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
Approach: Bringing together data and model for identifying oscillation trends

- Wide-area oscillation assessment for high renewable penetration level
  - Data-based oscillation assessment
    - Past oscillation freq. & damping trends
  - Model-based oscillation assessment
    - Future oscillation freq. & damping trends
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

- 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
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
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

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%.
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

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

a. NS-A mode

b. NS-B mode
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
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
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