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# Wide-Area Oscillation Assessment and Trending Analysis with High Penetration of Renewables

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# Background

- The electric power grid is evolving at an accelerated pace toward more diverse generation-mix consisting of high proportion of renewable energy sources (RES)
- Unlike synchronous machines, RES based machines are connected to the grid through inverters
  - This will affect several aspects of power systems behaviour, such as frequency response and system oscillatory behavior
- This presentation focuses on assessing the impact of increased penetration of inverter-based renewable sources on system oscillatory behavior of the WECC system

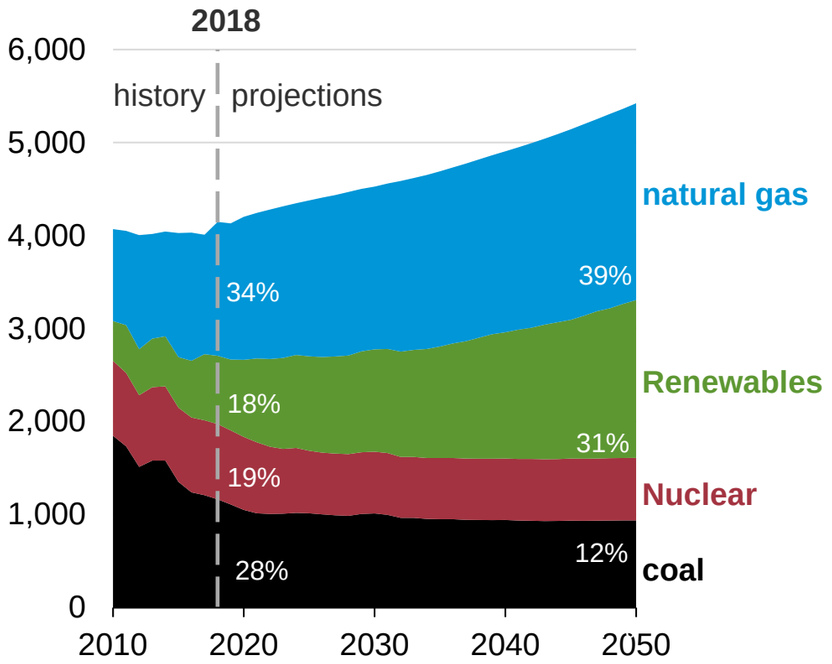
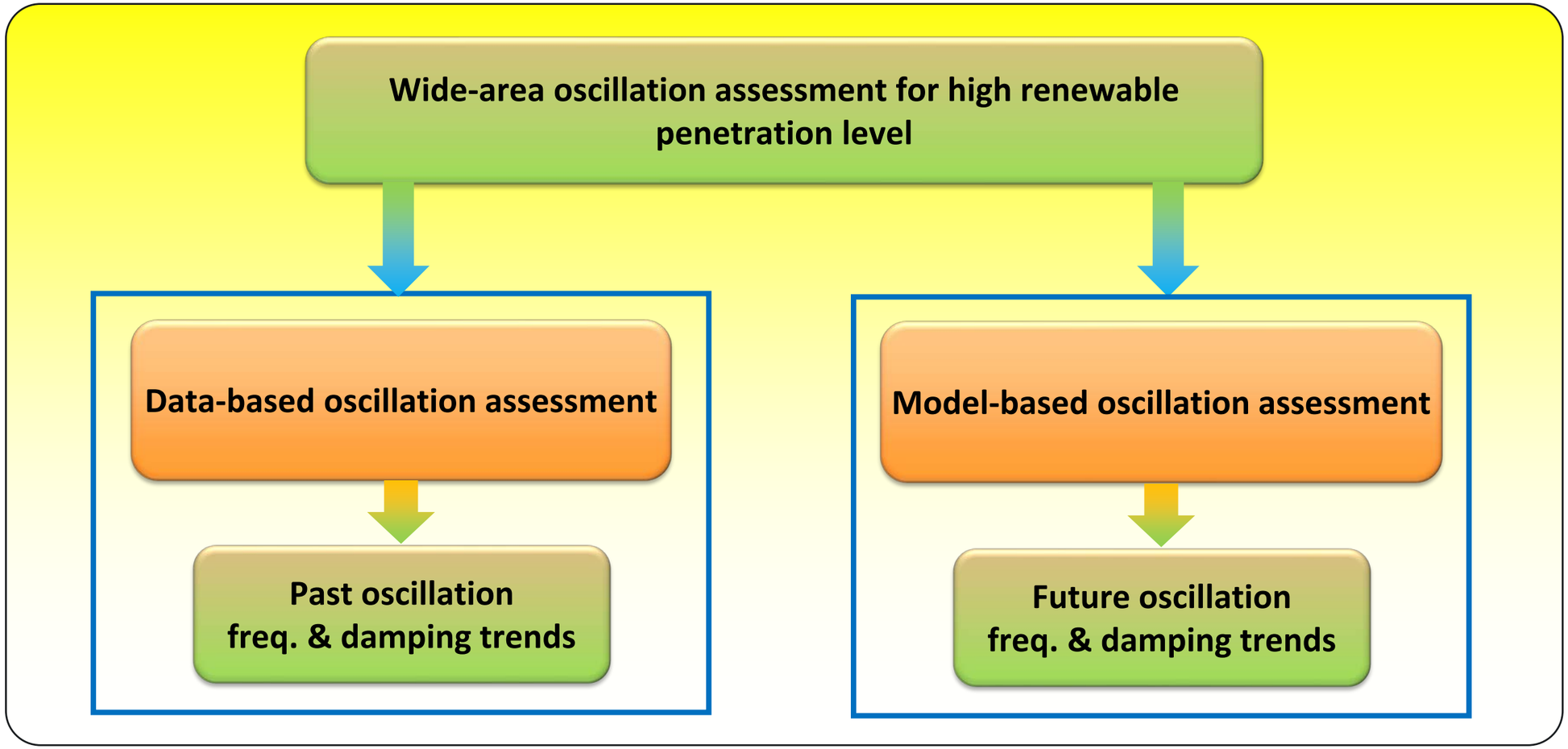



Figure: Electricity generation from selected fuels (Credit: EIA Annual Energy Outlook 2019)

# Approach: Bringing together data and model for identifying oscillation trends



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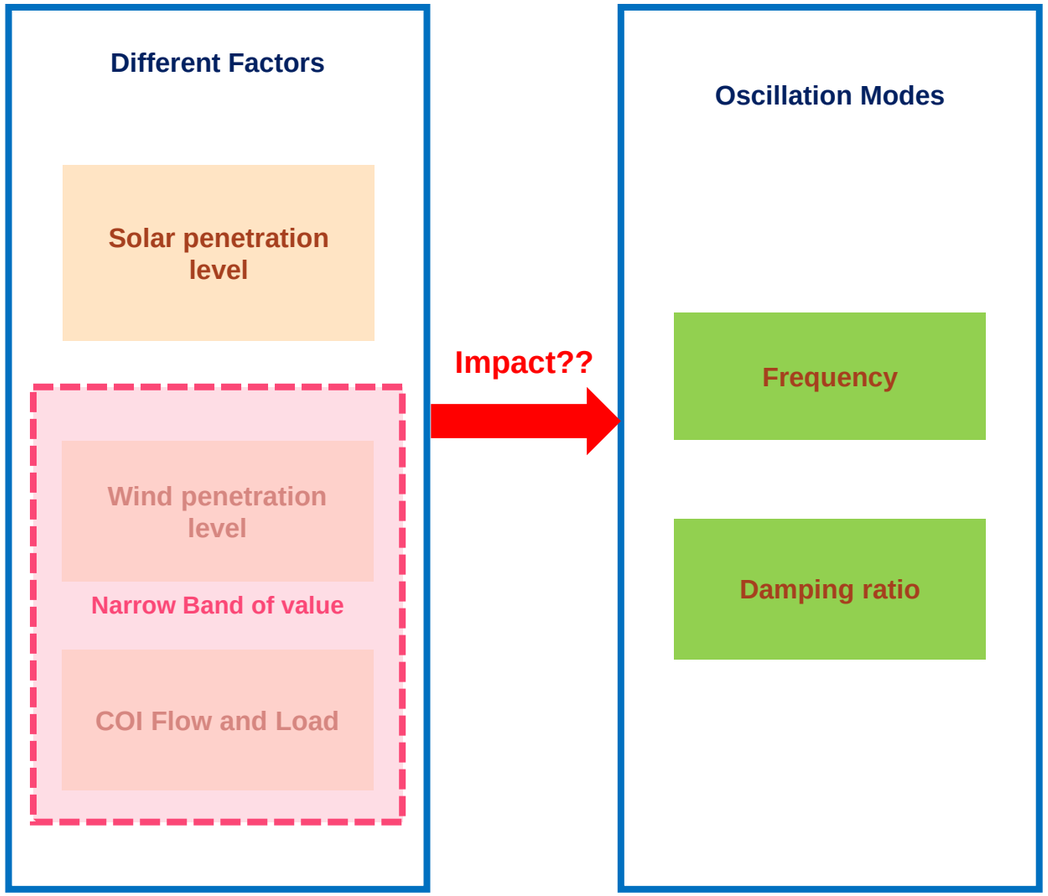
# Data-based approach using historical data

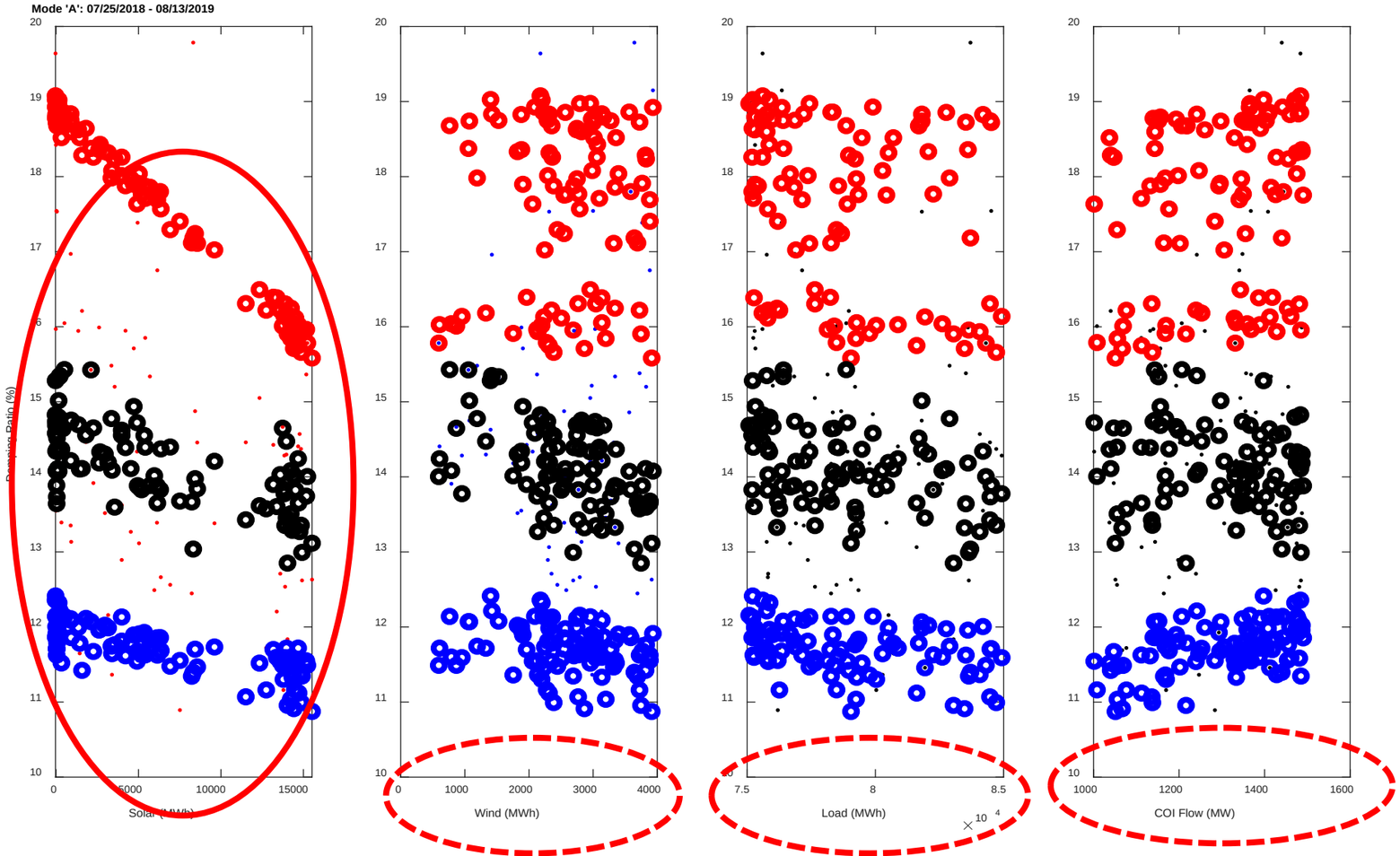
# Methodology

- Quantile-regression based correlation analysis carried out between renewable penetration level and mode estimates to identify trends
  - Data for the WECC system collected from the U.S. Energy Information Administration (EIA, 2019)
  - Mode estimates calculated using the Mode Meter
  - Influence of variables, such as system load, COI flow, etc., on mode estimates minimized by choosing a narrow range of value for these variables
- Analysis carried out for NS-A and NS-B modes observed in the WECC system



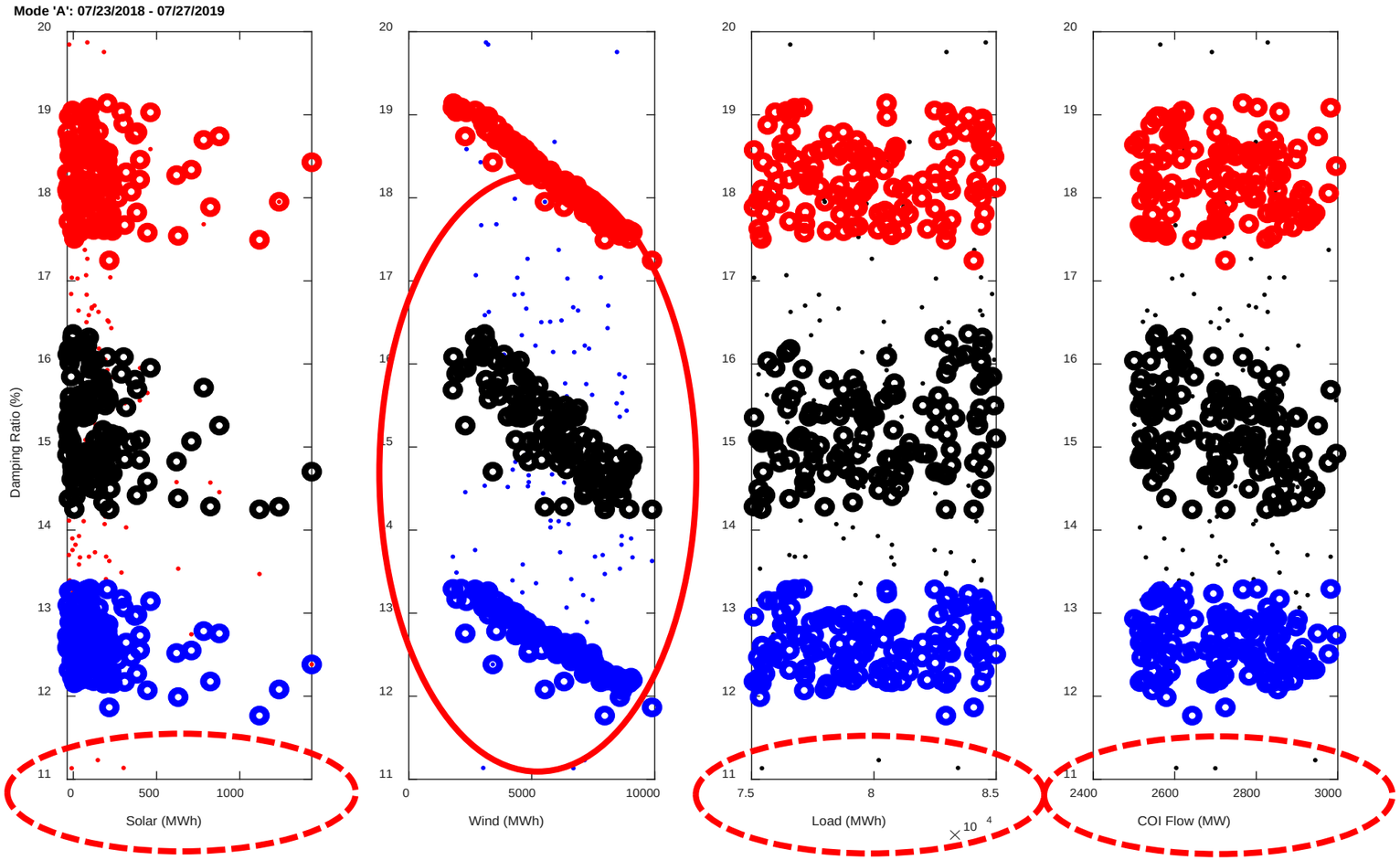
# Correlation Analysis for NS-A mode – Solar

- **Exclude COI flow impact** by choosing periods with a limited range of COI flow
- **Exclude wind renewable impact** by choosing periods with light wind generation
- **Exclude system load impact** by choosing periods with a limited range of system load



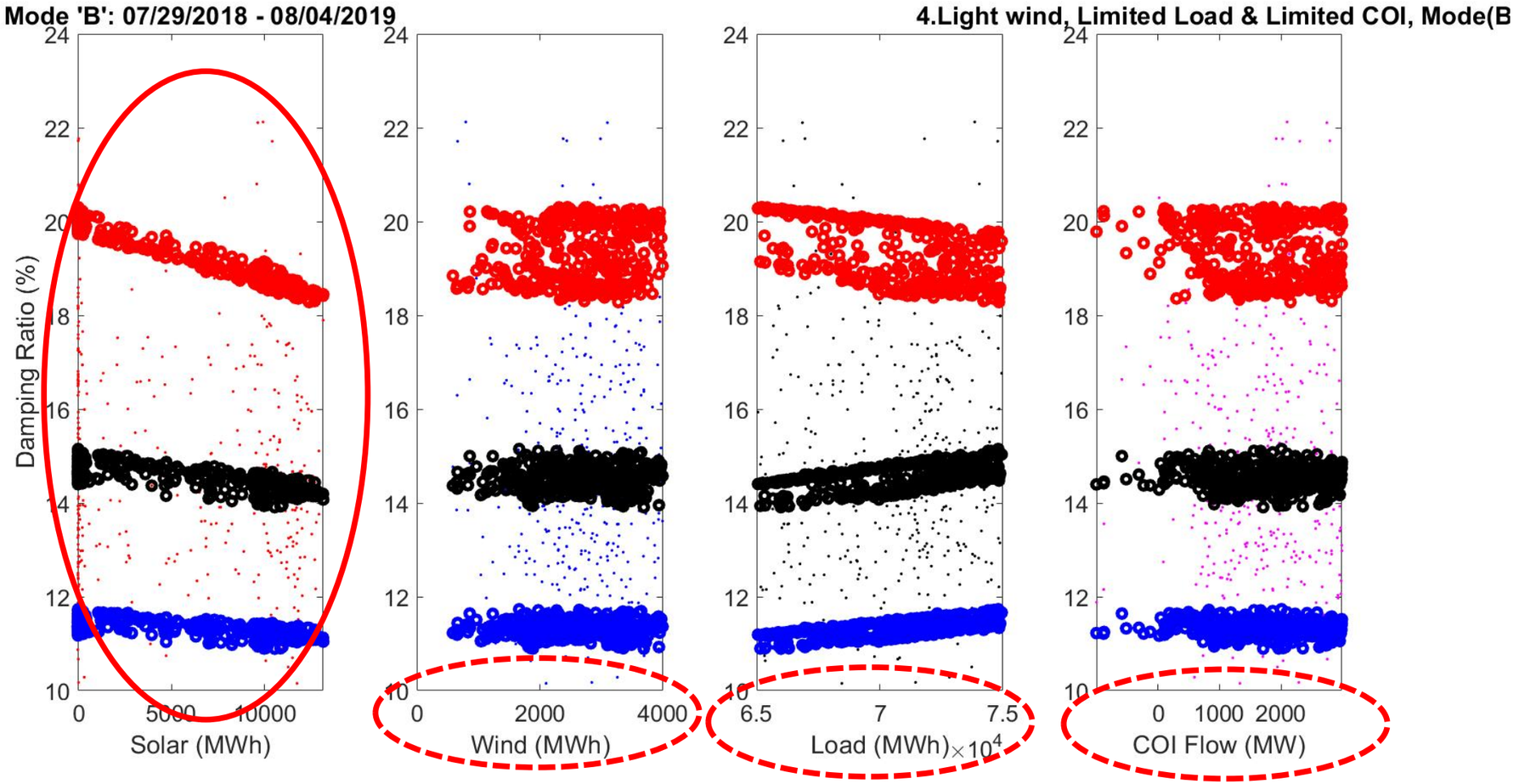
# Correlation Analysis for NS-A mode – Wind

- **Exclude COI flow impact** by choosing periods with a limited range of COI flow
- **Exclude solar renewable impact** by choosing periods with light solar generation
- **Exclude system load impact** by choosing periods with a limited range of system load



# Correlation Analysis for NS-B mode – Solar

- **Exclude COI flow impact** by choosing periods with a limited range of COI flow
- **Exclude wind renewable impact** by choosing periods with light wind generation
- **Exclude system load impact** by choosing periods with a limited range of system load



# Correlation Analysis for NS-B mode – Wind

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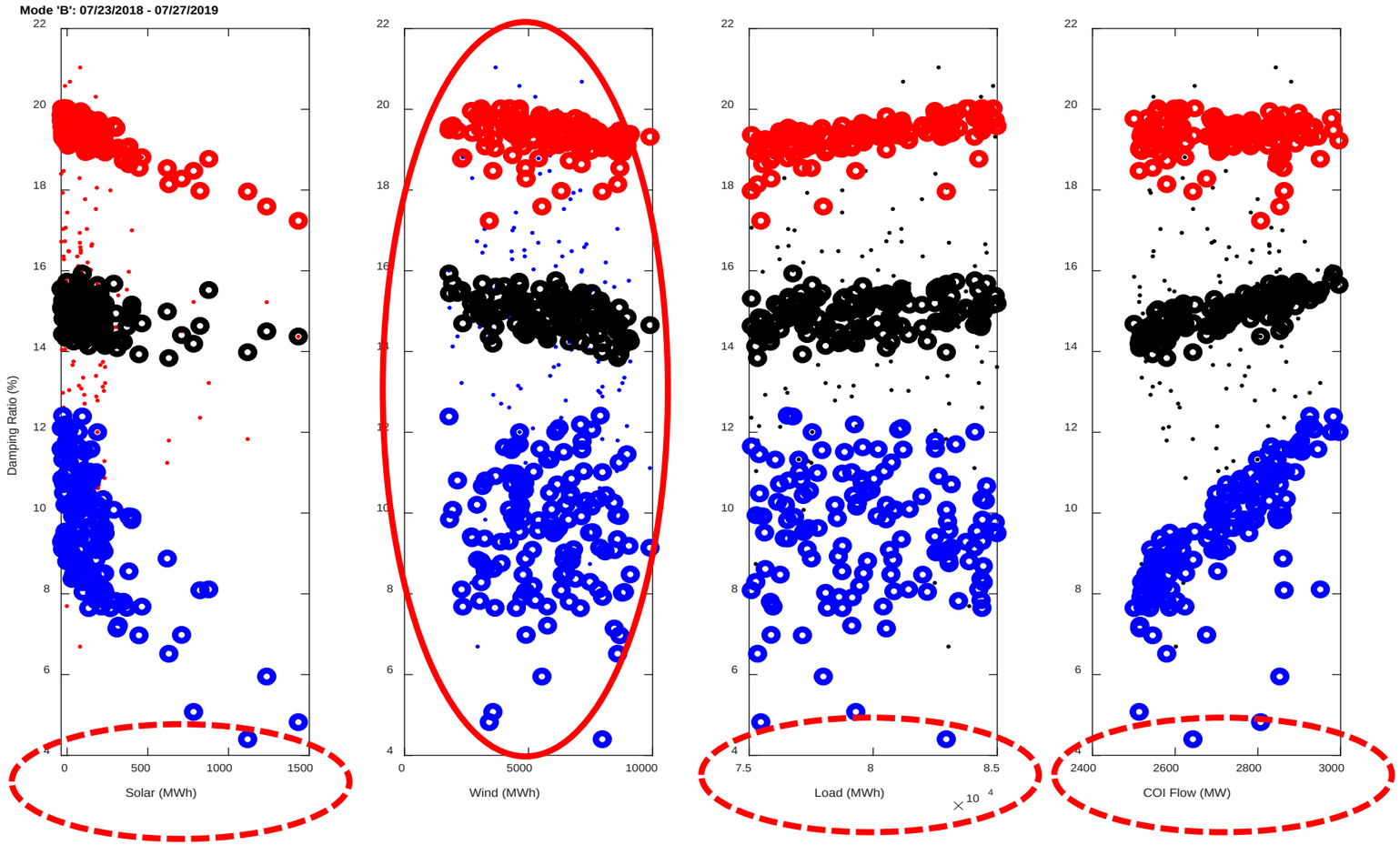
- **Exclude system load impact** by choosing periods with a limited range of system load



# Summary: Data-based Oscillation Assessment

- Impact on the NS-A damping ratio:
  - Higher renewable penetration level leads to lower damping ratio of NS-A
- Impact on the damping ratio of NS-B
  - Not conclusive

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# Model-based approach

# Methodology

- 2018 heavy summer operating WECC model used as the base-case
  - RES penetration level: 9%
- Several use-cases created by replacing synchronous generators with fully-converter based machine model
- Modal analysis using simulated data
  - Chief-Joseph brake insertion transient event used for generating ringdown oscillations
  - Multi-channel Prony method used to obtain estimates of system modes and mode shapes[1]
- Eigenvalue analysis performed to understand the trends observed in system modes

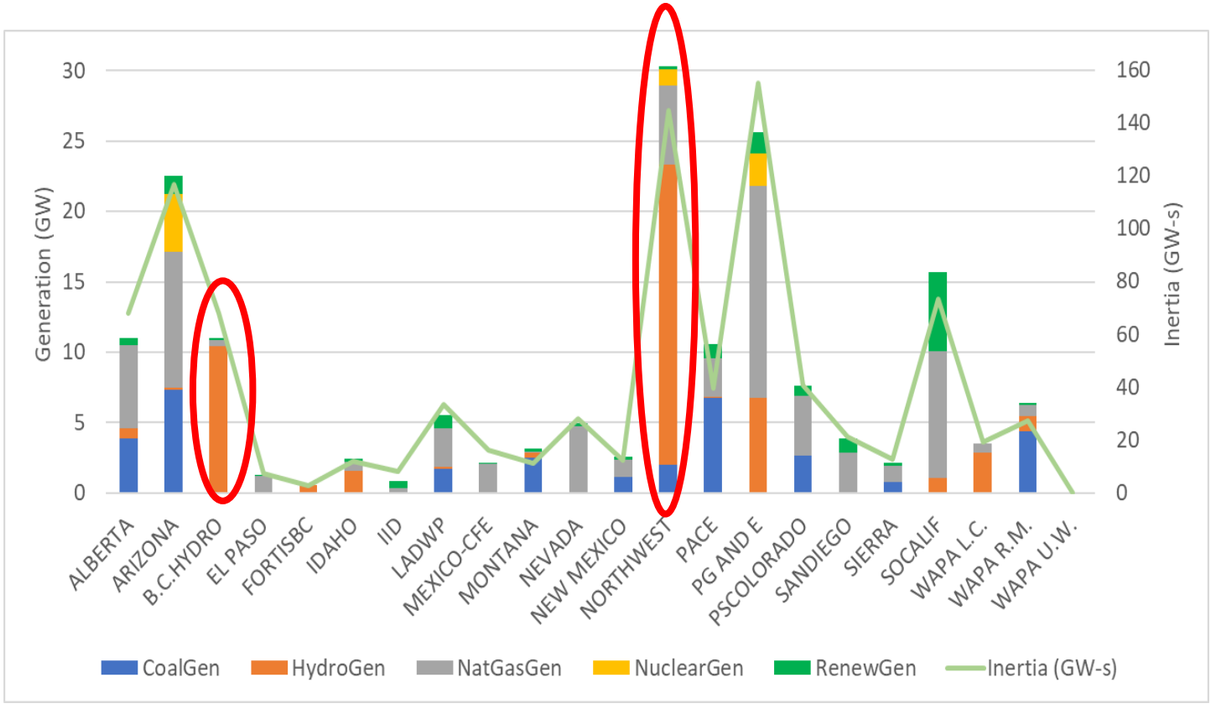



Figure: Area-wise generation mix and inertia for the base-case

[1] Trudnowski, Daniel J., J. M. Johnson, and John F. Hauer. "Making Prony analysis more accurate using multiple signals." *IEEE Transactions on power systems* 14.1 (1999): 226-231.

# Model-based Oscillation Assessment – Scenarios for Future trend analysis

- Several scenarios considered to assess the trends in modes for a system consisting of higher penetration of inverter-based renewable sources
  - System-wide increase of renewable generation
  - Increase of renewable generation in only specific area

# System-wide increased RES penetration level – S1

- Renewable 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 (Renewable energy sources) penetration of close to 60%.

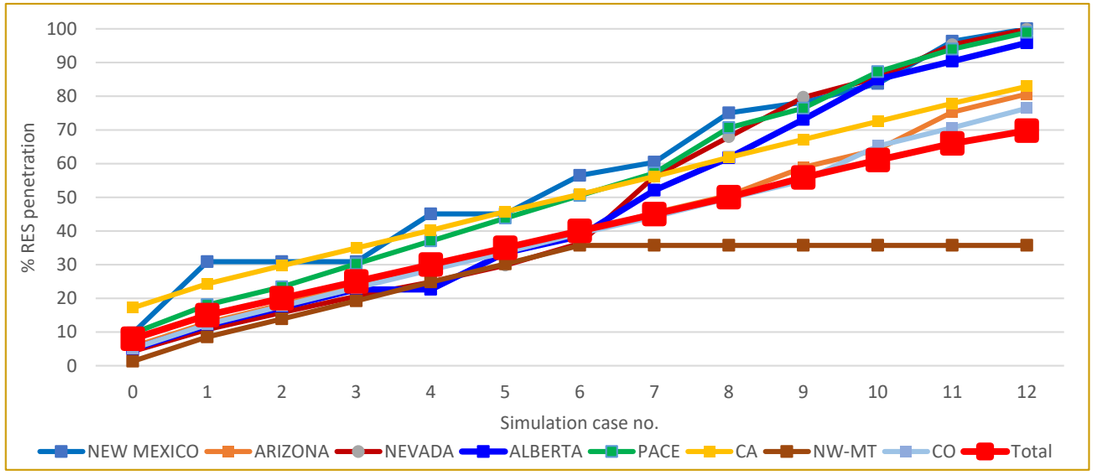



Figure: Renewable generation in different areas and system-wide for different cases in S1

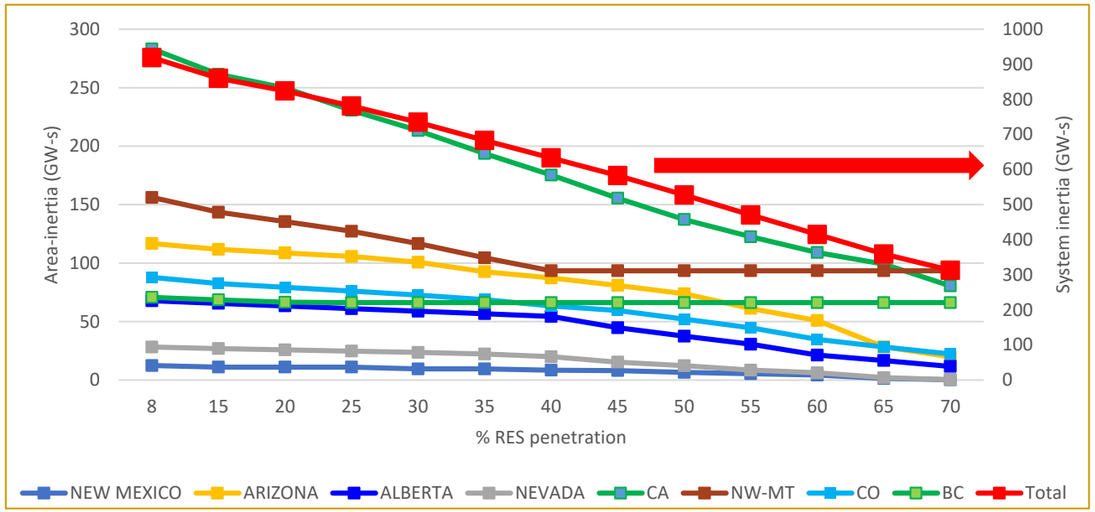
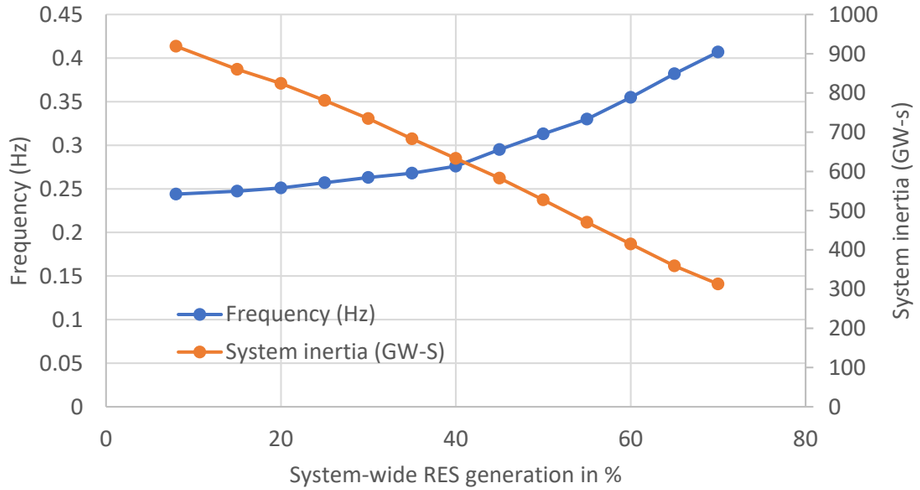
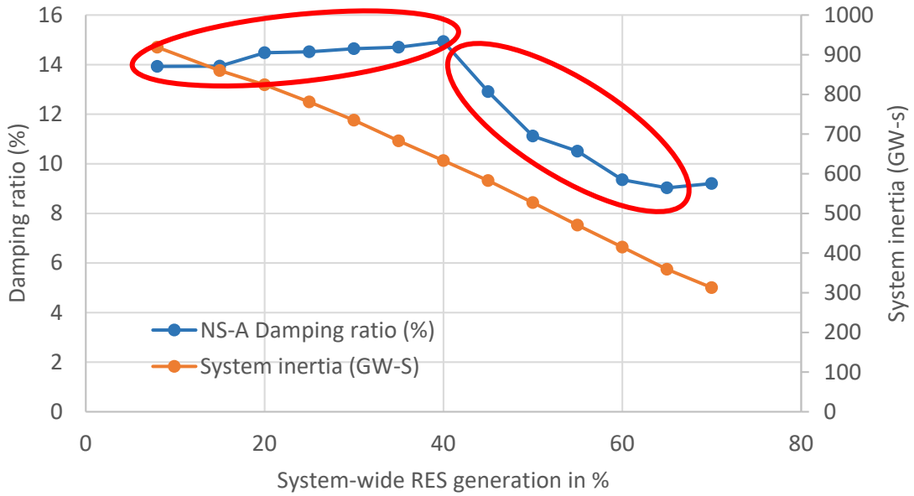


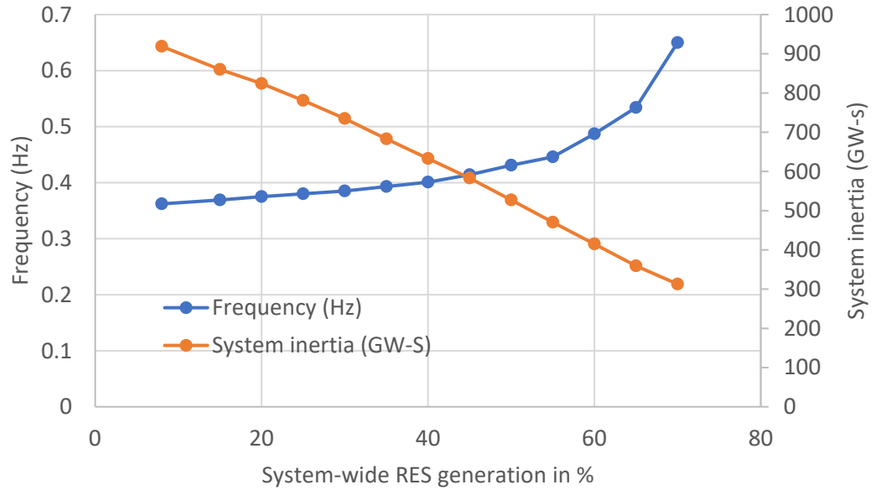

Figure: Change in inertia for different cases in S1

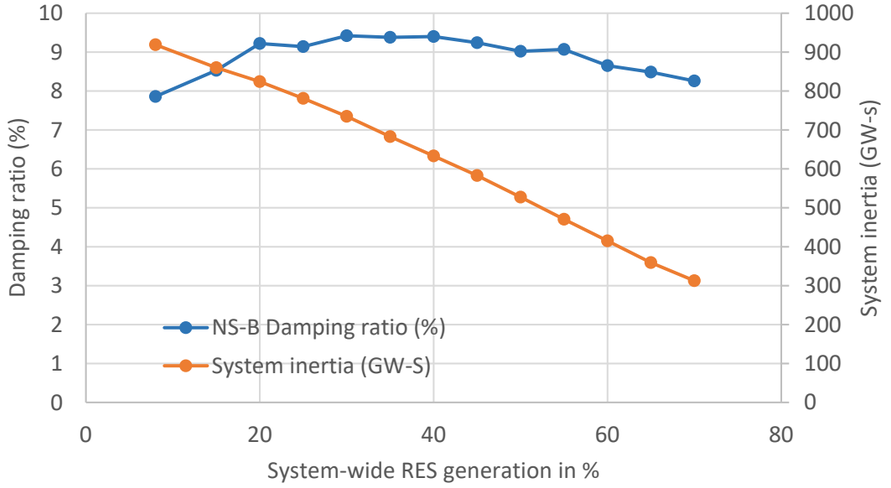
# Mode frequency and damping ratio estimates – S1



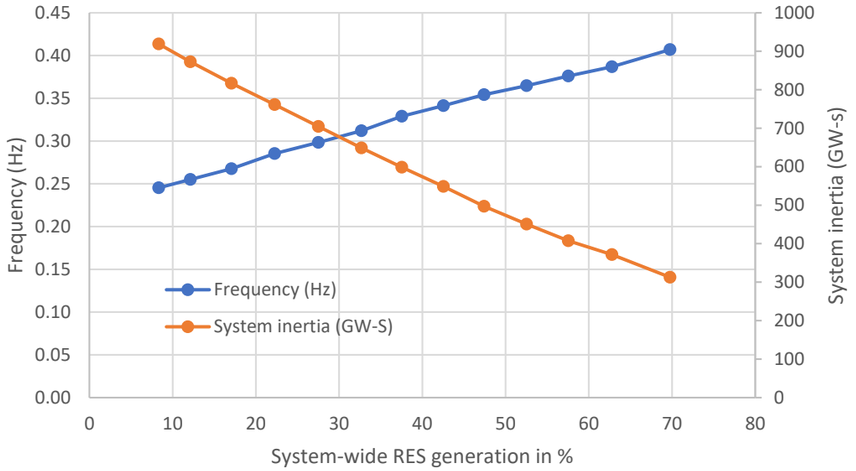

a. NS-A

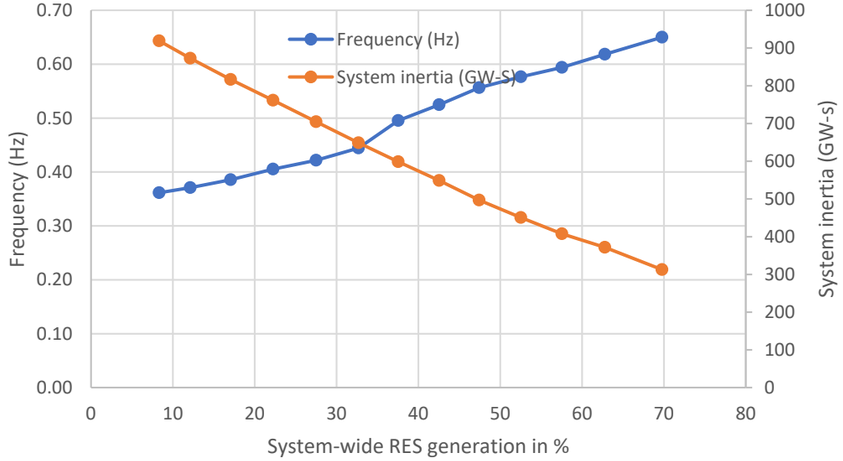


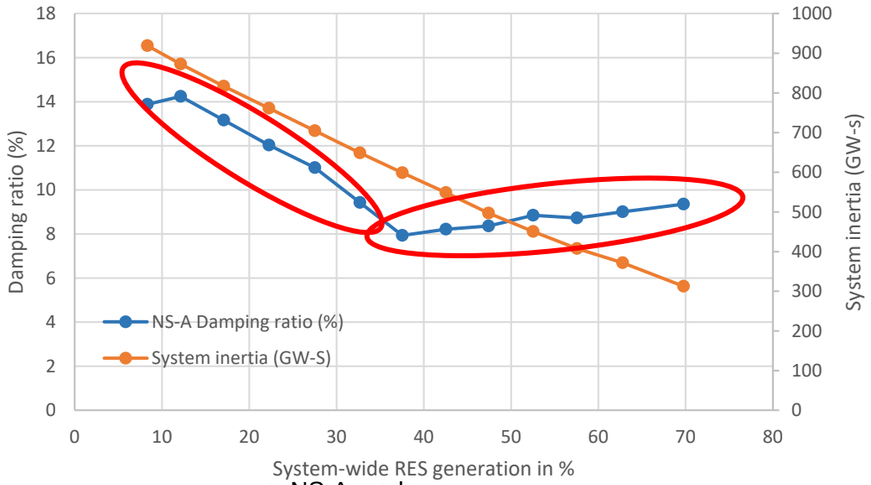




b. NS-B

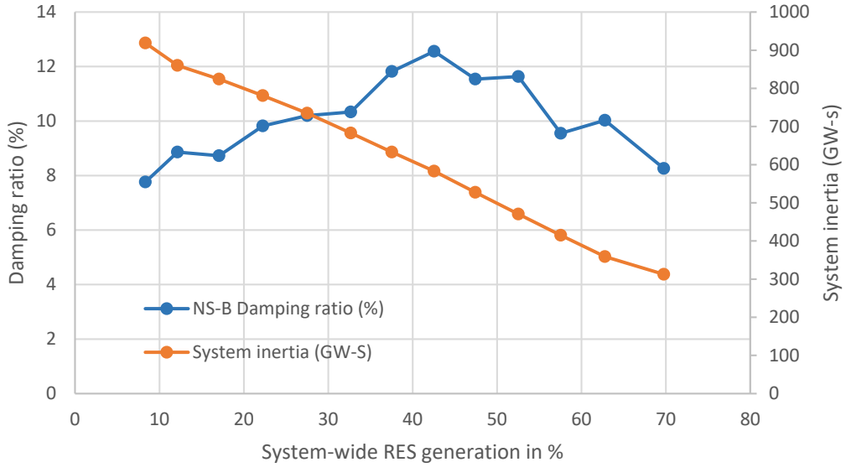
# Mode frequency and damping ratio estimates– S1 but reversing the order of generators being replaced



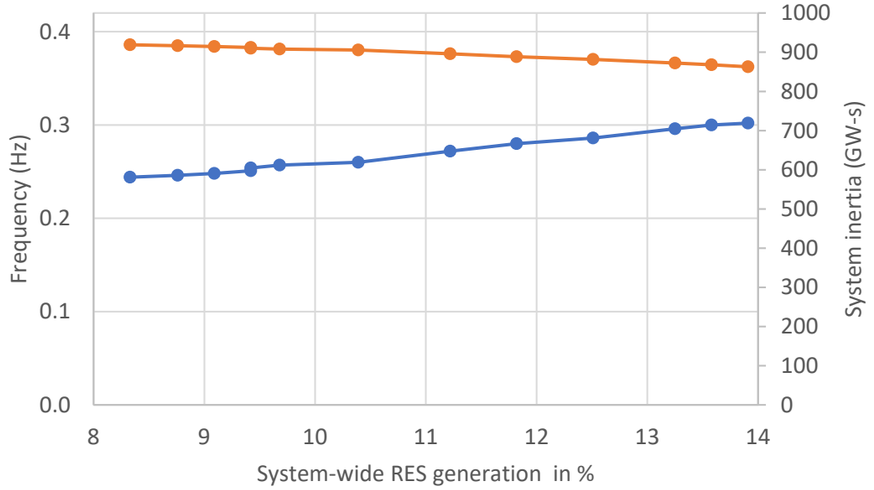

a. NS-A mode




b. NS-B mode

Figure: Impact of system-wide increased penetration of RES on N-S system modes

# Mode frequency and damping ratio estimates of NS-A mode – Area specific impact



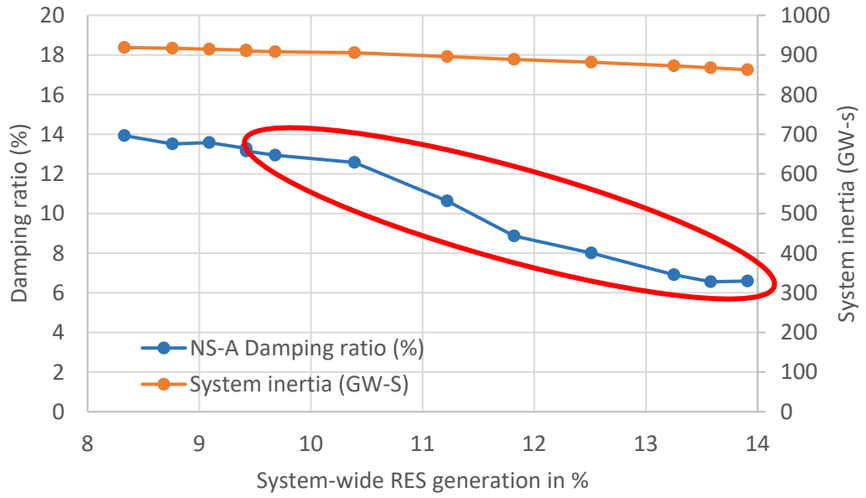
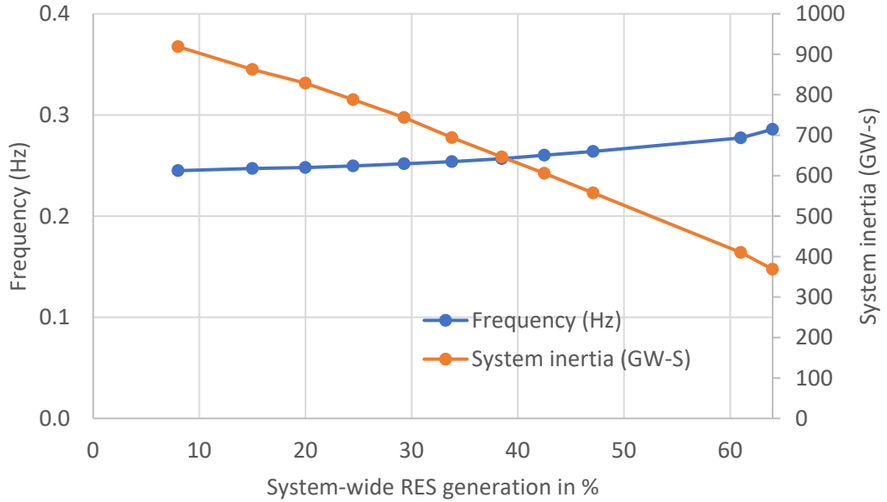




Figure: Impact of increased penetration of RES in Alberta on NS-A mode



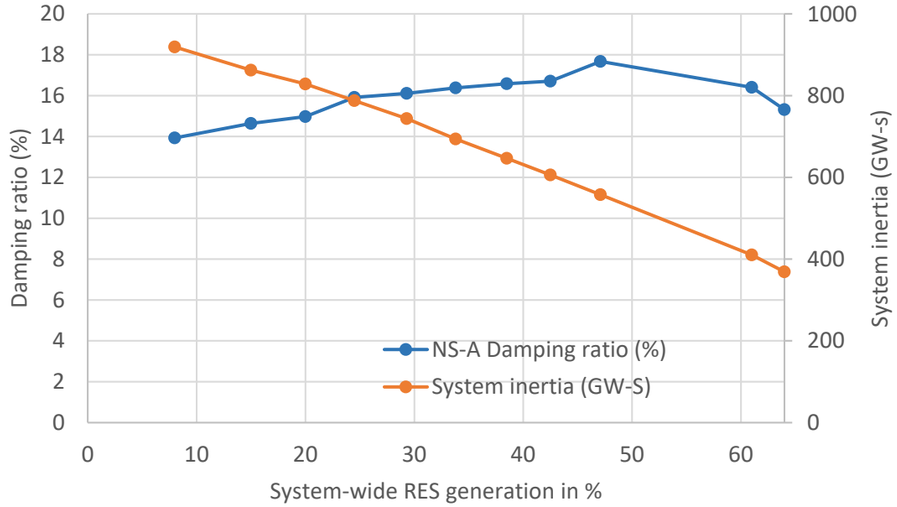




Figure: Impact of increased penetration of RES system-wide except in Alberta on NS-A mode

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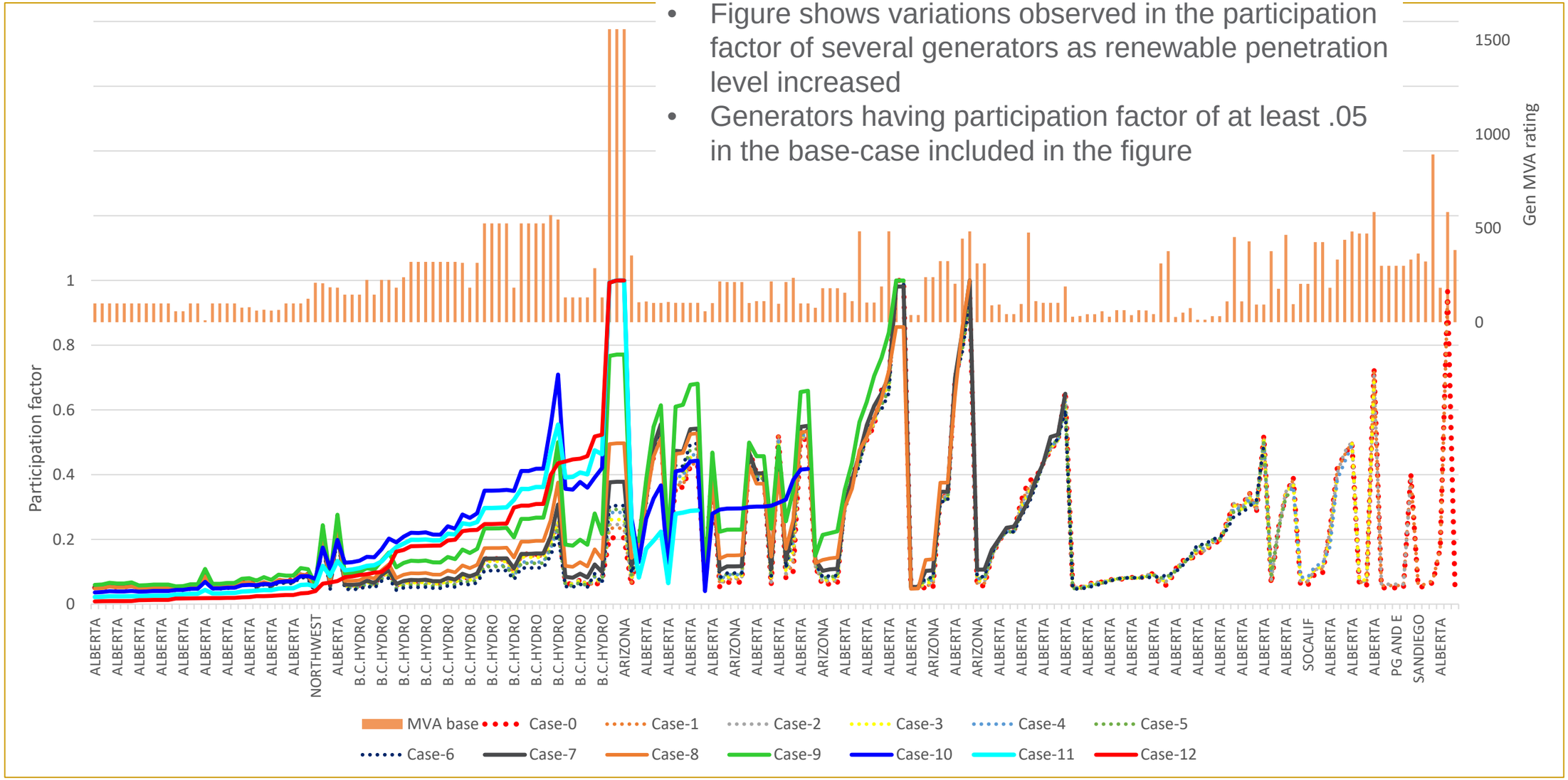
# Eigenvalue analysis

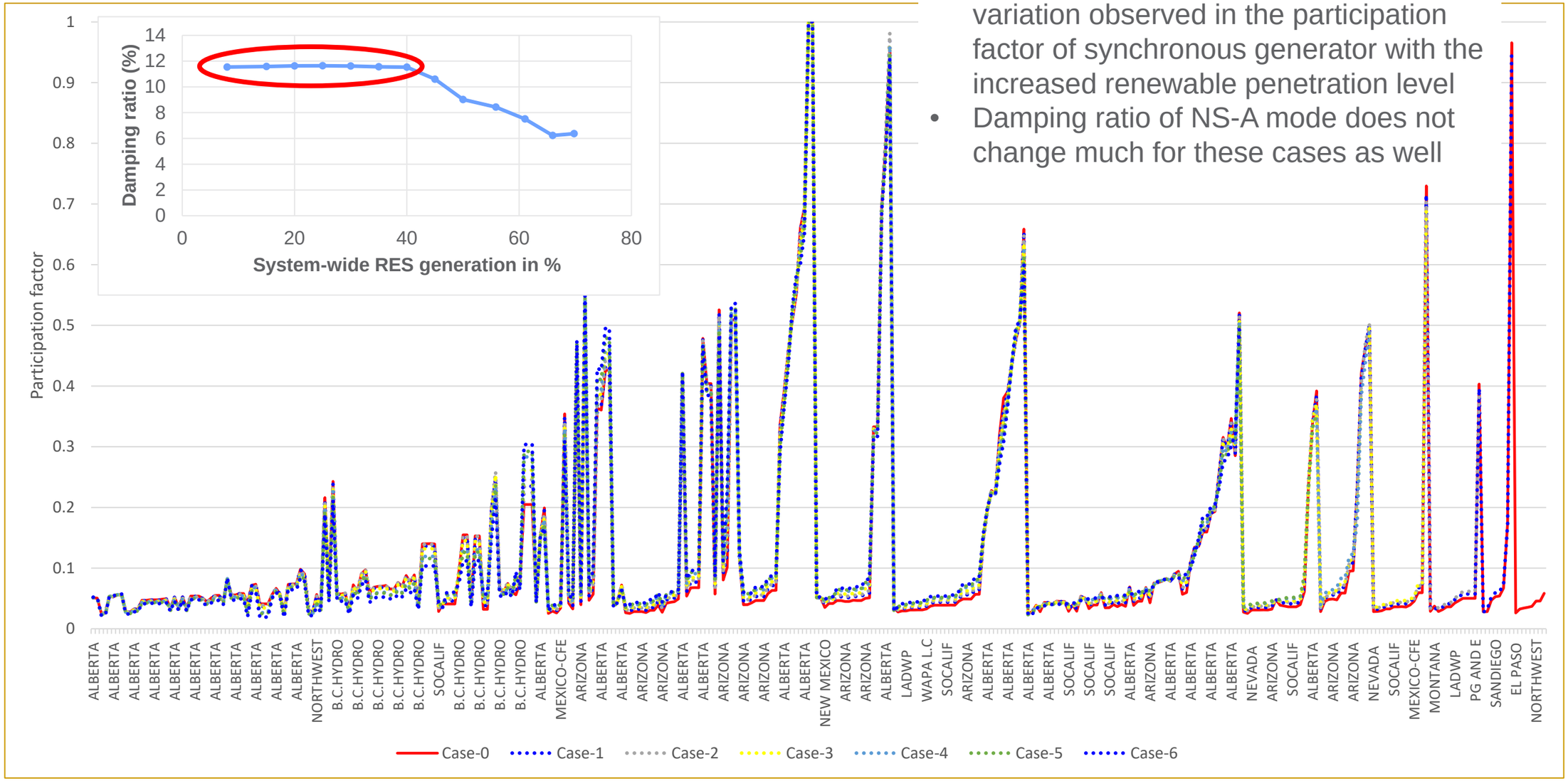
# Participation factor of generators for NS-A mode obtained using SSAT – S1

- 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

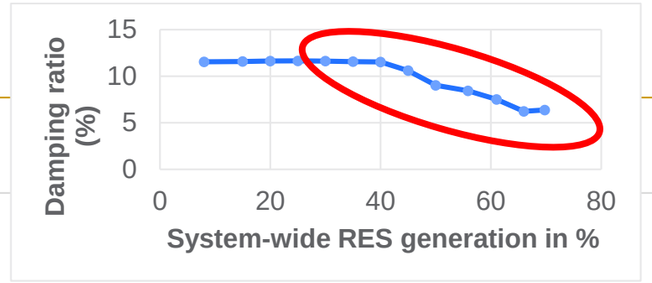


# Participation factor of generators for NS-A mode obtained using SSAT – S1

- 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 obtained using SSAT – S1




- From case-7 onward, participation factor of generators changes significantly
- Participation factor of Palo Verde units increases to 1 from case-11 onward

# Discussion and Conclusion

- Measurement-based analysis helped identify the correlation between the system modes and renewable penetration level
  - Analysis shows NS-A mode impacted more than NS-B mode
  - Aligns with the observations in the model-based analysis results
- Model-based analysis shows increased penetration of inverter-based renewable generation sources can impact frequency and damping ratio of system modes
  - Trends observed in the damping ratio of system modes related to the synchronous generators replaced by RES and their location
    - Trends explained by the change observed in the participation factors and/or mode shapes of remaining synchronous generators
  - Mode frequency increases with the increased renewable penetration level
    - However, change in the mode frequency not proportional to the change in the system inertia

# Acknowledgements


- We would like to acknowledge our gratitude to Ali Ghassemian Alireza.Ghassemian@hq.doe.gov, program manager of DOE-OE Advanced Grid Modeling (AGM) program, for funding this project.
- Also, we would like to thank Bahram Barazesh and Kent Davis from FERC for their great suggestions.

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# Thank you