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

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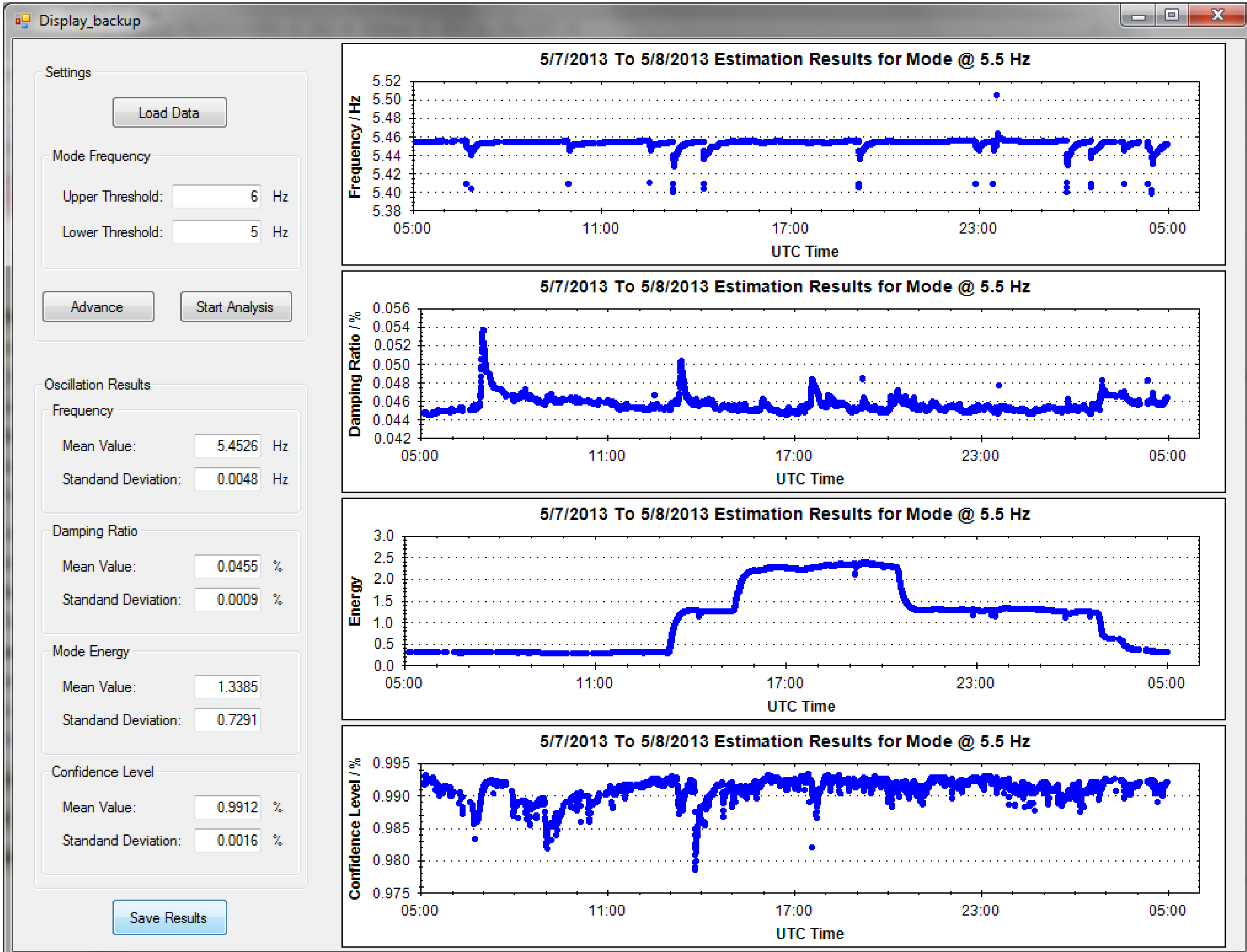
Entergy 5.5 Hz mode



Pattern different on different days

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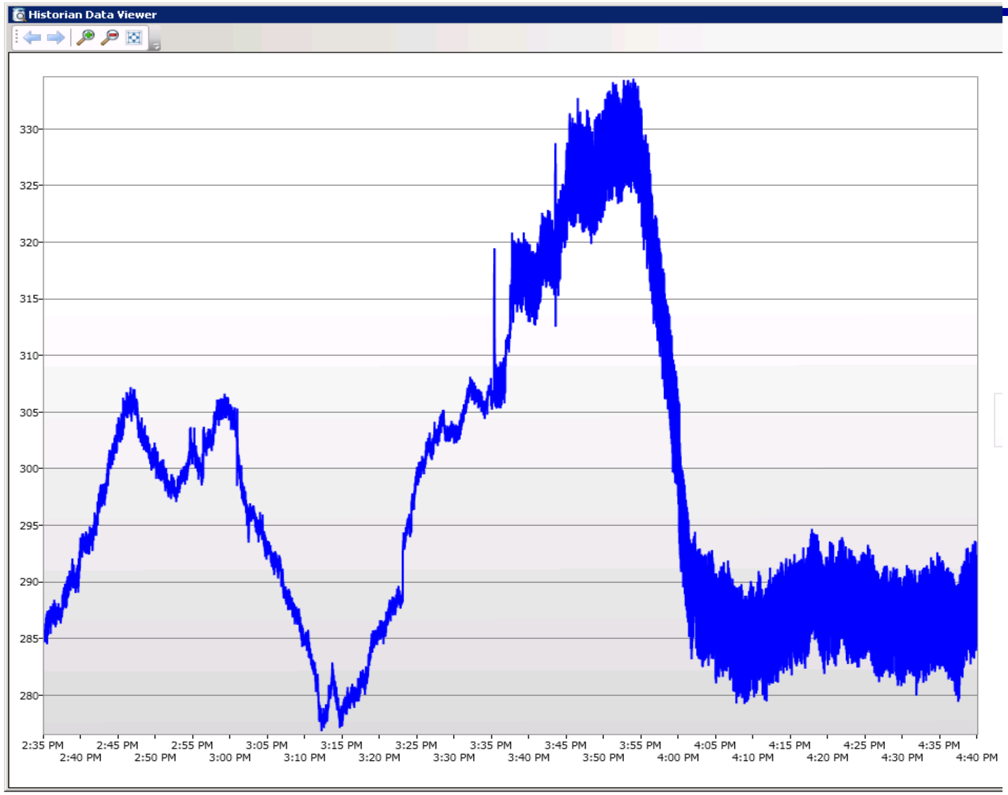
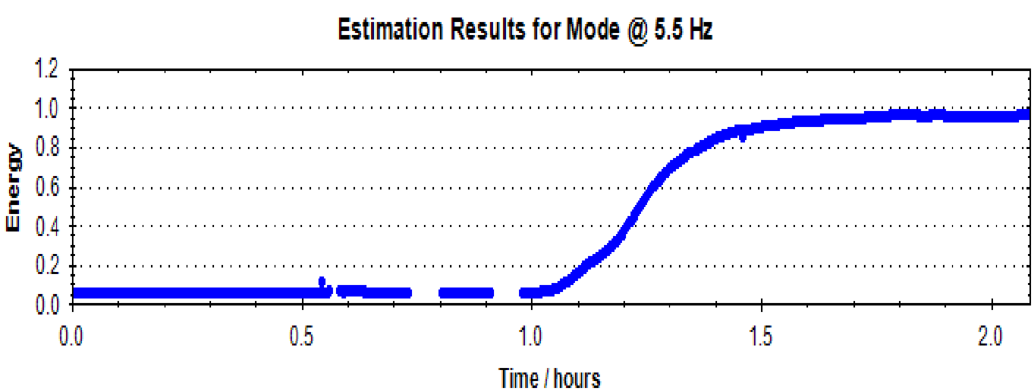
5.5 Hz mode



Actual Current Magnitude seen in PMU

(From openHistorian)



OMS FDD 5 Hz mode energy level captures the change.

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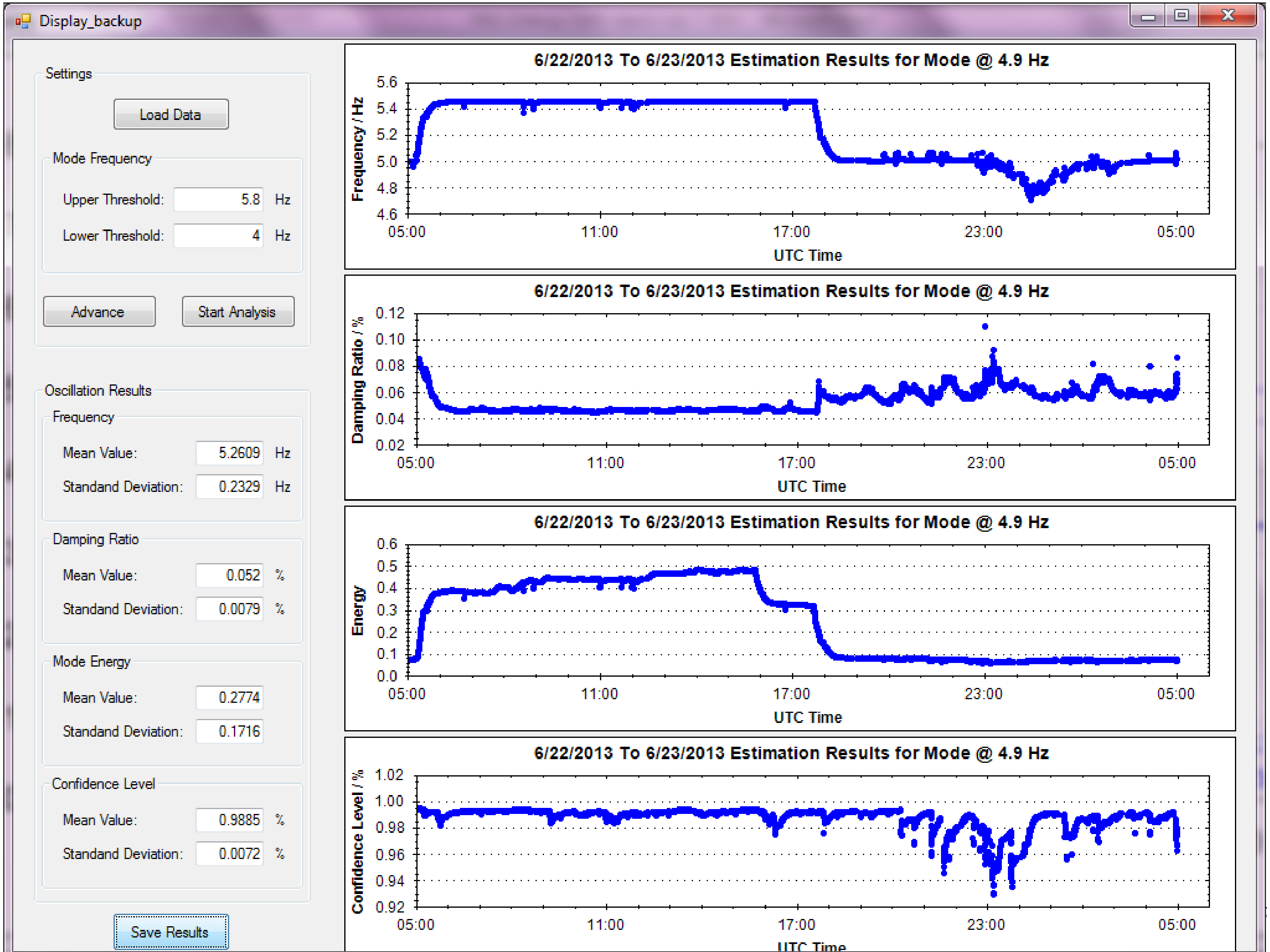
Entergy 5 Hz mode



Mode frequency changes during some days

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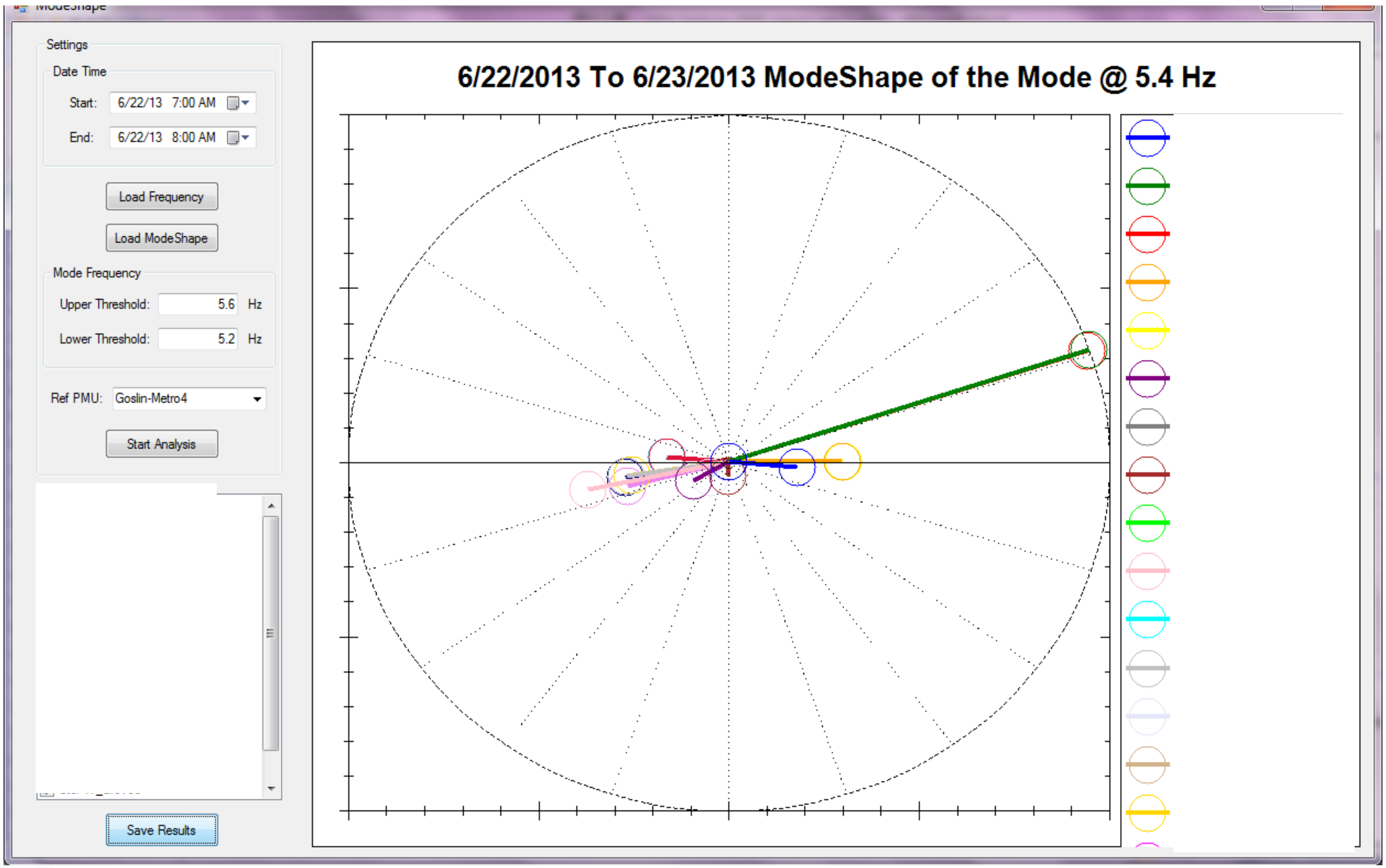
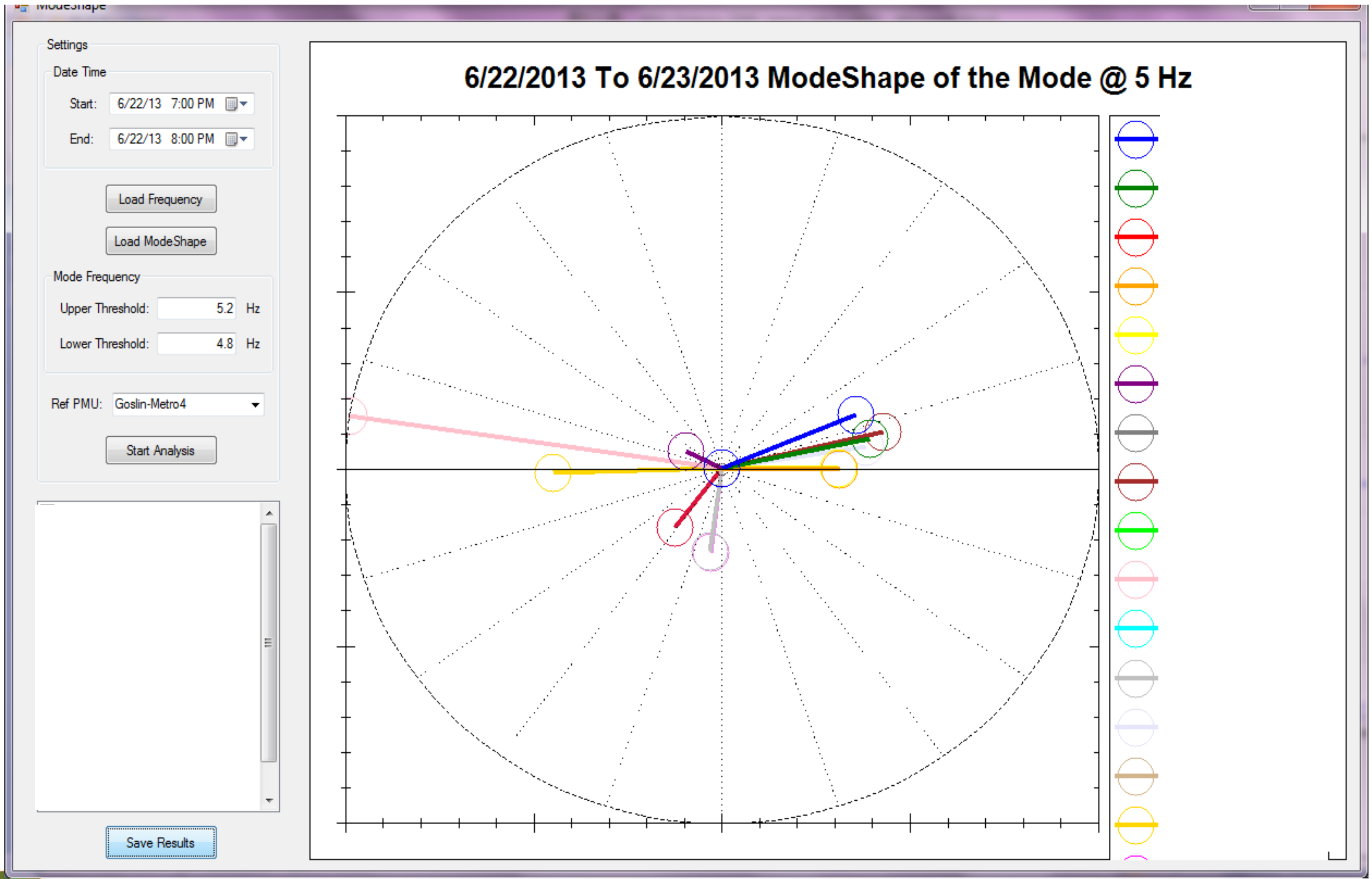
5.45 Hz mode shape



5 Hz mode shape – different mode



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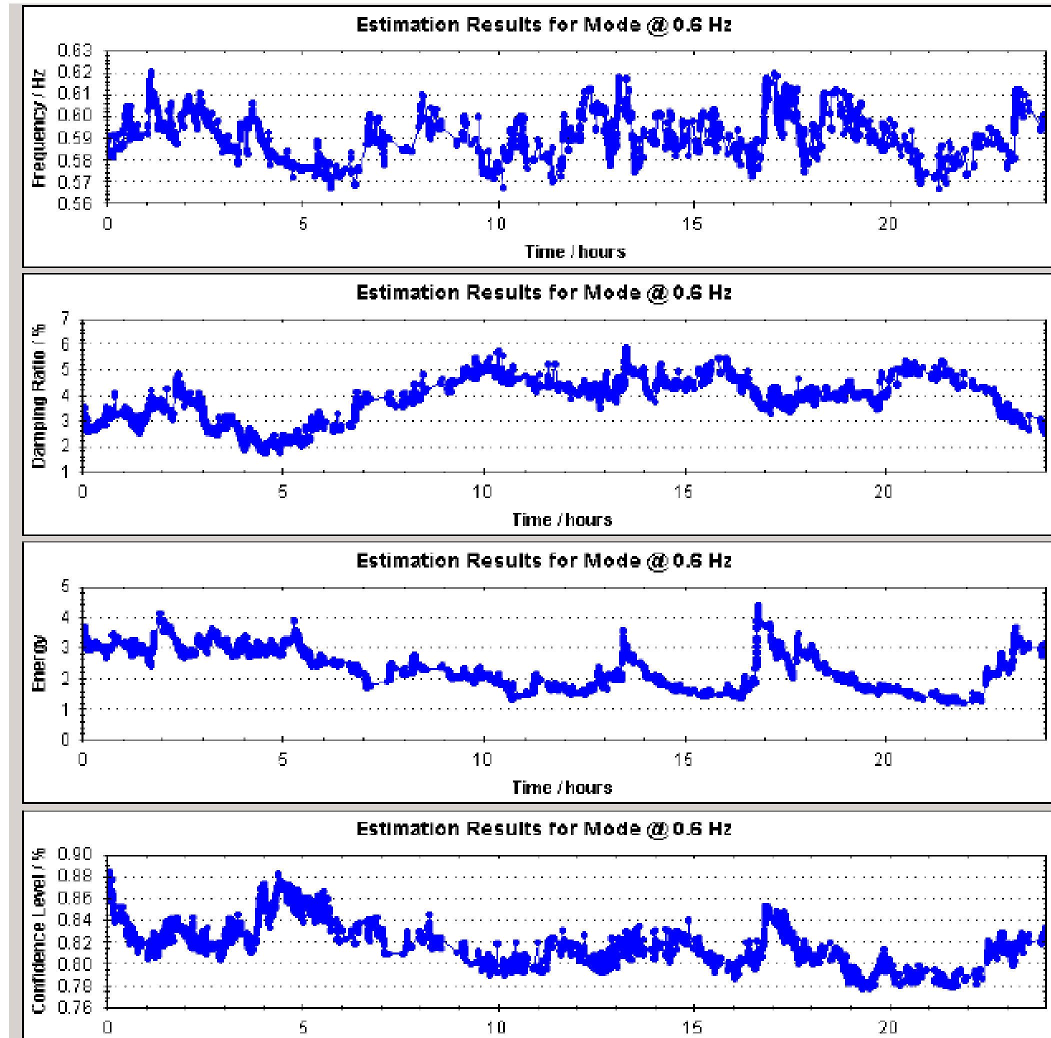
0.6 Hz Eastern system mode

- Mode Identified using **WSU OMS** in September 2013 by Entergy PMU team led by **Floyd**
- Mode seen in data from April 2013 and possibly in 2012
- Mode damping averages around 4% and goes as low as 2% with high energy
- Has been reproduced by Entergy via SSAT
- Study in early stages



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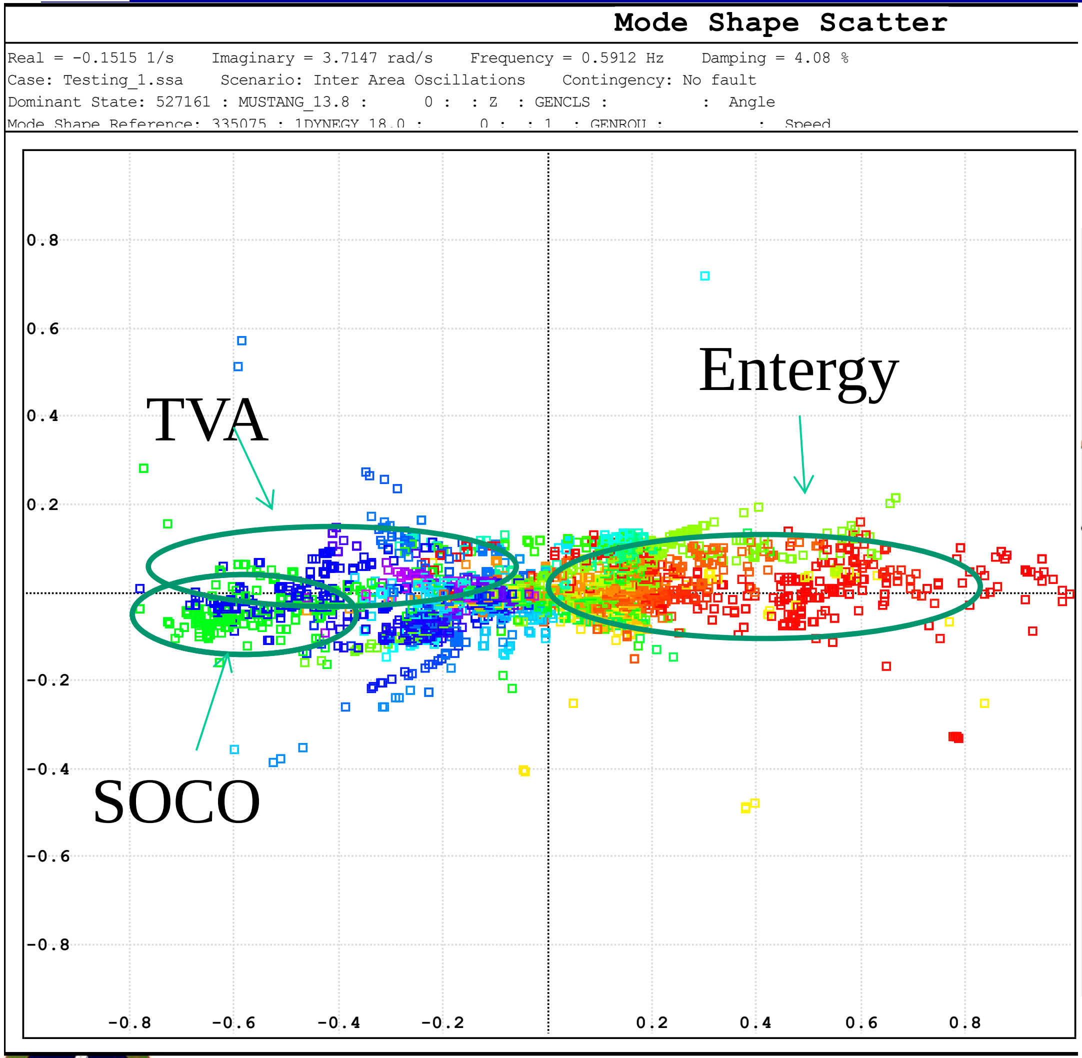
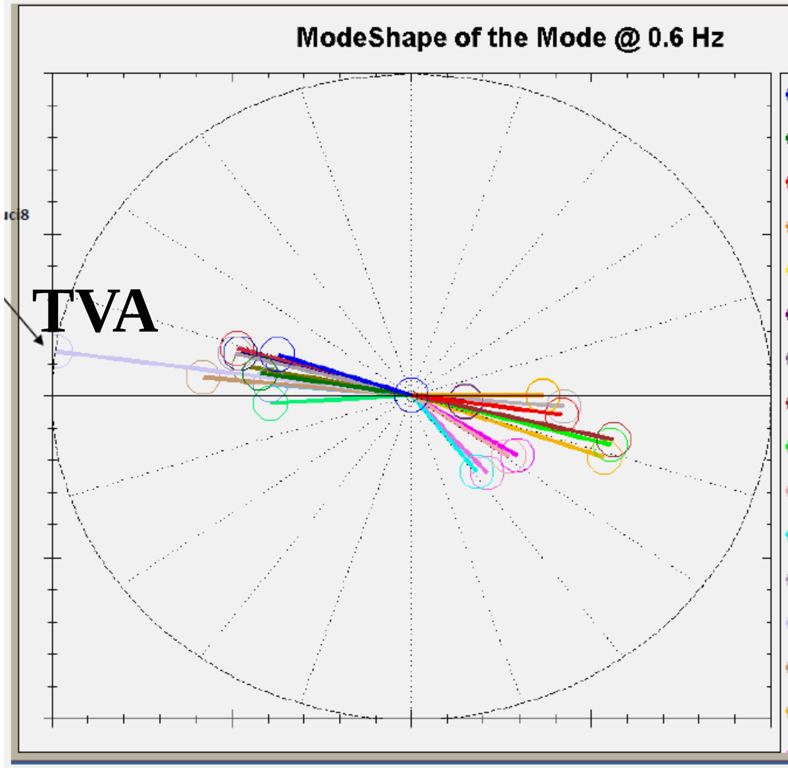
0.6 Hz Eastern system mode

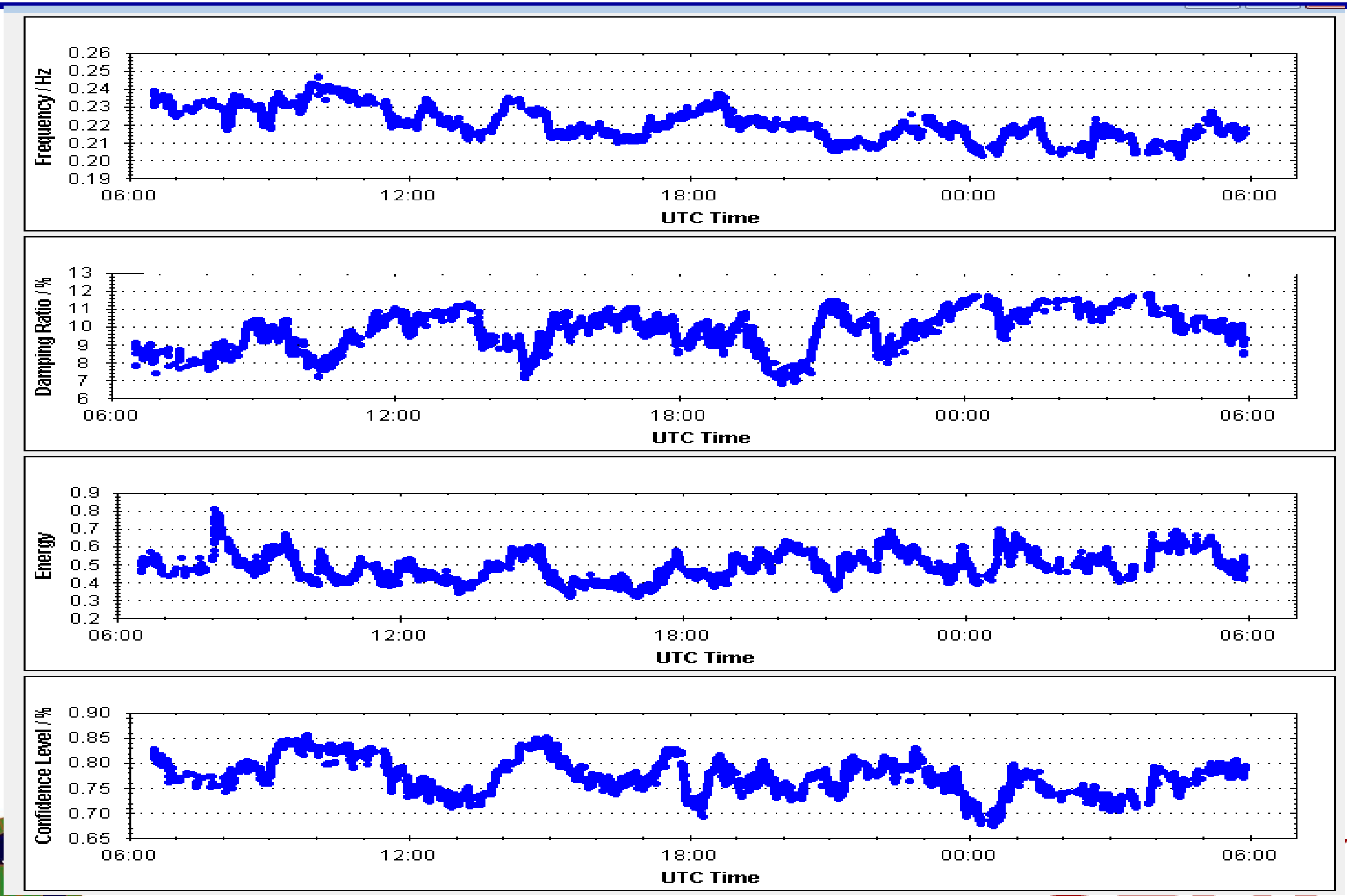
SSAT



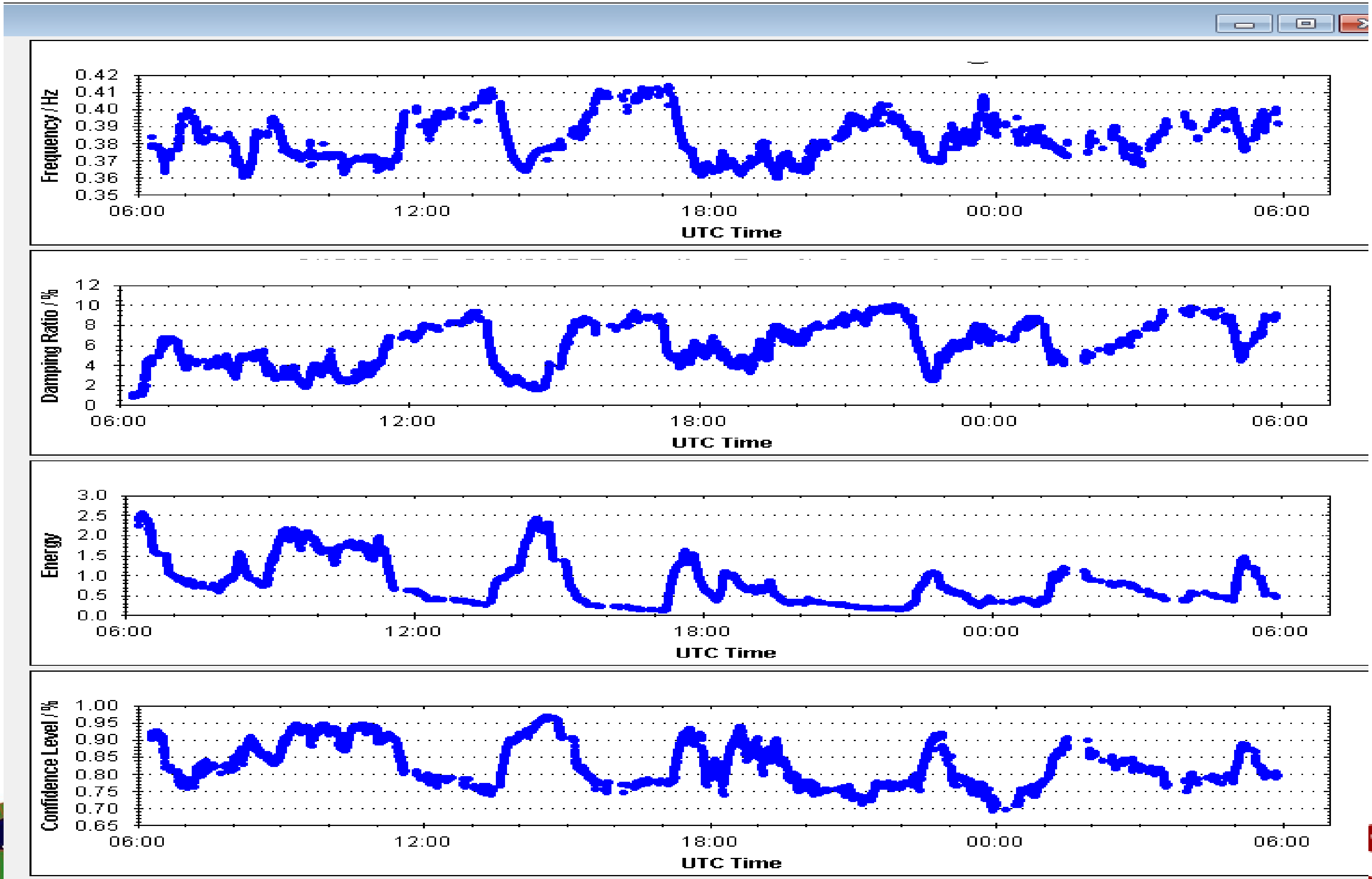
OMS Mode Shape



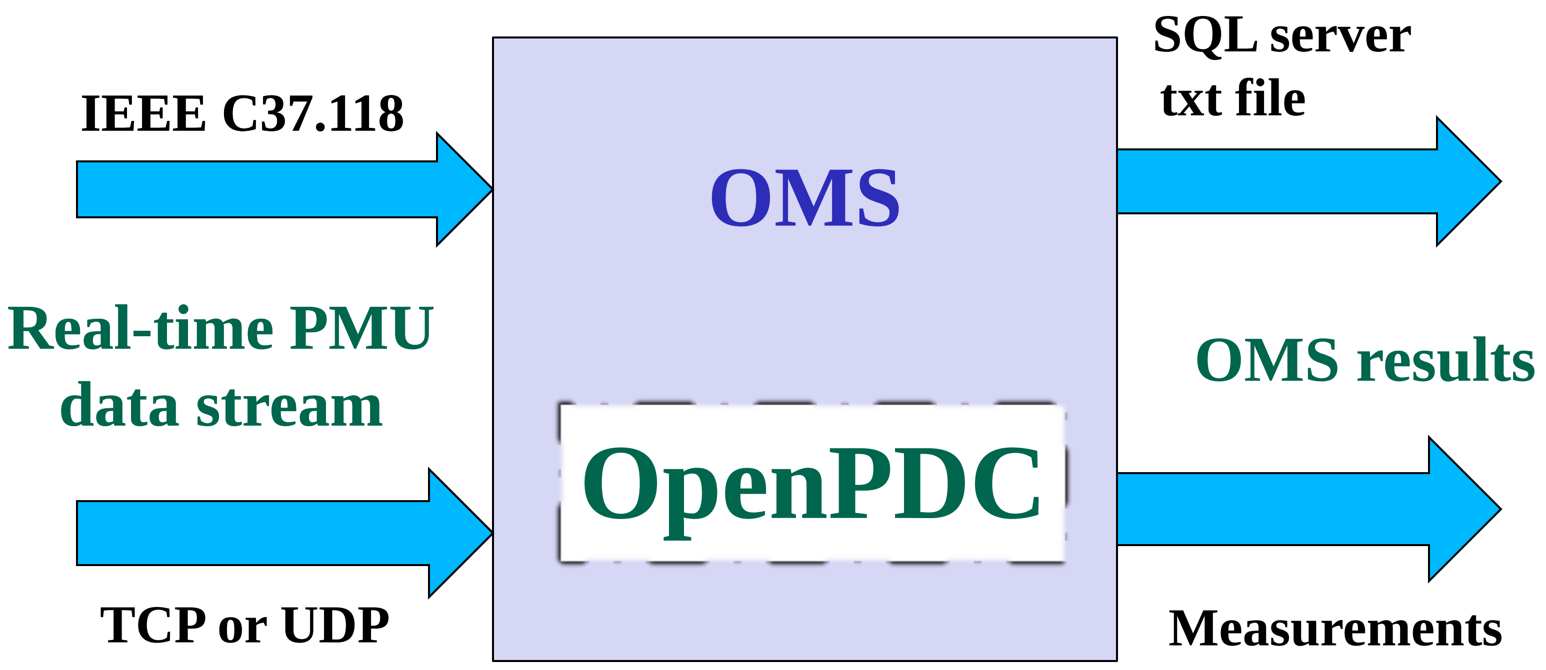
0.22 Hz WECC mode (well-damped)



0.38 Hz WECC mode (poorly damped)

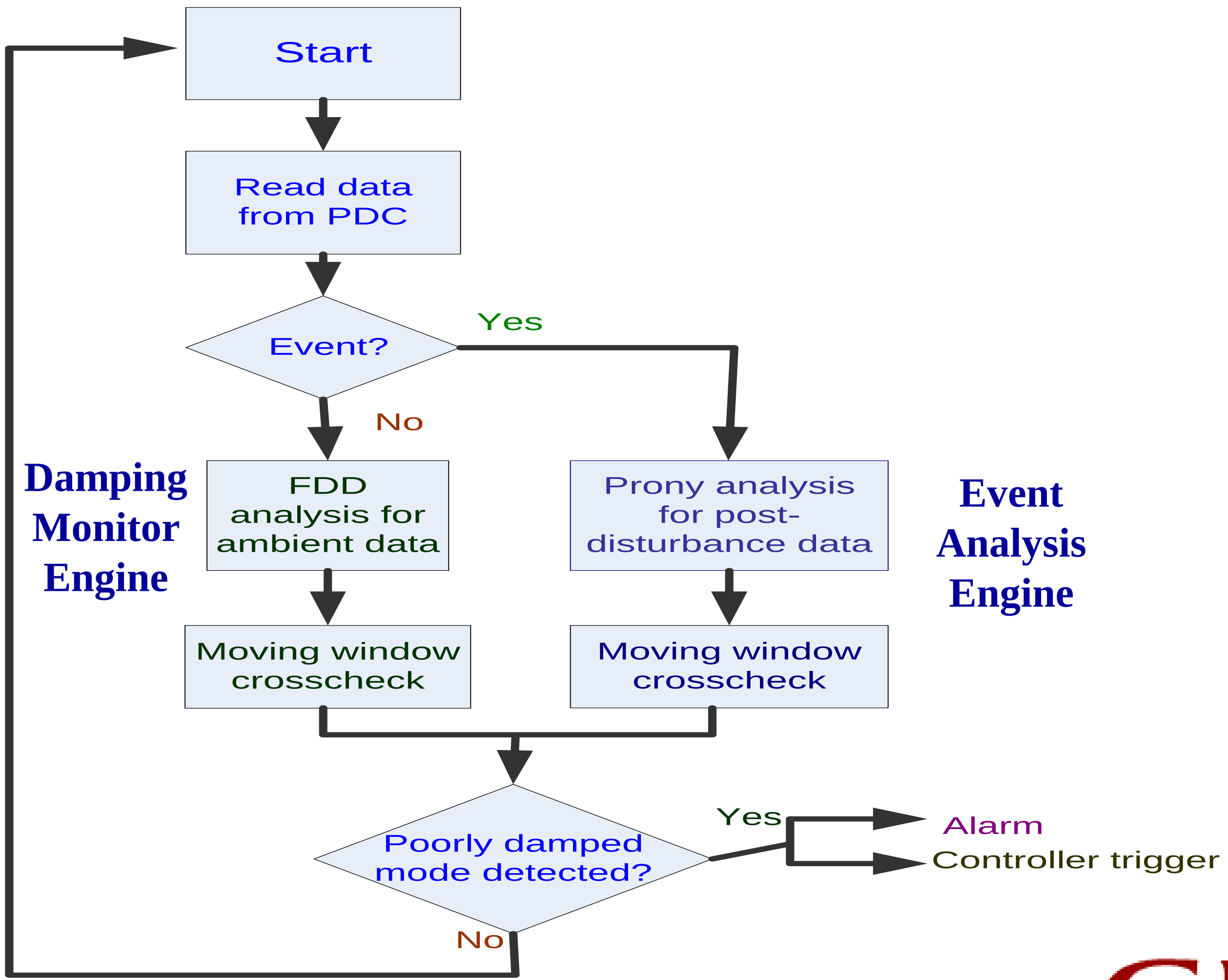


Framework



OMS built into OpenPDC 64 bit versions 1.5 and 2.

OMS Flowchart



Complementary Engines

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

Existing Ringdown Algorithms

- Prony, Matrix Pencil, ERA, and HTLS
  - High level of noise maybe an issue
  - **CPU Intensive and not scalable**
  - Can handle only a limited number of PMU signals for simultaneous processing
  - Selection of model order an issue
  - How to analyze ringdown response from hundreds of PMUs? New frequency domain algorithms developed:
    - Multidimensional Fourier Ringdown Algorithm (MFRA)
    - Modal Energy Trending for Ringdown Analysis (METRA)

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MFRA

- Designed for automatic analysis of 100s of signals.
- To appear in IEEE Trans Power Systems.
- Tracks energy trends of each dominant mode during events in frequency domain analysis.
- ***NOT*** CPU intensive. Fast Processing Time.
- Bad PMU signal detection based on χ^2 tests
- Suitable for real-time oscillation detection.
- Can even be integrated within PMU or a relay.
- Extends O'Shea work for analyzing one signal

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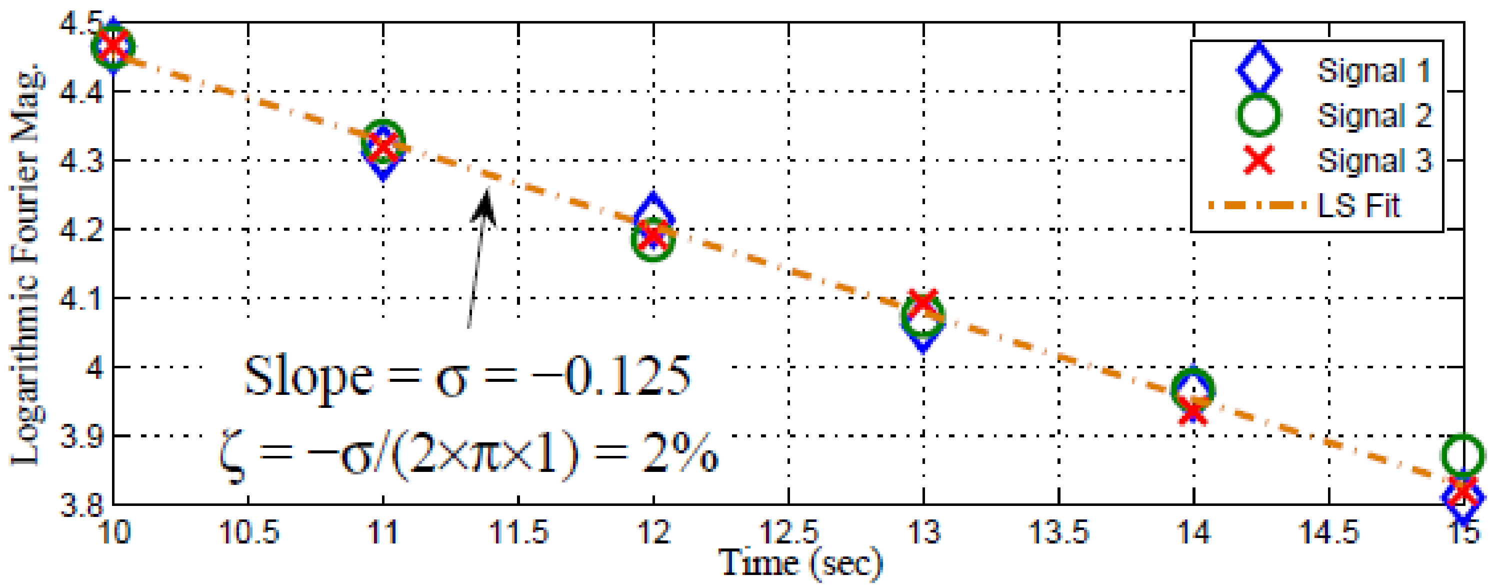
Least Square Fit

- The Damping Ratio (ζ) can be calculated by finding the energy decay slope using a **least square fit**

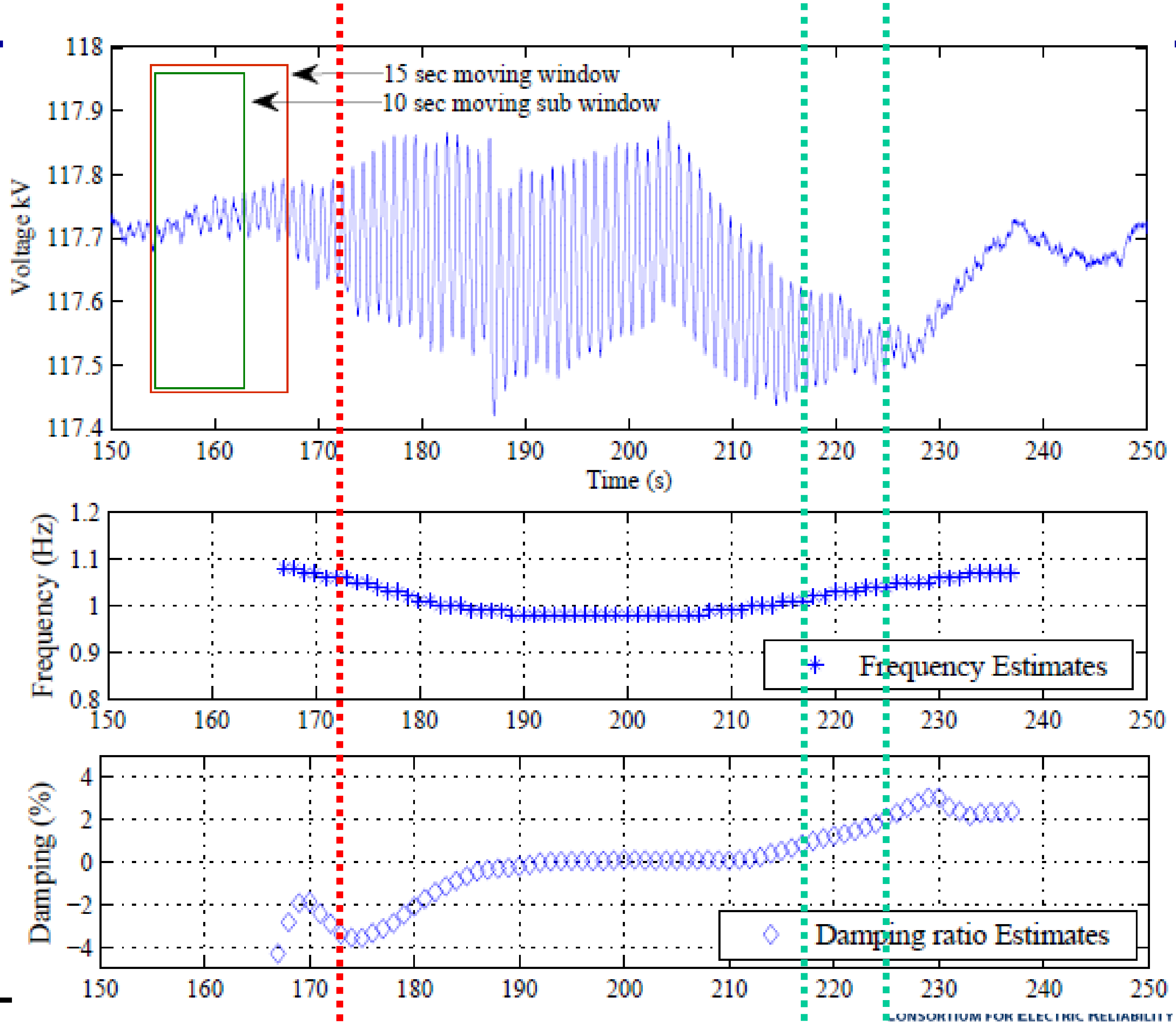


Processing Time

- For processing three signals, 14x faster than ERA & HTLS, 35x faster than Prony & Matrix Pencil
- Automatically recognizes dominant modes
- Scalable design
- Distributed
- Multi-threading

Algorithm	Processing Time (ms)	
	15 dB	25 dB
MFRA	9.64	9.81
Prony	437.81	377.44
Matrix Pencil	365.93	359.66
HTLS	176.04	126.58
ERA	168.44	127.57

WECC Event



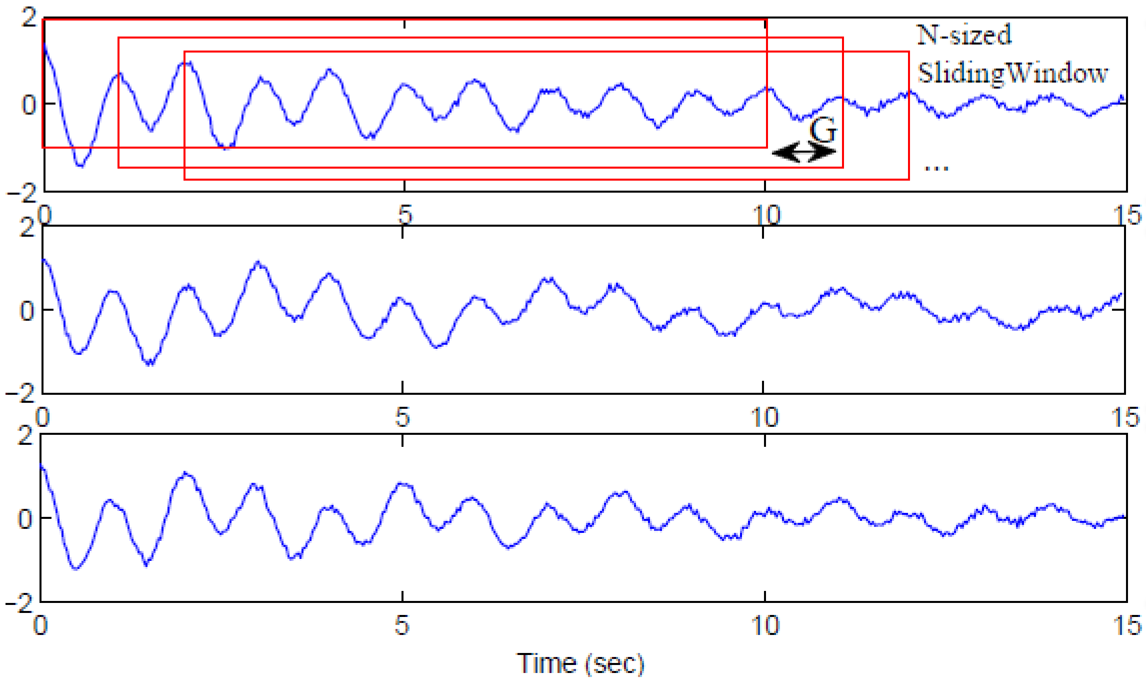
15 sec moving window
10 sec moving sub window
Voltage kV
Time (s)
Frequency (Hz)
Frequency Estimates
Damping (%)
Damping ratio Estimates

Summary

- PMUs enabling technology for online oscillation analysis
- Sustained oscillations may have been around for years – causing damage and unknown until monitored by OMS using PMUs
- System changing: adaptive engines needed.
- Oscillation modes: analyze full bandwidth of signals.
- Mode shape crucial for analysis: simultaneous processing of hundreds of PMU signals needed
- Distributed algorithms needed.

Example

- Three synthetic signals with one common 1 Hz mode at 2% damping ratio



0.5 Hz
5.0 %

0.25 Hz
3.0 %

0.35 Hz
4.0 %

G = 1/f = 1/1 = **1 second**

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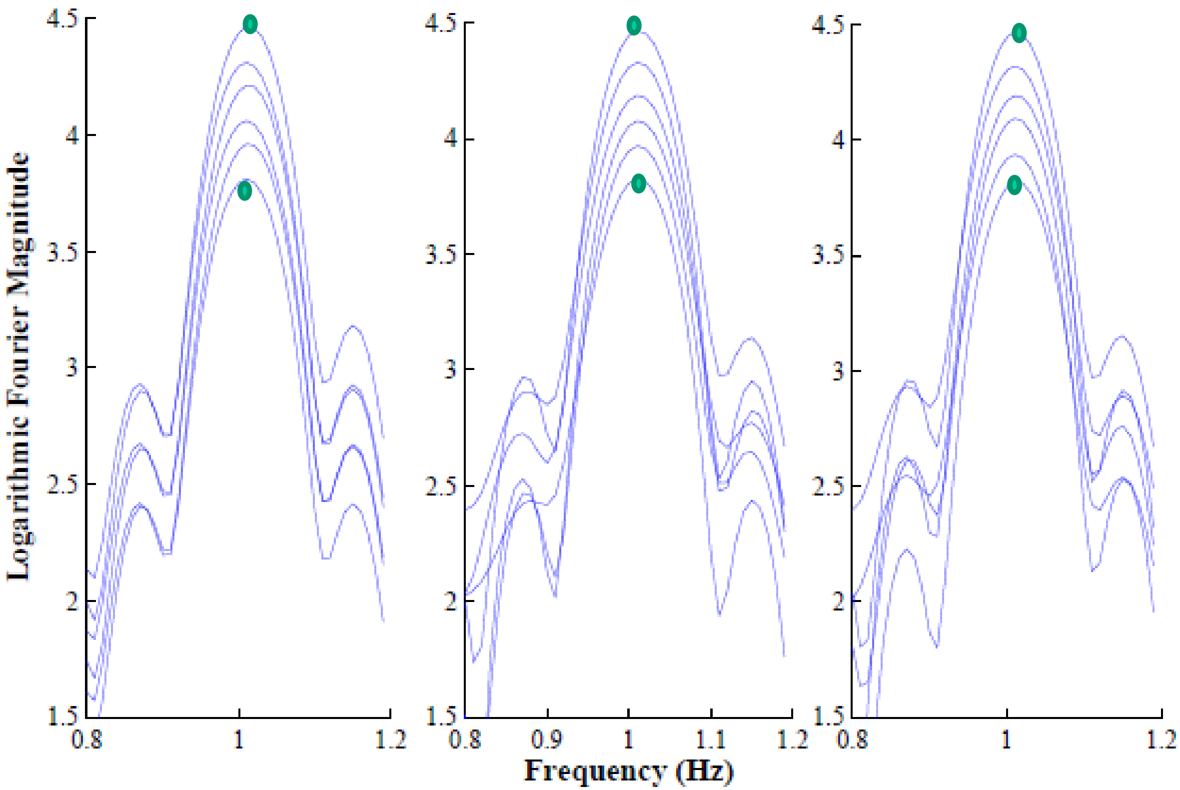
Mode Decay Rate

- The Logarithmic Fourier Magnitude of the *1 Hz* mode *decays* as window slides through the data



Least Square Fit

- The Damping Ratio (ζ) can be calculated by finding the energy decay slope using a **least square fit**