Cigre TB 909
"Guidelines for Subsynchronous Oscillation Studies in Power Electronics Dominated Power Systems"

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Different Chapters in TB 909

1. Introduction
2. Classification of Subsynchronous Oscillations in Power Systems
3. Industry Practices, Challenges and Experiences Related to SSO Issues
4. Screening of Potential SSO Risk
5. Detailed Evaluation of SSO
6. SSO Mitigation and Prevention
7. Monitoring and Protection Mechanisms for SSO
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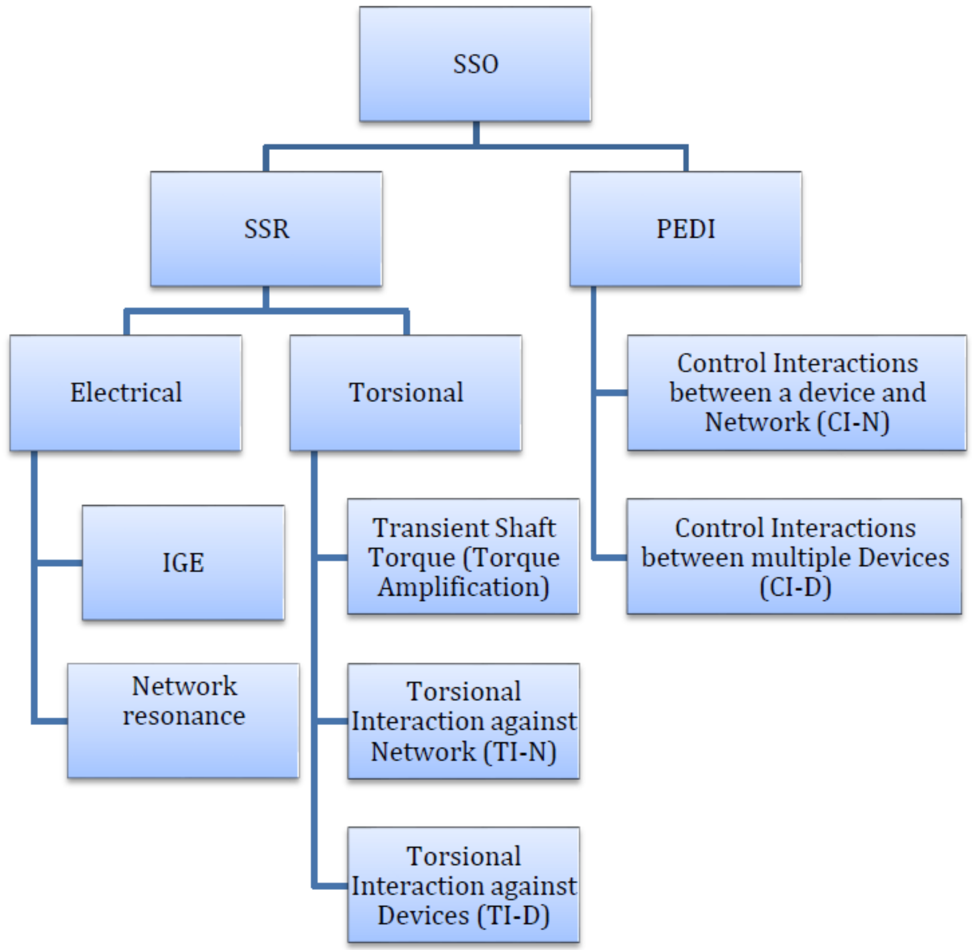
Classification of SSO

- **SSR:** Subsynchronous resonance can be a purely electrical resonance or a manifestation of both electrical and torsional dynamics.
- **IGE:** (Induction Generator Effect) The electrical system of a rotating machine offers a negative resistance to a subsynchronous network resonance mode resulting in a net negative resistance.
- **PEDI:** The integration of PE based devices can participate in subsynchronous control interaction (SSCI). These interactions, often caused by device controllers, can occur between a power electronic device and the network or between two devices across the network.



Subsynchronous Resonance - Torsional

Torsional Interaction Against Network (TI-N)

- Subsynchronous Resonance Torsional Interaction (SSR TI) can be caused by network creating electrical resonance. If electrical damping is negative and exceeds mechanical damping, torsional oscillations grow, causing fatigue and damage to the shaft.

Torsional Interaction Against Devices (TI-D)

- Subsynchronous Resonance Torsional Interaction (SSR TI) with a PE based device.
- PE based device can interact with torsional mode of mechanical system of generator.

Power Electronic Device Interactions (PEDI)

Control Interactions Between a Device and Network (CI-N)

- CI-N refers to control-related interactions between devices and the electrical grid.
- Interaction with passive elements of the network.

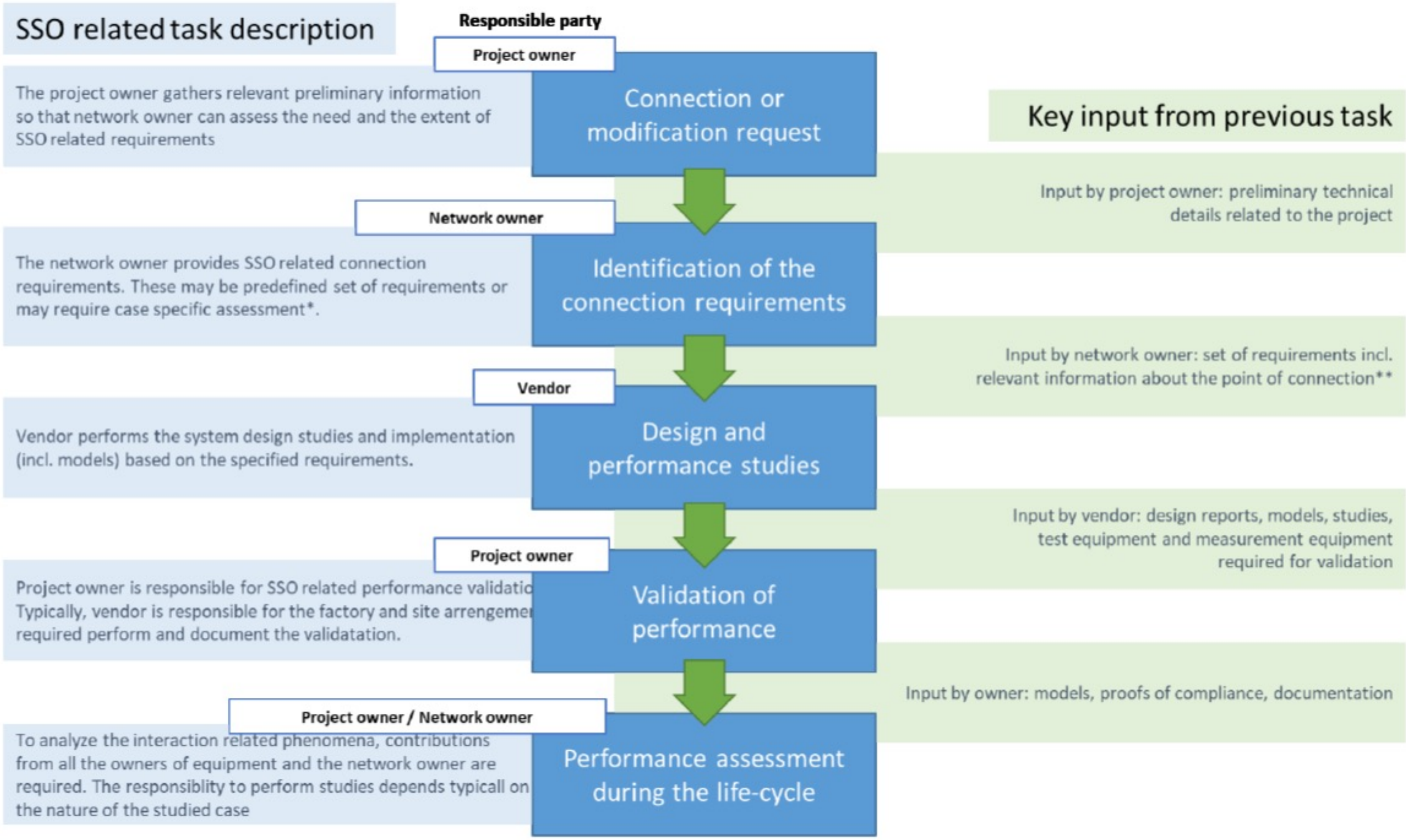
Control Interactions Between Multiple Devices (CI-D)

- Control interactions in power systems occur when device controllers and the network interact, causing instability and oscillations.
- These issues often arise in weak grids or from improper control settings and require careful analysis and design to mitigate.
- Interactions can occur in strong grid as well, depends on the system conditions.
- Critical role of advanced system studies.

SSO Classification in Terms of Interacting Components

Main Category	Subcategory	Interacting Component A	Interacting Component B
SSR (Electrical)	Induction Generator Effect (IGE)	Series Capacitors, other L-C resonant circuits (filters, line shunt compensation)	Synchronous and Asynchronous Machines (generators, motors), WTG Type 1-3
	Network Resonance		Power electronics (converters and controls)
	Wind-SSCI		WTG Type 3
SSR (Torsional Oscillation)	Transient Shaft Torques (TST)/Torque Amplification (TA)	Synchronous Machines (generators, motors), WTG Type 1-3 (shaft)	Series Capacitors (Transient)
	Torsional Interaction (TI)/ Torsional Interaction against Network (TI-N)		Series Capacitors (steady state)
	Torsional Interaction against Devices (TI-D)		Power electronics (converters and controls)
Power Electronic Device Interactions	Control Interactions against Network (CI-N)	Power electronics (converter and controls): WTG Type 3-4, IBR and other converters (HVDC, FACTS, SVC)	AC grid (weak grid)
	Control Interactions against Devices (CI-D)		Power electronics (converters and controls)

High level SSO study process for a connection or modification request



Screening of Potential SSO Risk

Unit Interaction Factor (UIF)

$$UIF_i = \frac{MVA_{\mathrm{HVDC}}}{MVA_{\mathrm{Gen}}}\left[1 - \frac{SC_{\mathrm{Ni}}}{SC_{\mathrm{Total}}}\right]^2$$

- This formula is commonly used, but it is not suitable for non-radial systems.
- It is normally recommended a UIF threshold of 0.1 for assessing SSTI risk with conventional converters, but VSC systems may require lower thresholds (0.01–0.02) for detailed analysis.

Impedance model-based analysis

- **Passive frequency scan** identifies resonance conditions and helps select severe contingencies for EMT analysis. However, it cannot account for system nonlinearities, fault characteristics, switching actions, or torsional amplification, so detailed EMT analysis is necessary for accurate results.
- **Dynamic frequency scan:** The frequency scanning method screens for critical operating conditions using frequency-dependent impedances and linear approximations, addressing only small-signal instabilities near stable points. However, it cannot handle large disturbances or nonlinear effects, and results depend on factors like control system, generation levels, and harmonic injection methods.

Radiality Factor (RF)

$$RF_{(f)} = \frac{2\left|Y_{12(f)}\right|}{\left|Y_{1G(f)}\right| + \left|Y_{2G(f)}\right| + 2\left|Y_{12(f)}\right|}$$

- The radiality factor is a screening method that evaluates the electrical closeness of two dynamic devices based on network impedance to assess the risk of interactions.

Available Screening Methods per SSO Type

Main Category	Unit Interaction Factor	Passive Frequency Scan	Dynamic/Hybrid Frequency Scan	Radiality Factor
Induction Generator Effect (IGE)		✓	✓	
Network Resonance		✓	✓	
Wind SSCI		✓*1	✓	
Torsional Interaction against Network (SSR TI-N)		✓	✓	
Torsional Interaction against Devices (SSR TI-D)	✓*2			✓
Control Interactions against Devices (SSCI-D)			✓*4	✓*3
Transient Shaft Torques (TST)/Torque Amplification (SSR TA)		✓	✓*4	
Control Interactions against Network (SSCI-N)			✓	

**1 – Passive frequency scans can be used at the early planning stage of a project to identify the potential network resonances identified at the POC.*

**2 – UIF calculations are applicable only for power electronic devices transferring power (e.g., HVDC systems) which are connected to the grids without series compensation in the vicinity.*

**3 – Radiality factor can only be used to determine the electrical closeness of any two devices in the system within subsynchronous frequency. The electrical closeness can be used as a possible indicator for controller interactions.*

**4 – Significant evidences are not yet available on the effectiveness of dynamic frequency scans for*

Detailed Evaluation of SSO

EMT Simulations

- EMT simulations analyze fast power system transients and are essential for subsynchronous oscillation studies
- Transient stability analysis lacks accuracy for SSO purpose.

Small signal stability analysis using Eigen analysis techniques

- Small signal stability analysis evaluates the electromechanical oscillations of interconnected power systems by linearizing nonlinear dynamics at a steady-state operating point.
- The system matrix's eigenvalues are analyzed to determine stability, damping, and oscillatory modes.
- Participation factors identify device contributions to oscillations.

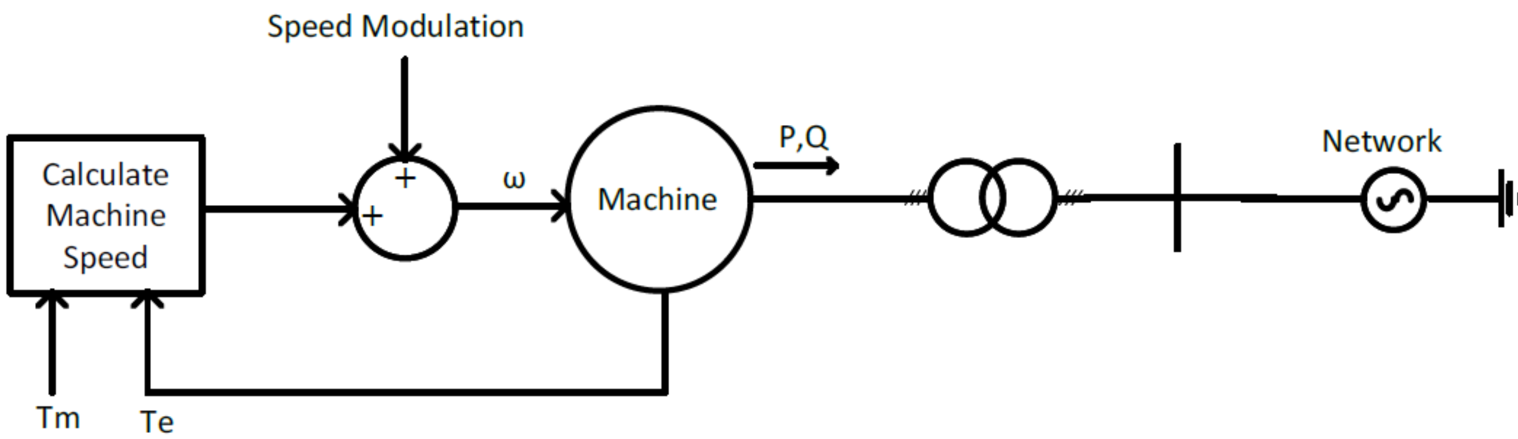
EMT modelling requirements

- Detailed models of generators
- Size of the network
- Transformer saturation
- Surge arrester data
- Frequency dependent line models
- Series capacitors
- Load flow conditions
- Device dispatch level and units in service
- Nearby thermal generators on/off

Evaluation of Electrical damping for SSTI

Electrical damping (De) is calculated using EMT simulations by injecting a low-amplitude perturbation into the generator's mechanical power and varying its frequency in small steps within the subsynchronous range.

$$D_e(\omega) = Real\left(\frac{\Delta T_{eg}}{\Delta \omega_r}\right)$$



SSO Mitigation and Prevention

- Operational restrictions
- Control adjustments
- Subsynchronous damping controllers (SSDCs)
- Adjustments to series capacitors
- Adjustments to power plants
- Introduction of shunt compensation (SVCs and STATCOMs) with SSO damping controllers

Recommendations by TB 909

- Understanding of the SSO categories
- Screening studies
- Detail studies
- Mitigation Measures
- Monitoring and Protection
- Implement steps systematically: **Screening → Detailed Studies → Mitigation → Monitoring**.