California ISO

Impacts of Forced Oscillations on Power Systems

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Outline

- Power systems oscillations – Overview
- Forced oscillations – Types
- Forced Oscillations – Examples
- Forced Oscillations – Impacts
  - Examples of Wide-area Forced Oscillations
- Discussion and Conclusion

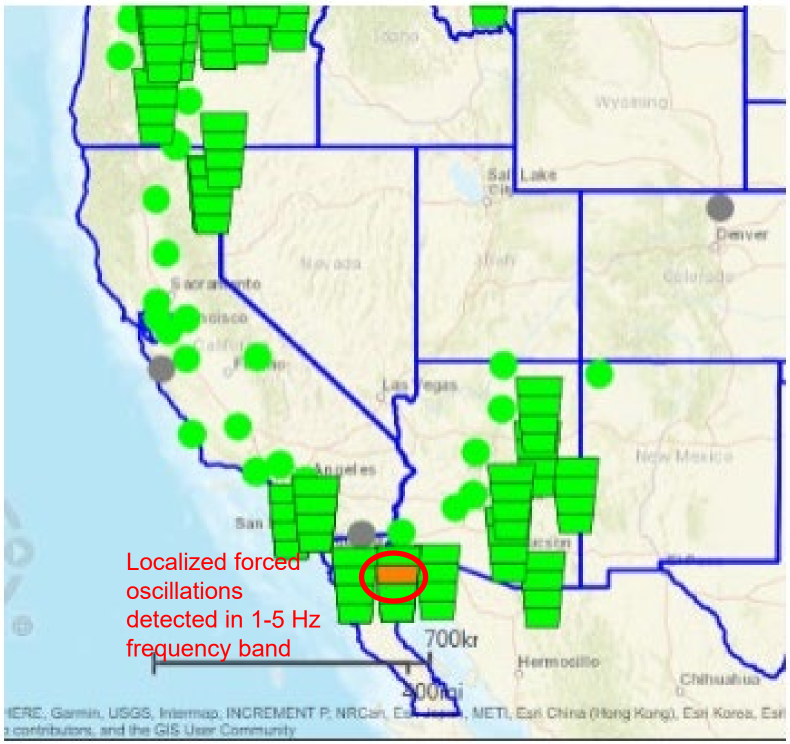
Power Systems Oscillations - Overview

- Understanding power systems oscillations is important for maintaining secure and reliable power systems operations
- Depending on the type of disturbance, power systems oscillation can be categorized into two types:
  - Natural oscillations: System's natural response to transient event and small-signal random disturbances
    - Determined by the frequency and damping ratio of system modes and a function of overall system dynamics
  - Forced oscillations: System's response to forced periodic disturbance, such as cyclic load and malfunctioning control valve.
    - Forced response of the system given by the transfer function of the system from the input location to the measurement location
    - Determined by the frequency of the forced input

Forced Oscillations - Types

- Depending on their frequencies, forced oscillations can be categorized into two types
  - Localized forced oscillations: Frequency of forced input above the frequency range of inter-area modes
    - Due to the inductive nature of power systems, these forced oscillations do not propagate over wide-area
  - Wide-area forced oscillations: Frequency of forced input is in the frequency range of inter-area modes
    - Forced oscillations observed across wide-area
    - Amplitude of forced oscillations can be high depending on the damping ratio of the system mode that has frequency close to the forced oscillations' frequency
    - **Severe case ("near-resonance"):** When frequency of forced oscillations closely matches with a system mode having low damping ratio

Forced Oscillations - Examples



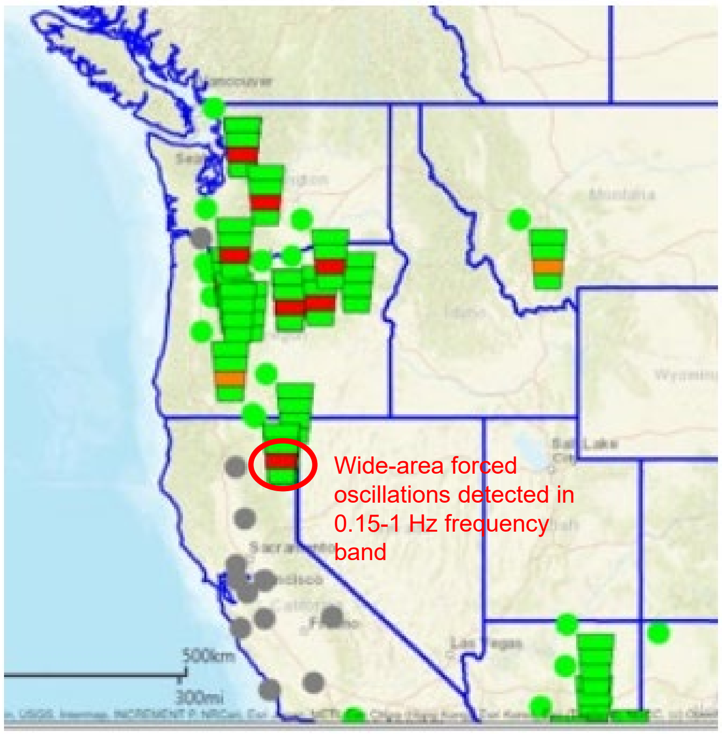


Figure: Example of localized forced oscillations (left) and wide-area forced oscillations (right).

Forced Oscillations – Impacts on Power Systems

Forced Oscillations – Potential Impacts on Power Systems (1)

- Equipment failure
- Inadvertent control actions
- Thermal problems
- AGC problems
- Inadvertent trippings

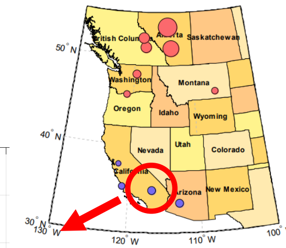
Forced Oscillations – Potential Impacts on Power Systems (2)

- Severe impact of forced oscillations likely to occur during “near-resonance” condition[1]
  - Condition 1: Frequency of forced oscillations closely matches with the frequency of a system-mode
  - Condition 2: Damping ratio of that system mode is low
  - Condition 3: The source of the forced oscillation is at a highly participating location of that system mode.
- Severity depends on how closely these conditions are met
  - The most severe impact to occur during the resonance condition in which the frequency of the periodic disturbance exactly matches with the frequency of a system mode that has zero damping ratio
    - During this condition, small-signal stability margin of a system is zero and the system is susceptible to not just forced disturbances but any other small-signal or transient disturbances

[1] NERC, “Recommended Oscillation Analysis for Monitoring and Mitigation Reference Document”, November 2021, Available at https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Oscillation_Analysis_for_Monitoring_And_Mitigation_TRD.pdf.

Wide-area Forced Oscillations – Examples

Wide-area Forced Oscillations – Examples (1)



- A wide-area forced oscillation event recently occurred in the Western Interconnection in January 2022
  - Disturbance source was a battery storage system in the Southern California
  - Frequency of forced oscillation close to that of NS-A mode and the disturbance source in the area participating in the NS-A mode ("near-Resonance" Conditions 1 & 3)
  - Damping ratio estimate of the NS-A mode biased toward 0%
  - Forced oscillations lasted for close to 15 minutes and were observed wide-area

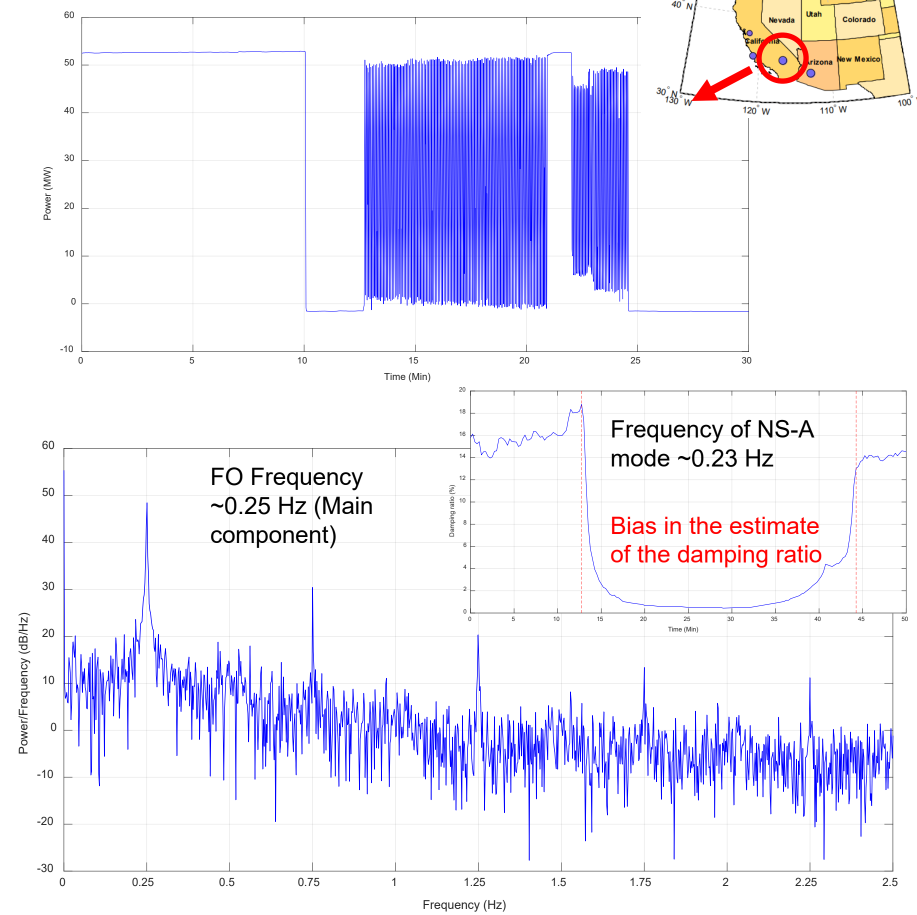


Figure: Example of wide-area forced oscillations in Western Interconnection that originated in Southern California. Figure shows PMU measurement and the calculated periodogram spectrum for the oscillation originating unit.

[1] Mode-shape plot obtained from: WECC, "Modes of Inter-Area Power Oscillations in Western Interconnection", May 2014.

Wide- area Forced Oscillations – Examples (2)

- Oscillations observed in several locations in the North and in inter-tie flows such as California – Oregon Intertie (COI).
  - 200 MW power swings observed in COI flow
  - With lower damping ratio of the NS-A mode, this disturbance could have resulted in serious consequences because of higher power swings and possibly triggering of the tripping actions and affecting overall system operations and stability

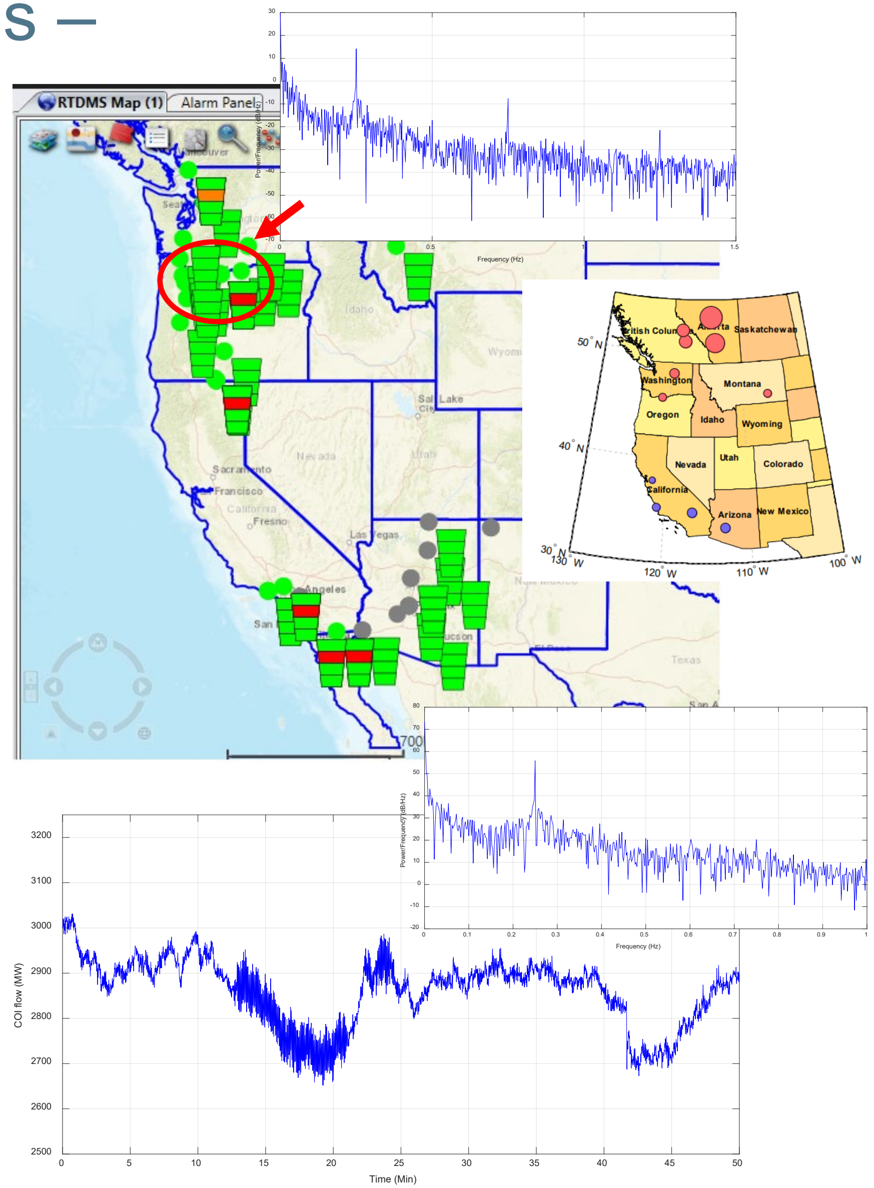


Figure: Example of wide-area forced oscillations in Western Interconnection originating in Southern California.

Wide- area Forced Oscillations – Examples (3)

- 0.25 Hz forced oscillation observed across several areas in the Eastern Inter-connection
  - Frequency close to that of a well-known North-South mode of EI having a frequency of 0.22 Hz and forced disturbance source in the area of high participation of that mode (“near-Resonance” conditions 1 and 3)
  - Power swings of close to 200 MW observed in Florida
  - With lower damping ratio, the amplitude of the oscillations could have been much higher

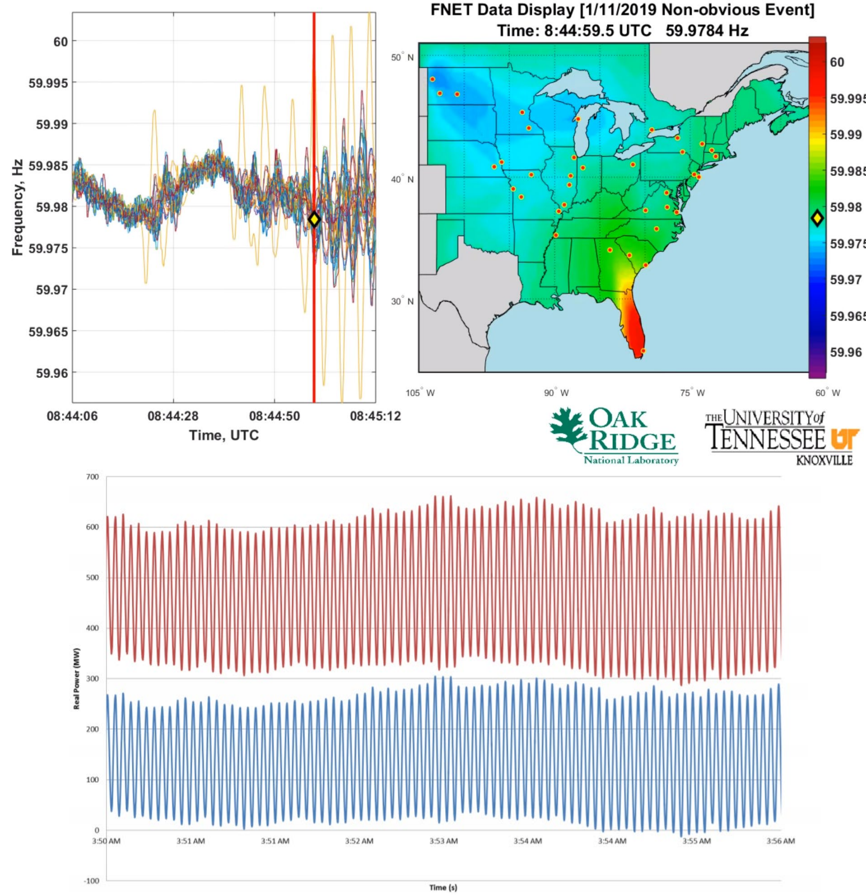


Figure: Example of resonance in Florida in January 2019 [1].

[1] NERC, “Eastern Interconnection Oscillation Disturbance - January 11, 2019 Forced Oscillation Event”, December 2019, Available at https://www.nerc.com/pa/rrm/ea/Documents/January_11_Oscillation_Event_Report.pdf.

Discussion and Conclusion

- To conclude, forced oscillations can pose a serious threat to power systems reliable operations
- Severity depends on how closely the “near-resonance” condition is met
  - High power swings during the “near-resonance” condition can result in various reliability impacts
- Mitigation strategies for forced oscillations involve identifying the source of disturbance and then taking steps to mitigate the disturbance source
  - For situations when the damping ratio of a mode having frequency close to the forced oscillations is low, additional measures may need to be taken to improve the damping ratio of system mode so as to lower the amplitude of the oscillations while the source of disturbance is being identified

Thank you!!!

Questions??