MontanaTech
THE UNIVERSITY OF MONTANA

Oscillation Use Cases

NASPI Meeting

Orlando, FL

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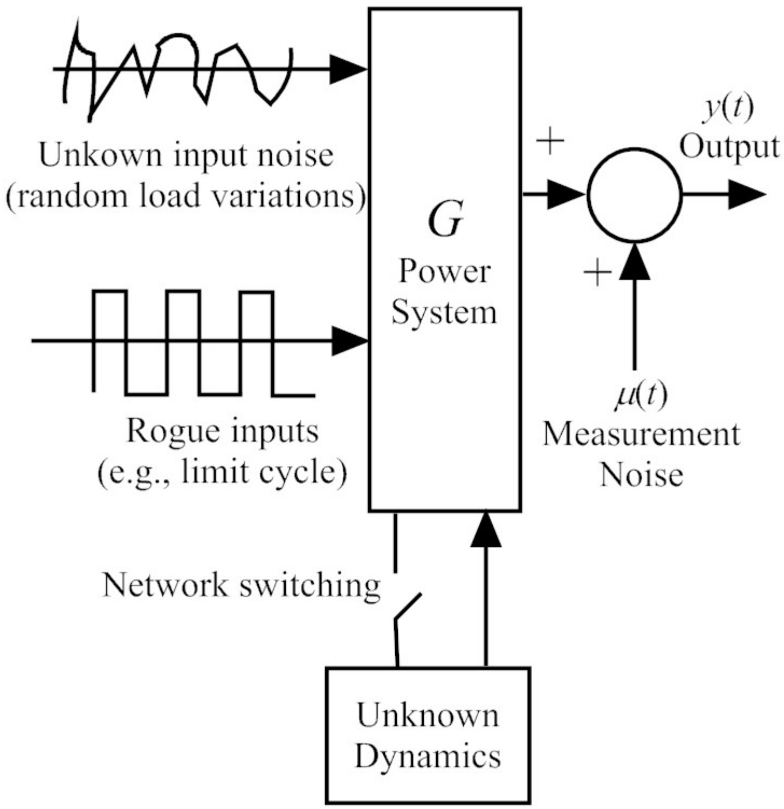
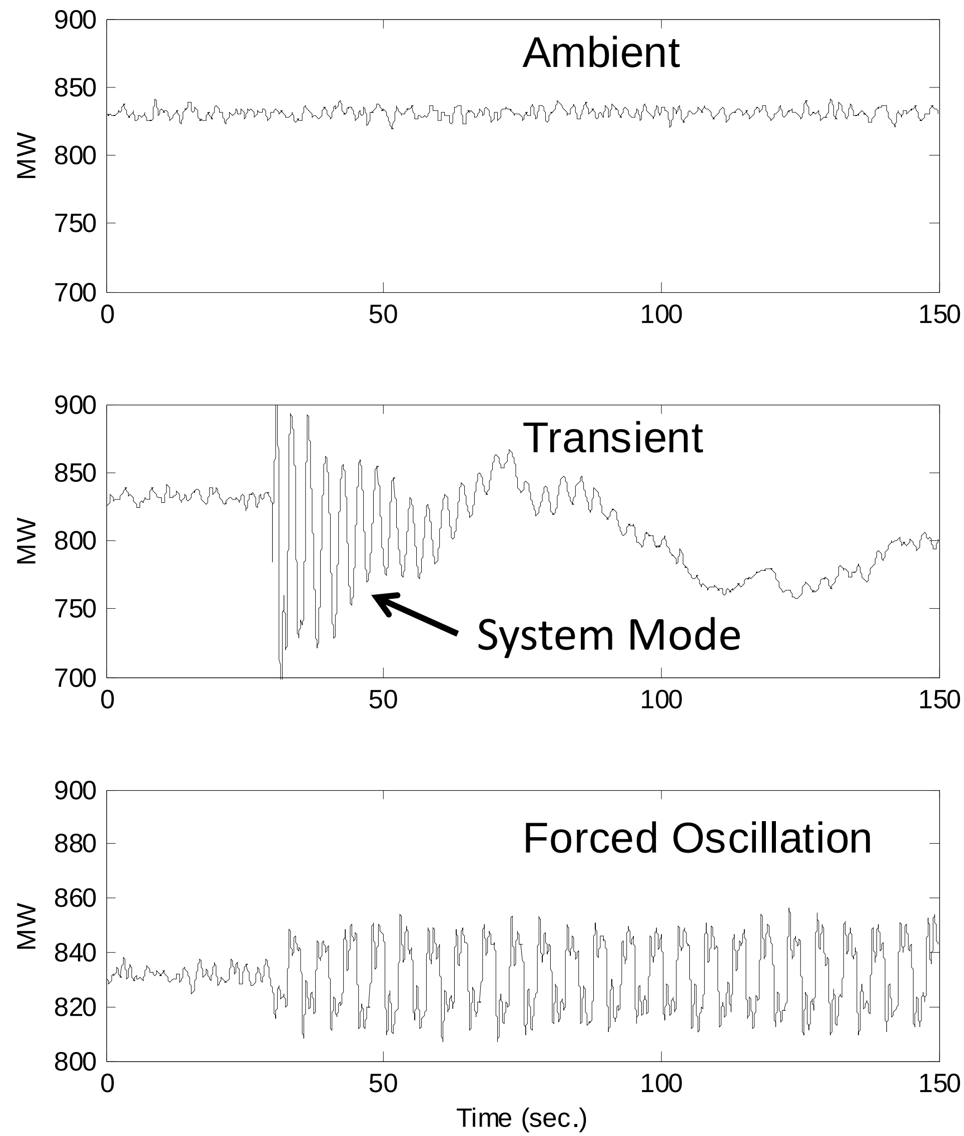
Feb. 29 – Mar. 1, 2012

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



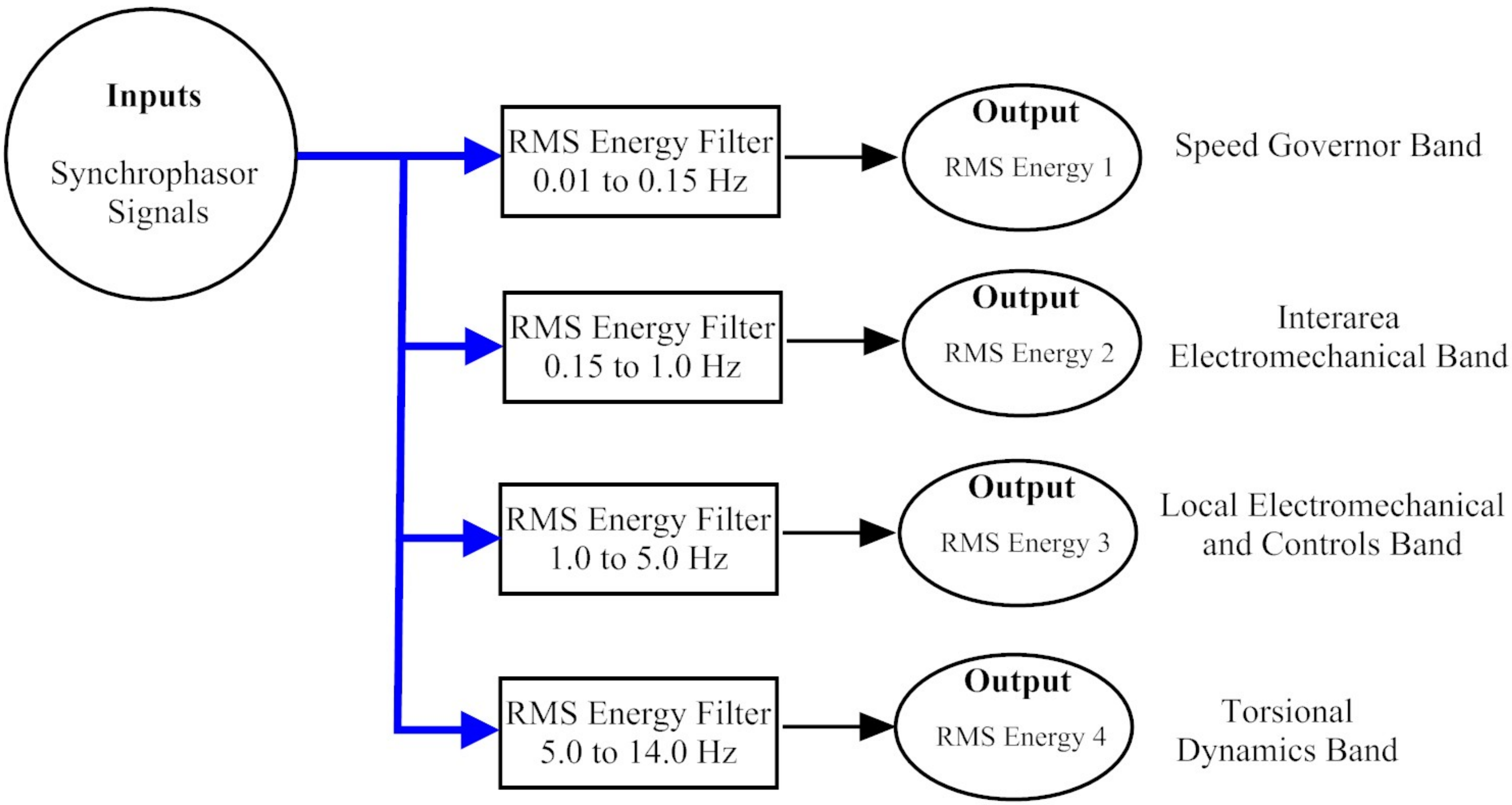


Algorithm Classes

- 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

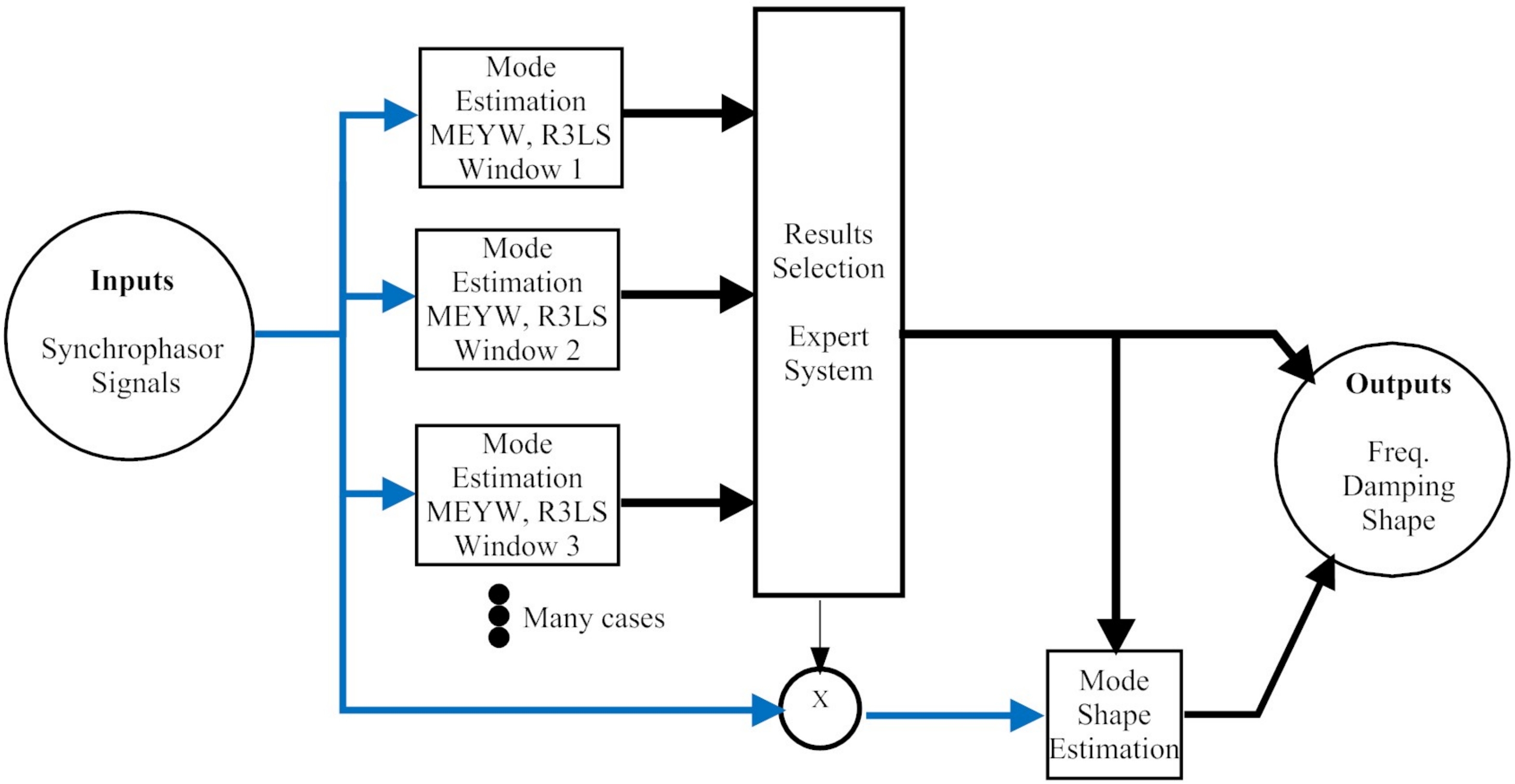
[1] IEEE/PES Task Force on Electromechanical Mode Estimation

Oscillation Detection (OD)



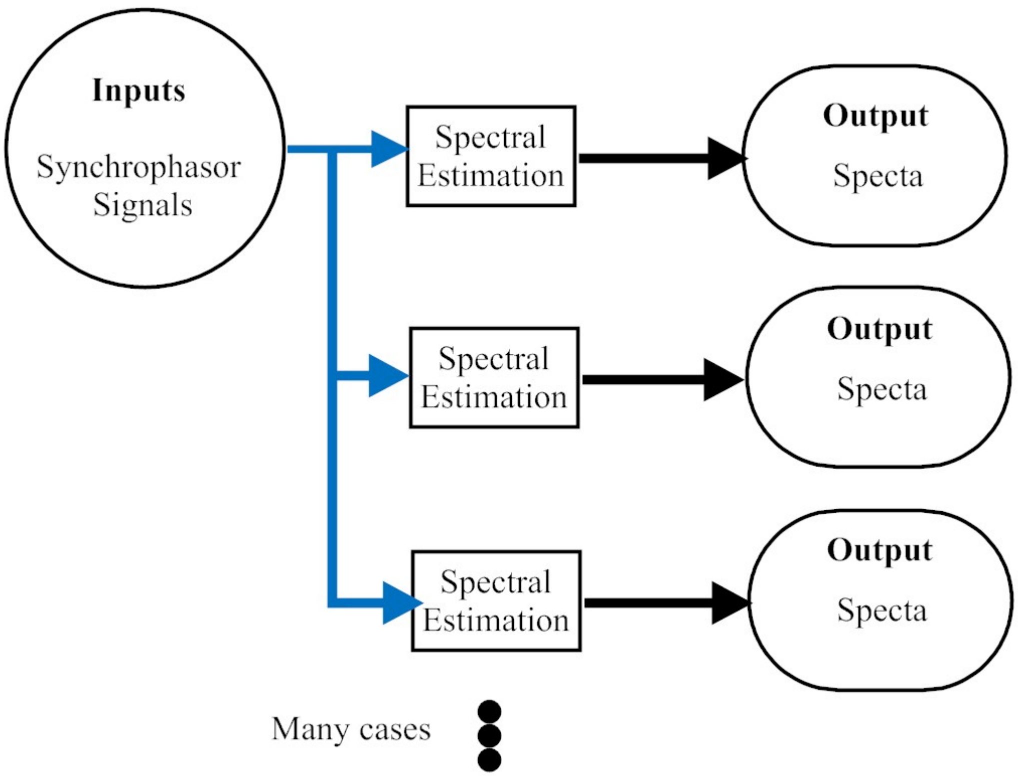
- Best applied to generator output and intertie MW signals, and key voltage signals.

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.

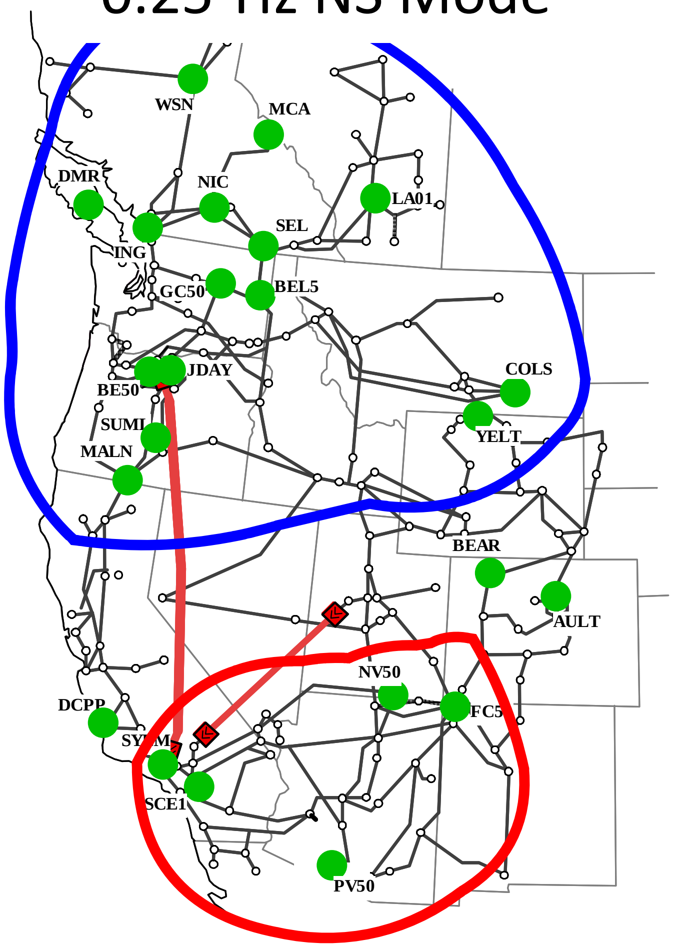
Baselining

Knowledge Base for Decisions

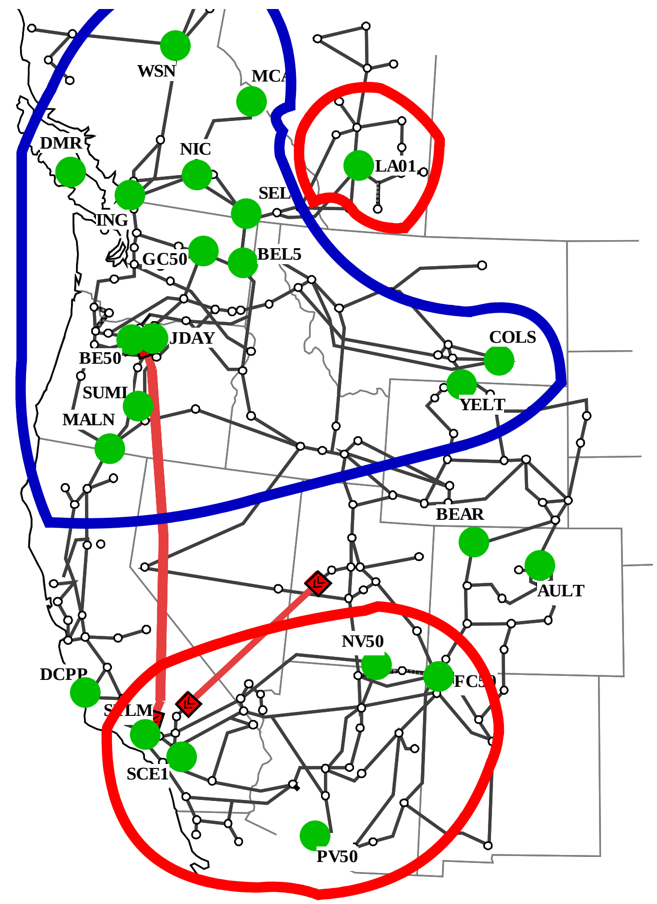
- What are the normal system modes and their typical damping, frequencies, and shapes?
- What is the "ambient" RMS energy and Spectrum in the system?
- How do the modes, RMS energy, and spectra change with system operating conditions?
- How often do forced oscillations occur and what are their typical 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



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)

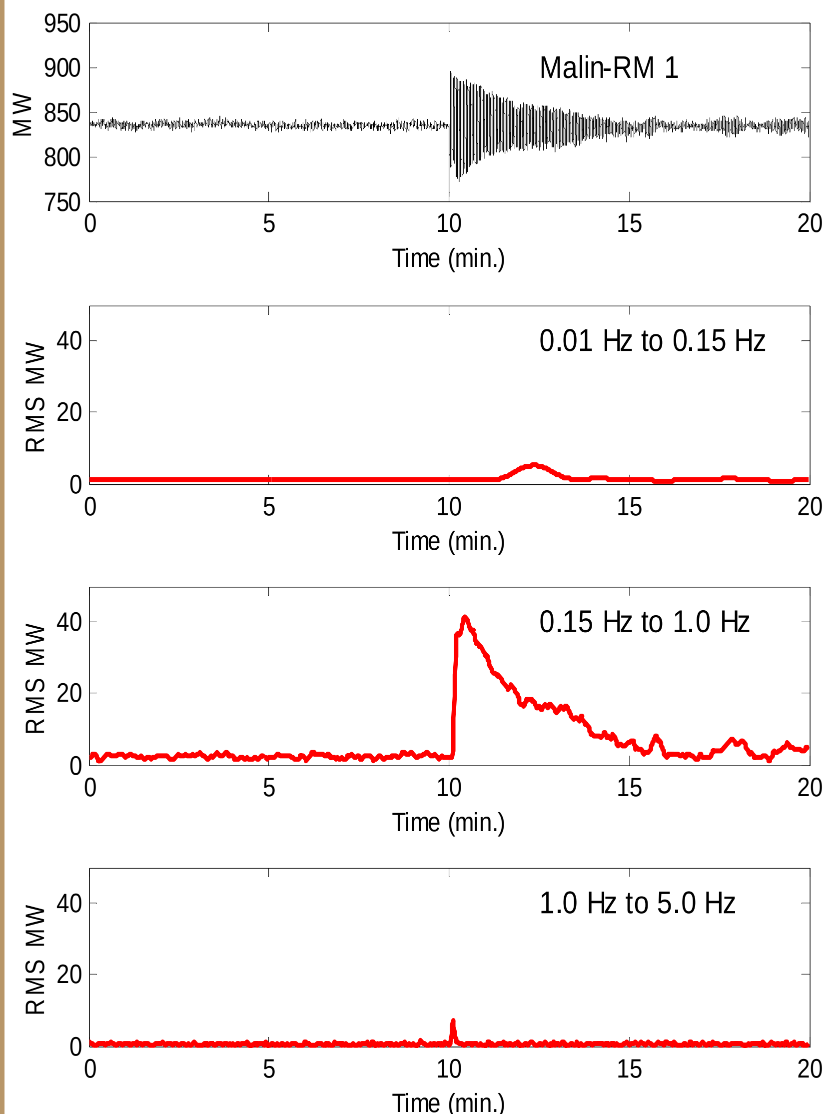
Case 1: Transient with Poorly-Damped or Growing Wide-Area Oscillation

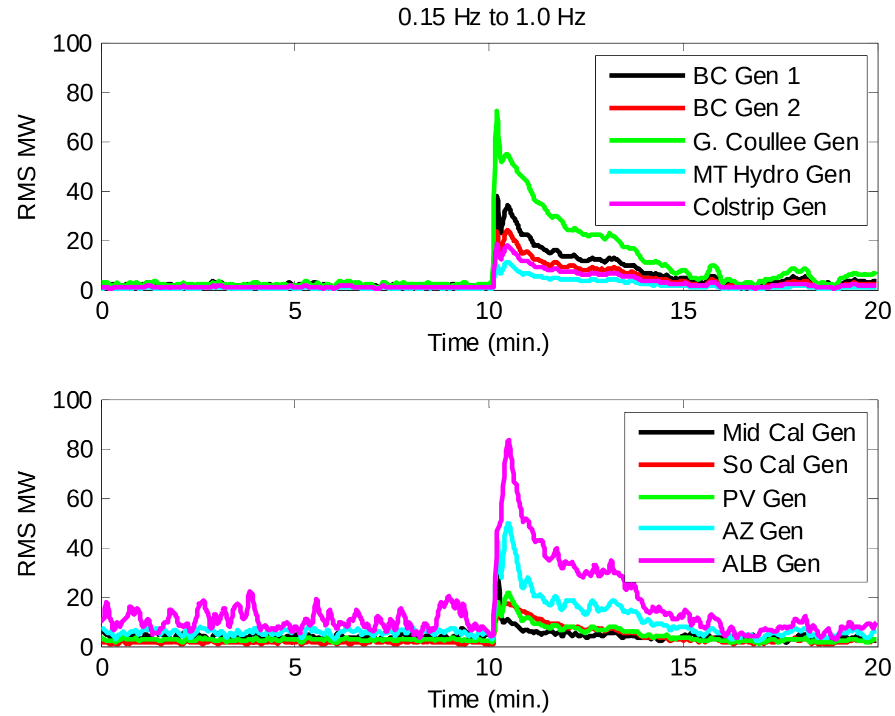
- Immediately, OD monitors will alarm for several signals throughout system indicating a wide-area event.
- MM will alarm within 1 min. indicating poor damping and mode shape.
- If oscillation is sustained, SE will show frequencies of oscillation within 1 min. or less. NOTE: It may be a Forced Oscillation 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

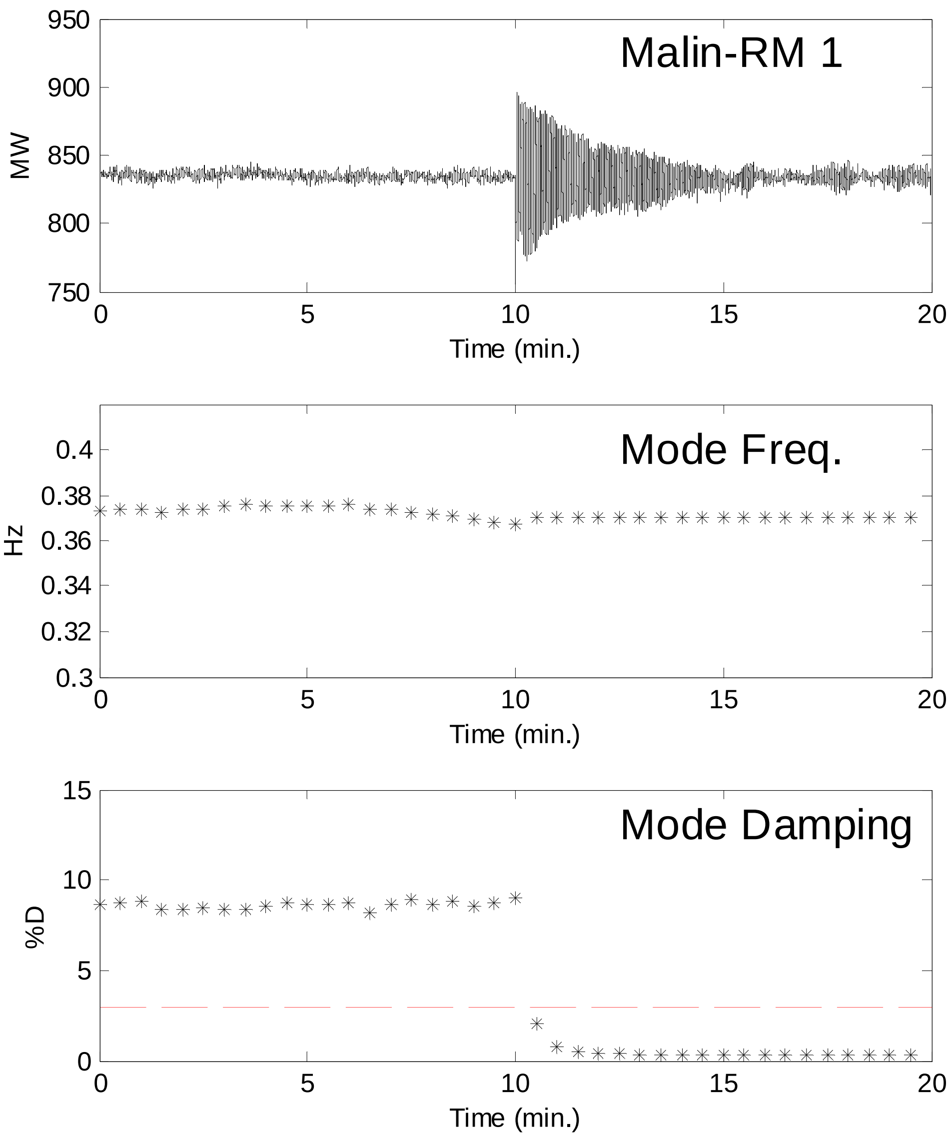


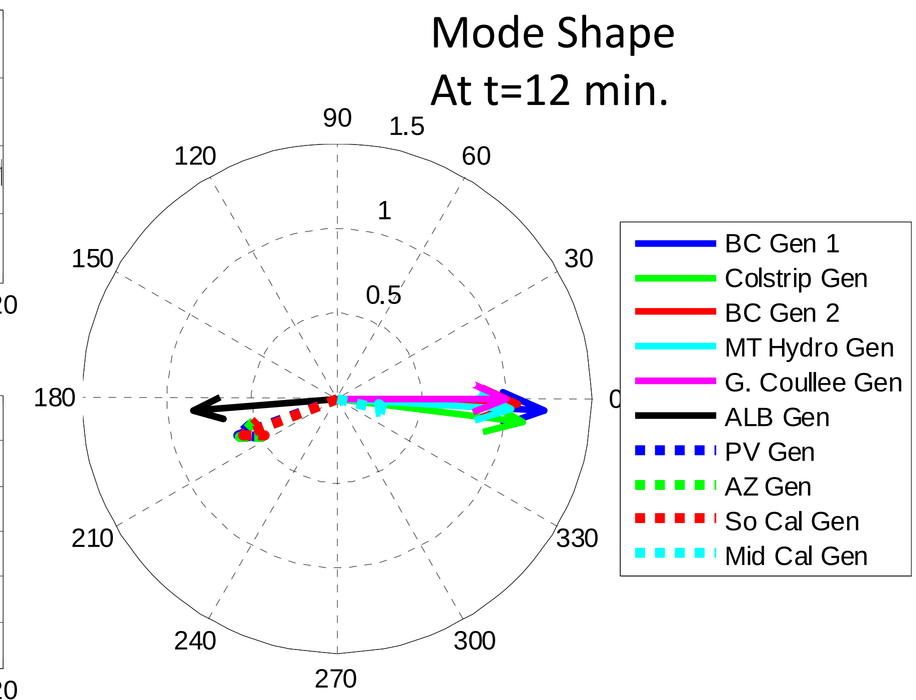


Observations

- OD immediately indicates wide-spread 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

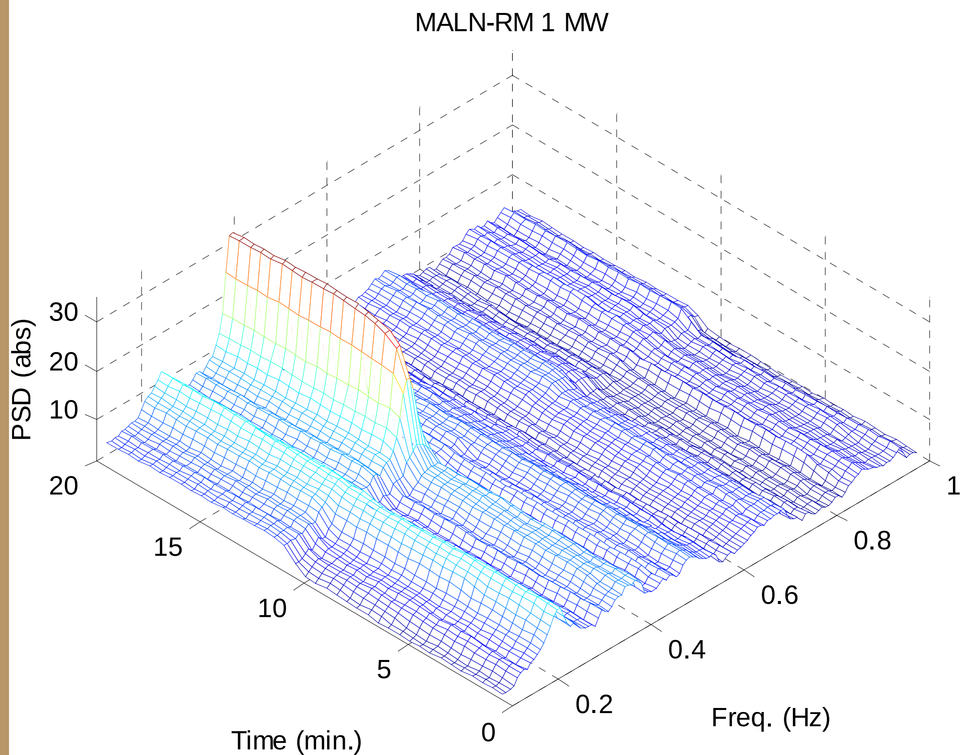


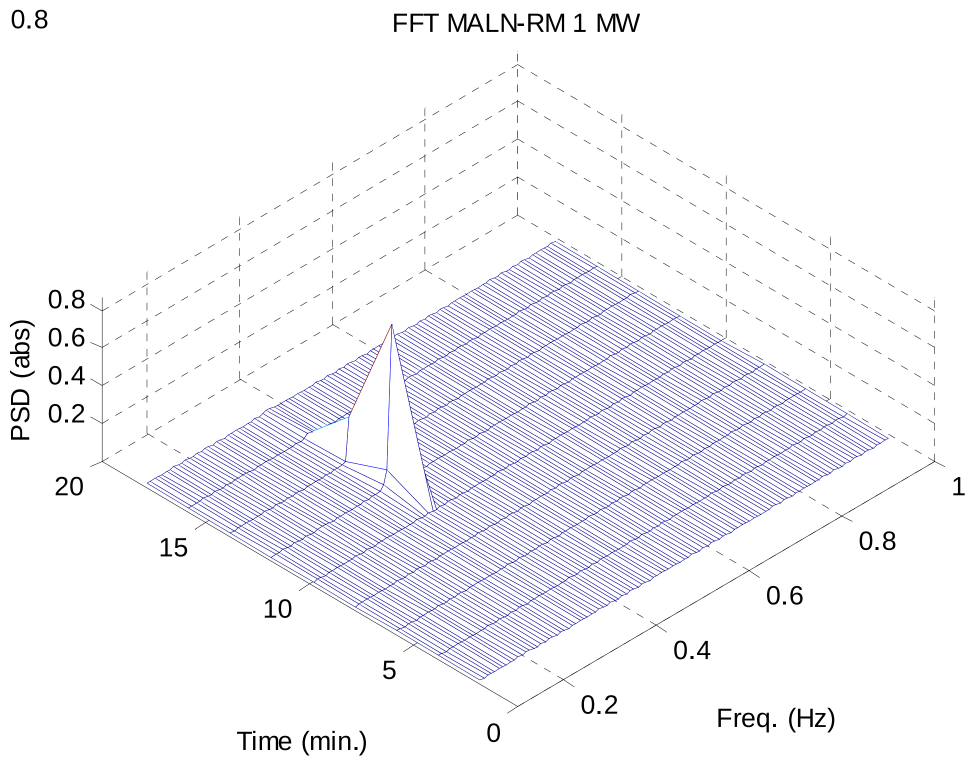


Observations

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

Case 1 Example: SE





Observations

- Oscillation has no harmonics, therefore likely NOT a forced oscillation.

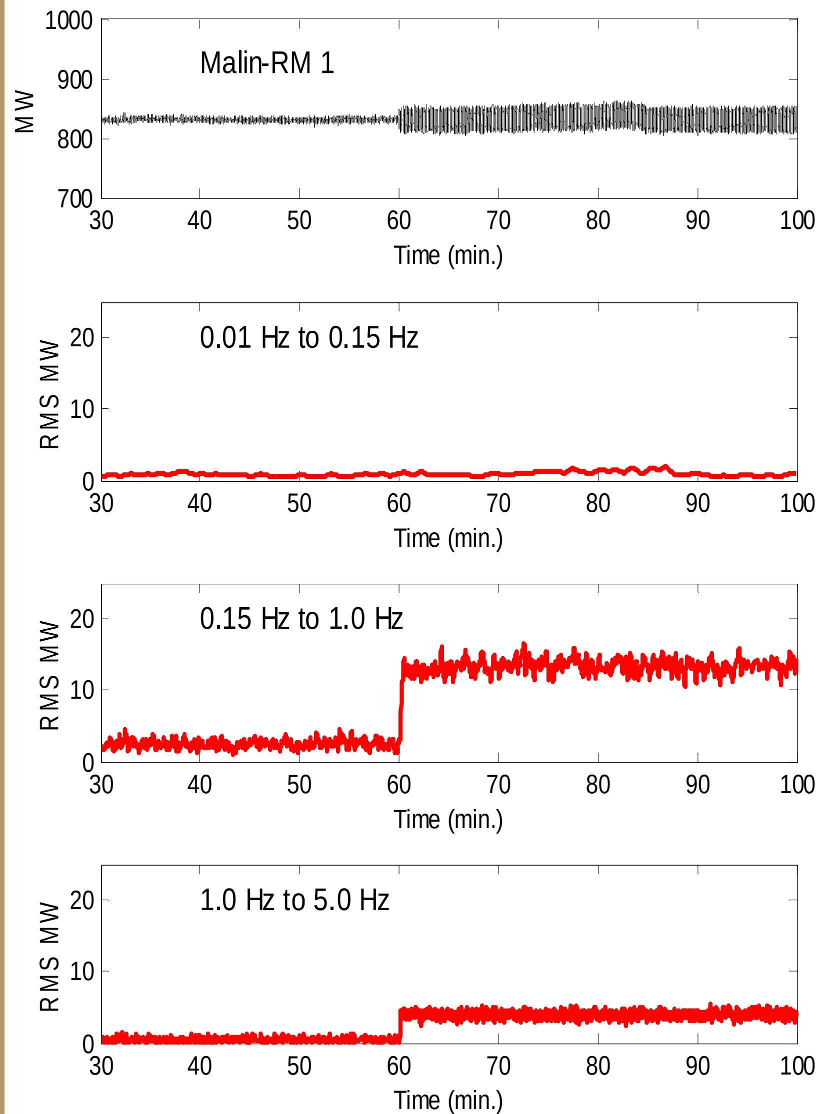
Case 2: Forced Oscillation

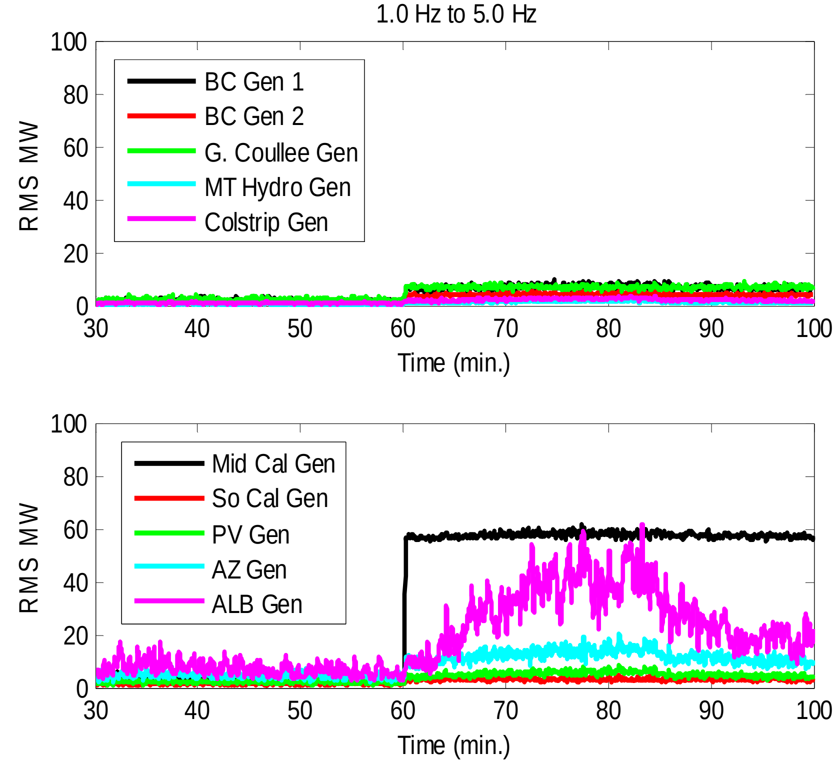
- OD will alarm near location of forced oscillation. Location of rogue controller will have largest RMS Energy. The extent of the alarms will indicate oscillation propagation.
- If oscillation is near system mode, MM will alarm; but, mode shape will not be as normal. This will give indication to technical 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

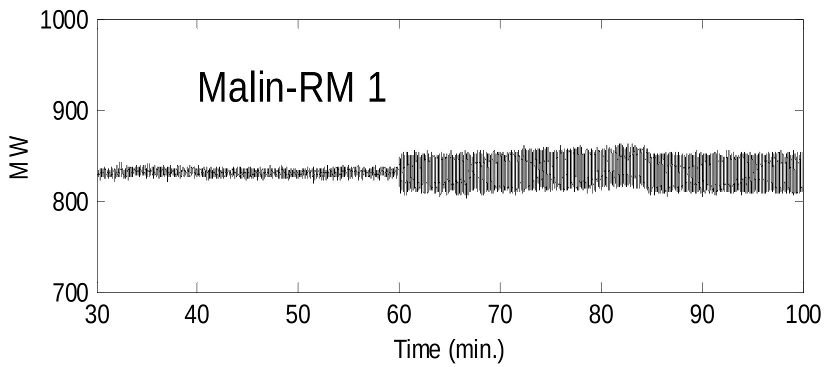


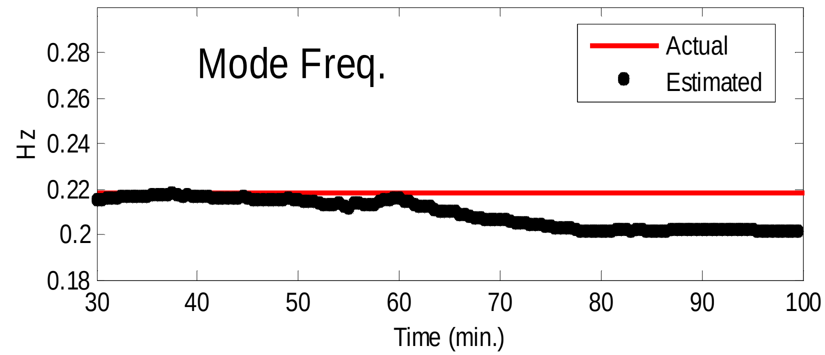


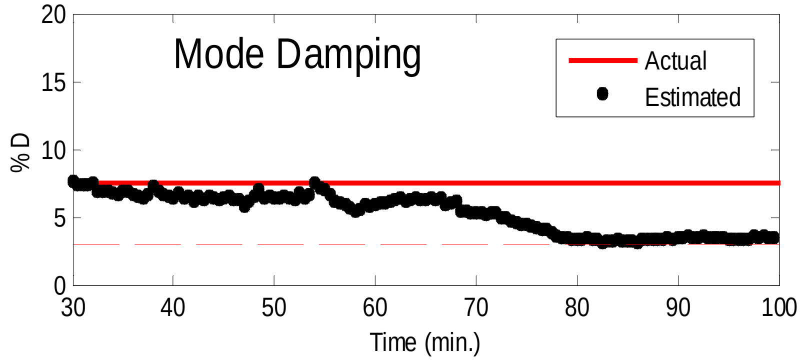
Observation

- OD dominated by 0.15 Hz to 1.0 Hz range.
- OD dominated by one generator site indicating a forced oscillation.

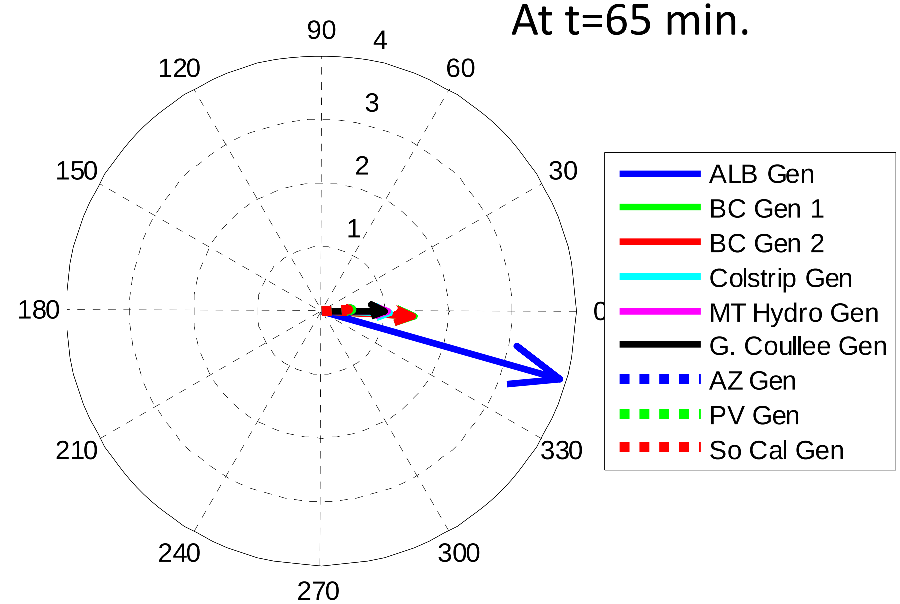
Case 2 Example: MM







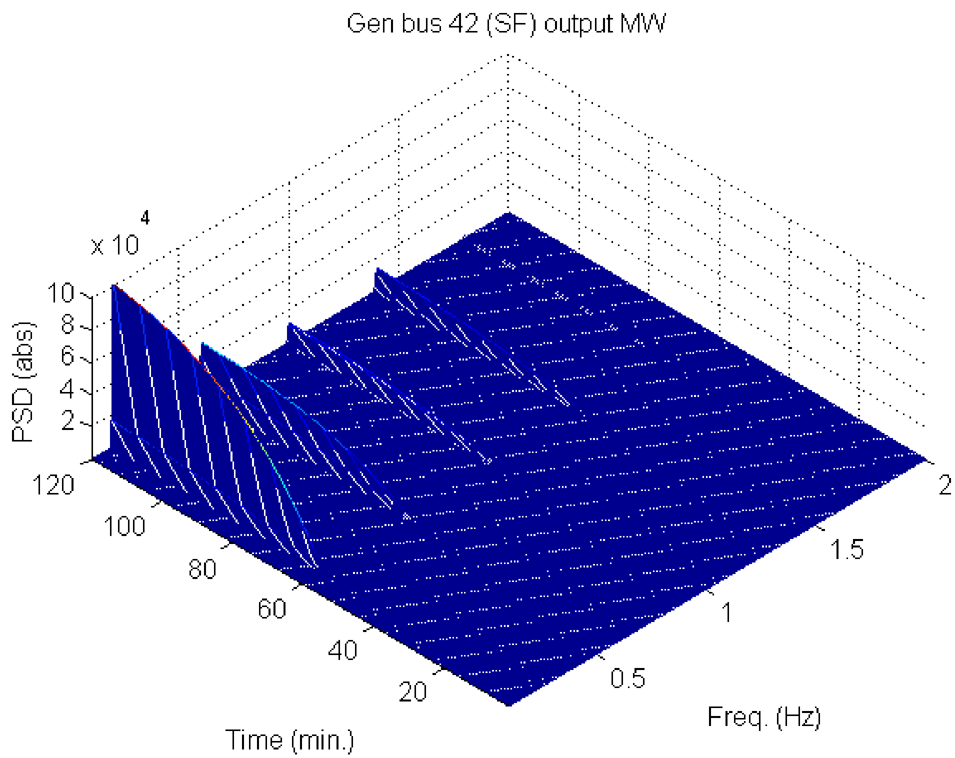
Mode Shape
At t=65 min.

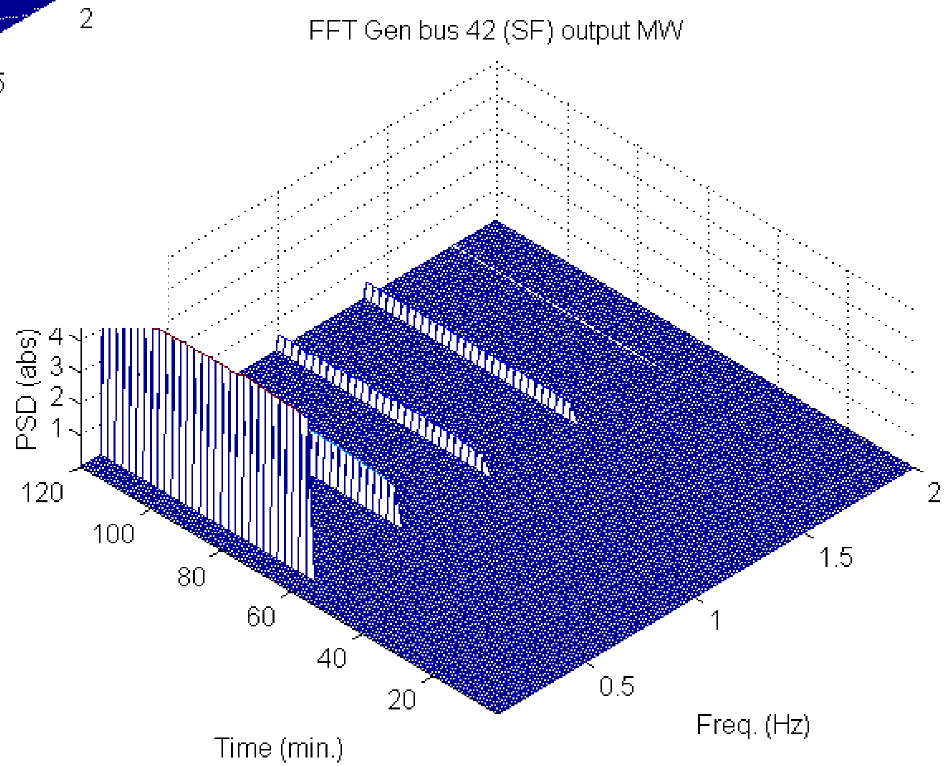


Observations

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

Case 2 Example: SE





Observations

- Spectrums show harmonics indicating a forced oscillation.

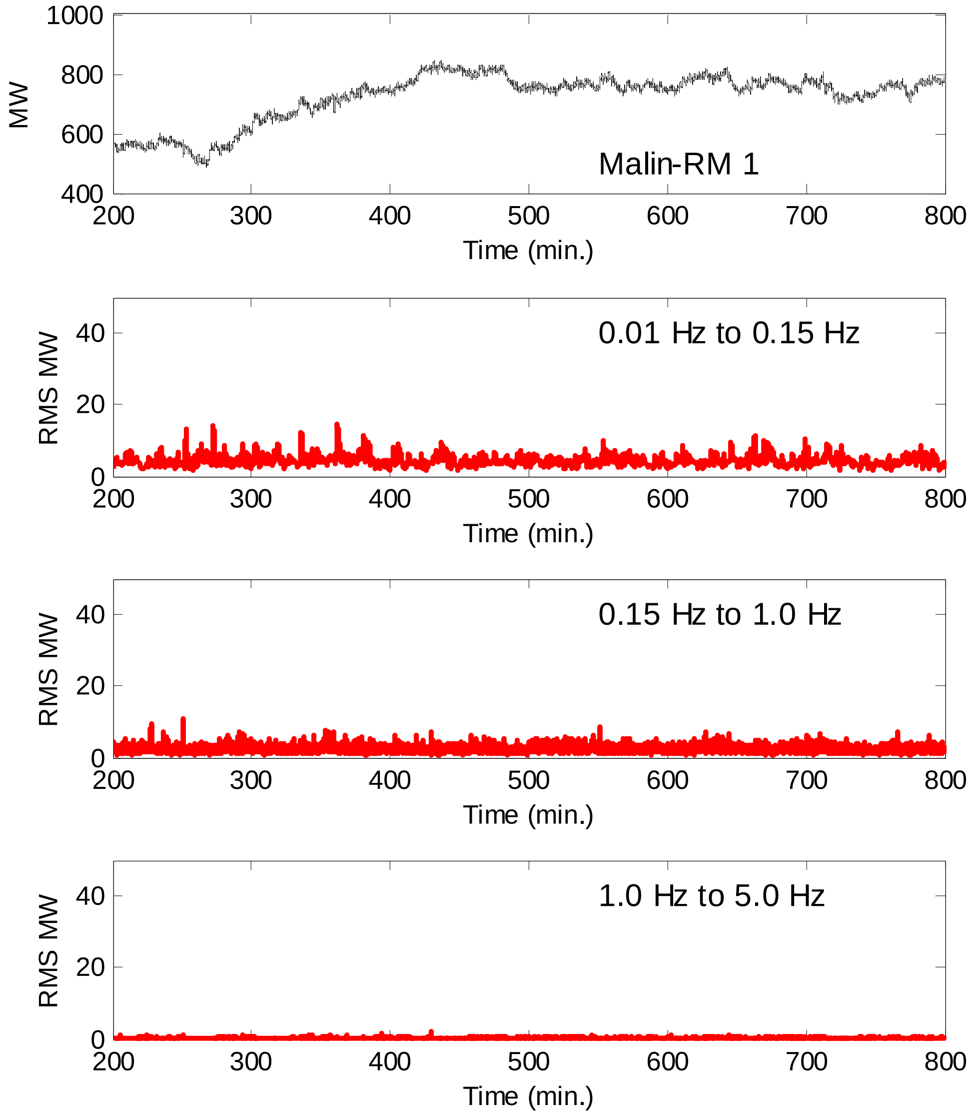
Case 3: Low Damping Under Ambient Condition

- 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.

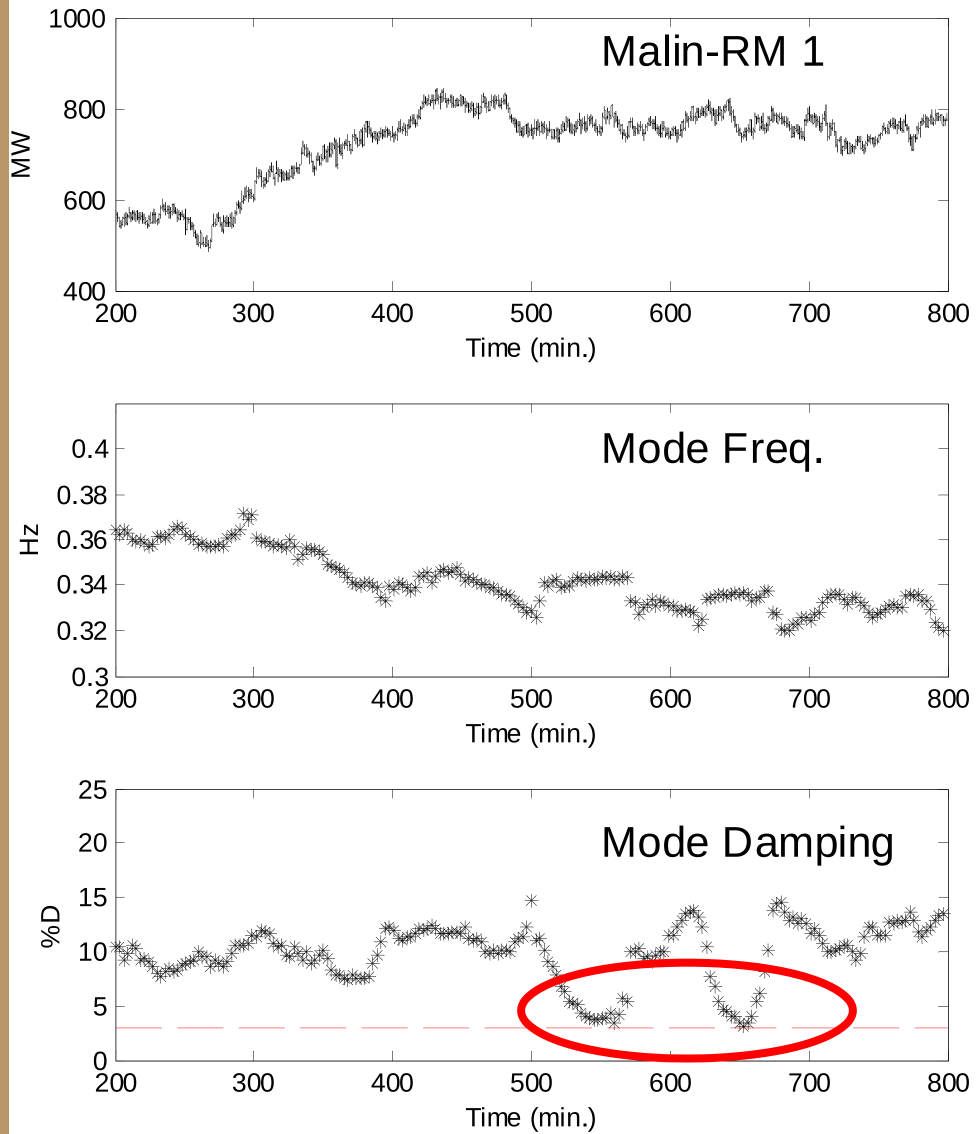
Case 3 Example: OD

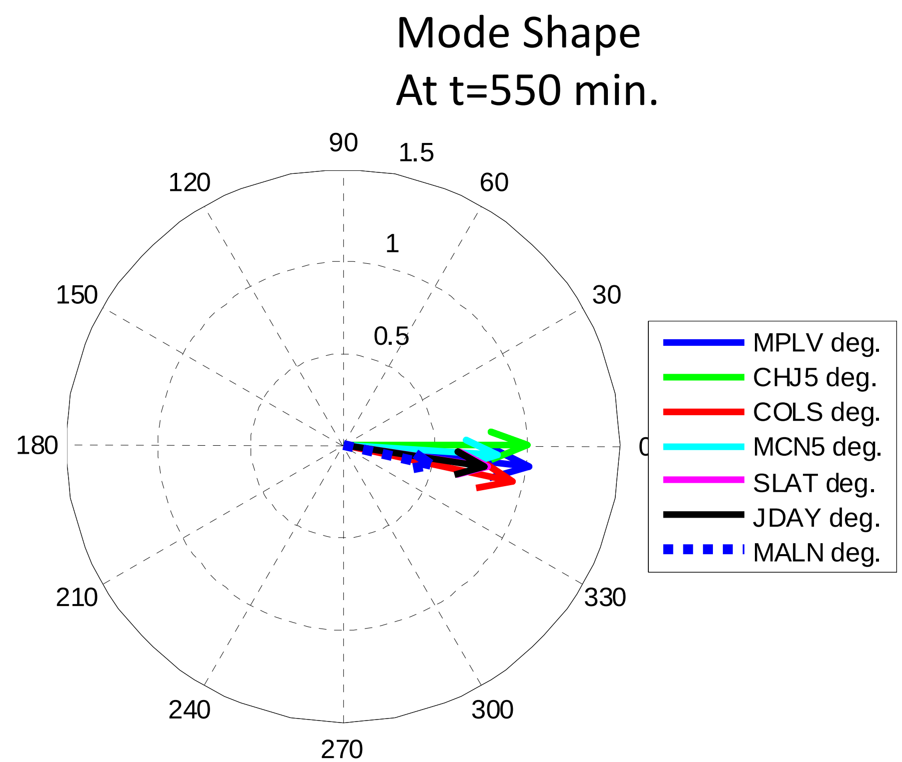


Observations

- OD shows low RMS energy indicating no current oscillations.

Case 3 Example: MM

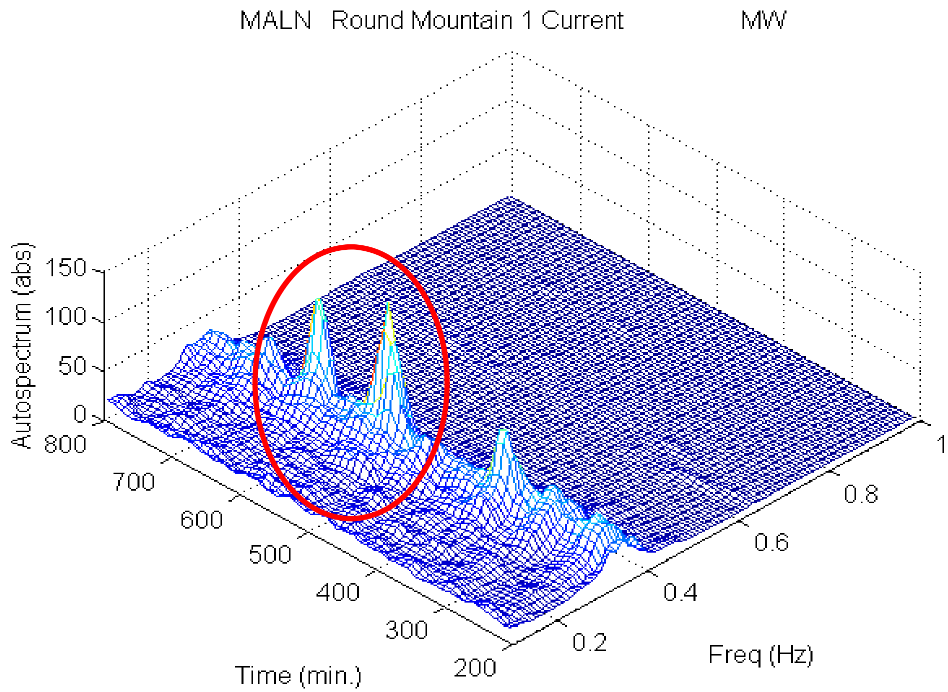


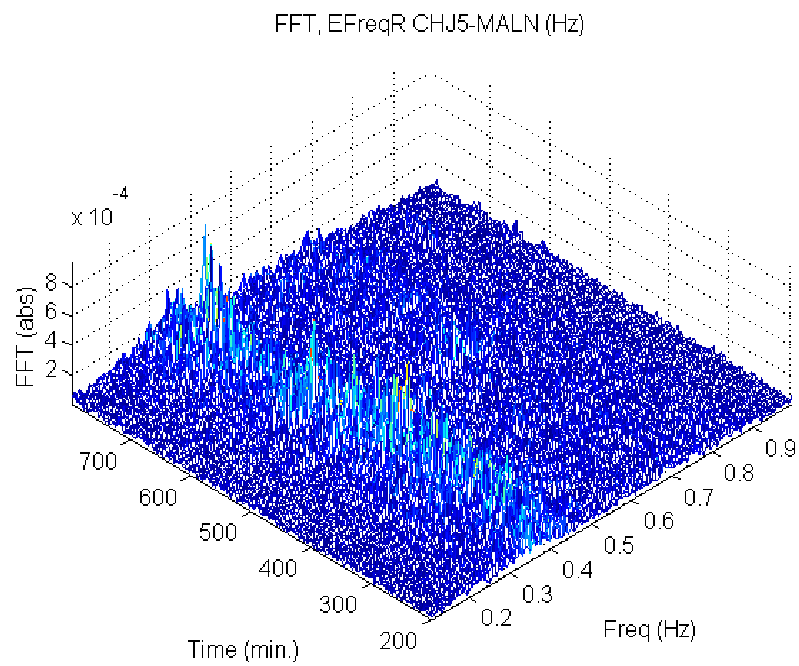


Observations

- 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.