- SCADA PI data trend shows forced oscillation on this unit



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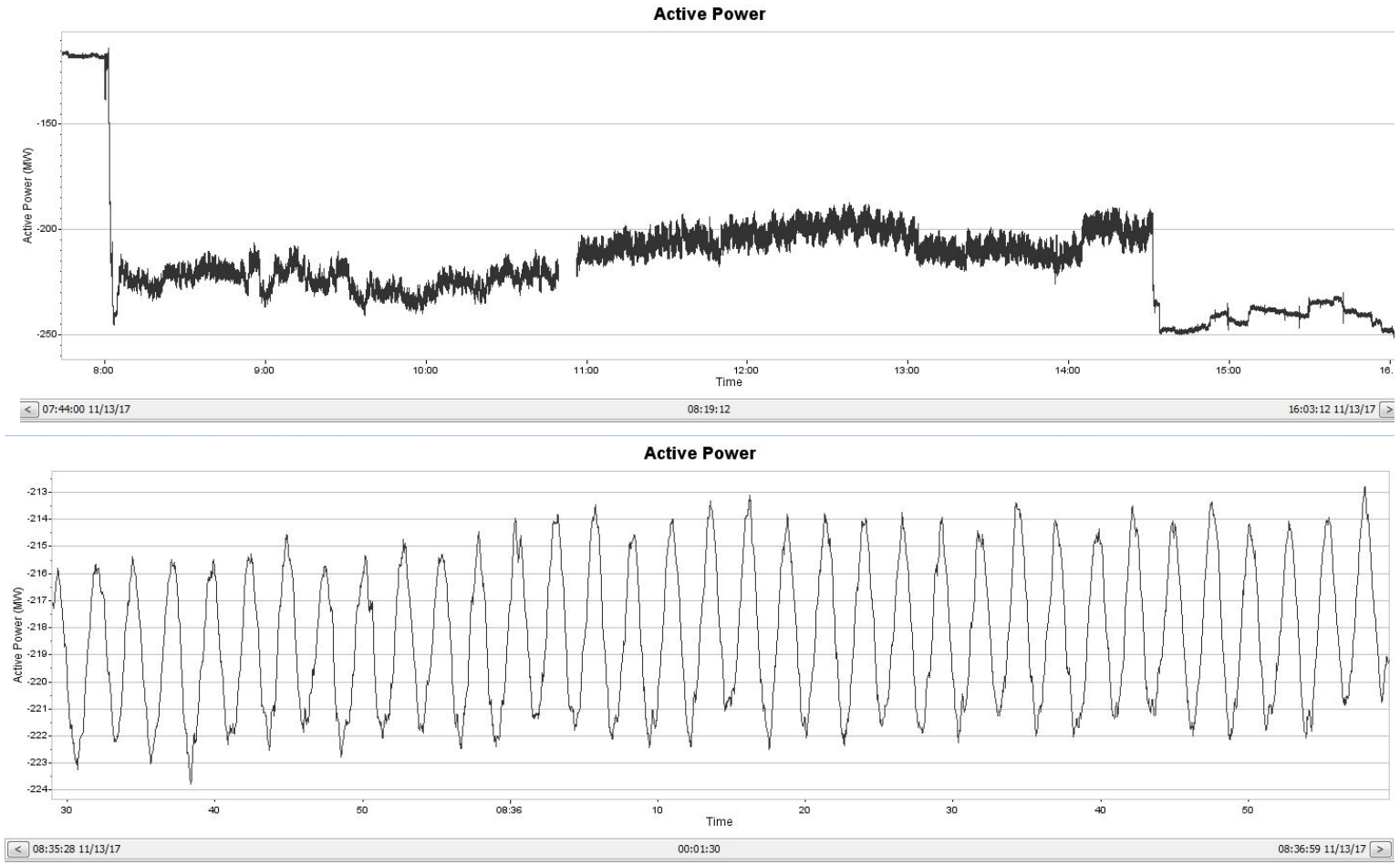
Forced Oscillation Event Analysis 2

- Oscillation frequency is about 0.4 Hz by checking PMU data



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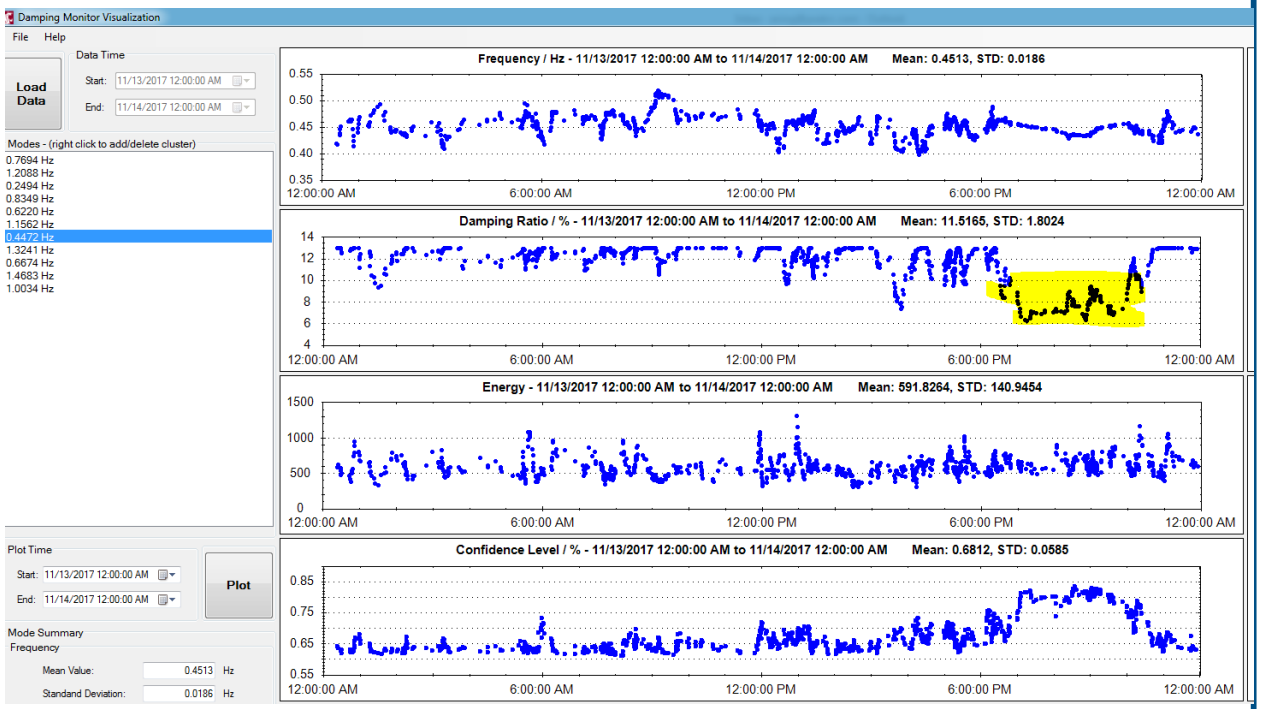
Forced Oscillation Event Analysis 2

- It turns out the location of forced oscillation is very close to the signal been used by Mode Meter
- No resonance has been caused by forced oscillation but forced oscillation has biased Mode Meter results
- WSU OMS tool estimated damping also got affected
- Not much responses from Power Plant owner
- Have not started another Forced Oscillation from the plant since this event



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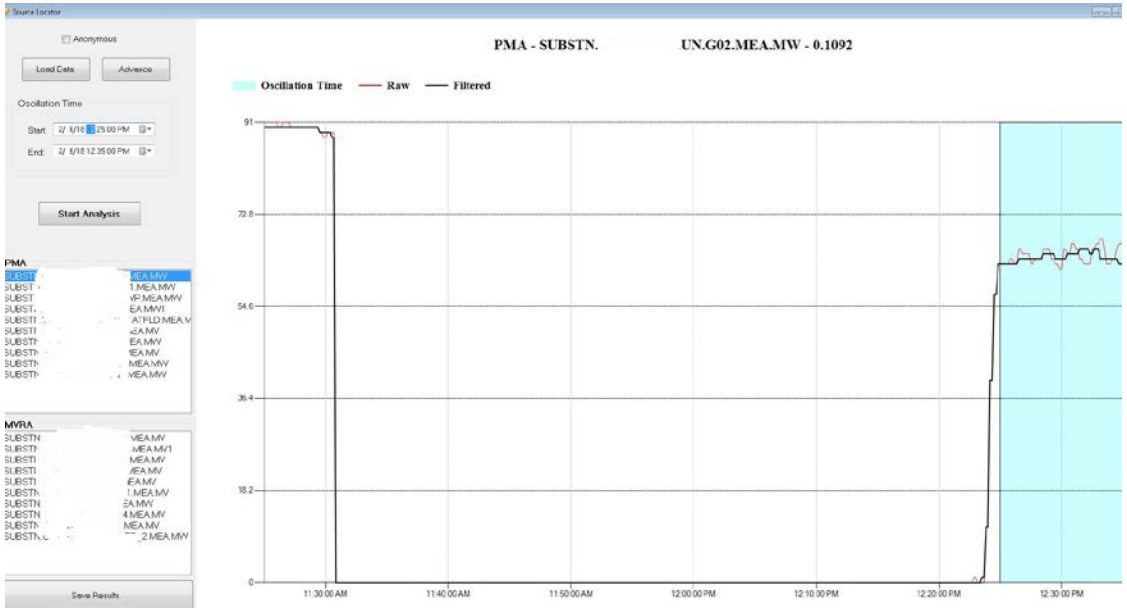
Forced Oscillation Event Analysis 3

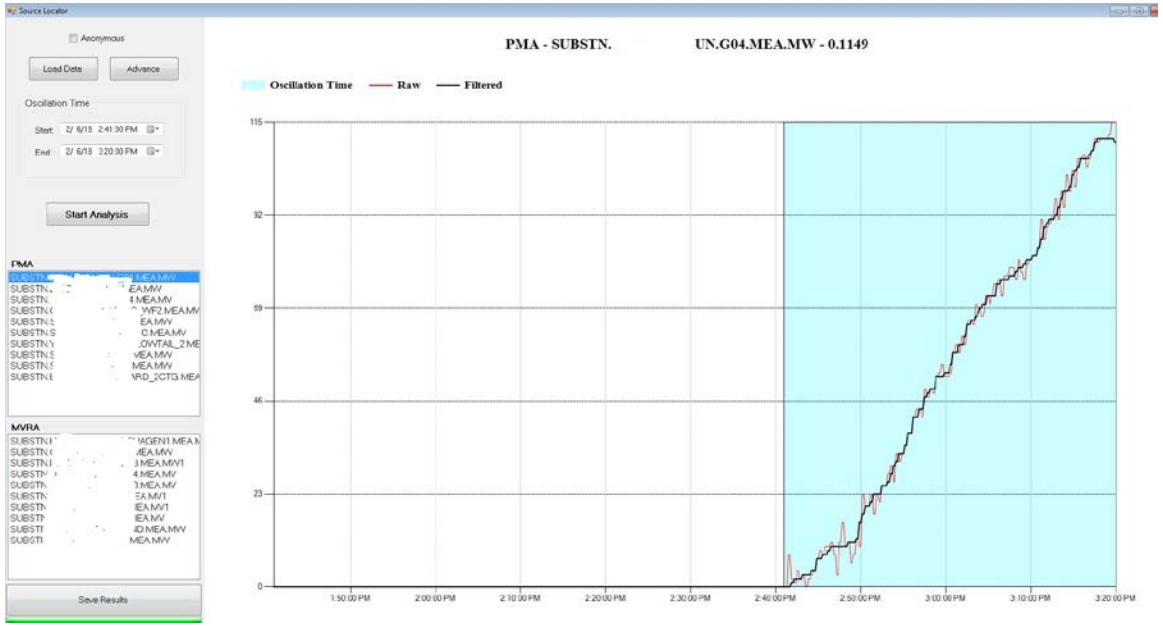
- Intermittent forced oscillation, each lasted about 5 to 10 minutes
- Alarmed by ODM (Band 2)

Event Start Time	Duration (sec)	Event End Time	Energy Band
06-Feb-18 16:35:20	600	06-Feb-18 16:45:20	2
06-Feb-18 15:30:30	160	06-Feb-18 15:33:10	2
06-Feb-18 15:17:40	310	06-Feb-18 15:22:50	2
06-Feb-18 14:42:50	480	06-Feb-18 14:50:50	2
06-Feb-18 14:12:40	420	06-Feb-18 14:19:40	2
06-Feb-18 08:16:30	290	06-Feb-18 08:21:20	2

Forced Oscillation Event Analysis 3

- Two units in the same power plant are found as the potential sources by FODSL





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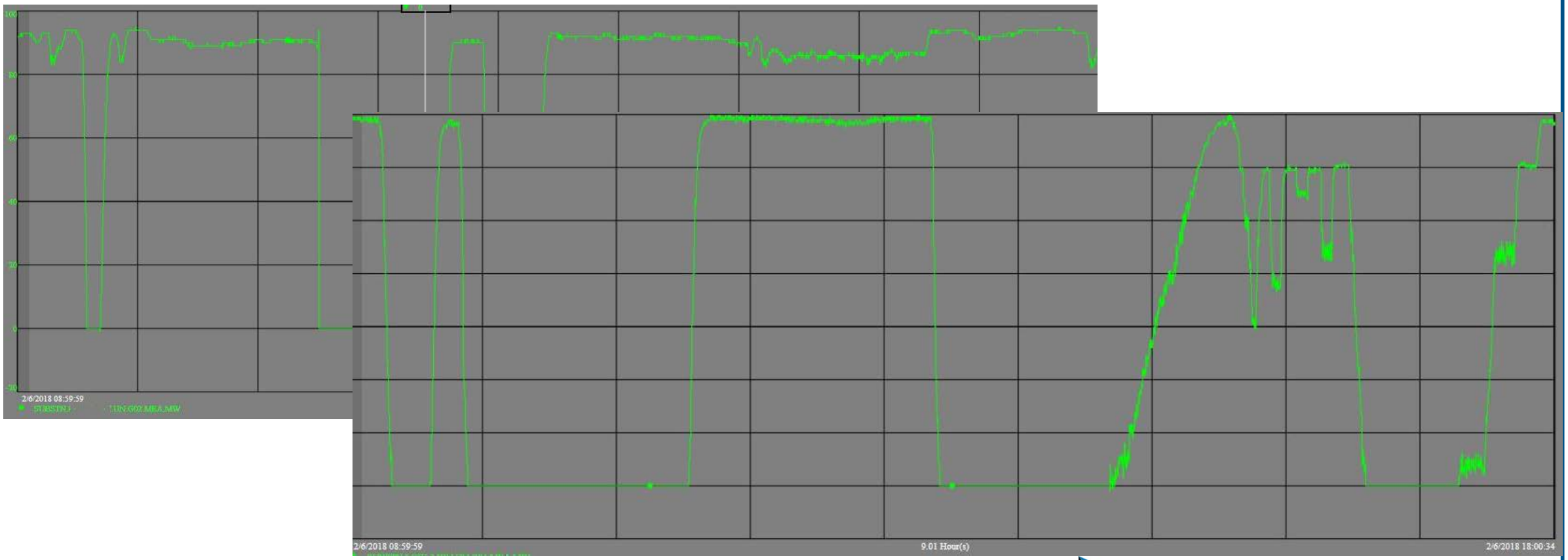
Forced Oscillation Event Analysis 3

- SCADA PI data trend shows forced oscillation on these units



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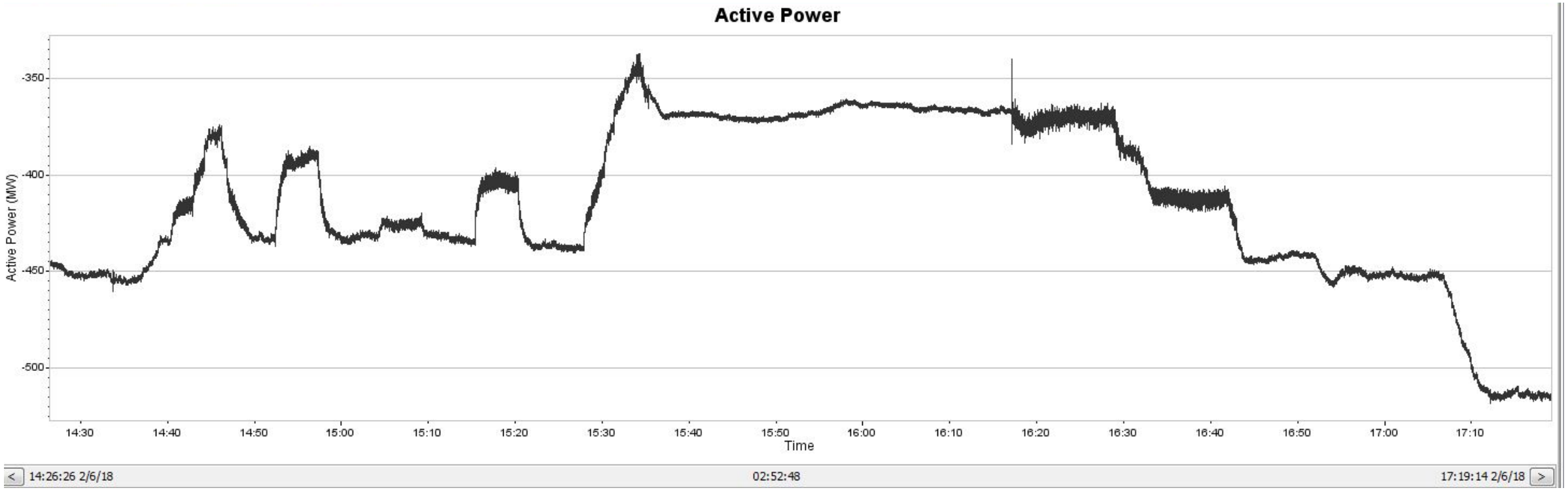
Forced Oscillation Event Analysis 3

- PMU data (at high side of GSU) shows forced oscillation



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Forced Oscillation Event Analysis 3

- The generators were operating in rough zone which caused forced oscillation
- Forced oscillation frequency has changed during the event
- Plant owner investigated and troubleshoot the issue
- “It looks like when the unit is loaded up using GDACS (Generic Data Acquisition and Control System) it ramps very slowly, which places us in the rough zone for too long.”

Lessons Learned from Event Analysis

- There are many effective ways to detect and locate forced oscillation
- Besides PMU data, SCADA data can also witness forced oscillation
- It is not very common for resonance to happen between forced oscillation mode and system natural oscillation mode
- Most forced oscillation does not impose imminent threat on grid
- NERC standard is needed on Forced Oscillation Mitigation
- Reliability Coordinator detects forced oscillation, locates the source and notifies the plant owner is benefiting both parties

Ongoing Efforts

- Test/tune parameters for PMA and MVRA and add new and more advanced algorithm for SCADA oscillation source location
- Keep developing the real-time FODSL tool
- Collaborate with entities for events discussion and validation
  - Peak SMART Real-time Oscillation Detection and Source Locating taskforce meeting
  - WECC JSIS Oscillations Analysis Work Group meeting
- Control room training

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