Oscillation Use Cases

NASPI Meeting
Orlando, FL

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Feb. 29 – Mar. 1, 2012
Overview

• Engineering Applications
  – Analysis tools - what information they provide?
  – Baselining: What is normal?
    • WECC Probing tests
  – PMU Requirements

• Operations scenarios
  – For each scenario, what will the tools tell you?
    What actions need to take place?
    1. Lightly-damped disturbance
    2. Forced oscillation near a system mode
    2. Ambient during light damping
Dynamic Response Types

- Ambient
- Transient
- Forced Oscillation

Unknown input noise (random load variations)
Rogue inputs (e.g., limit cycle)
Network switching
Unknown Dynamics

$G$
Power System

$y(t)$
Output

$\mu(t)$
Measurement Noise

System Mode
Algorithm Classes

- **Oscillation Detector (OD):** Estimates RMS Energy in specified frequency band.
  - Very fast
  - Very robust
  - Operations and Engineering tool
- **Mode Meter (MM):** Estimates a mode’s frequency, damping, and shape. (E.g., MEYW, R3LS, FDD, MEYW-F, RML, etc. [1]).
  - Requires minutes of data under ambient data
  - Requires seconds of data under transient
  - Robust
  - Operations and Engineering
- **Spectral Estimator (SE):** Estimate the spectra of a signal. FFT averaging or single-window FFT
  - Requires minutes of data for averaged spectra
  - Requires sec. of data for single window fft
  - Very robust
  - Operations and Engineering (Lots of data management and visualization)
- **Ringdown Estimator (RE):** Estimates a mode’s frequency, damping, and shape. (E.g., Prony, Matrix Pencil, ERA, etc. [1]).
  - Only works on transient data, requires seconds of data.
  - Not robust. Easy to fool (e.g., multiple switchings)
  - Engineering

- Best applied to generator output and intertie MW signals, and key voltage signals.
Mode Meter (MM)

- **Mode Estimation** = Use MEYW and R3LS algorithms with unique window.
- **Results Selection** = Expert system to select best mode estimate.
Spectral Estimation (SE)

- Each Spectral Estimation block uses unique settings.
- For example, single fft window versus several averaged windows.
Baselining
Knowledge Base for Decisions

- What are the normal system modes and their typical damping, frequencies, and shapes?
- What is the “ambient” RMS energy and Spectrum in the system?
- How do the modes, RMS energy, and spectra change with system operating conditions?
- How often do forced oscillations occur and what are their typical RMS energy and spectra signatures?
- What are the critical oscillatory contingencies?
- WECC:
  - PDCI modulation and Chief Jo brake tests
  - Conducted on a regular basis
WECC

0.25-Hz NS Mode

0.4-Hz Alberta Mode

Alberta Mode


WECC
PMU Requirements

• 30 sps min. class M PMUs for electromechanical dynamics. 60 sps for controls.
• Cannot filter data prior to analysis!
• Cannot down-sample data prior to analysis!
• Beware of phase wrapping.
• WISP software MT Tech is developing REQUIRES raw voltage and current phasors as measured at the PMU.
Operational Decisions

• Oscillation vs. Ambient

• Ambient
  – Mode damping is primary indicator of problem (MM)
  – Mode shape provides information on which line flows need reduction (MM)

• Oscillation
  – Must first determine if oscillation is a system mode or a forced mode.
    – Forced:
      • RMS Energy is first indicator and will point toward rogue input (OD)
      • Harmonics often occur (SE)
      • Mode shape does not fit base line
    – System
      • RMS Energy wide-spread and fits baseline (OD)
      • Mode Shape provides information on which line flows need reduction (MM)
      • No harmonics (SE)
Case 1: Transient with Poorly-Damped or Growing Wide-Area Oscillation

- Immediately, OD monitors will alarm for several signals throughout system indicating a wide-area event.
- MM will alarm within 1 min. indicating poor damping and mode shape.
- If oscillation is sustained, SE will show frequencies of oscillation within 1 min. or less. NOTE: It may be a Forced Oscillation if
  - Spectra is harmonic
  - Detected mode frequencies not near baseline
  - MM shape is not close to baseline
- Technical staff can use mode shape to adjust line flows.
Case 1 Example

- WECC simulation
- Conditions
  - Pre-fault Alberta mode at 8% damping
  - Post fault damping less than 1%. 
Case 1 Example: OD

Observations

- OD immediately indicates widespread oscillation in the 0.15 Hz to 1.0 Hz range matching a system mode baseline.
- Oscillation is damped but it takes several minutes of OD to determine this.
Case 1 Example: MM

Observations

• Within one minute, MM indicates frequency, damping, and shape of oscillation.
• It is a VERY LOW damped mode.
• Shape matches “Alberta” mode.
Observations

- Oscillation has no harmonics, therefore likely NOT a forced oscillation.
Case 2: Forced Oscillation

• OD will alarm near location of forced oscillation. Location of rogue controller will have largest RMS Energy. The extent of the alarms will indicate oscillation propagation.

• If oscillation is near system mode, MM will alarm; but, mode shape will not be as normal. This will give indication to technical staff that it is a forced oscillation.

• Comparison of averaged and single-window fft will show indications of forced oscillation. E.g., harmonics.
Case 2 Example: Forced Oscillation Simulation

- WECC simulation
- Conditions
  - 1 MW limit cycle on Gen. 18 (near San Francisco) at 0.2 Hz (NS mode at 0.218 Hz).
  - This is a relatively small forced oscillation very near a system mode causing resonance.
  - Worst-case scenario for forced oscillation.
Case 2 Example: ODM

Observation

- OD dominated by 0.15 Hz to 1.0 Hz range.
- OD dominated by one generator site indicating a forced oscillation.
Case 2 Example: MM

Observations

- MM drifts to low damping.
- Shape does not match any baseline system mode. All generators in phase indicating a forced oscillation.
- Coherency also indicates a forced oscillation (Mid-Cal has low coherency).
Observations

- Spectrums show harmonics indicating a forced oscillation.
Case 3: Low Damping Under Ambient Condition

- OD will not alarm as an oscillation is not yet taking place.
- MM will alarm indicating the modes that are poorly damped. Technical staff can use mode shape to adjust line flows.
- SE
  - Averaged will show a sharper peak during low damping.
  - FFT will show no significant peaks as system is in ambient condition.
Case 3 Example

- WECC actual condition
- Alberta disconnected
- Light damping observed.
- No disturbances.
Case 3 Example: OD

Observations
- OD shows low RMS energy indicating no current oscillations.
Case 3 Example: MM

**Observations**
- MM shows 2 sections of low damping.
- Shape is only for BPA; need wider coverage.
Case 3 Example: SE

Observations

- Averaged SE shows sharp peak indicating low damping.
- No major peaks in FFT indicating it is not a forced oscillation or transient.
Conclusions

• Tools:
  – **OD** very fast, simple, and very robust.
  – **MM** more complex and robust.
  – **SE** more complex and very robust. Data intensive.
  – **RE** more complex, not robust. More of an engineering tool.

• Operational Decisions
  – Ambient vs. Oscillation
  – System mode vs. Forced oscillation
  – System
    • Mode Shape provides key decision information
  – Forced
    • RMS energy and mode shape provide key decision information

• Continual Base-lining critical to the successful application of tools.