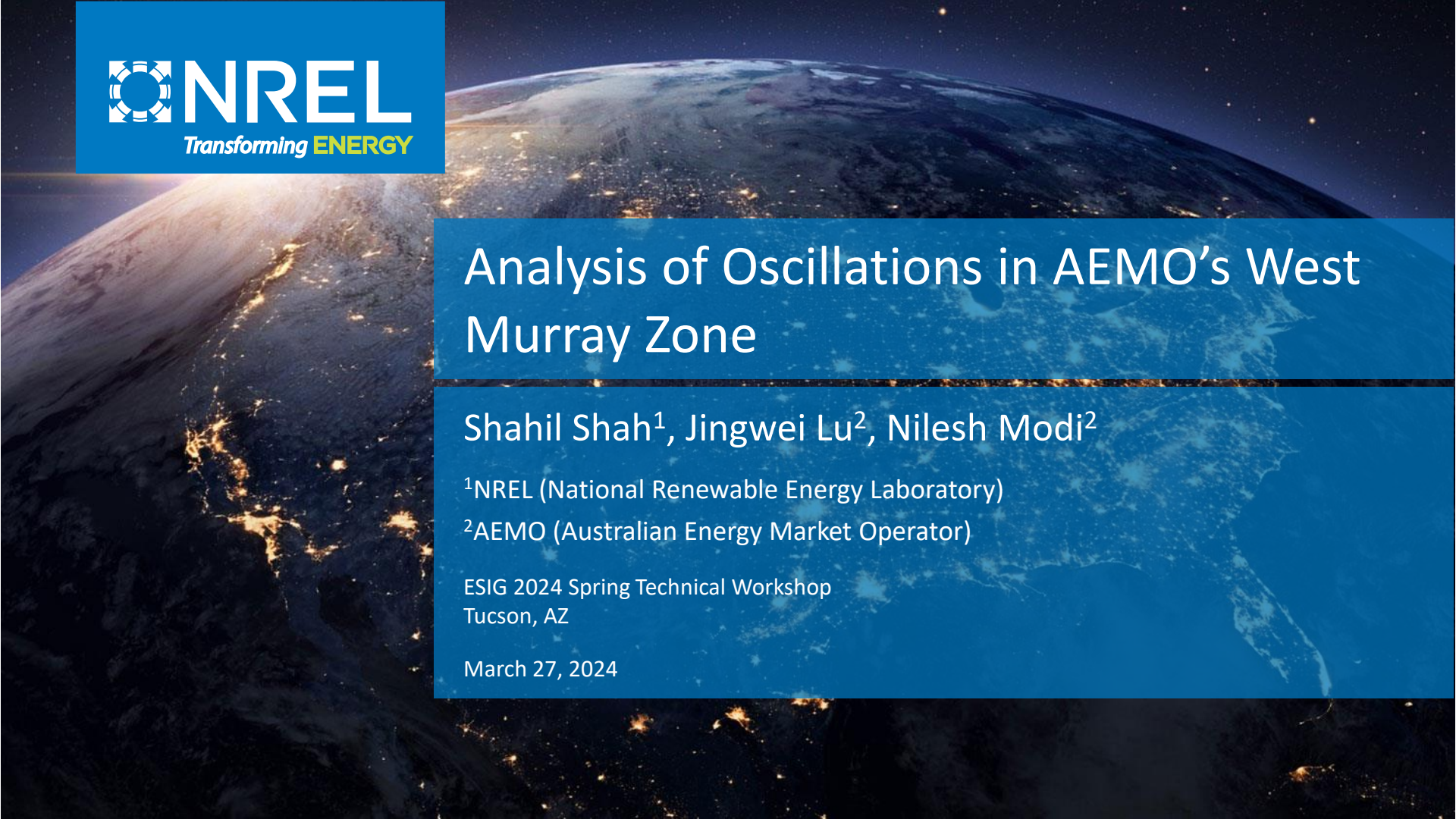

Analysis of Oscillations in AEMO's West Murray Zone

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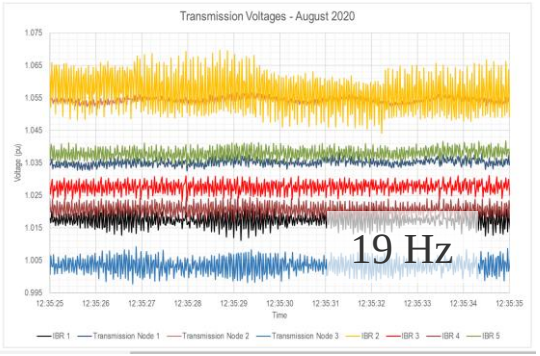
Tucson, AZ

March 27, 2024

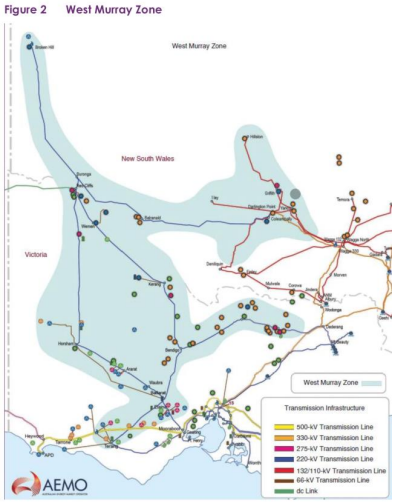
Outline

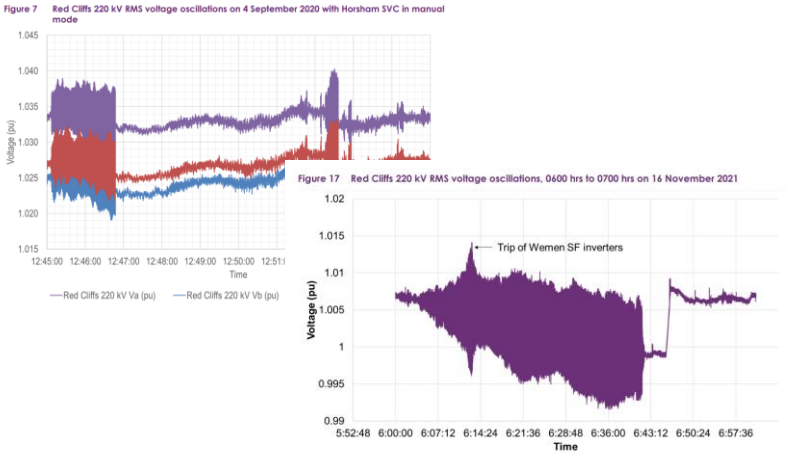
1. Subsynchronous Oscillations in AEMO Grid
2. NREL's Grid Impedance Scan Tool (GIST)
3. Impedance Scan of IBRs in SMIB Configuration
4. Impedance Scan of Wide Area Network EMT Model
5. Summary

Subsynchronous Oscillations in AEMO Grid



Source: Jalali, et. al. (AEMO), CIGRE 2021.

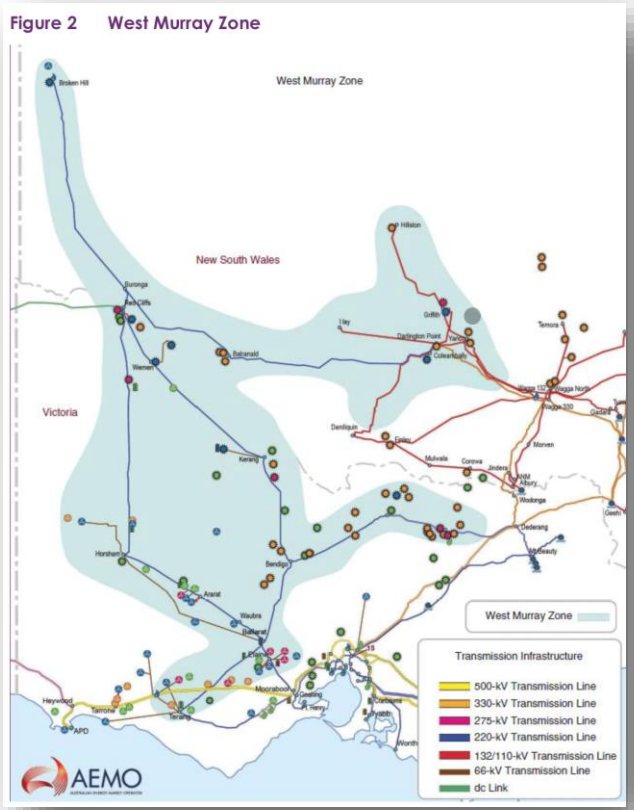




Source: West Murray Zone Power System Oscillations, AEMO, Feb. 2023.

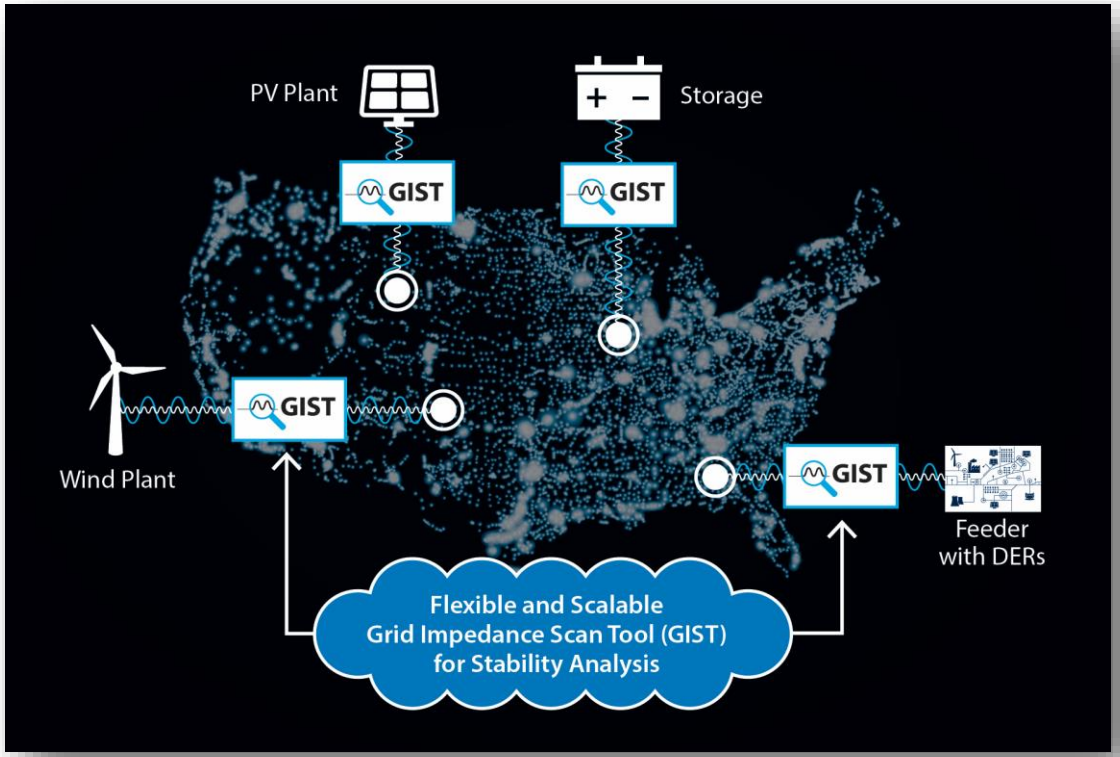
- AEMO (Australia) has experienced 17-20 Hz oscillation events in the West Murray Zone since August 2020. They are triggered often in the absence of a disturbance.
  - Question: What is triggering these oscillations?

AEMO's Previous Findings



- Source: AEMO Feb. 2023 Report
  - Oscillations contained within area west to the Bendigo and Darlington Point
  - Oscillations were observed during outage of Red Cliffs to Burongo 220 kV line and during periods when Murraylink DC was disconnected
  - Likely source of oscillations within north-west Victoria.

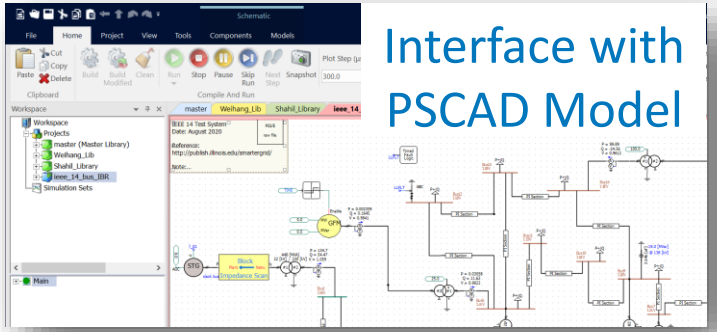
Grid Impedance Scan Tool (GIST)



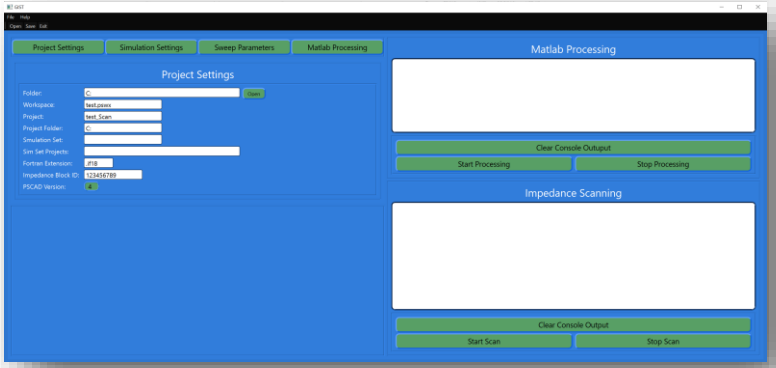
- GIST scans IBR and grid impedances using PSCAD models across wide range of frequencies
- GIST evaluates the impact of the IBR on grid stability using impedance Scans
- Fully automated scans
- Performs accurate scans even when the fundamental frequency is not exactly 50 or 60 Hz
- Outputs scan data in all reference frames: stationary, rotating (dq), power-domain

GIST Workflow

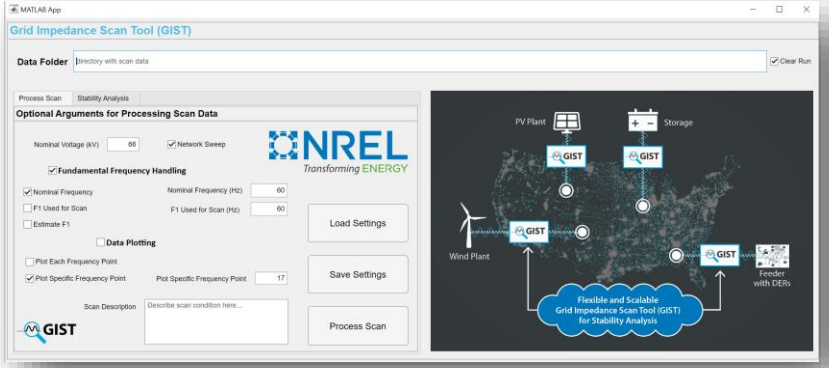
- GIST block is inserted between an IBR and the rest of grid inside a PSCAD model.



Impedance Scan Interface



Postprocessing/Analysis Interface

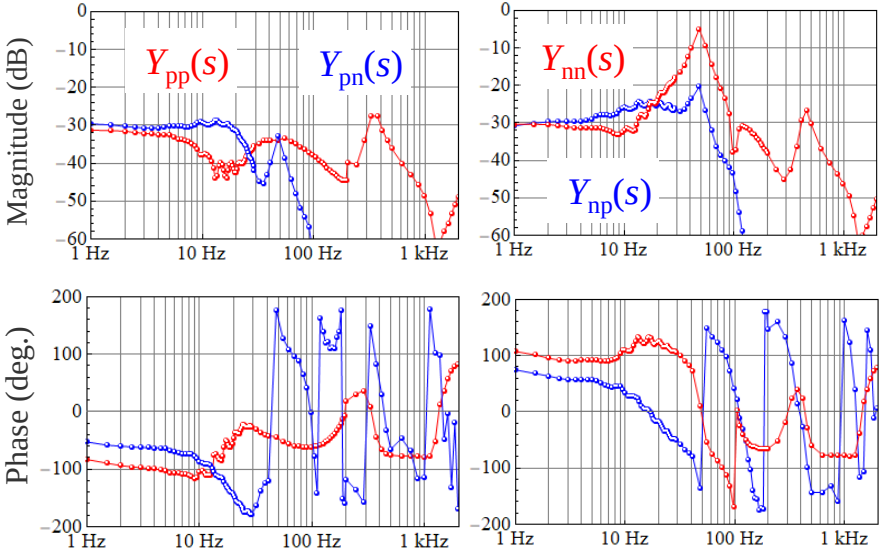


Approach for Impedance Scan Analysis

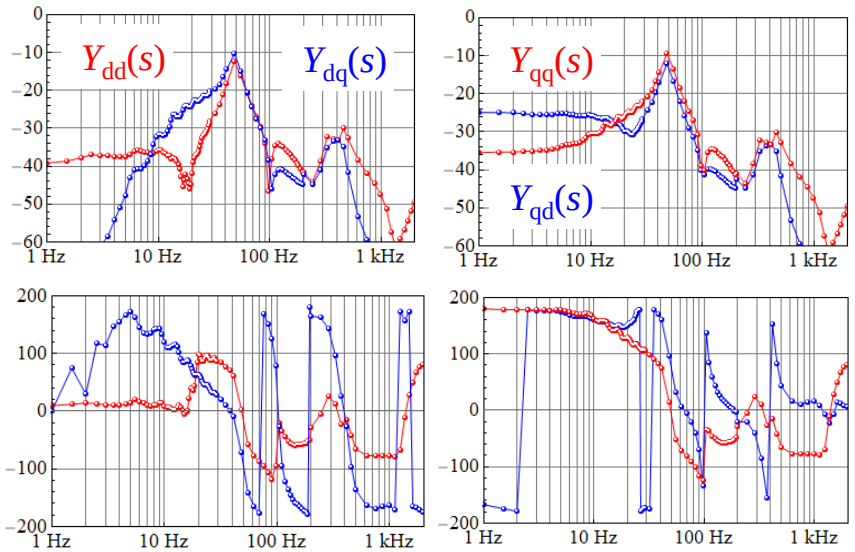
- **Step 1**: Identify IBRs and their operation conditions that are suspected to have significant role in the observed oscillations.
- **Step 2, SMIB IBR Scan**: Perform impedance scans at IBRs in SMIB (single machine infinite bus) format
  - Identify internal resonance modes of IBRs and evaluate their ability to operate stably with grids of different strength conditions (SCR, X/R)
- **Step 3, Wide Area Network Scan**: Perform impedance scans of the grid at the terminal of an IBR using wide-area network EMT model
  - Identify oscillation modes in the grid and contribution of the IBR to its damping
  - Repeat this step as needed at other IBRs

Impedance Scan of an IBR; Operating Condition 1 (Low-Risk)

Sequence Admittance



DQ Admittance

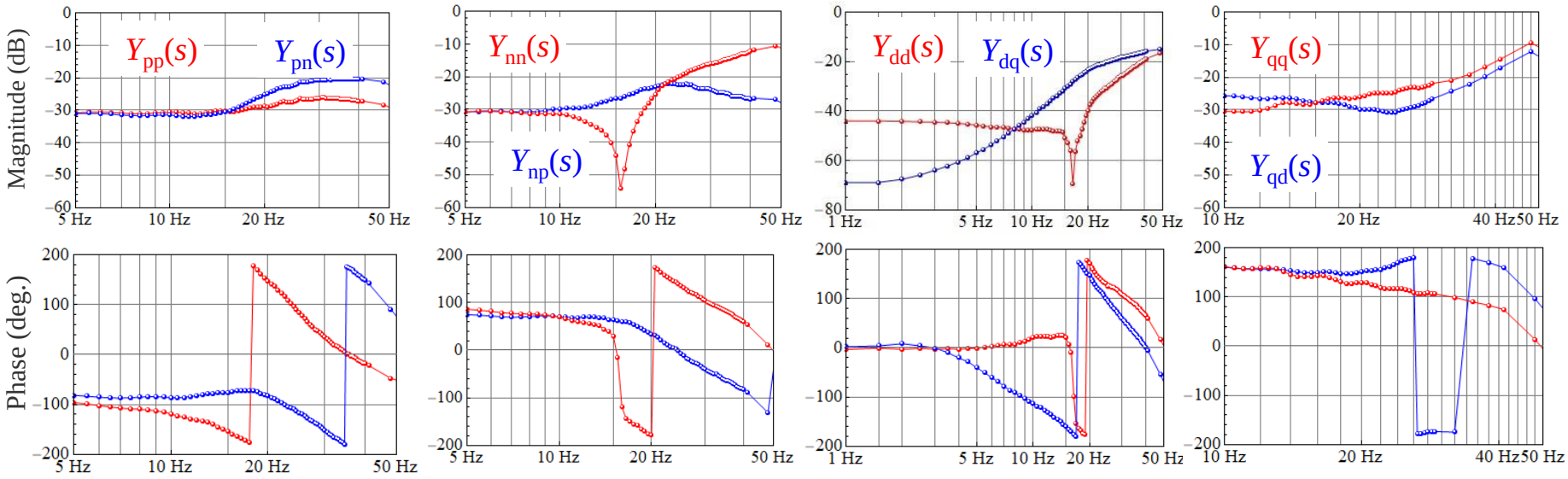


- $Y_{dd}(s)$ shows damped of resonance near 18 Hz.

Impedance Scan of an IBR; Operating Condition 2 (High-Risk)

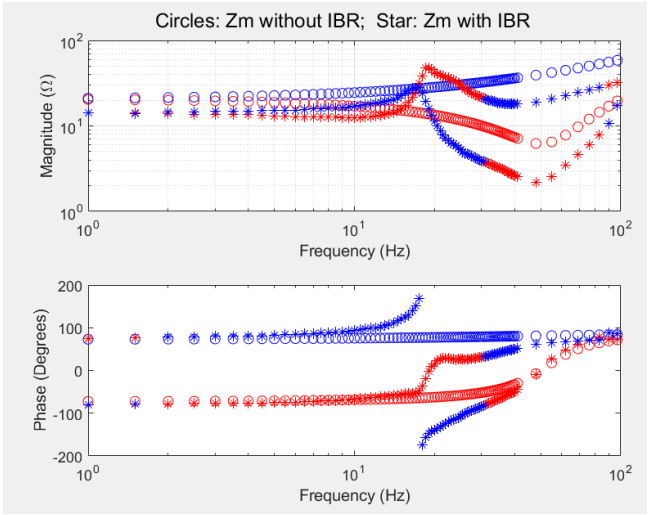
Sequence Admittance

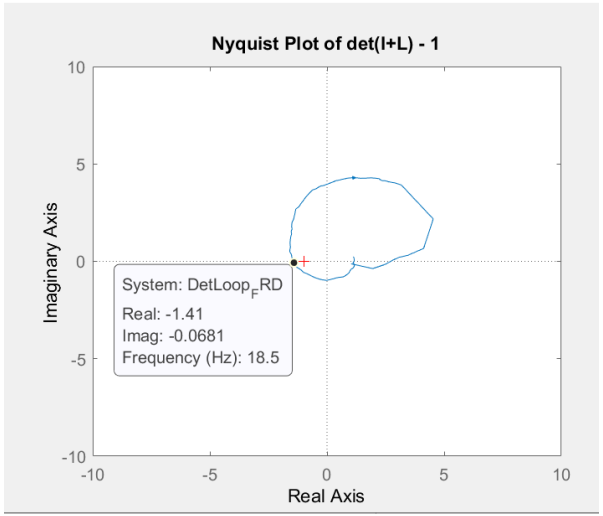
DQ Admittance

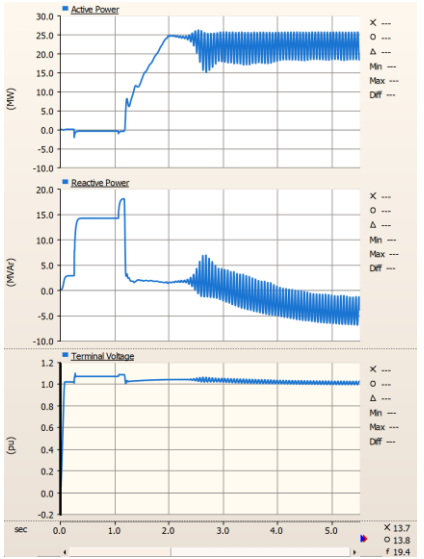


- Severe resonance at 17 Hz in $Y_{dd}(s)$

Stability Analysis for SCR 2.1 and X/R 3.2

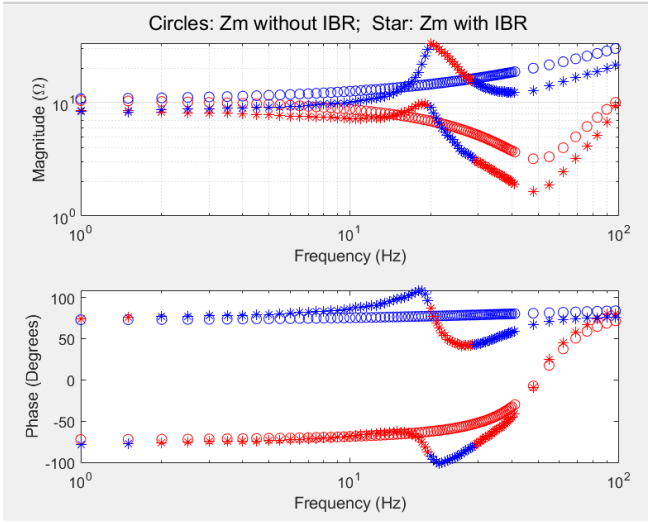


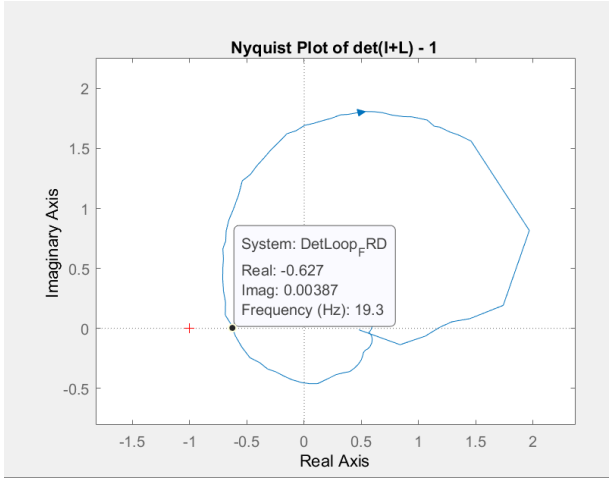


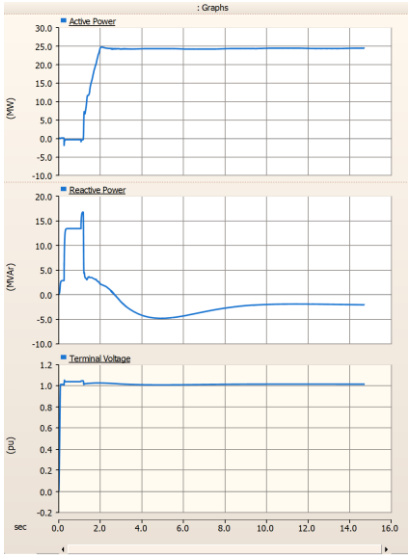


- IBR plant is unstable – confirmed by time-domain simulations (17.4 Hz)

Stability Analysis for SCR 4.1 and X/R 3.2





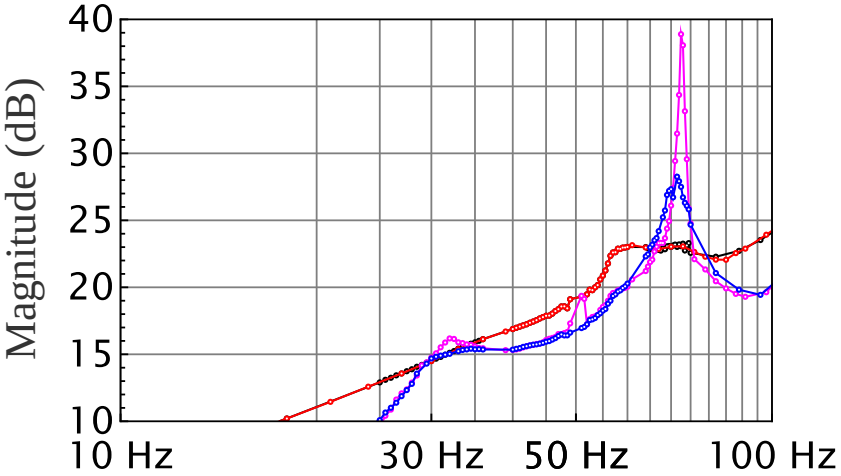


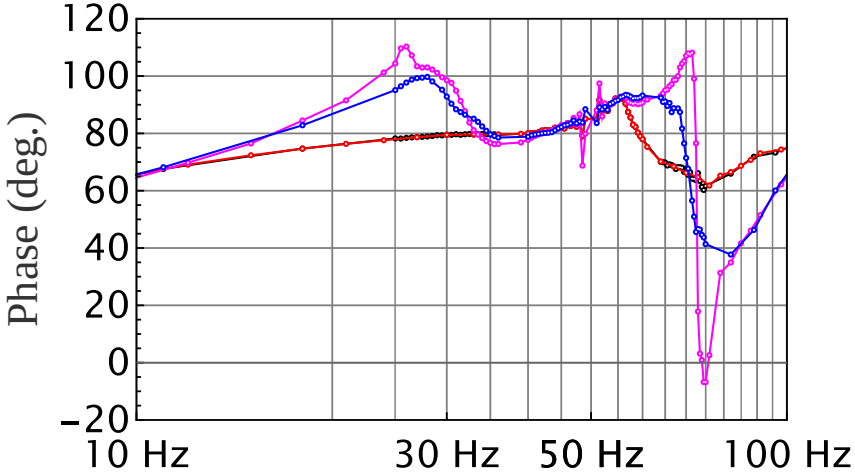
- IBR plant is stable with low stability margin – Plant still has highly underdamped resonance mode, but it will not excite oscillations in the absence of a disturbance

Outcome of SMIB IBR Scan Study

- Some IBRs have underdamped 17 Hz mode for a particular operating condition
- The mode becomes unstable if any of the IBR is connected to a grid with SCR below 2.1
  - Grid strength estimated using positive sequence power flow models is significantly higher than 2.1.
- The SMIB analysis models grid as an R-L branch
  - It does not reveal complex control interactions among IBRs
  - It does not reveal how certain IBRs modify the grid characteristic seen by other IBRs in proximity

Impedance Scan of WMZ Grid from IBR-1

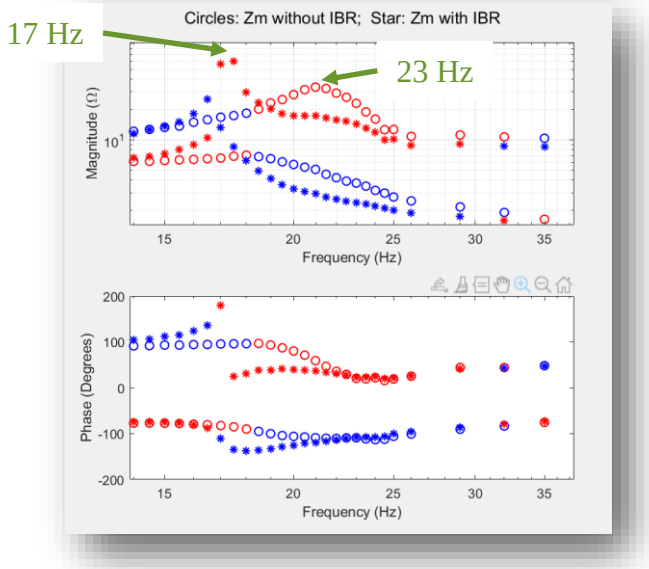




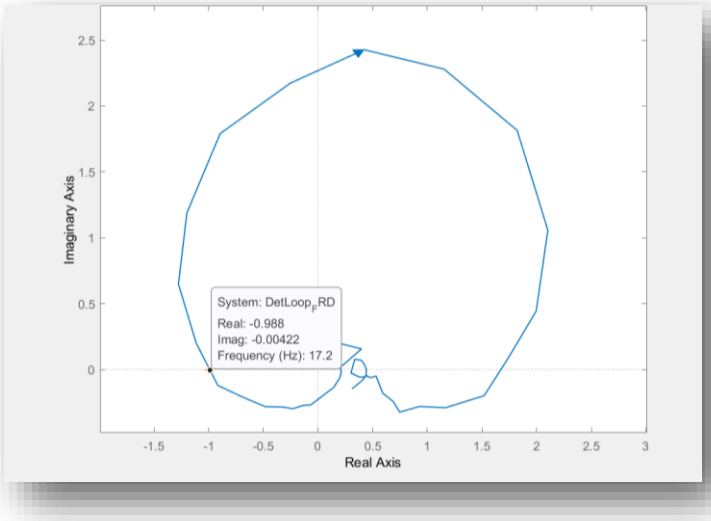
- IBR-2 and IBR-3 are disabled; IBR-2 and IBR-3 operate at low-risk condition; IBR-2 operates at high-risk condition and IBR-3 is disabled; IBR-2 and IBR-3 operate at high-risk condition

Stability Analysis using Wide Area Network Scan

- Stability Analysis at IBR-1



Nyquist plot of $Z_{net.}/Z_{IBR}$



- IBR-1 forms an unstable resonance mode at 17 Hz with WMZ system
  - It moves a 23 Hz mode in WMZ grid to 17 Hz and reduces its damping

Summary

- Impedance-based analysis provides a systematic solution for evaluating the root-cause of power system oscillations using highly accurate Blackbox EMT models of IBRs.
- Use of SCR can result in over-optimistic estimation of grid strength

Thank you!

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