Sub-Synchronous Oscillations in Power Systems

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Overview

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- **Impact of Sub-Synchronous Oscillations and the Mitigation Strategies**
- **Role of Measurement-based Tools to Mitigate Sub-synchronous Oscillations**
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Introductions

Introduction

- Sub-synchronous oscillations (SSOs) refer to the oscillations that occur at frequencies below the system's fundamental frequency (50/60 Hz).
  - SSOs do not involve coherent motion of all synchronous machines.
  - Involve interactions with series capacitors, converters, or turbine-generator shafts creating localized resonance effects.
- With the increasing penetration of inverter-based resources (IBRs), SSOs have become a major concern for grid stability.
  - Commonly occur in systems with series-compensated lines or inverter-based resources.
  - Series-compensated lines increase system power transfer capability but introduce sub-synchronous modes.
- This presentation will focus on two type of SSOs observed in power systems
  - Sub-synchronous resonance (SSR)
  - Sub-synchronous control interaction (SSCI).

Causes of Sub-synchronous oscillations

Causes of Sub-Synchronous Oscillations

- Planned or forced outages that result in inverter-based resources (IBRs) or conventional machines being radially connected to series-compensated lines can lead to SSOs.
- Series-compensated lines, when combined with system inductance, can create resonant conditions within the frequency range of 10 to 50 Hz.
- Sub-synchronous resonance (SSR)
  - SSR occurs when the frequency of the generator shaft modes closely matches with the resonant frequency of the grid.
- Sub-synchronous control interactions (SSCI)
  - Control loops of the IBRs can interact with the grid contributing negative damping at the resonant frequency causing SSOs.

Impact of system topology on Sub-Synchronous Oscillations

- The figure below presents passive impedance scan results, which illustrate the impedance observed from the generator for three different network topologies.
  - Results demonstrate the influence of system topology changes on SSOs.
  - In this example, the generator encounters a network resonant condition near 45 Hz only when it is connected radially to the series-compensated line.

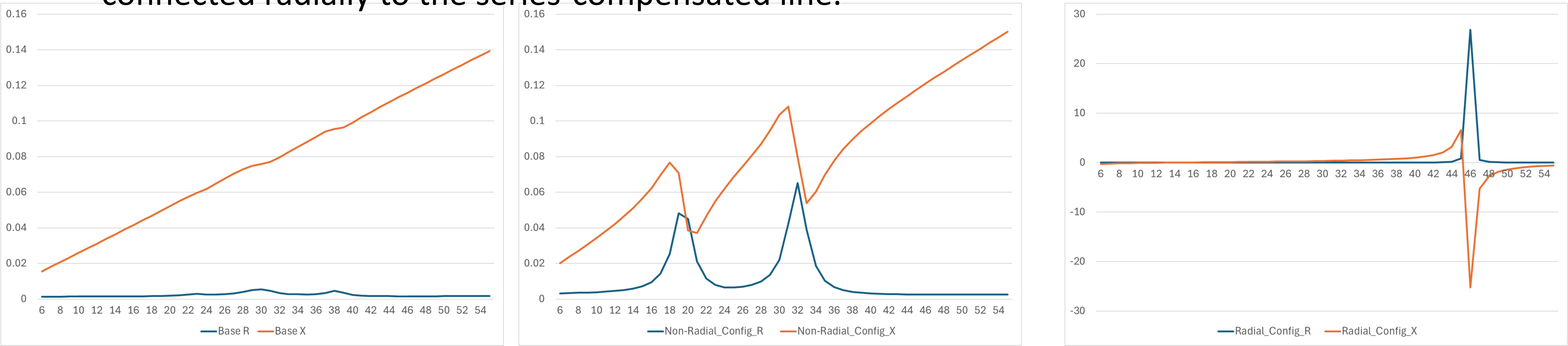

Figure: Passive impedance scan plots showing how the changes in system topology could result in SSR/SSCI concerns. a. Base-case with several lines connected to the bus connected to the generator under study b. Generator bus connected to series compensated line and one another non-radial line c. Generator bus radially connected to the series compensated line. (X-axis represents frequency in Hz and Y-axis represents resistance, R, and reactance, X, in p.u.)

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Impact of Sub-synchronous oscillations and the Mitigation Strategies

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Impact of Sub-Synchronous Oscillations

- Despite their localized nature, SSOs present significant challenges to the reliable operation of the grid, especially with the increasing integration of IBRs.
- Some of the impacts include:
  - Equipment damage
  - Tripping of generators with potential to result in a wide-area reliability issues
  - Reduced power transfer due to the SSO limits on the use of series compensated lines.
- Case Example: 2009 SSCI in South Texas
  - In 2009, SSCI in South Texas resulted in sustained oscillations with a magnitude of approx. 150% of rated voltage and caused tripping of additional transmission facilities and damage to the series capacitors and wind farm [1-2].

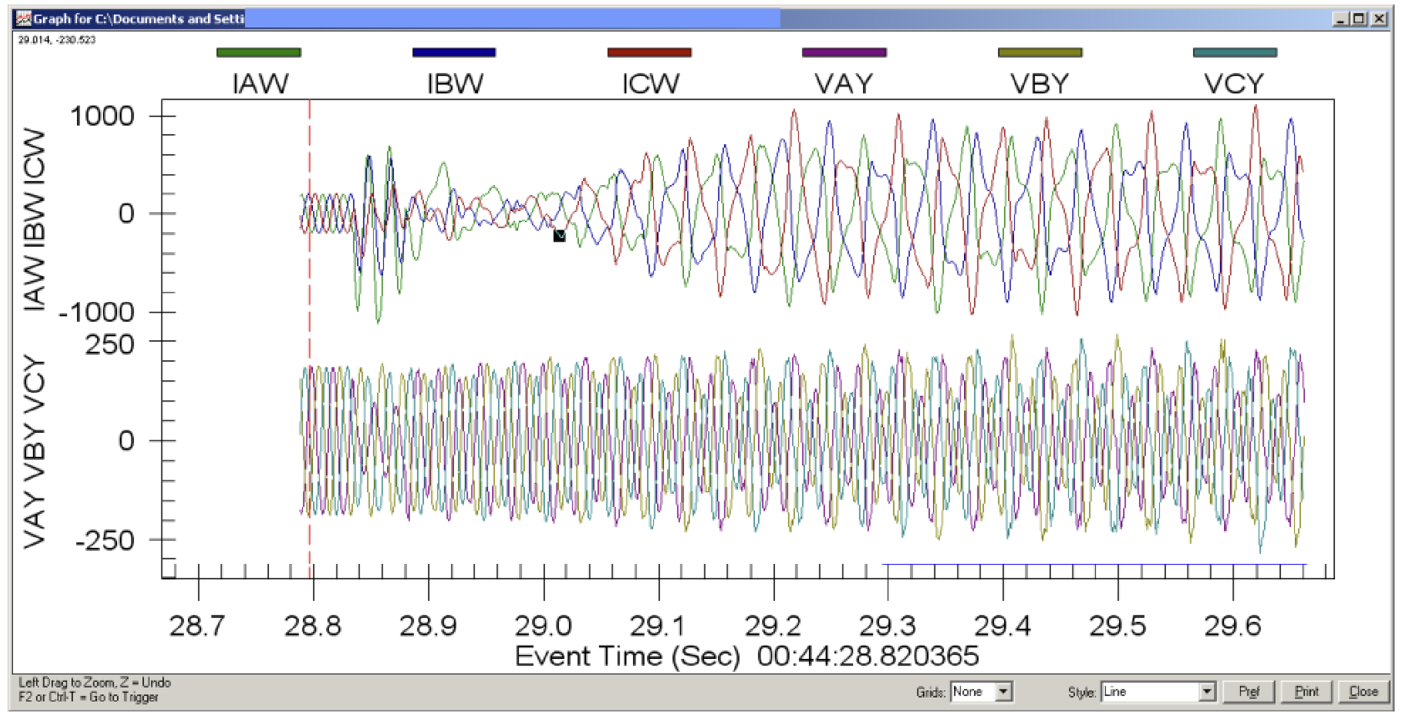

Figure: Voltage and current waveforms during SSO event in 2009 [1].

[1] Gross, Lawrence C. "Sub-synchronous grid conditions: New event, new problem, and new solutions." Proc. Western Protective Relay Conf. Vol. 2010. 2010.
[2] https://www.nerc.com/pa/rrm/ea/Lessons%20Learned%20Document%20Library/LL20110705_Sub-Synchronous_Interaction.pdf

Mitigation Strategies

- Due to the damaging nature of the SSOs, several strategies have been introduced to mitigate these oscillations.
  - A thorough investigation conducted in the planning phase to assess potential SSR/SSCI concerns for generation units or power electronics equipment located near series-compensated lines.
  - Preventive Measures (If Concerns are Identified)
    - Lowering Series Compensation Levels
    - Tuning IBR Control Parameters
    - Replacing Series Capacitors with thyristor-controlled series capacitors
    - Installing SSR Filters
    - Installing SSR Relays and Protection Schemes
    - Installing sub-synchronous damping controllers

Mitigation Strategies - Challenges

- Modeling Inaccuracies
  - Inaccuracies in PSCAD models can result in misleading results related to SSR/SSCI concerns.
- Grid Condition Variability
  - Many preventive measures require careful tuning and may not be effective under varying grid conditions.
- Need for Rapid Response
  - The damaging nature of SSOs demands quick detection and immediate action to prevent equipment damage.

Role of Measurement-Based Tools

- Model validation
  - Validating models can improve accuracy of the model-based studies performed to identify potential SSR/SSCI concerns.
- Real-Time Monitoring and Detection of SSOs
  - Measurement-based tools enable continuous tracking of system behavior, allowing operators to quickly detect SSOs as they occur.
  - The oscillations typically exhibit localized behavior, making it easier for the measurement-based tools to pinpoint the participating resources and series-compensated lines.
    - Frequency-band based energy detector, for example, can be helpful for detection and localization of the SSOs in power systems.
  - Tools needed that can provide early warning for the possibility of the occurrence of SSOs that allow operators to take preventive actions.

Conclusions

Conclusions

- The damaging nature of SSOs makes it a critical concern for grid stability and reliable operations with the increasing integration of IBRs and series-compensated lines
  - Despite their localized nature, SSOs can cause equipment damage, generator tripping, and reduced power transfer, leading to potential wide-area reliability issues.
- With changing grid conditions, planning studies used to identify potential SSR/SSCI risks may not always be sufficient.
- Timely detection and prompt mitigation actions are essential to prevent the damaging impacts of SSOs.
- Measurement-based tools can play a critical role in the early detection of sub-synchronous issues, enabling operators to take preventive actions.

Thank You!

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