DOE/OE Transmission Reliability Program

Oscillation Monitoring System

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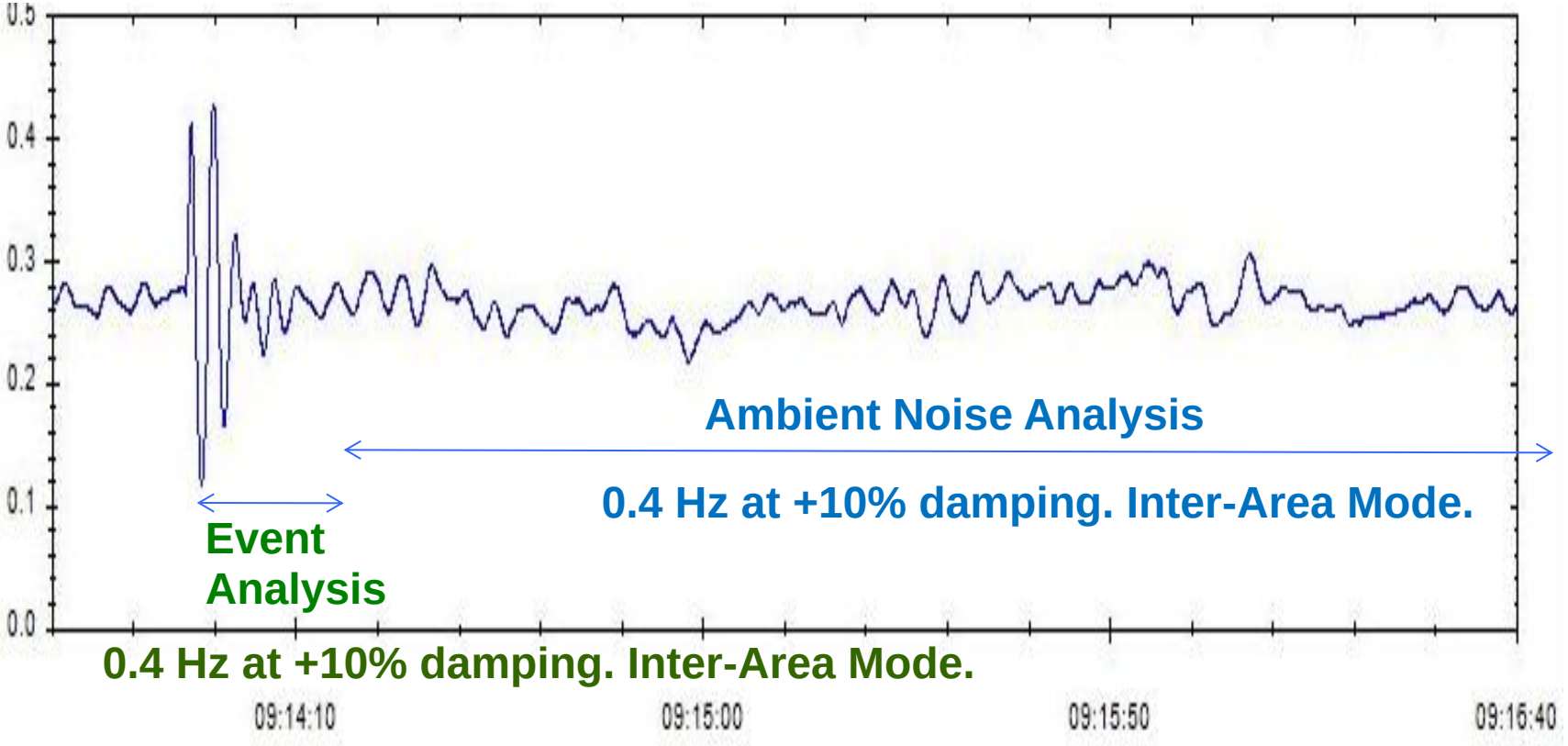
CERTS

CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

Project Objectives

- **Oscillation Monitoring System for large power systems**
- **Monitoring hundreds of PMUs simultaneously**
- **System modes are changing – adaptive engines needed**
- **Damping Monitor Engine – ambient data analysis**
- **Event Analysis Engine – detection and analysis of ringdowns and oscillations**
- **Real-time engines and off-line engines**

Two Analytical Engines



Complementary Engines

- Event Analysis Engine (EAE)
  - Multiple algorithms
  - **Prony, Matrix Pencil, HTLS, ERA**, MFRA, and METRA.
  - Aimed at events resulting in sudden changes in damping
- Damping Monitor Engine (DME)
  - Ambient noise based. Continuous. Provides early warning on poorly damped modes.
  - Several algorithms
  - **Fast Frequency Domain Decomposition (FFDD)**, **Fast Stochastic Subspace Identification (FSSI)**, DFDO, Recursive Adaptive Stochastic Subspace Identification (RASSI), FDSSI, DFDD, RFDD, and DRSSI

Key Accomplishments

- Fast algorithms developed for handling large number of PMU measurements: Damping Monitor: FFDD, FSSI, Event Analysis: Accelerated versions of Prony, Matrix Pencil, ERA and HTLS
- Theory for resonance effects between forced oscillations and inter-area modes developed.
- Off-line beta versions Damping Monitor Offline (DMO) and Event Analysis Offline (EAO) delivered to Entergy and Peak Reliability Corporation. Has proved useful.
- Fast easy interface to PI historians major step forward for Entergy. Can track/analyze oscillations from previous years.

Technical Objectives in FY15

- **Damping Monitor Engine and Event Analysis Engine**
  - Support of **off-line** engines (Stage 3)
    - Testing, Training
    - Deliverables: Documentation (6/15), Training (ongoing), and Support for Peak RC, WECC and Entergy (ongoing)
  - Development of **on-line** engines (Stage 3)
    - Coding, Testing, Training
    - Deliverables: Beta versions (8/15), Testing and Training for Peak RC, and Entergy (ongoing)

Risk Factors in FY15

- **Event Analysis Engine and Damping Monitor Engine**
  - **PMU data quality**
  - **Computational complexity of algorithms**
  - **Real-time data issues**

Technical Objectives in FY16

- **Damping Monitor Engine and Event Analysis Engine**
  - On-line and Off-line Engines (Stage 3)
    - Testing, Tuning, and Support
    - Deliverables: Official versions for Entergy/WECC (1/16), Training (ongoing), and Support (ongoing)
  - Commercialization road-maps (12/15)

Publications

- RASSI, IEEE Trans. Power Systems, January 2014
- MFRA, IEEE Trans. Power Systems, March 2014
- PMU applications, Springer-Verlag, M. Kezunovic, S. Meliopolous, V. Venkatasubramanian and V. Vittal, 2014
- Proc. HICSS: METRA, January 2014, iMETRA, January 2015
- FFDD, IEEE Trans. Electric Power Delivery, to appear
- Inter-area Resonance, IEEE Trans. Power Systems, to appear
- Fast SVD methods, IEEE Trans. Power Systems, to appear
- WSD, IEEE Trans. Smart Grid, to appear
- DFDD and DRSSI, IEEE Trans. Power Systems, to appear
- SSR, IEEE Trans. Power Systems, to appear

Turbo Oscillation Monitoring

- FFDD can process large number of signals 1000+ simultaneously in real-time: needed for reliable estimation and source location.
- Offline mode: Can get a quick overview of system modal properties by fast analysis of historical data. Can study mode trends.
- An hour of data from 200 PMU signals can be analyzed in less than 2 minutes on a desktop
- Implemented in C# using Intel Math library. Multi-threaded. Scalable solutions offered.

Forced Oscillations in WECC

- Summer 2013 24 hour data: 0.37 Hz oscillations observed for several hours. Confirmed to be forced oscillations at a hydro plant from vortex effect.
- 2014 data: Another 0.5 Hz oscillation also observed. Source points to hydro unit as well. And 0.7 Hz. And 1.12 Hz. And 2 Hz.
- Detection? Impact on nearby system modes?
- Resonance possible when system mode poorly damped and close. Resonance observed in model simulations.

Resonance with Inter-area Mode

Resonance effect high when:

- Forced Oscillation freq near System Mode freq
- System Mode poorly damped
- Forced Oscillation location near the two distant ends of the System Mode

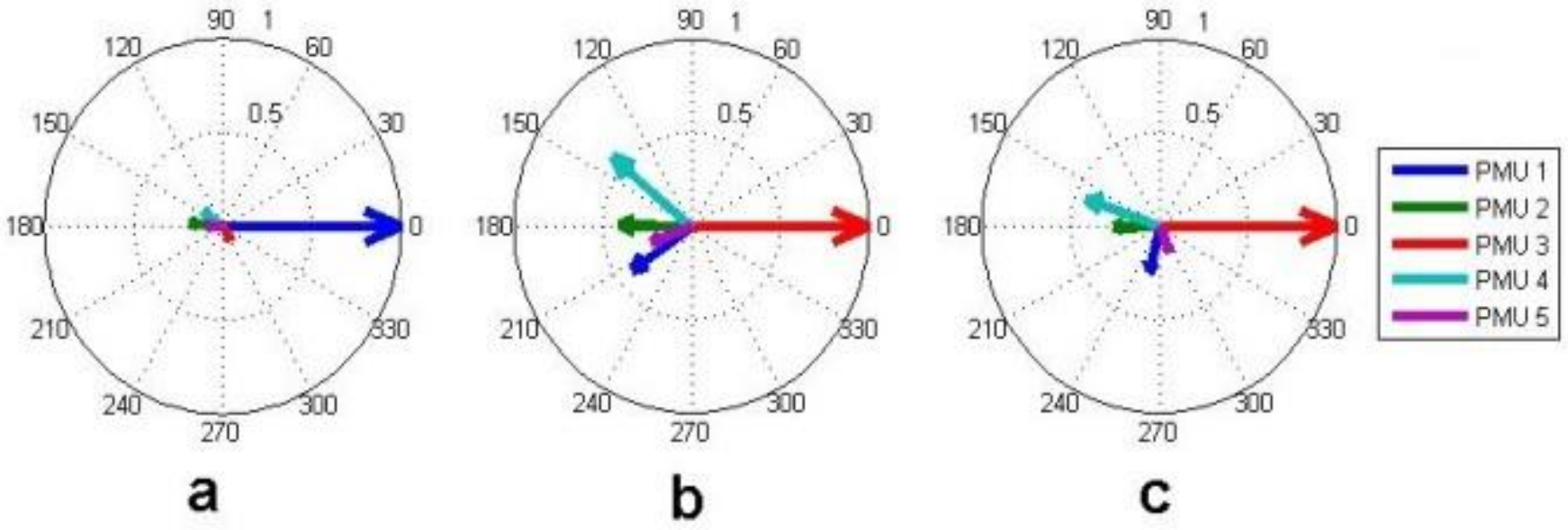
Resonance effect medium when:

- Some conditions hold

Resonance effect small when:

- None of the conditions holds

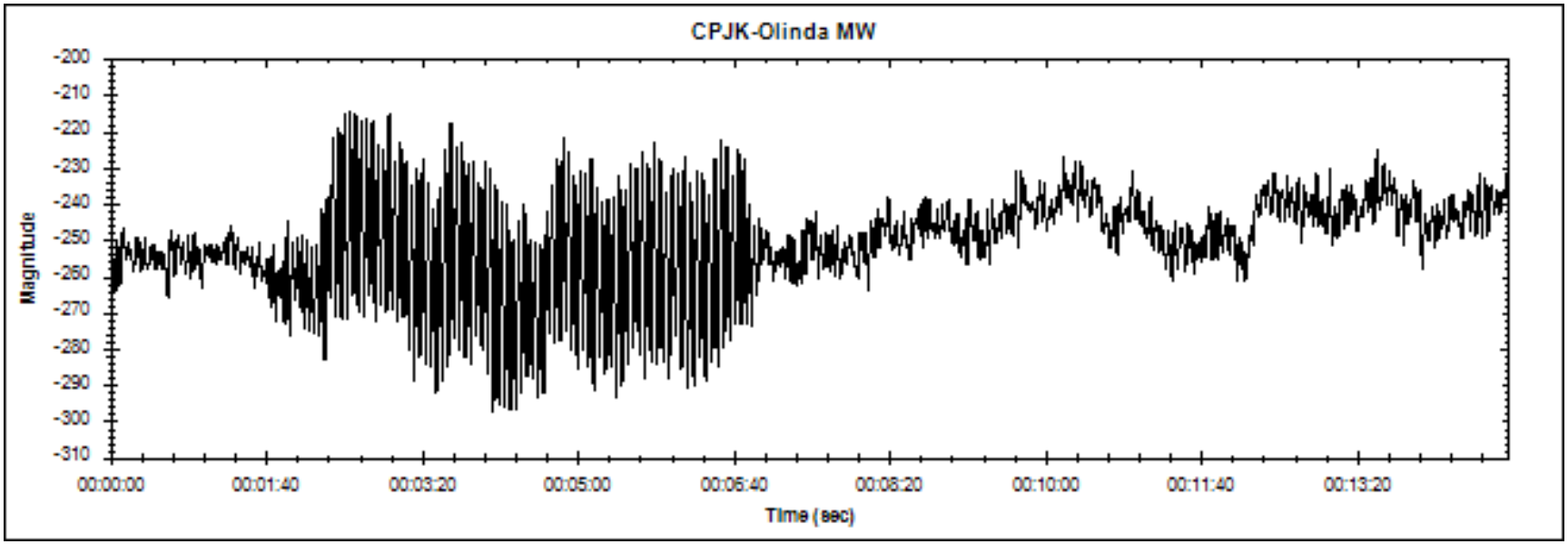
No resonance on June 13, 2013



Case 1	Case 1	Case 2
0.37 Hz	0.4 Hz at	0.4 Hz at
Forced Oscillation	15% Damping Ratio	14% Damping Ratio

Resonance effect low because system mode well-damped and FO location near the center of the mode. No tie-line oscillations from 10 MW forced oscilltion.

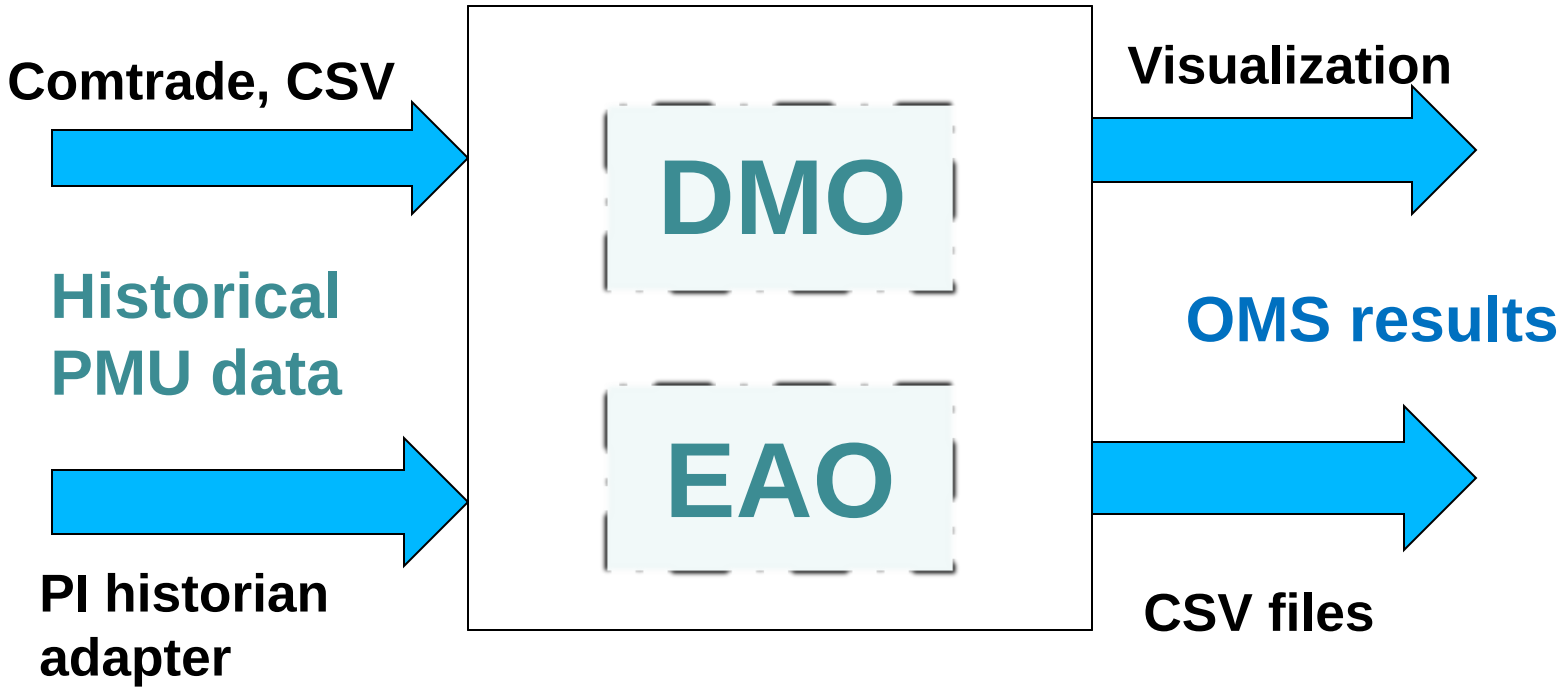
Medium Resonance on November 29, 2005



- 20 MW 0.26 Hz Forced Oscillation in Alberta Canada.
- 200 MW Oscillations on California-Oregon Inter-tie.
- System mode 0.27 Hz at 8% damping.
- Two out of the three conditions were true.
- Preparing a paper with detailed analysis….

Thanks to Armando Salazar (SCE) and Greg Stults (BPA)

Oscillation Monitoring Off-line



Stand alone oscillation analysis programs for analyzing historical PMU data.

Damping Monitor Offline Demo