DOE/OE Transmission Reliability Program

Oscillation Monitoring System

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June 7-8, 2016
Washington, DC

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Project Objectives

- **Oscillation Monitoring System for large power systems**
- **Monitoring hundreds of PMUs simultaneously**
- **System modes, forced oscillations and interactions**
- **Damping Monitor Engine – ambient data analysis**
- **Event Analysis Engine – detection and analysis of ringdowns and oscillations**
- **Real-time engines and off-line engines, Implementation at Entergy and Peak Reliability Corporation**

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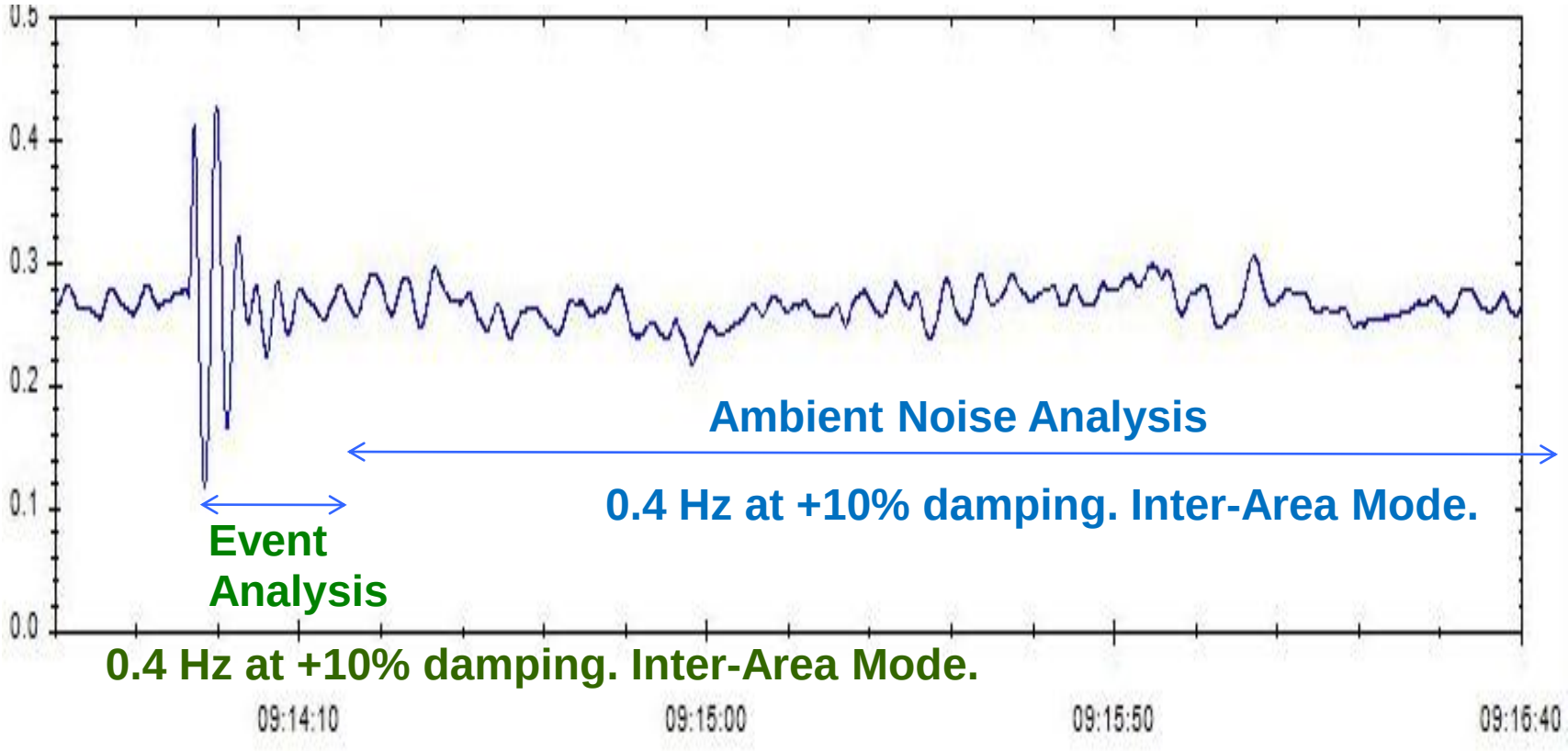
Two Analytical Engines



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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. Detects poorly damped modes and forced oscillations.
  - **Fast Frequency Domain Decomposition (FFDD), Fast Stochastic Subspace Identification (FSSI)**, DFDO, RASSI, FDSSI, DFDD, RFDD, and DRSSI

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Key Accomplishments

- Fast algorithms developed for handling large number of PMU measurements
- Damping Monitor (Ambient data)
  - Fast Frequency Domain Decomposition (1000+ signals)
  - Fast Stochastic Subspace Identification (500+ signals) (simultaneous estimation of system mode and a forced oscillation in resonance)
- Event Analysis (Ringdown data)
  - Accelerated versions of Prony, Matrix Pencil, ERA and HTLS, Improved METRA

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Key Accomplishments

- Rough zone oscillations in hydro power plants interacting with system modes
- Theory for resonance effects between forced oscillations and inter-area modes developed
- November 29, 2005 WECC event was an inter-area resonance event – 20 MW Alberta oscillation led to 200 MW tie-line swings. 0.25 Hz system mode at 7% damping.
- September 5, 2015 WECC event another inter-area resonance event – 6 MW oscillation in the south led to 40 MW tie-line swings. 0.4 Hz system mode at 10% damping.

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Key Accomplishments

- Damping Monitor Offline and Event Analysis Offline Version 1.5 delivered to Entergy and Peak RC
- Offline versions have been used by Peak RC and Entergy for analysis of forced oscillations and system events
- Damping Monitor Online Version 2 and Event Analysis Online Version 1 have been delivered to Entergy and Peak RC
  - Each configured for several hundred signals
  - Under beta testing
- Several Training Workshops: July 2015 (Hosted by SCS, Atlanta, GA), Peak RC, Entergy

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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
- FFDD, IEEE Trans. Electric Power Delivery, 2015
- DFDD and DRSSI, IEEE Trans. Power Systems, 2015
- WSD, IEEE Trans. Smart Grid, 2015
- Inter-area Resonance, IEEE Trans. Power Systems, 2016
- Fast SVD methods, IEEE Trans. Power Systems, 2016
- SSR, IEEE Trans. Power Systems, 2016
- Nov 29 2005 event, IEEE Trans. Power Systems, to appear
- RFDD, IEEE Trans. Power Systems, to appear
- Unwrapping, IEEE Trans. Power Systems, to appear

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Next Steps

- Final Documentations for Offline and Online modules
- Continue training activities
- Software and Engineering support for Peak RC and Entergy
- Commercialization efforts, vendor support
- Publications

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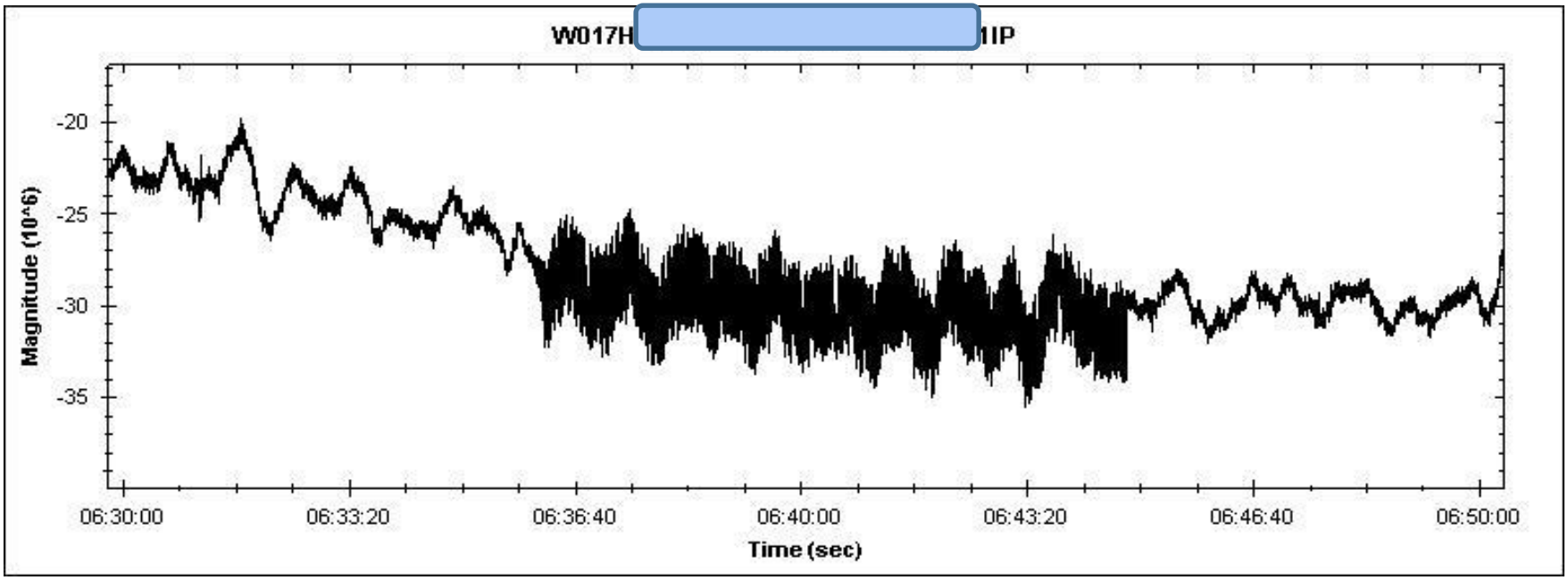
September 5 2015 WECC event

- This is MW flow from a PMU on a 500kV line near the source.



Slide from Peak RC

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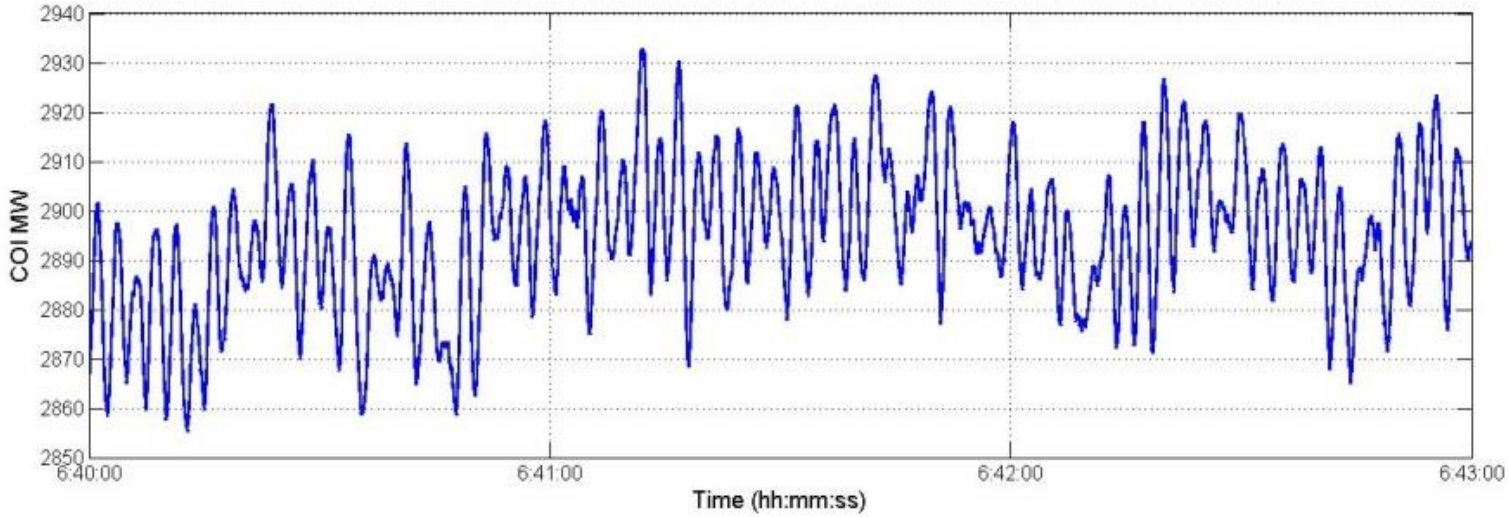
COI (Path 66) Impact (NS-B Mode)

- The resonant excitation of this 0.4 Hz mode can be seen through the ~6 MW oscillations at Hxxx resulting in ~40 MW oscillations on the COI.



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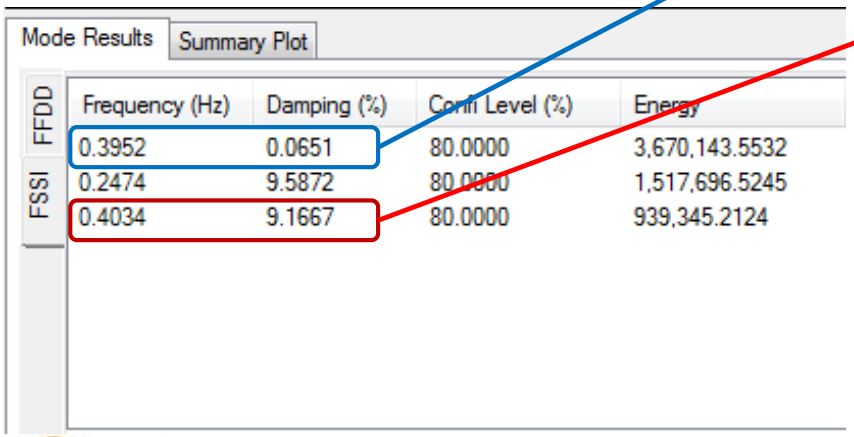
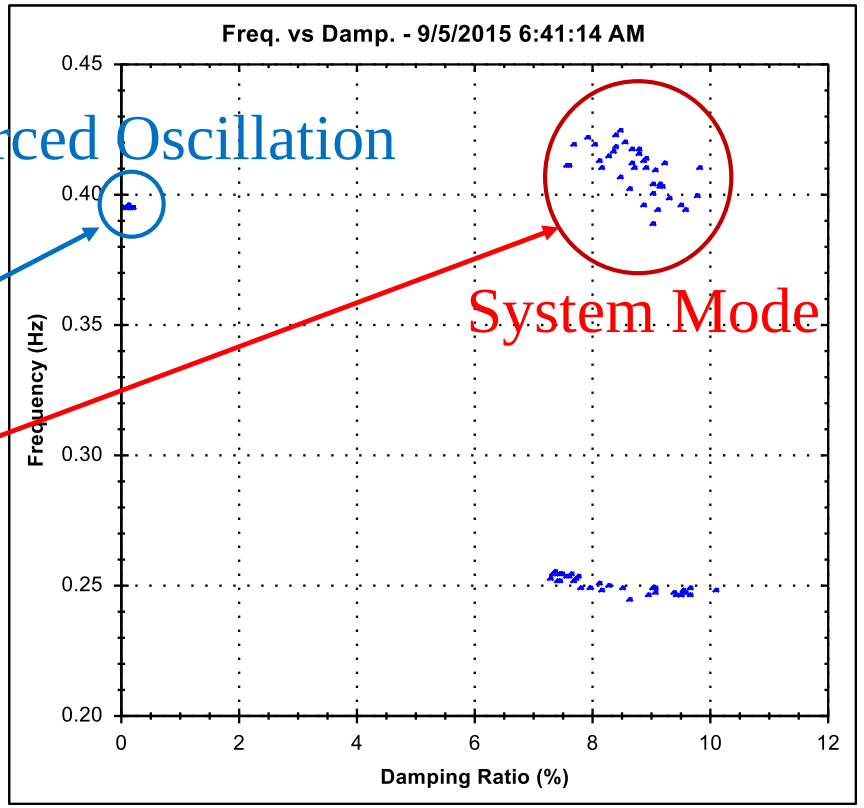
Resonance Phenomenon

- The analysis was further performed using **WSU Fast Stochastic Subspace Identification** tool
- The two separate oscillations are distinguishable clearly





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