DOE/OE Transmission Reliability Program

Oscillation Monitoring System

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Project Objectives

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

Project Background for Entergy

- **SGIG project:**
  - **Damping Monitor Engine - Real-time (DMR) based on FDD. Implemented since July 2011**
  - **Can handle up to 30 PMUs simultaneously**
- **CERTS project:**
  - **Extending the capability of real-time DME, Verification of results and follow-up**
  - **Event Analysis Engine (EAE) real-time and off-line engines, Validation of results**

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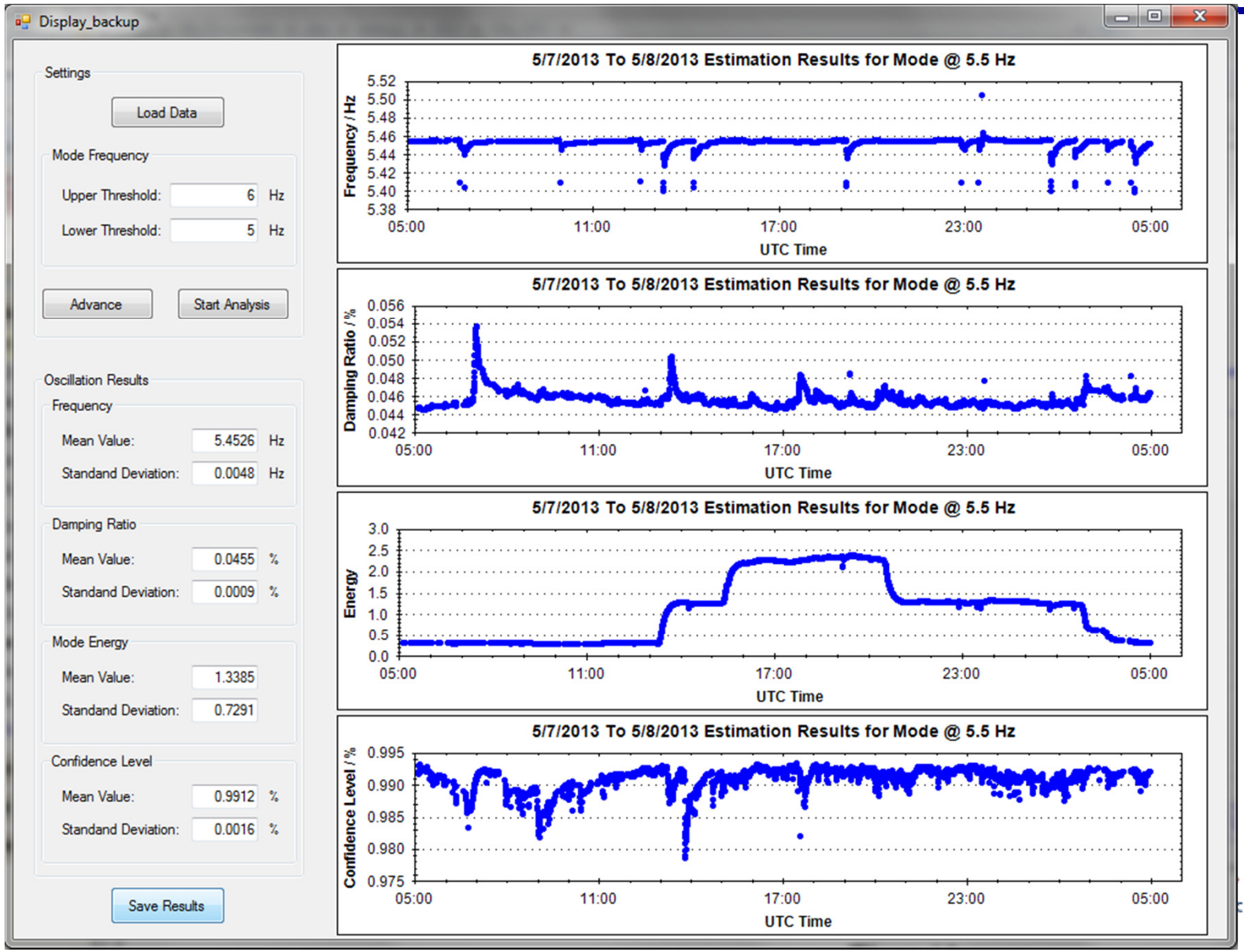
Entergy 5 Hz mode on May 7, 2013



Pattern on May 7th different from other days

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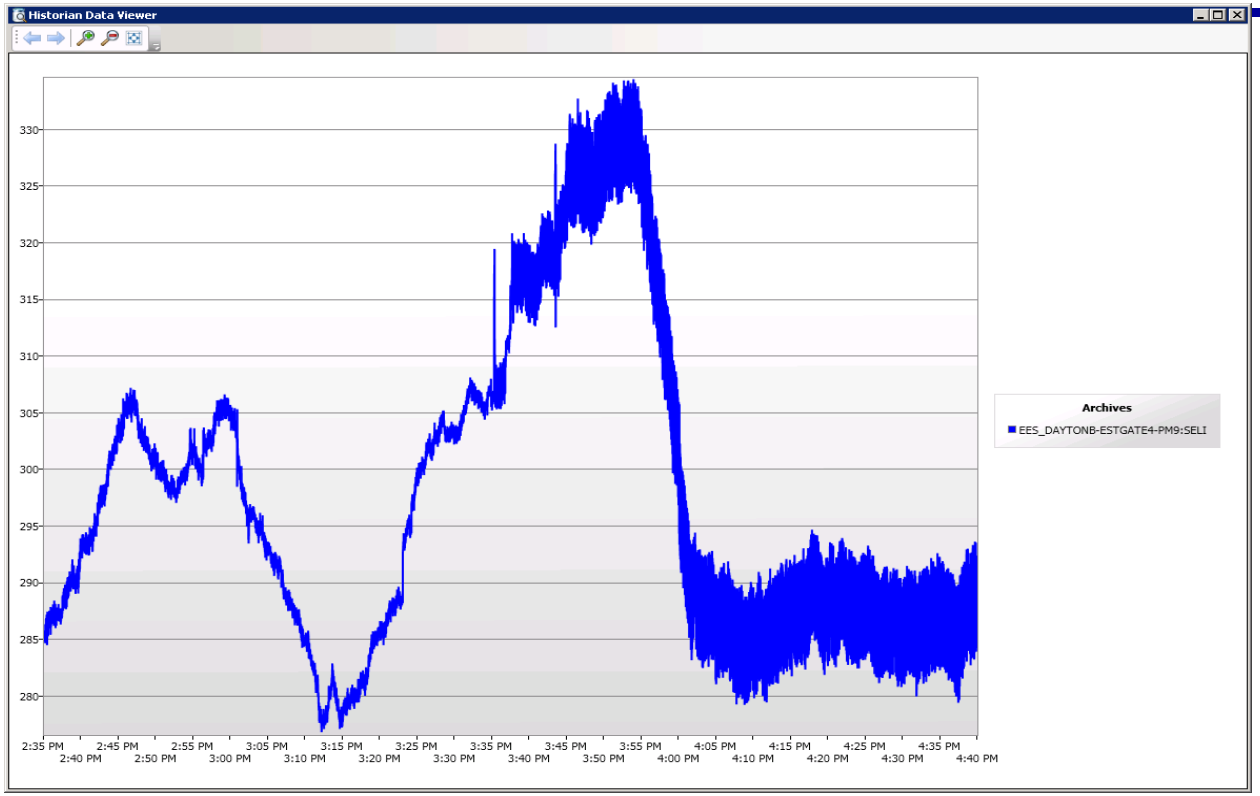
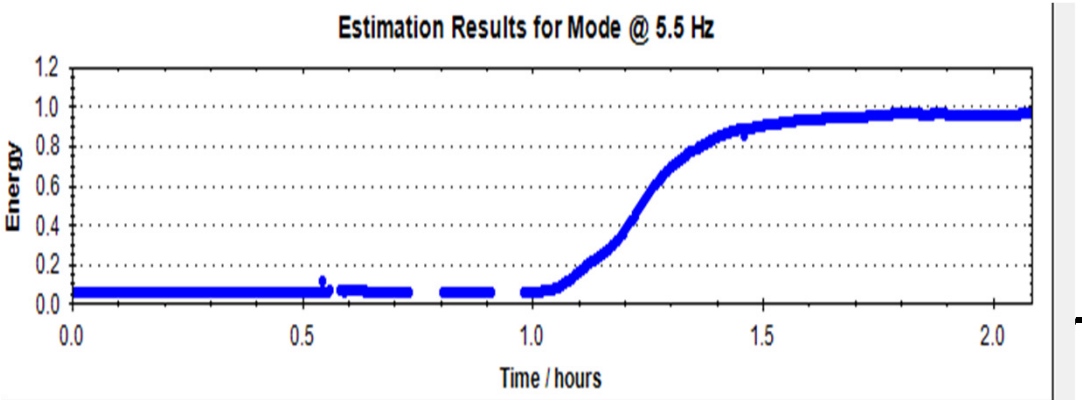
5 Hz mode on April 14, 2013



Actual Current Magnitude seen in Entergy PMU

(From openHistorian)



OMS FDD 5 Hz mode energy level captures the change.

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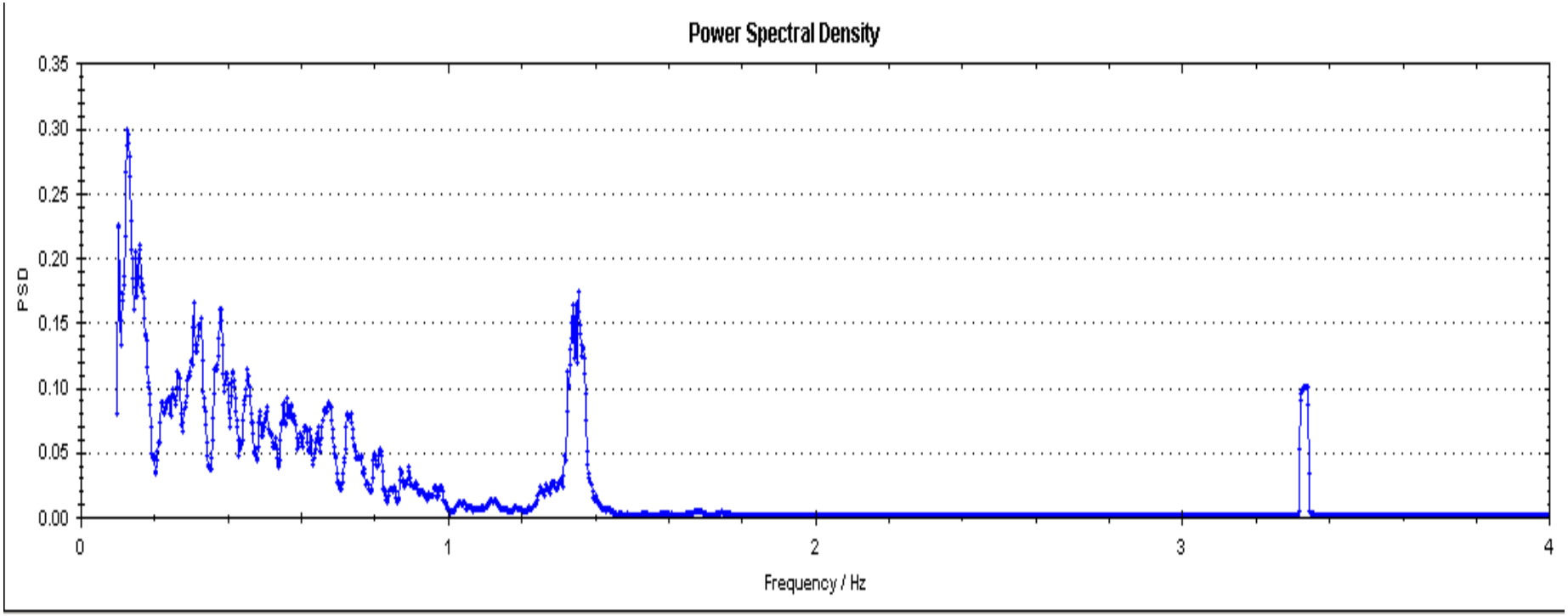
Different modes in a real system



Poorly damped local mode at 1.3 Hz

Zero damping mode at 3.3 Hz

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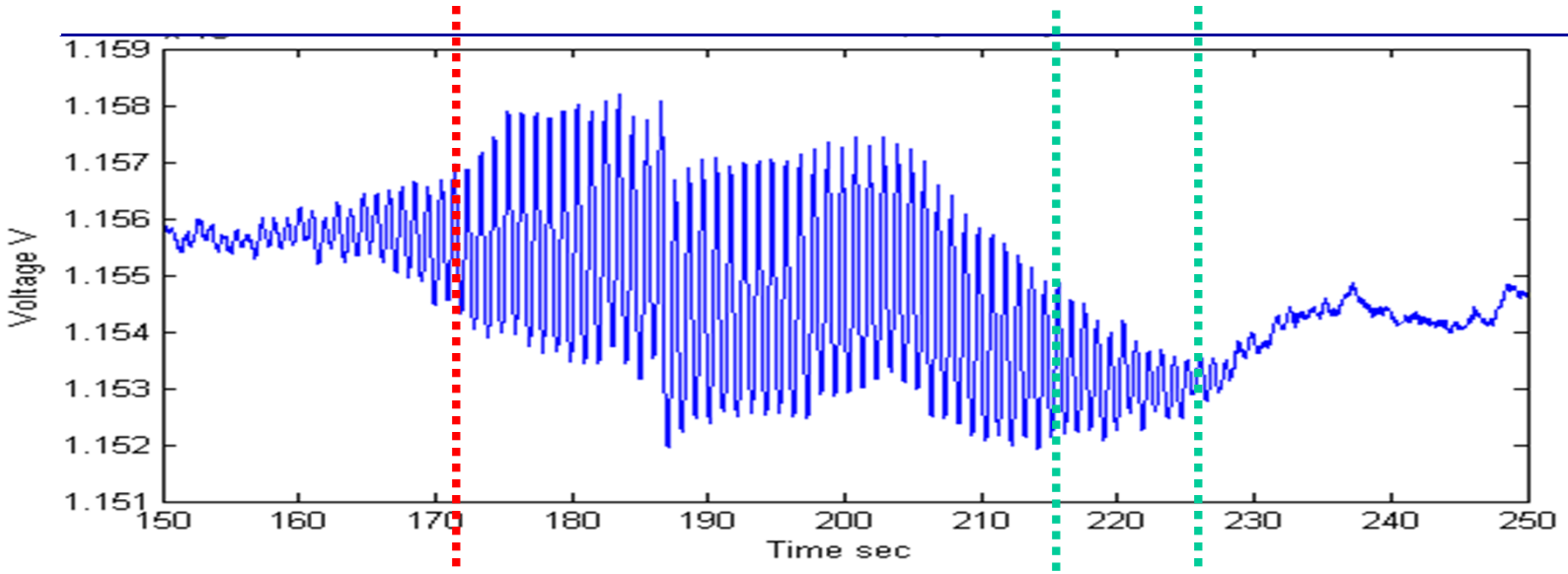
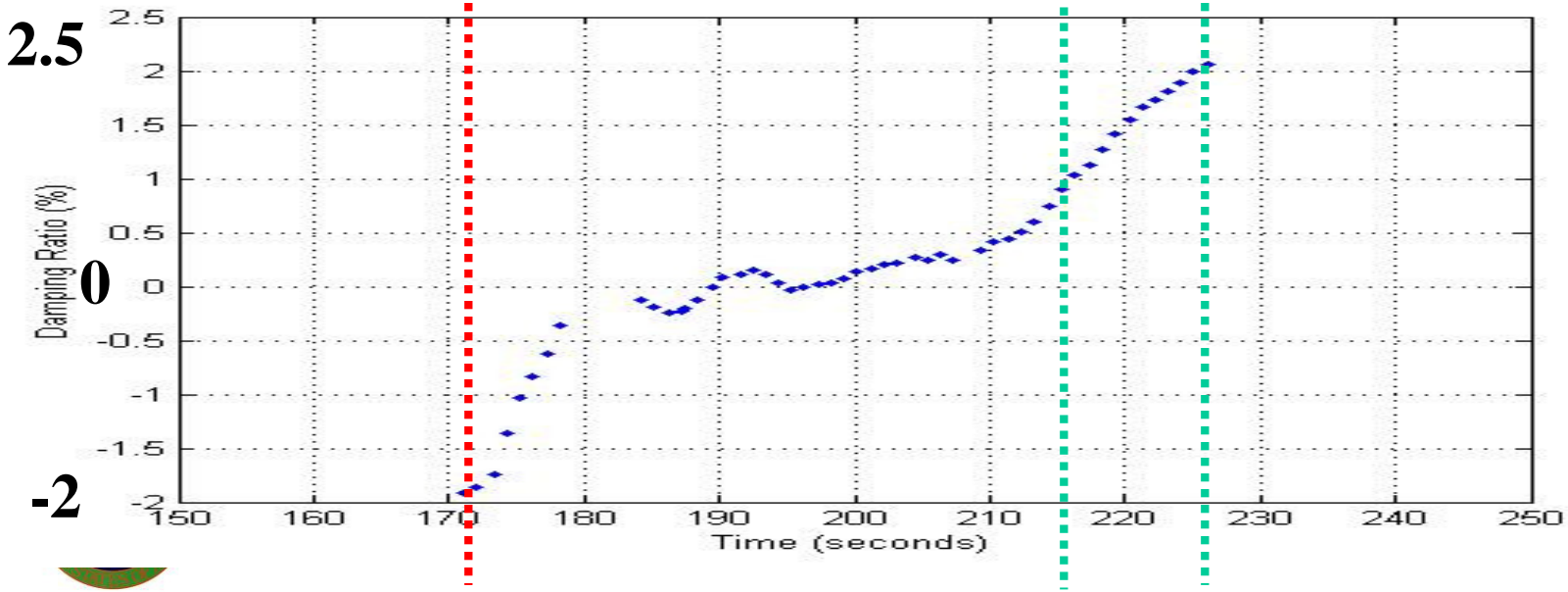
Event Analysis Engine Example



PMU Bus Voltage



Event Analysis Damping Estimate

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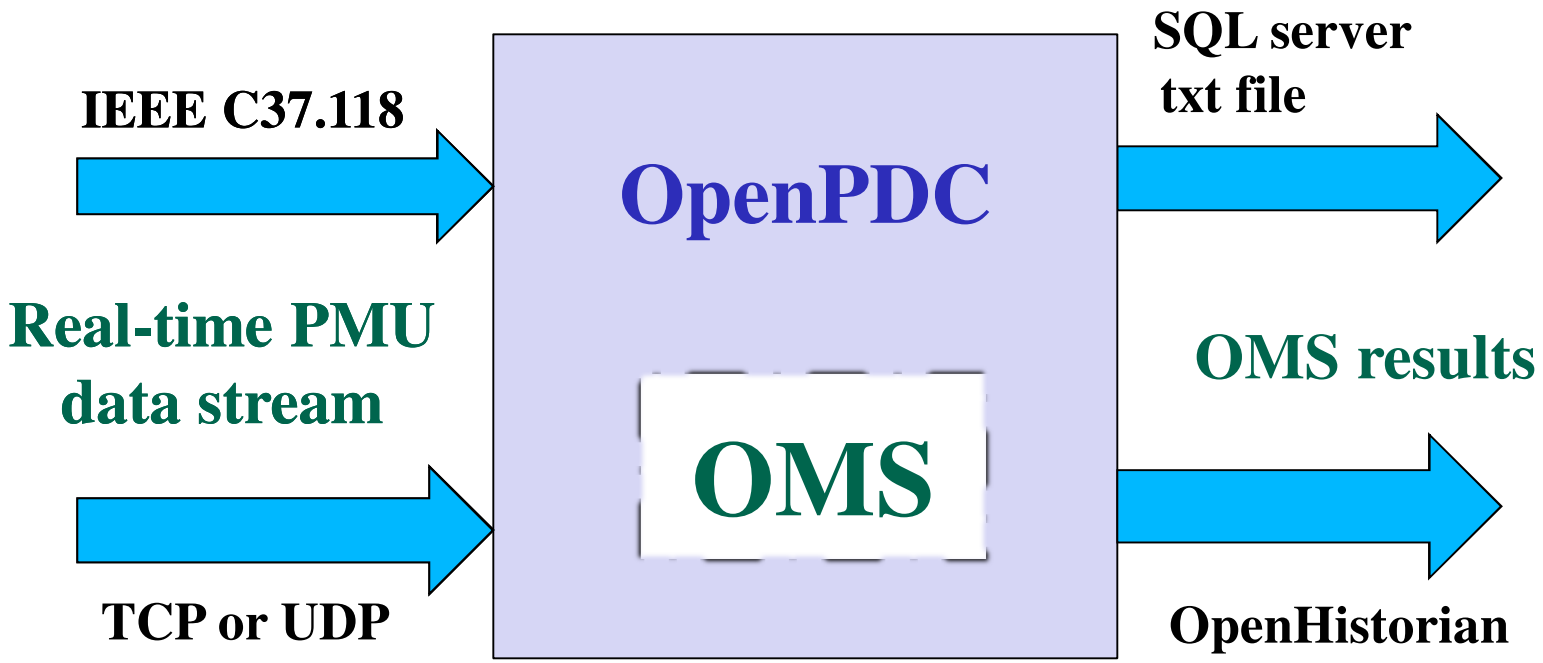
Forced Oscillations

- **Oscillations from "outside the system"**
  - Unmodeled dynamics
  - Oscillations not to be affected by the grid side
  - Operator actions have no effect?
- **Terminology overused in power systems**
  - Hunting of Exciter control valve? Capacitor switching?
  - Wind farm oscillations: Converter controls not tuned.
  - Mechanisms not well-understood.

Framework



OMS action adapter built into OpenPDC 64 bit version 1.5.

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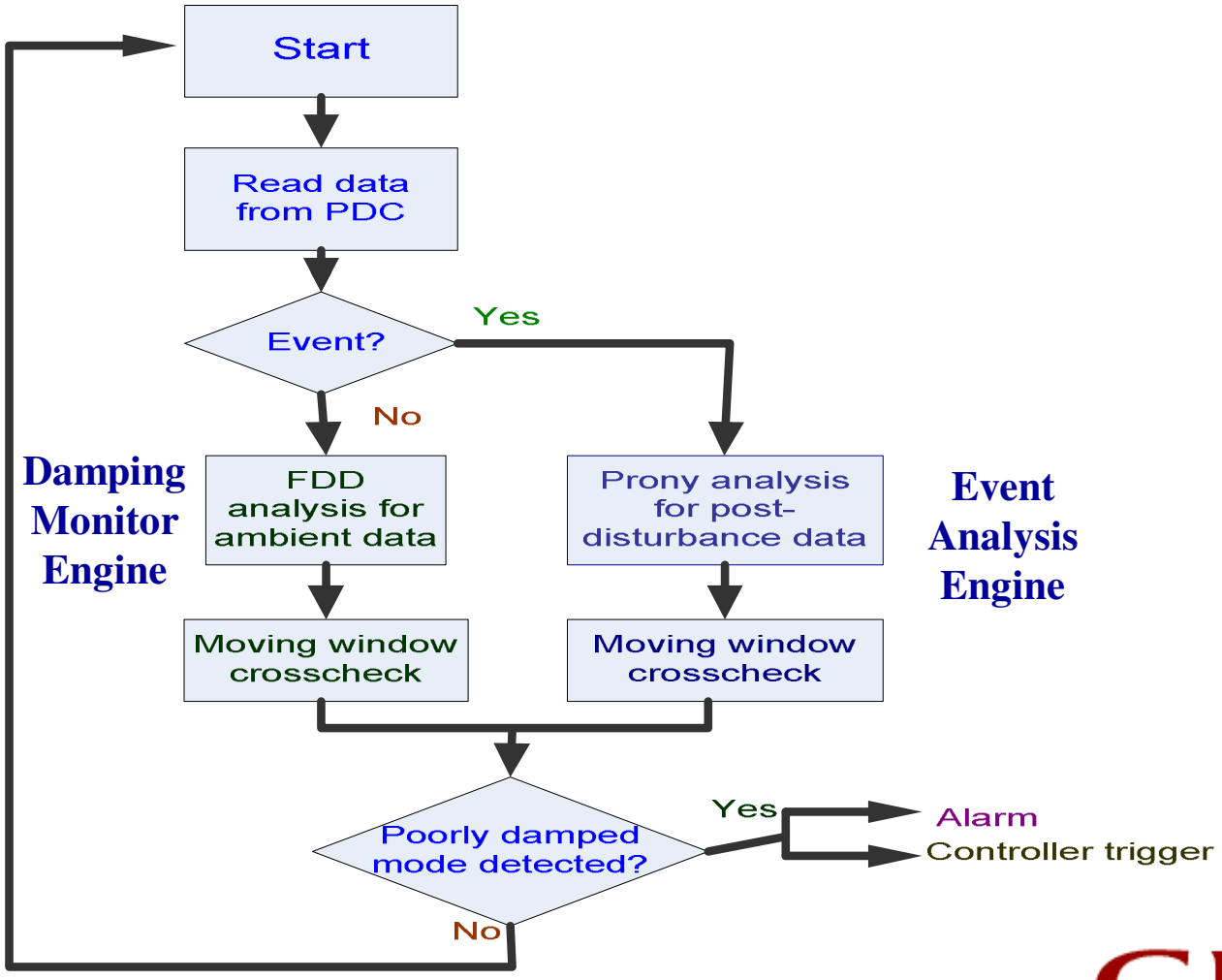
OMS Flowchart



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Complementary Engines

- **Event Analysis Engine (EAE)**
  - Five algorithms: Prony, Matrix Pencil, HTLS, ERA, and **Multidimensional Fourier Ringdown Algorithm**
  - Aimed at events resulting in sudden changes in damping
- **Damping Monitor Engine (DME)**
  - Ambient noise based. Continuous. Provides early warning on poorly damped modes
  - Three algorithms: Frequency Domain Decomposition, **Distributed Frequency Domain Optimization**, and **Recursive Adaptive Stochastic Subspace Identification**

OMS Engines

- Event Monitor Engine
  - Automated Prony type analysis of oscillatory ringdown responses, Time-domain and Frequency domain methods
  - *Ten seconds* of PMU data analyzed every *one second*
- Damping Monitor Engine
  - Automated analysis of ambient noise data
  - Block methods and recursive methods
  - *Four minutes* of PMU data analyzed every *ten seconds*
  - Can handle large number of PMU signals

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Technical Objectives in FY13

- **Damping Monitor Engine**
  - Design of off-line engine (Stage 3)
    - Specifications and code development, Testing
    - Deliverables: Test report
  - Algorithms for real-time engine (Stage 2)
    - Specifications and coding
    - Deliverables: Beta for Entergy test lab

Technical Objectives in FY13

- **Event Analysis Engine**
  - Design of off-line engine for WECC and Entergy (Stage 3)
    - Specifications, coding and testing
    - Deliverables: Beta for WECC engineer testing
  - Algorithm designs for real-time engine (Stage 2)
    - Specifications, coding and testing
    - Deliverables: Test report

Risk Factors in FY13

- **Event Analysis Engine and Damping Monitor Engine**
  - **Off-line engines: Availability of good test cases (events) for WECC and Entergy**
  - **Real-time engines: PMU data quality, computational capability of servers**

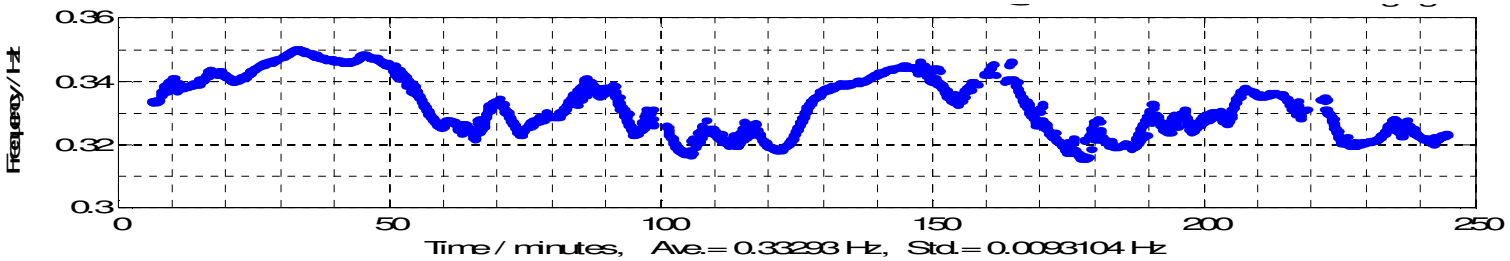
Technical Objectives in FY14

- **Damping Monitor Engine**
  - Beta version of off-line engine for WECC and Entergy (Stage 4)
    - Code testing and tuning
    - Deliverables: Beta version
  - Prototype of real-time engine for Entergy (Stage 4)
    - Code testing, tuning and improvements
    - Deliverables: Prototype for Entergy and WECC

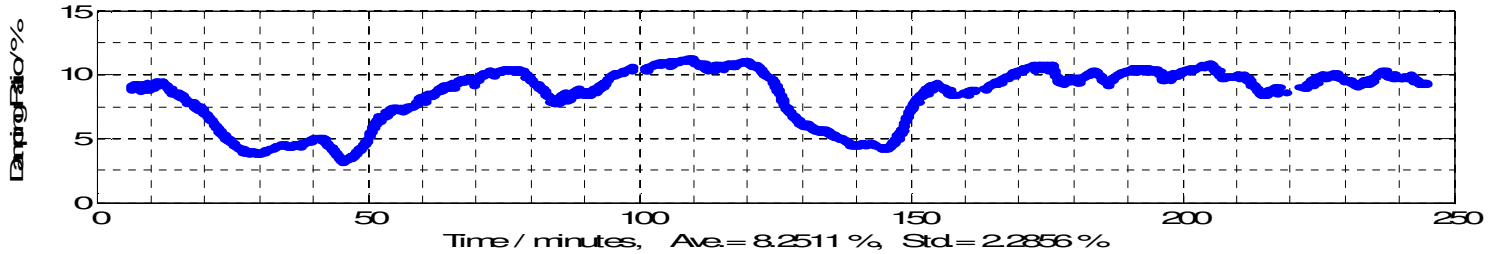
Technical Objectives in FY14

- **Event Analysis Engine**
  - Beta version of off-line engine for WECC and Entergy (Stage 4)
    - Code testing and tuning
    - Deliverables: Beta version
  - Beta version of real-time engine for Entergy (Stage 4)
    - Code testing, tuning and enhancements
    - Deliverables: Prototype for Entergy and WECC

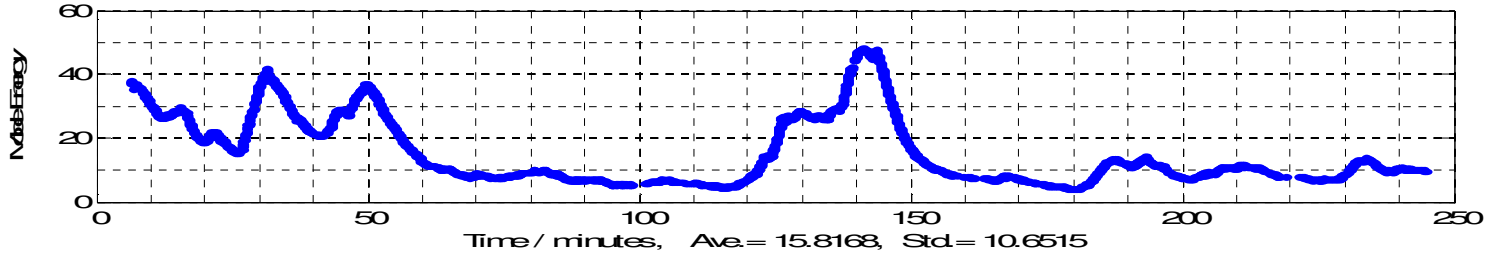
Damping Monitor Engine Example



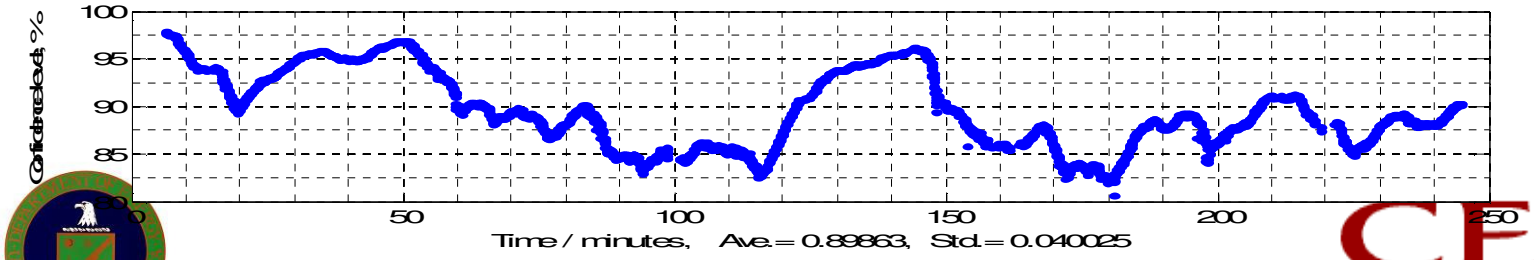
Mode Frequency



Damping Ratio



Energy Estimate



Estimation Confidence

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Key Technical Accomplishments in FY13

- **Damping Monitor Engine**
  - Prototypes running at Entergy and Idaho Power Company
  - Two new algorithms developed: Distributed Frequency Domain Optimization (DFDO) and Recursive Adaptive Stochastic Subspace Identification (RASSI)
  - DFDO: Can handle very large number of PMU measurements, fully distributed computation, auto-selection of signals for each mode.
  - RASSI: fast recursive engine, short initialization time, adaptive to changing system conditions.

Key Technical Accomplishments in FY13

- **Event Analysis Engine**
  - Off-line prototype developed.
  - Demo at WECC JSIS.