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Impact of Reduced System Inertia on Oscillatory Behavior of Power Systems

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Outline

- Background
- Power Systems Oscillations
- Methodology
- Results
- Discussion and Conclusion

Background

- The electric power grid is evolving at an accelerated pace toward high proportion of inverter-based renewable energy sources (RES)
- Unlike synchronous machines, RES have no rotating mass and hence no inherent inertia
  - This change in generation-mix will affect several aspects of power systems behaviour, such as frequency response and system dynamic response
- In this presentation, I will be discussing how critical system inertia is for maintaining stable oscillatory behavior in power systems
  - Results obtained by performing oscillation assessment of use-cases having different RES penetration level
  - Results obtained for several scenarios for a thorough study

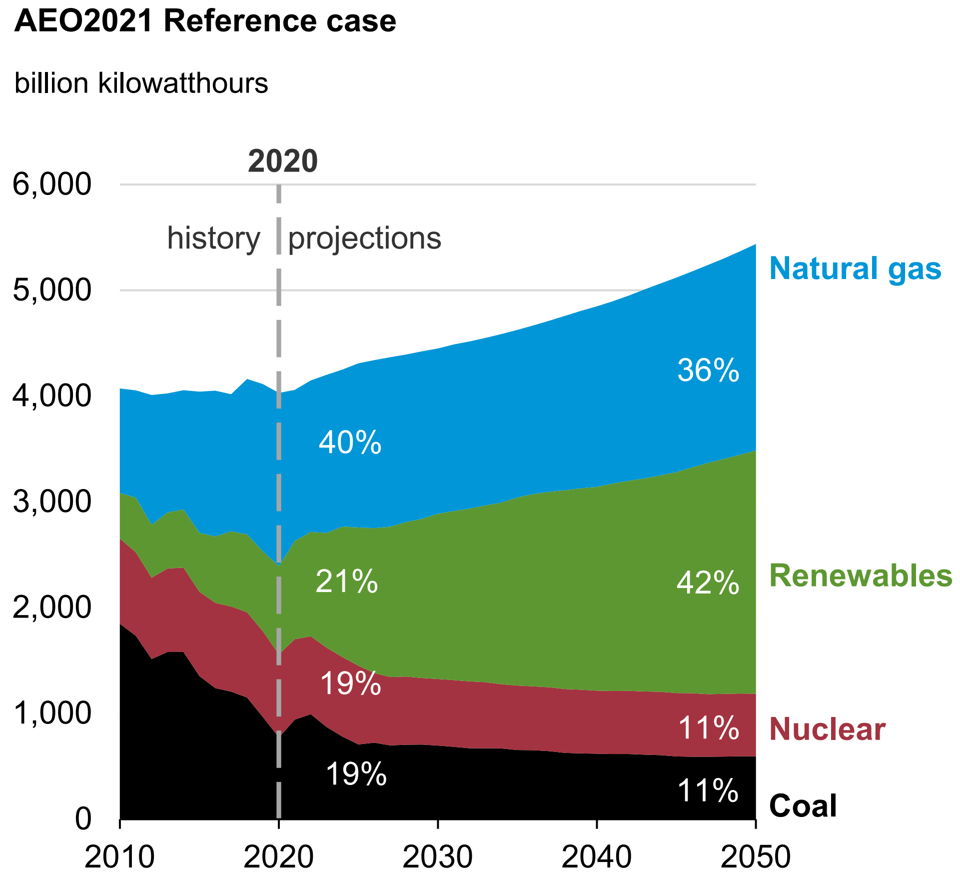


Figure: U.S. electricity generation from selected fuels[1]

[1] https://www.eia.gov/outlooks/aeo/ppt/04%20AEO2021%20Electricity.pptx

Power Systems Oscillations

- Electromechanical oscillations, also called as natural oscillations, are a continuously occurring phenomenon in power systems arising from dynamic interactions among power systems components
  - This system oscillatory behavior is determined by system modes, which are a function of overall system dynamics and system operating condition
  - Small-signal stability margin of a system quantified by damping ratio of system modes
- Increasing proportion of RES generation will result in changes to the overall system dynamics and to the system oscillatory behavior
  - Several studies have concluded that increased RES penetration level and therefore decreased system inertia results in decrease of the damping ratio of modes, thereby decreasing small-signal stability of a system and making system vulnerable to events
  - Our results show that the impact of increased RES penetration level depends on the generators being retired and the interaction among the remaining synchronous generators

Analyzing the Impact of Reduced System Inertia on System Modes - Methodology

- For studying the impact of decreasing system inertia on system modes, 2018 heavy summer operating WECC model used as a base-case
  - RES penetration level: 9%
  - Total system inertia: 920 GW-s
- Several scenarios considered to assess the trends in the frequency and the damping ratio of system modes
  - System-wide increase of RES penetration level
  - Area-specific increase of RES penetration level
- Several use-cases created for each scenario having different RES penetration level
  - Modal analysis performed for each use-case to estimate frequency and damping ratio of the modes of interest to perform trending analysis with respect to the system inertia
- Modes of interest: North South - A and North South - B dominant WECC modes

Oscillation Assessment Results

System-wide Increase in RES Penetration Level – S1

- RES generation increased system-wide by replacing synchronous generators with fully converter-based machine model
- Generation dispatch, line flow and system load remained unchanged
- System inertia decreased from 920 GW-s to 310 GW-s for an increase in the RES penetration level of close to 60%.

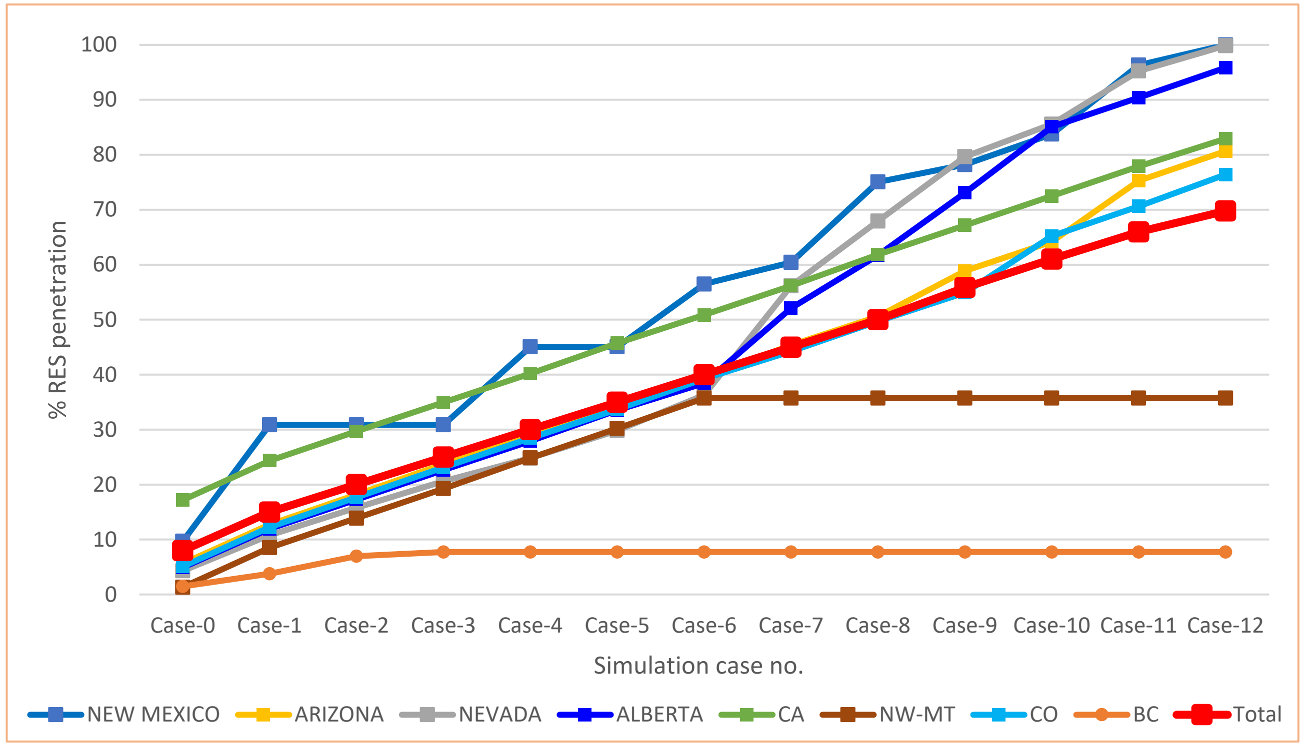


Figure: Renewable generation in different areas and system-wide for different cases in S1

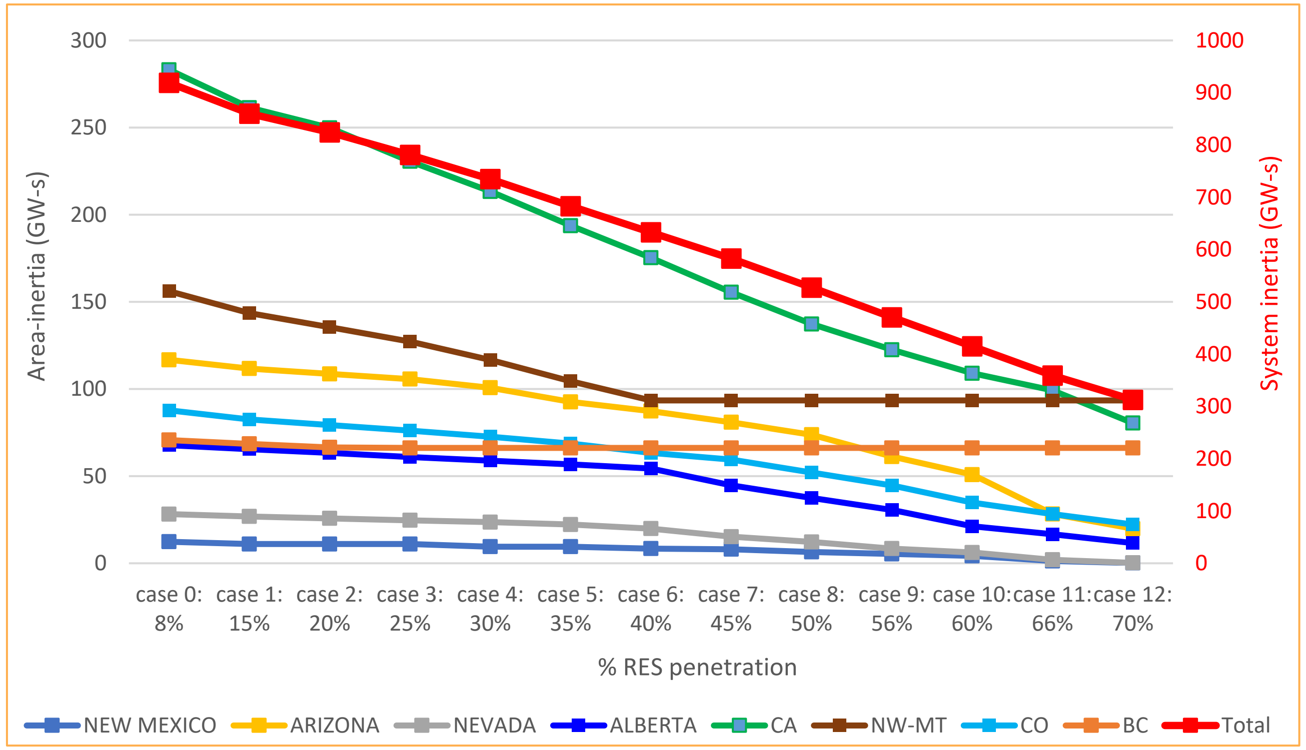
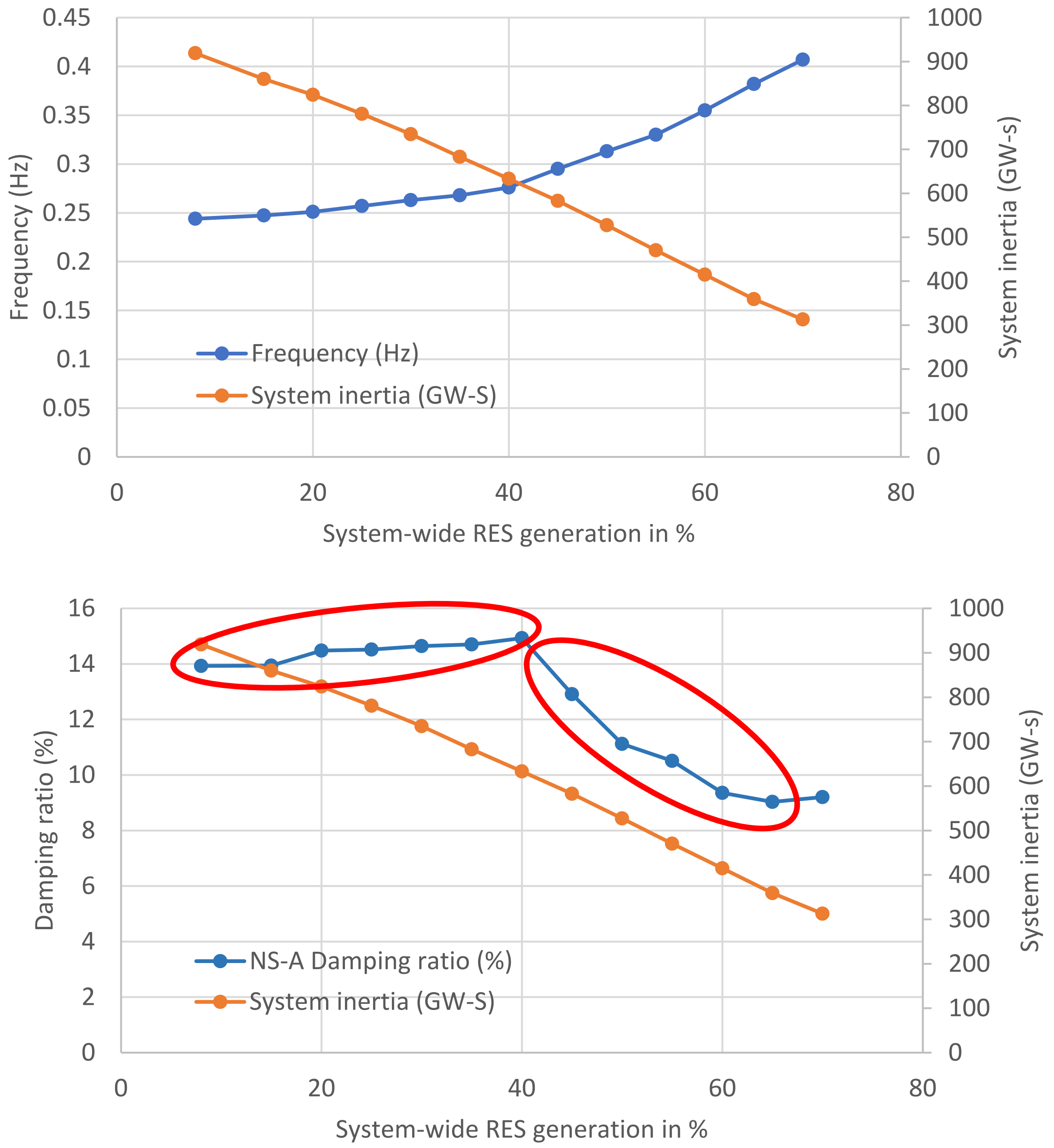
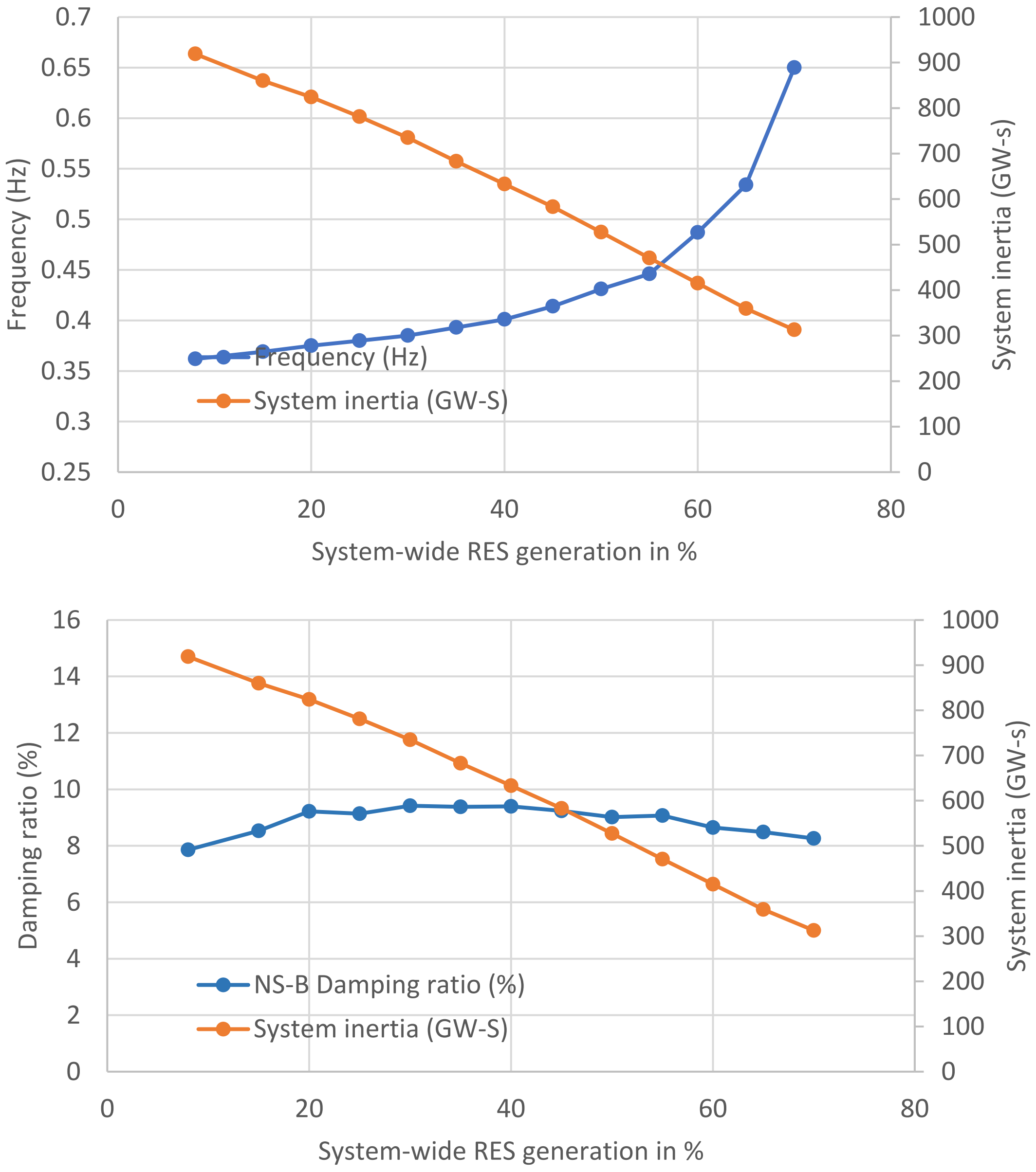


Figure: Change in inertia for different cases in S1

Mode Frequency and Damping Ratio Estimates – S1



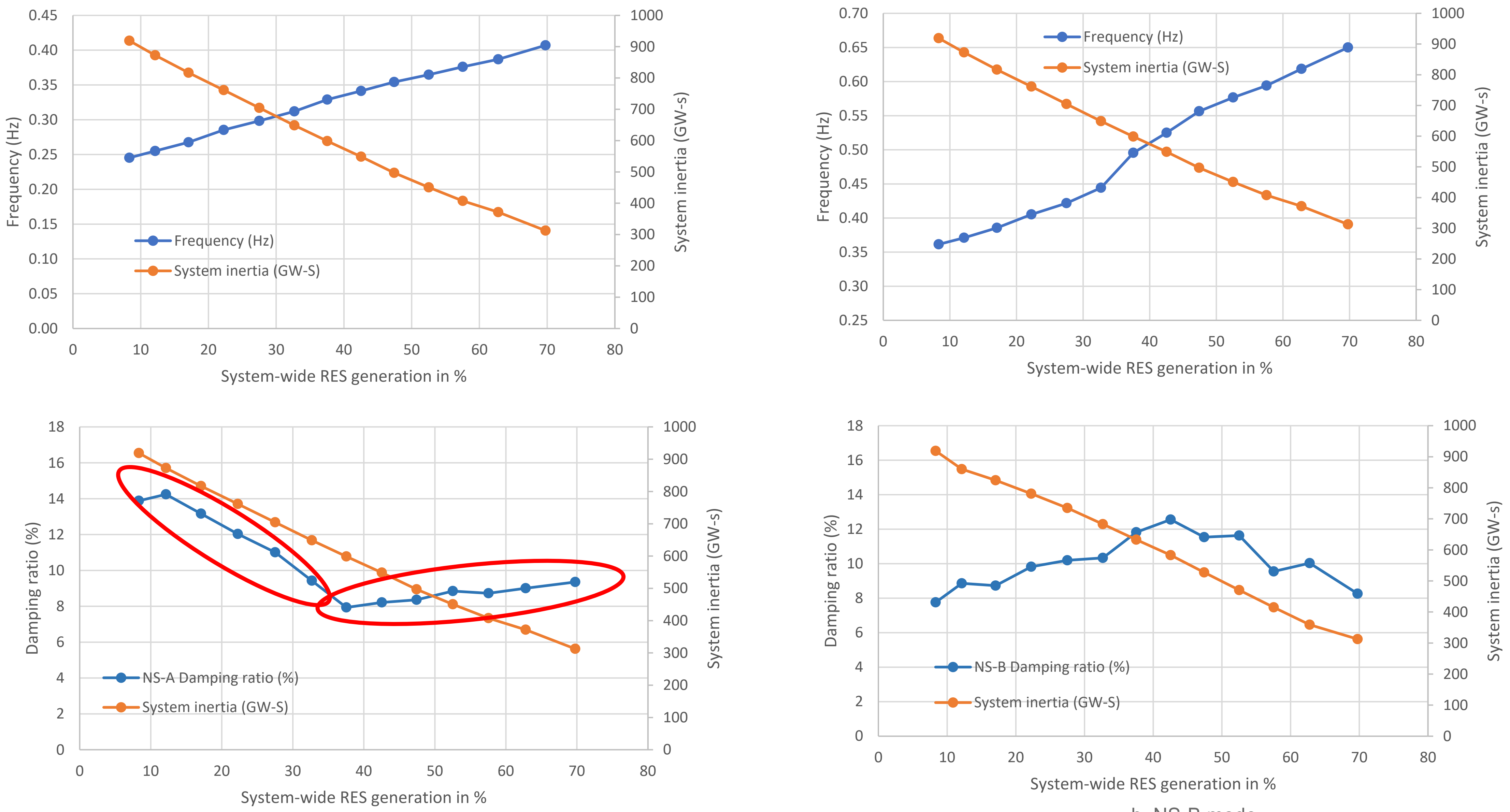
a. NS-A



b. NS-B

Figure: Impact of system-wide increased RES penetration level on N-S system modes for Scenario S1

Mode Frequency and Damping Ratio Estimates – S2



a. NS-A mode

b. NS-B mode

Figure: Impact of system-wide increased RES penetration level on N-S system modes for Scenario S2

Mode Frequency and Damping Ratio Estimates of NS A mode – Area specific impact

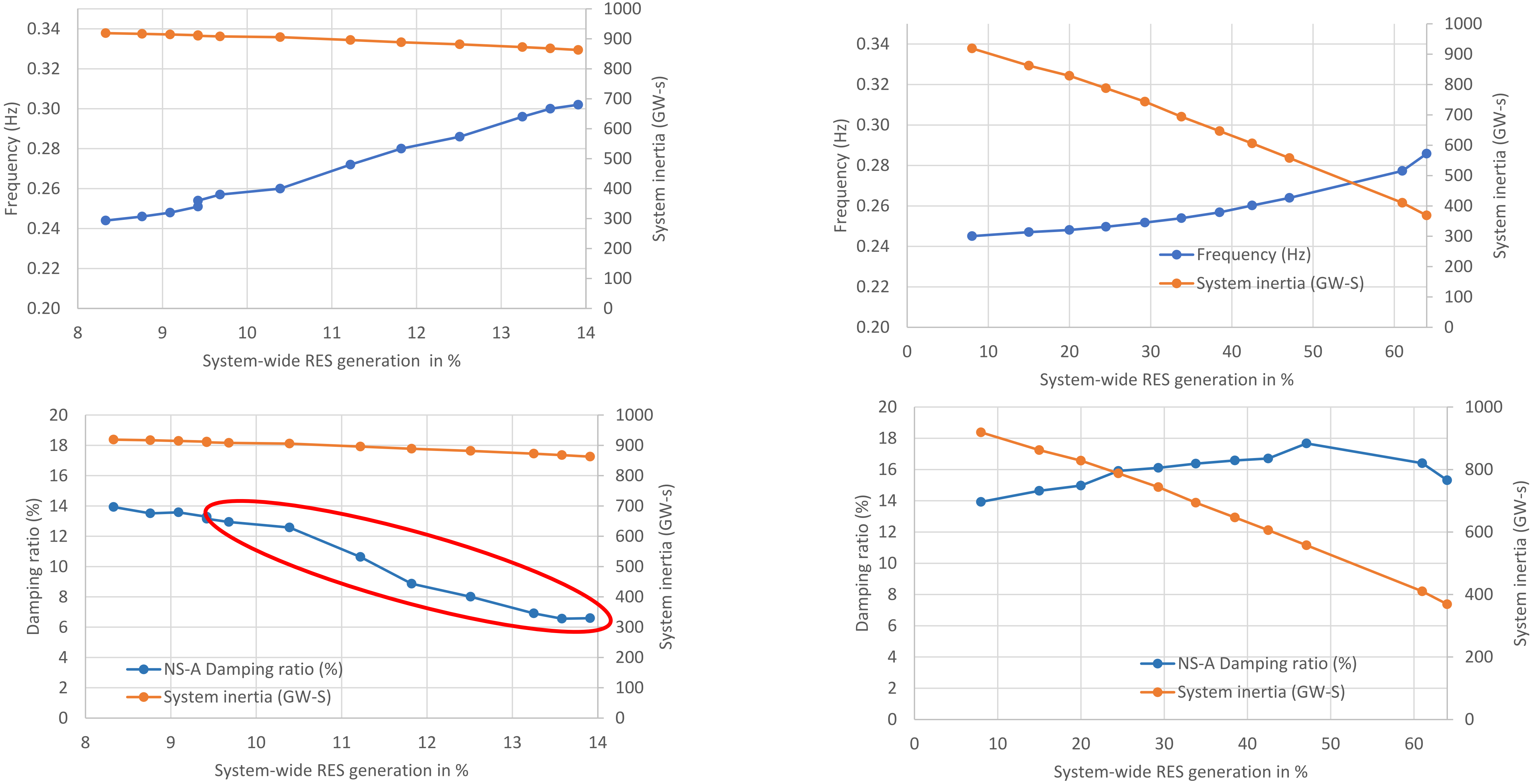


Figure: Impact of increased penetration of RES in Alberta on NS-A mode for Scenario S3

Figure: Impact of increased RES penetration level system-wide except in Alberta on NS-A mode for Scenario S4

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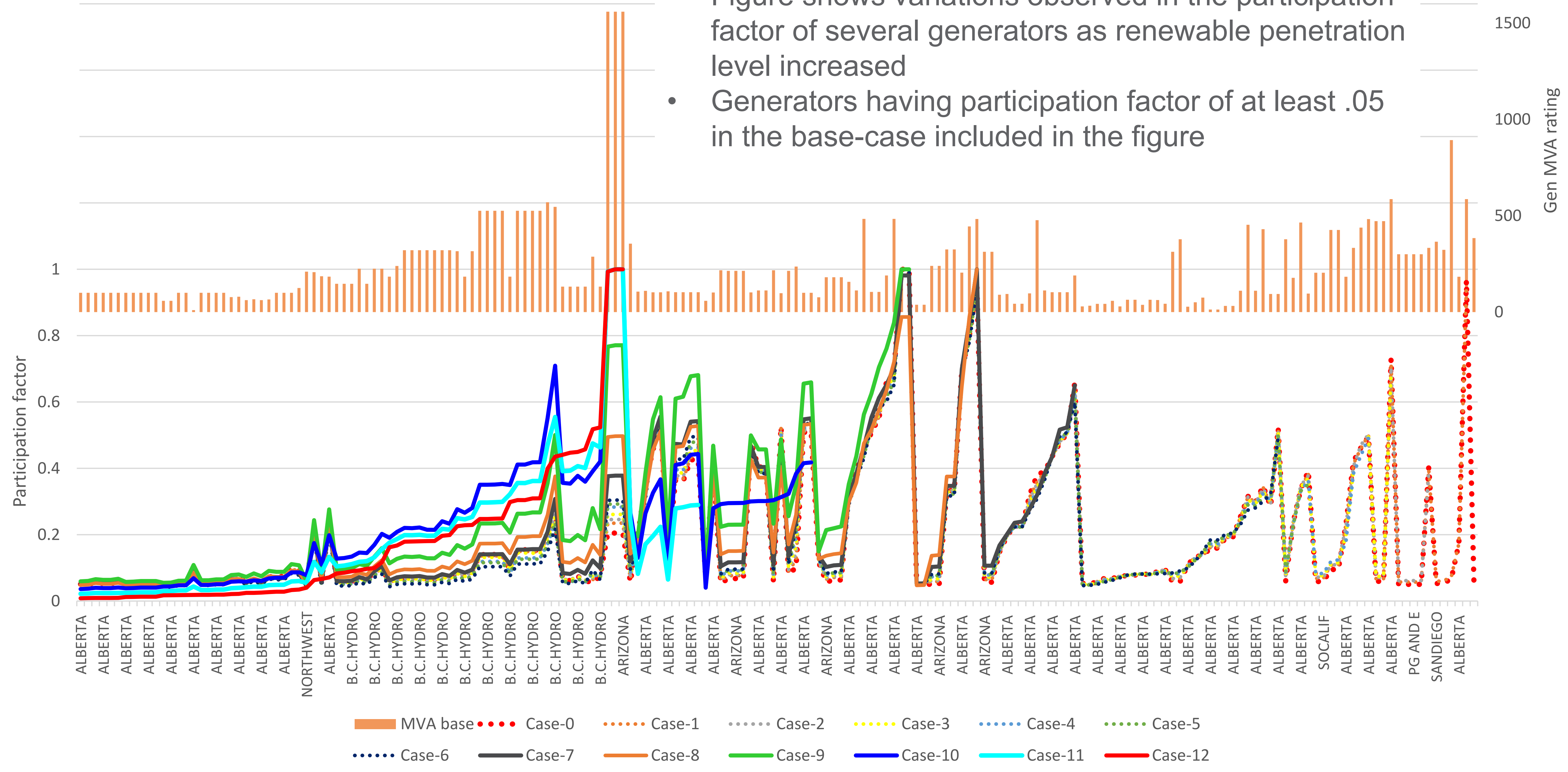
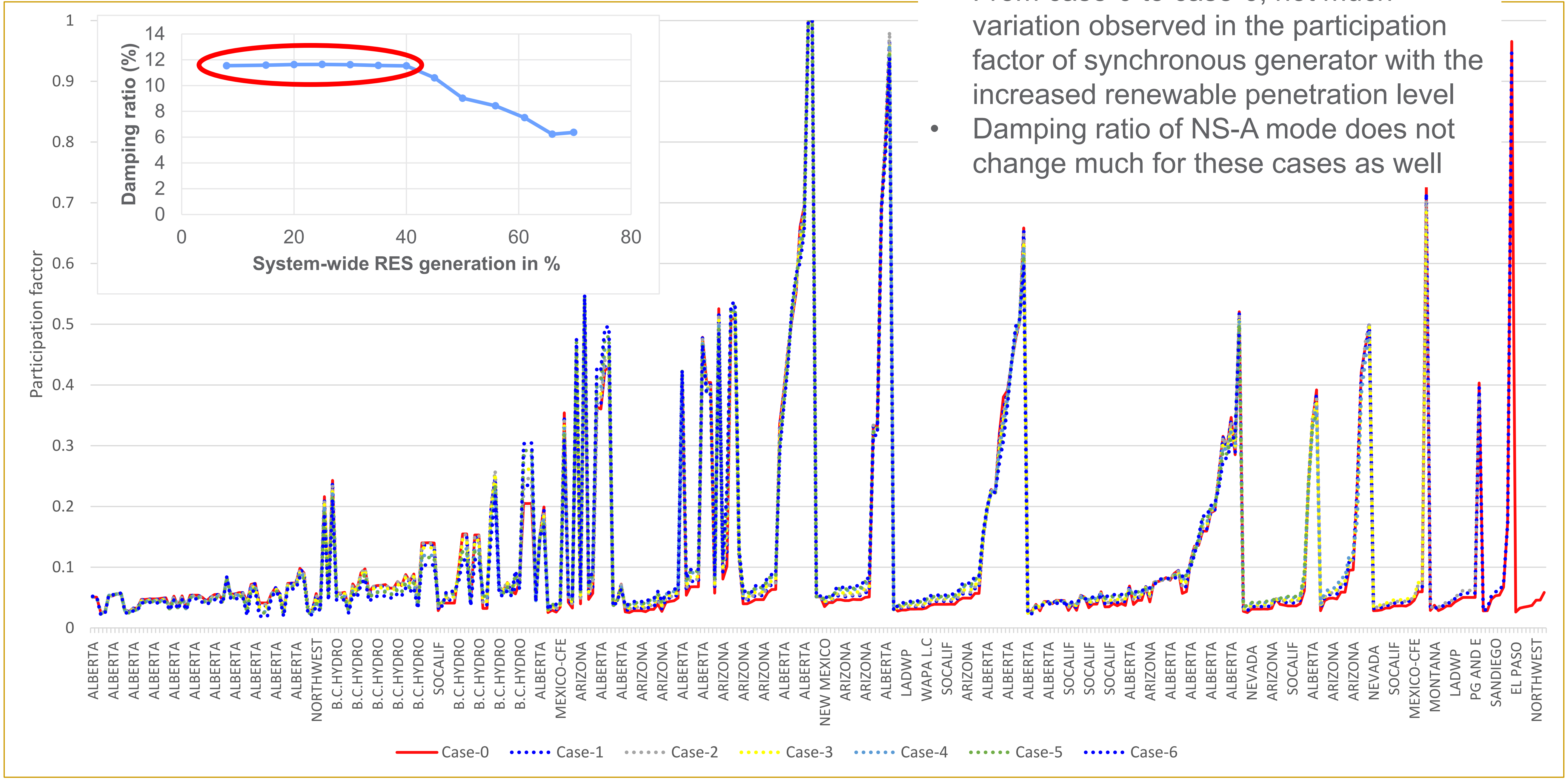
Eigenvalue Analysis for Scenario S1

Participation Factor of Generators for NS-A Mode – S1 (1)

- Figure shows variations observed in the participation factor of several generators as renewable penetration level increased
- Generators having participation factor of at least .05 in the base-case included in the figure

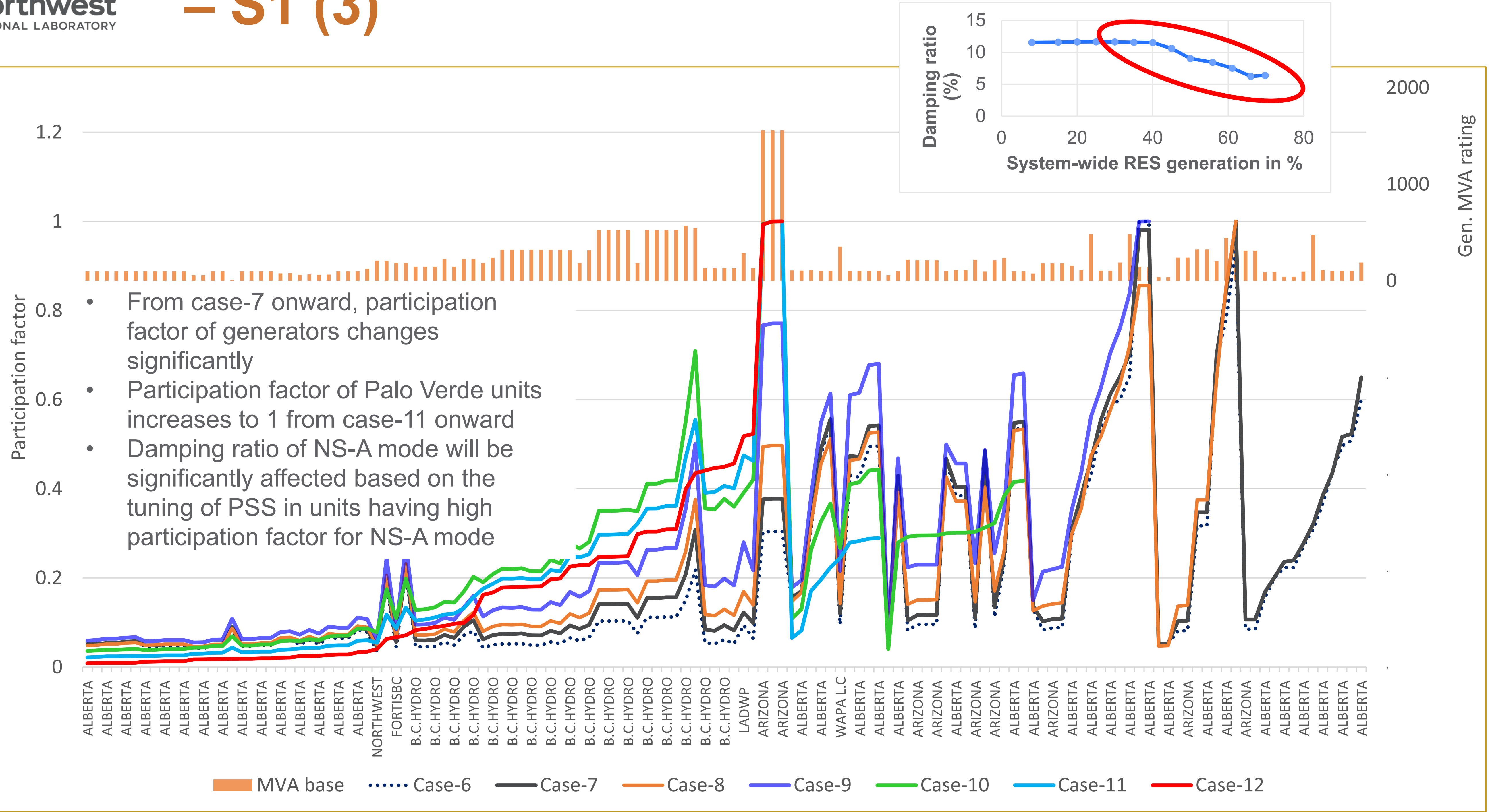


Participation Factor of Generators for NS-A Mode – S1 (2)



- From case-0 to case-6, not much variation observed in the participation factor of synchronous generator with the increased renewable penetration level
- Damping ratio of NS-A mode does not change much for these cases as well

Participation Factor of Generators for NS-A Mode – S1 (3)



- From case-7 onward, participation factor of generators changes significantly
- Participation factor of Palo Verde units increases to 1 from case-11 onward
- Damping ratio of NS-A mode will be significantly affected based on the tuning of PSS in units having high participation factor for NS-A mode

Discussion and Conclusion

- NS-A mode impacted more than the NS-B mode by increased renewable penetration level
  - S1 – Damping ratio of NS-A mode increases slightly when the renewable penetration increases up by 30% and then decreases rapidly
  - S2 – Damping ratio of NS-A mode decreases sharply first and then increases slowly.
  - Changes observed in system modes dependent on generators being replaced.
- No trend observed in the damping ratio of system modes with respect to system inertia
  - Trends observed in the damping ratio explained by the change in the participation factor and/or mode shape of remaining synchronous generator
  - Damping ratio of a mode will depend on the damping contribution by the generators heavily participating in that mode as the system evolves
- Increase in the frequency with increased IBR penetration level not directly proportional to the system inertia based on results obtained for Scenarios S3 and S4

Acknowledgements

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Thank you