Spectral Analysis of Power Grid PMU Data

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Project Overview

- **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)
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
Technical Approaches:

**Spectral Analysis**

- Spectrum is chosen because it can reveal how total power is distributed over frequency.
Early Warnings based on PMU data

August 10, 1996 Western Power System Breakup
California-Oregon Intertie

Time Domain

Freq Domain

Power (MW)

Damping
~ 8.4%

< ~3.5%

Early Warning
~6 minutes

~ -3.1%
Technical Approaches:

Spectral Baseline

Goal: Build a threshold curve for spectra to detect unusual oscillations
Technical Approaches:
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
Most of data are ambient data

Transient data carry significantly larger amount of energy in lower frequency range
Technical Approaches:

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
Technical Approaches:

Histograms with Smooth Long Tails

Gaussian distribution: $6 \times \text{std} \Rightarrow 99.9999998027\%$
Technical Approaches:
Detect Transient Events

**Brake Insertion**
- Spectrum
- MAD Threshold
- Violation

**Grid Separation**
- Spectrum
- MAD Threshold
- Violation

**Gen Loss**
- Spectrum
- MAD Threshold
- Violation

**Gen Drop**
- Spectrum
- MAD Threshold
- Violation
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.
Deliverables and schedule under FY 12 funding

Planned Studies in FY 12

 Enrique

- 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?
- **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.
Technical Approaches:

Negative Impact of Outliers on a Spectrum

Data with Outliers

Outliers Detected and Patched