Pacific Northwest
NATIONAL LABORATORY
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Spectral Analysis of Power Grid PMU Data

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Pacific Northwest National Laboratory

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Project Overview

Pacific Northwest NATIONAL LABORATORY
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- Time line
  - Feb 2012 – May 2012
- PNNL Team:
  - Ning Zhou
  - Jian Yin
  - Bora Akyol
- Advisors:
  - Dmitry Kosterev (BPA)
  - Dan Trudnowski (MT)
  - Jeff Dagle (PNNL)
  - Zhenyu Huang (PNNL)
  - John Pierre (UW)

Project Objective:

Detect and Analyze Dynamic Events

Problem formulation:

Some dynamic events (e.g. mistuned PSS, tie-line tripping, malfunction of generator controllers) may push the system into alert and emergency states, if proper control actions cannot be taken in time.

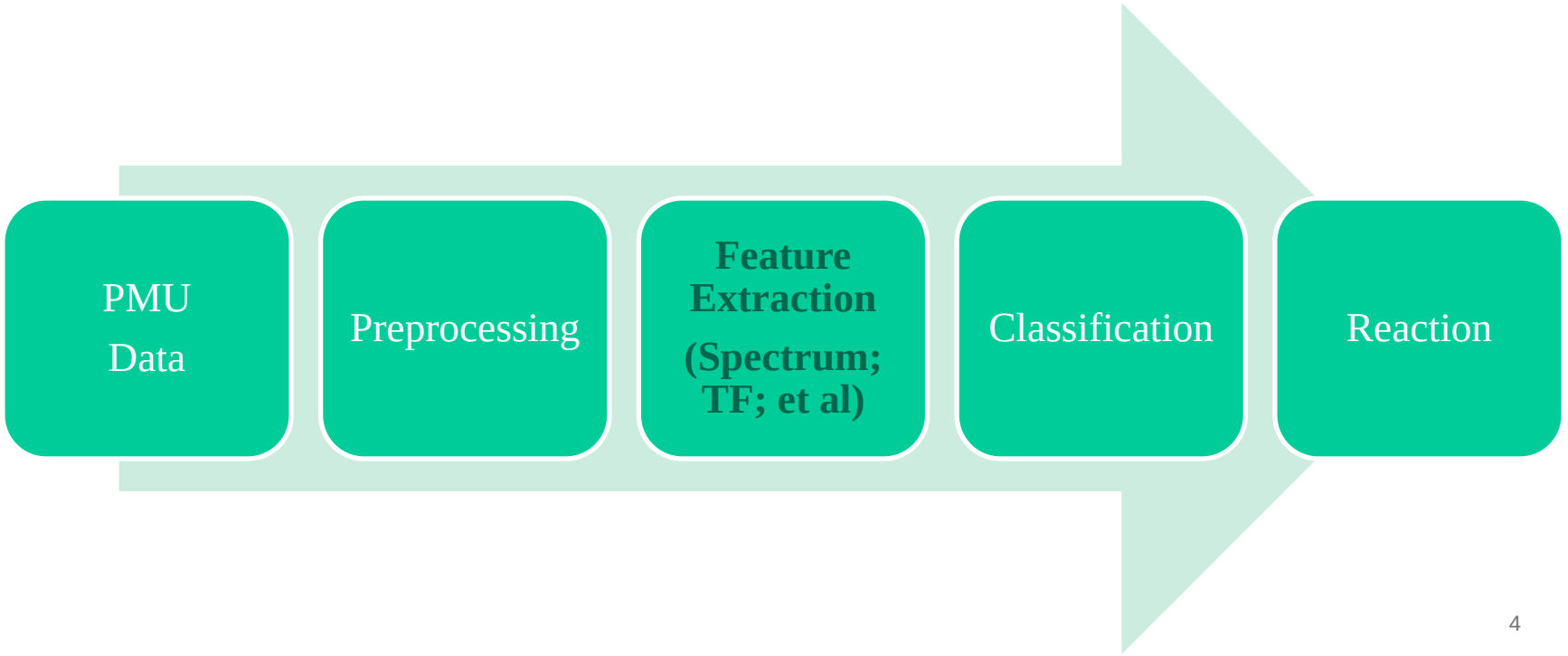
Objective:

Enable operators to detect and react to dynamic events by extracting and analyzing spectral features from PMU measurements.

Challenges & Approaches

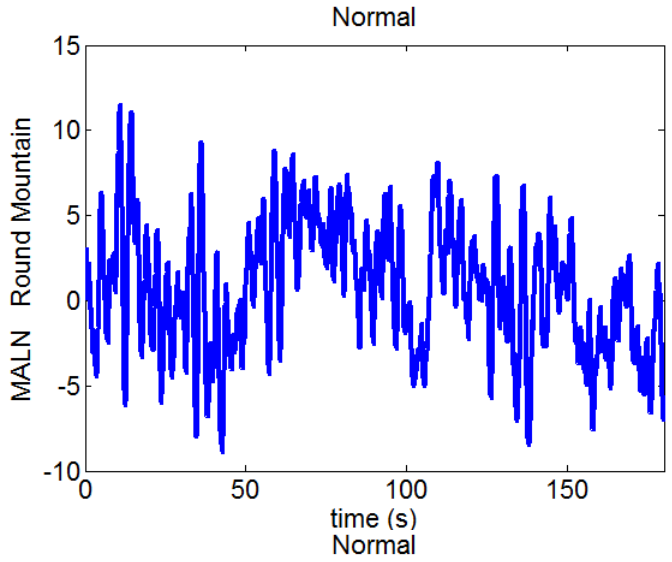
- Challenges:
  - The time domain PMU data often do NOT reveal dynamic features in a straightforward manner

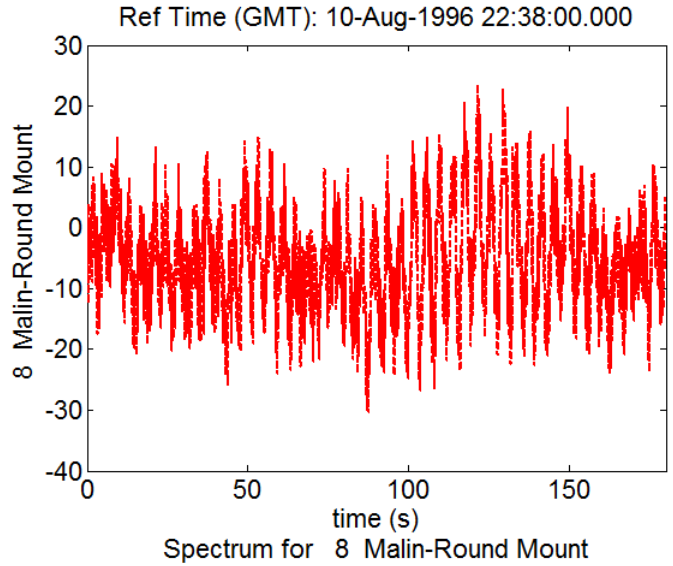
- Approaches:
  - Transform the data into features

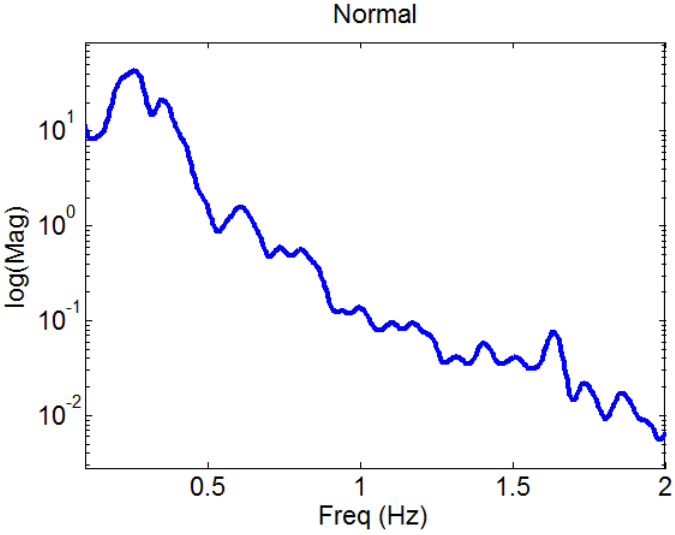


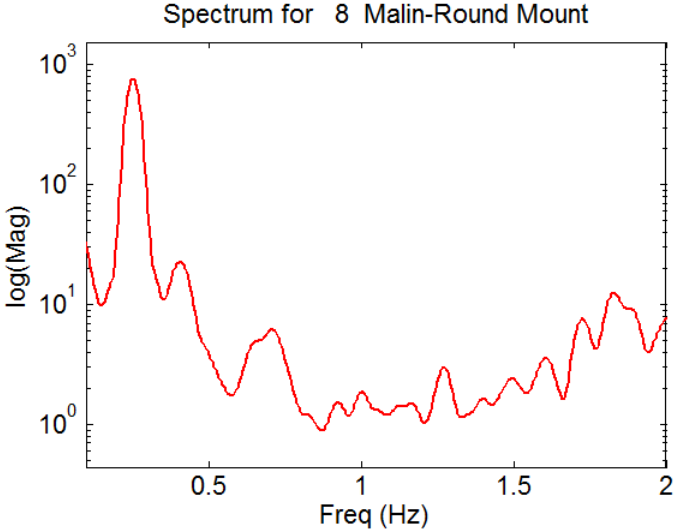
Spectral Analysis

- Spectrum is chosen because it can reveal how total power is distributed over frequency.

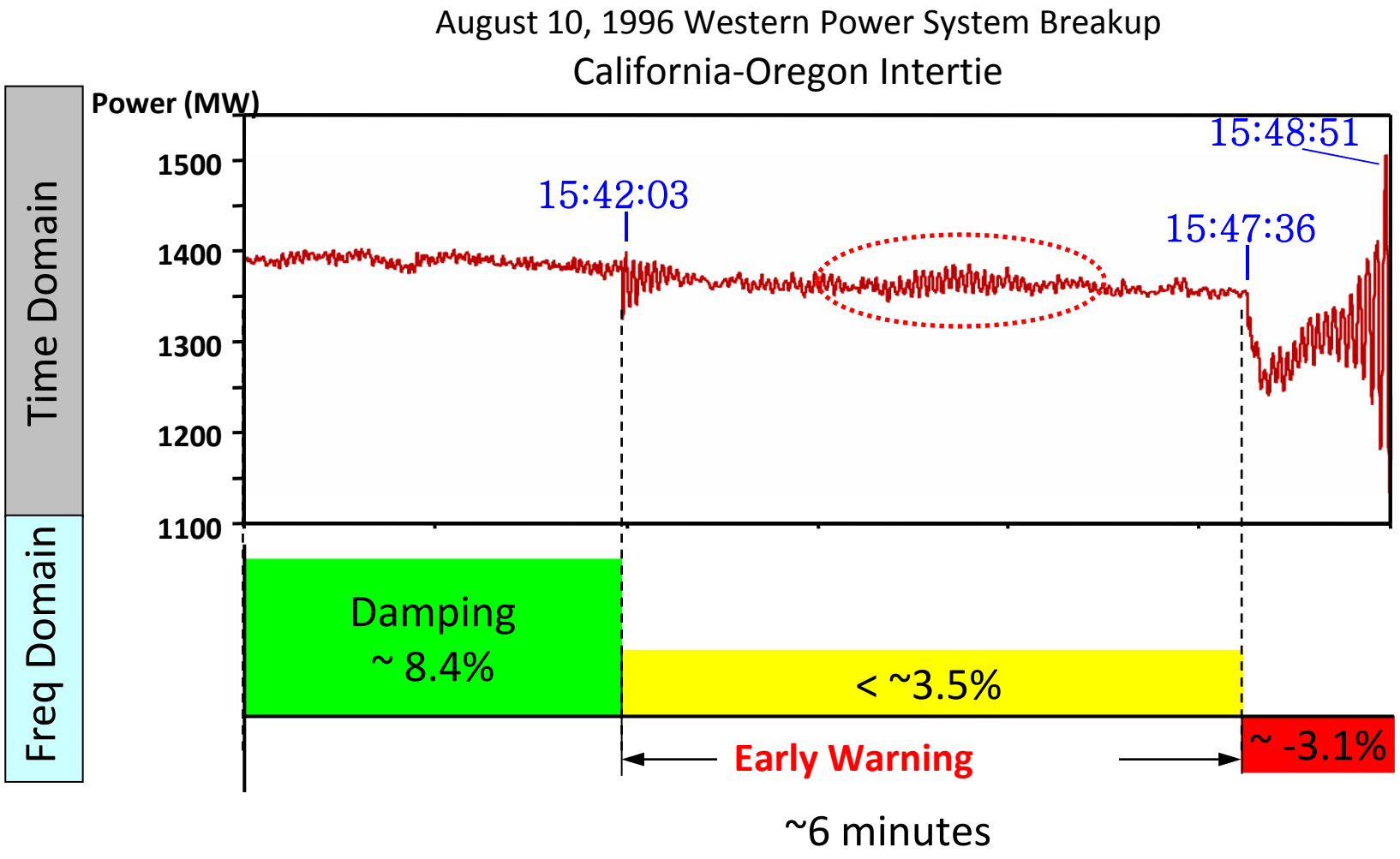






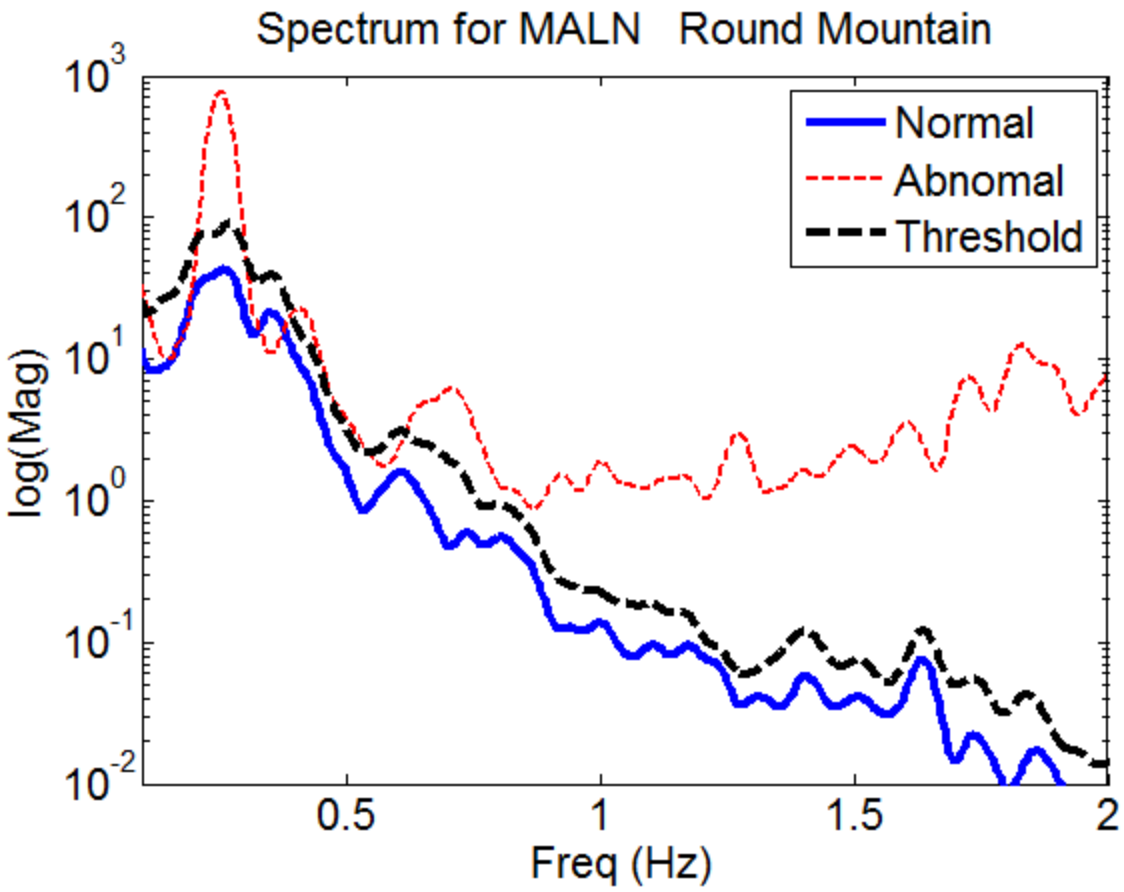


Early Warnings based on PMU data

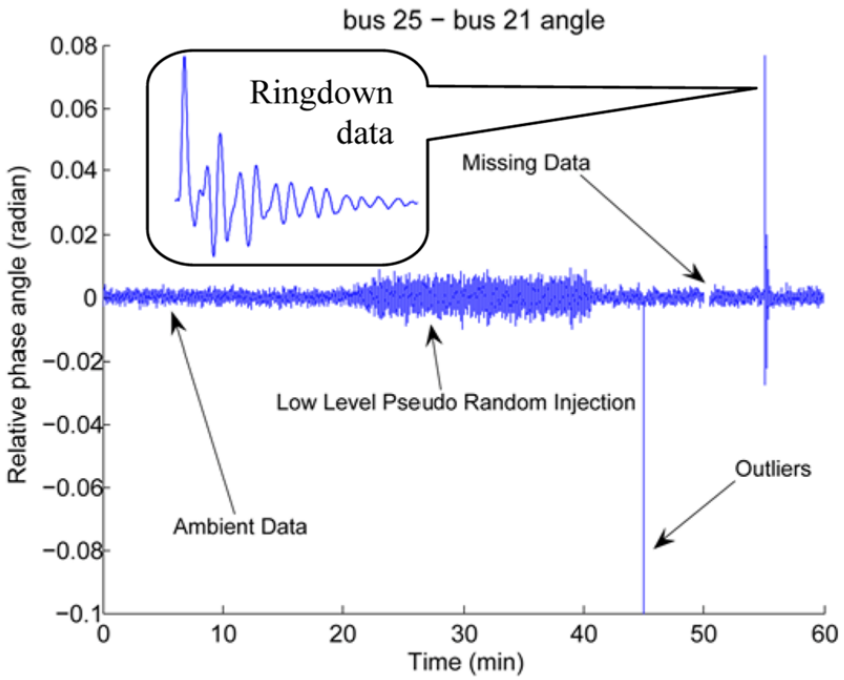


Spectral Baseline

- **Goal:** Build a threshold curve for spectra to detect unusual oscillations



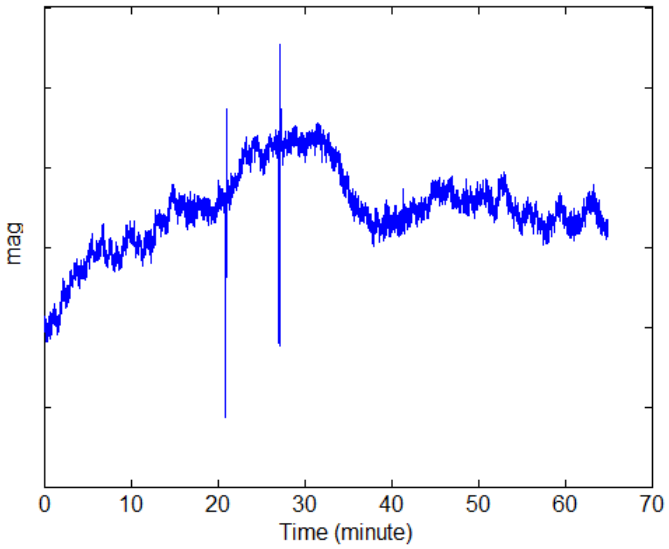
Typical and Non-typical PMU Data

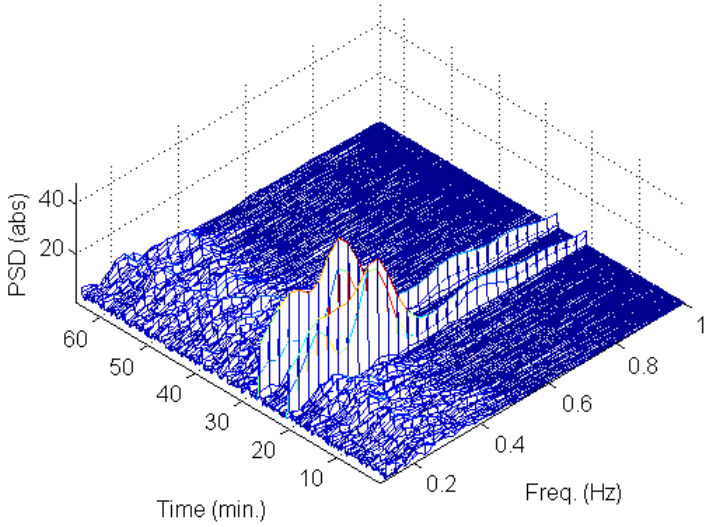


- **Typical data:**
  - **Ambient Data:** random changes with small amplitudes caused by small amplitude random load changes
  - **Transient Data:** strong oscillations that last for short periods, (e.g. ringdown caused by major disturbance such as tripping lines and brake insertion)
  - **Sustained Oscillation:** oscillations that last for extended periods. (e.g. probing, forced oscillations)

- **Non-typical data:**
  - **Missing Data:** dropped out data points, which may result from temporary communication and measurement device failure
  - **Outliers:** significantly deviated from normal values which may be generated by temporary sensor failure or high level interference)

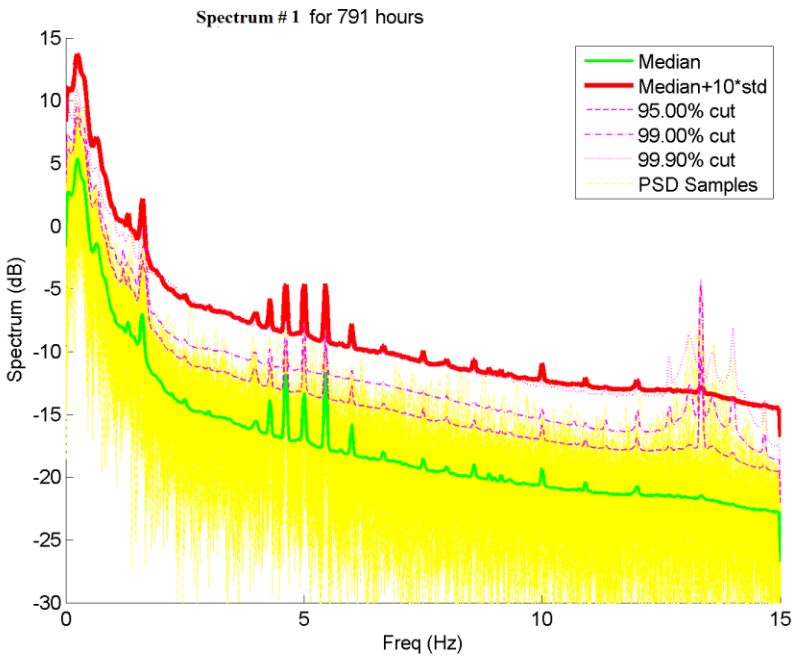
The Spectrum during Transient Events

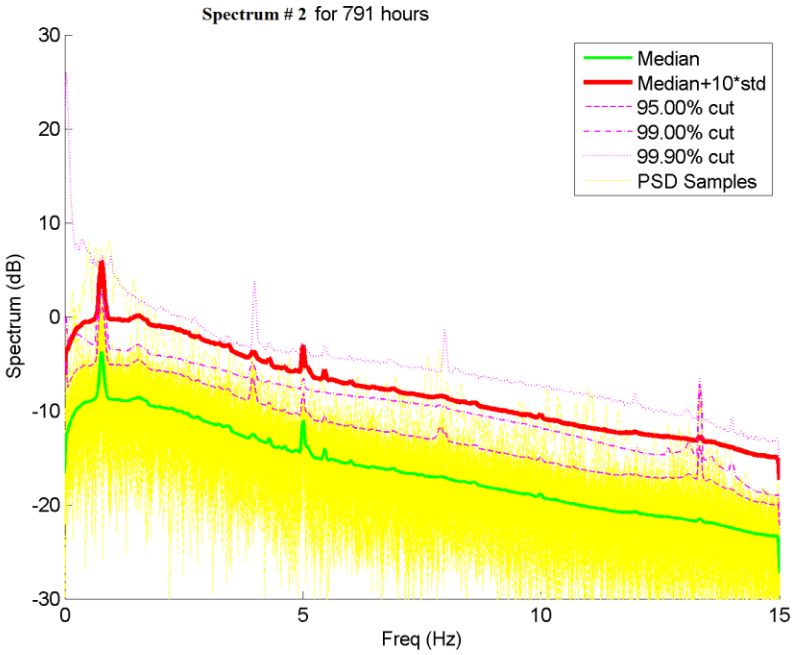




- **Most of data are ambient data**
- **Transient data carry significantly larger amount of energy in lower frequency range**

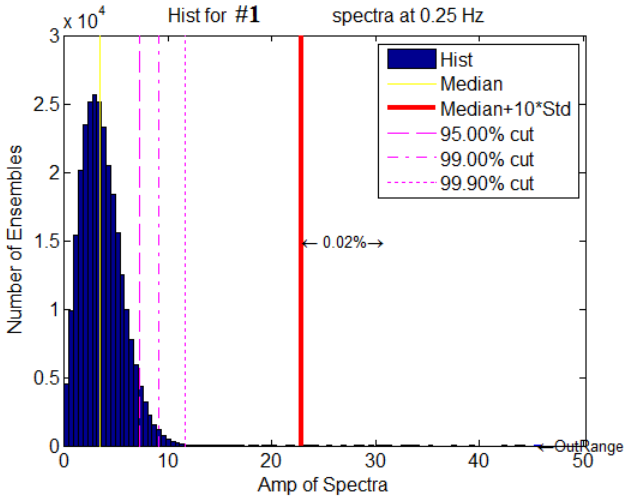
Use Median for Determining Thresholds

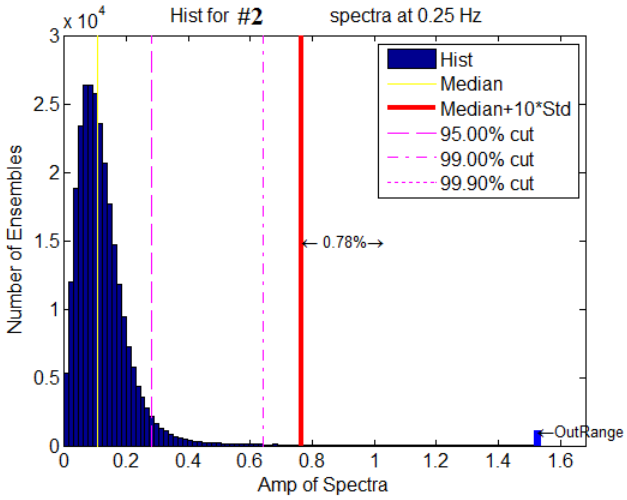


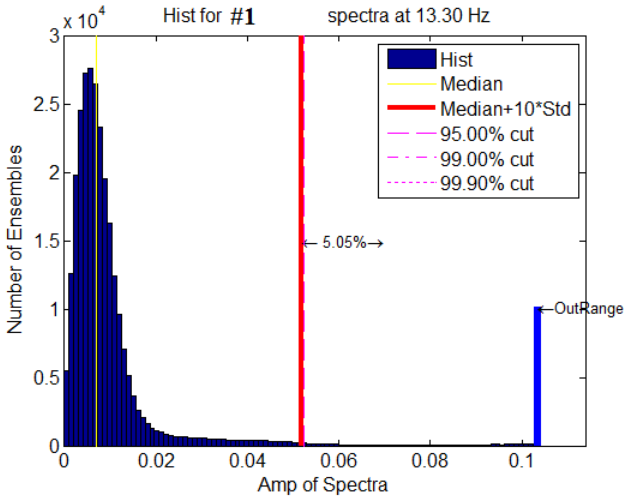


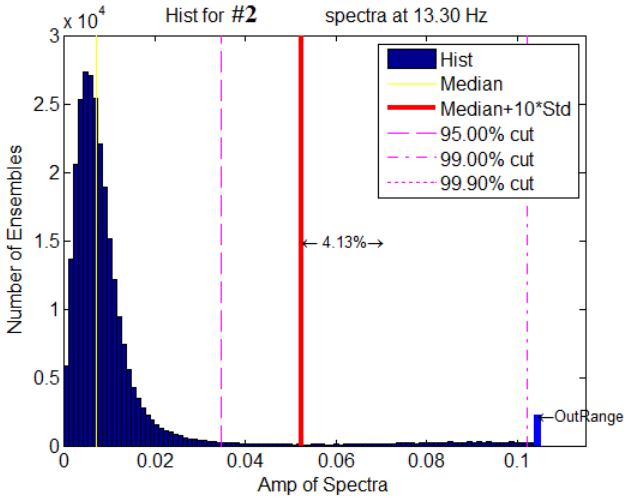
- **'Median' is more robust in measuring variability than 'mean'**
- **Most of energy of the PSD are concentrated below 2.0 Hz**

Histograms with Smooth Long Tails





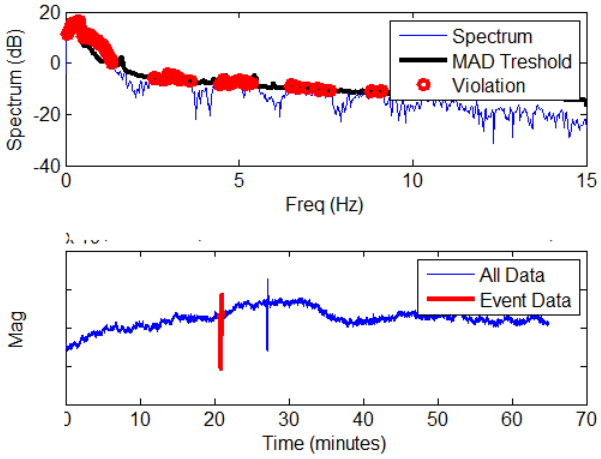




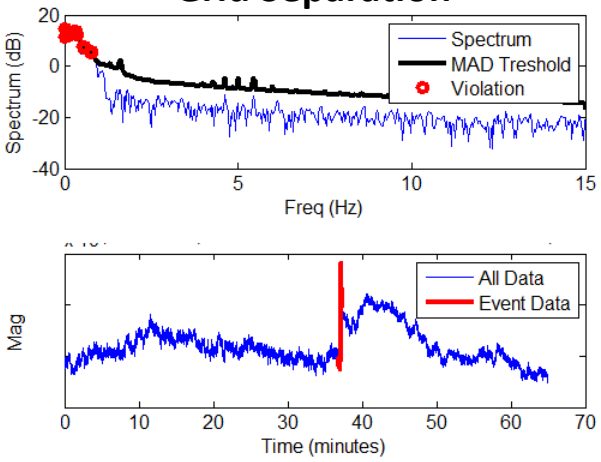
- **Gaussian distribution: 6*std => 99.9999998027%**

Detect Transient Events

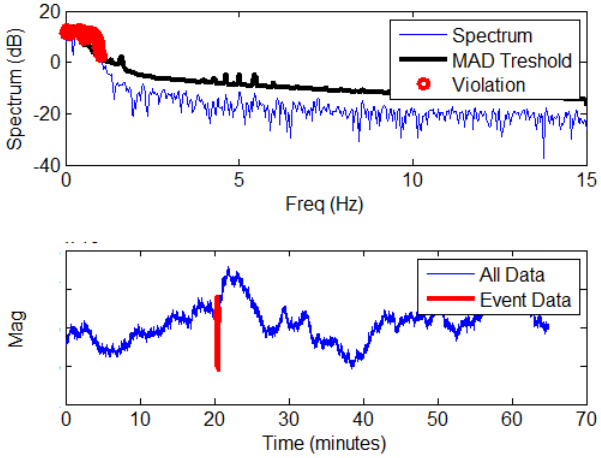
Brake Insertion



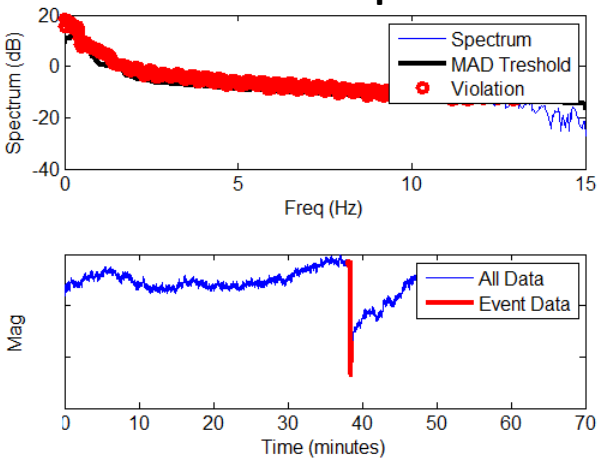
Grid Separation



Gen Loss



Gen Drop



Technical Accomplishments:

- RD&D stage: Modeling/Simulation (using real world data).
- Attended MT and UW training to improve understanding of SEM
- Met with Dr. Dmitry Kosterev (BPA) to clarify the needs
- Attended the WECC JSIS to get inputs from industrial experts
- A framework has been established to
  1. Extract PMU data from saved data file;
  2. Perform spectral analysis;
  3. Generate threshold curves;
  4. Detect dynamic events according to the threshold curves.

Planned Studies in FY 12

- Enhance the preprocessing function for outlier detection.
- Separate the different types of data so that spectral analysis parameters can be adjusted accordingly (For example, long windows for ambient; short window for transient).
- Add some additional factors (time of the day, work day/weekend, coherency, transfer functions) to help classify oscillations.
- Perform a cross-validation test to evaluate the performance.
- Explore methods for managing data.

Early thoughts on FY 13 studies

- Build a database for major transient events
- Evaluate and enhance feature extraction
- Develop a machine-learning based classification method
- Initial study on actionable rules
- Improve the efficiency of using spectral analysis

Technical Transfer

- Working with industrial experts in BPA to align the studies to the needs
- Working with professors in MT and UW to get input and advise in using SEM
- Use field measurement PMU data from BPA for evaluation and testing

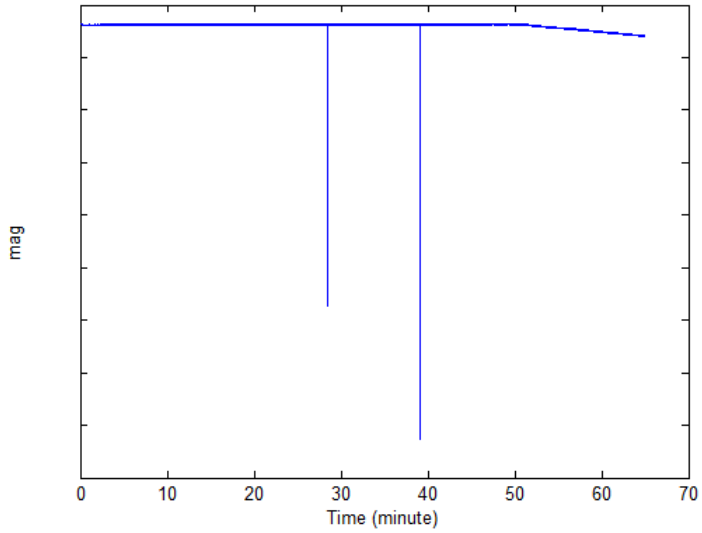
Questions?

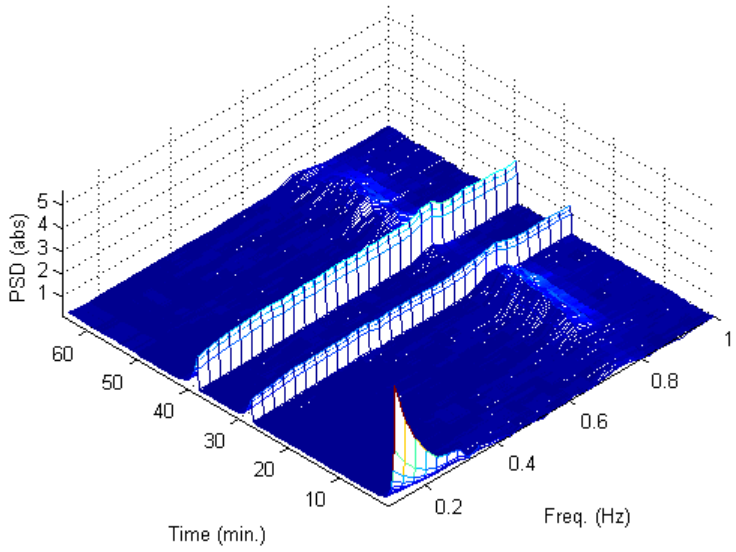
Spectral Baseline

- **Goal:** Build a threshold curve for spectra to detect unusual oscillations
- **Approaches:**
  - Identify and obtain one month of **real world PMU data** in *.dst format;
  - Identify **major events** in the data;
  - Select some sample **channels** which are known to be able to capture oscillations in the past;
  - **Parse** the PMU data into MATLAB format;
  - Convert the time domain data into **spectrum** (using SEM from MT and UW);
  - Build **a threshold curve** for the spectrum;
  - Design a method of detecting unusual oscillations using the **threshold curve;**
  - **Verify** whether the unusual oscillatory spectrum can be well separated from usual spectra.

Negative Impact of Outliers on a Spectrum

Data with Outliers





Outliers Detected and Patched