Analysis of Sub-synchronous Frequency Interactions in Power Systems Using TG*SSR*

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Outline

- Introduction to TG*SSR*
- Applications
  - Generator-turbine - series capacitor SSR
  - Generator-turbine – HVDC torsional interactions
  - Generator-turbine – VSC torsional interactions
  - Wind plant - series capacitor SSR
- Applicability in Modern Power Systems

Introduction to TG*SSR*

- Dynamic phasor based small signal stability assessment.
  - Not another small signal stability program meant for electromechanical oscillation analysis
  - Network dynamics are modelled using dynamic phasors.
  - Generator stator dynamics are modeled.
  - Models are accurate up to the frequency at which the system harmonics and the frequency dependency of network components can be ignored.
  - Main focus is on sub-synchronous frequency range.

Introduction to TGSSR

- Process

Input
- Read PSS/E raw data
- Read Dynamic data

Process-1
- Create linearized models of dynamic devices
- Combine with dynamic phasor network model

Output
- Save A and B matrices ($\Delta\dot{X} = A\,\Delta X + B\,\Delta U$) to text files
- Save state and input data to text files

Process-2
- Eigen analysis of A matrix
- Small signal time domain simulations

Output
- Eigen values and vectors, participation factors
- Polar plots, frequency responses

Introduction to TG*SSR*

- Present Capabilities
  - Synchronous generator models including exciters, governors, stabilizers (PSS) and multi-mass turbine units.
  - Single and double cage induction generator/motor models.
  - Network components – Tx lines, two and three winding transformers, series capacitors and zero impedance lines.
  - Static and dynamic load models.

Introduction to TGSSR

- Present Capabilities
  - Monopole and Bipole HVDC models including detailed controllers and DC transmission system.
  - Monopole and Bipole VSC models.
  - SVC and STATCOM models – Detailed and PSS/E type.
  - Wind plant models (DFIG type)
  - *The models have been validated against PSCAD*

Introduction to TG*SSR*

- Applications
  - Generator-turbine – Series capacitor sub-synchronous resonances.
  - Generator-turbine – HVDC torsional interactions.
  - Wind turbine – Series capacitor sub-synchronous resonances.
  - HVDC control interactions and DC resonance issues.
  - Multi-in-feed HVDC interactions.

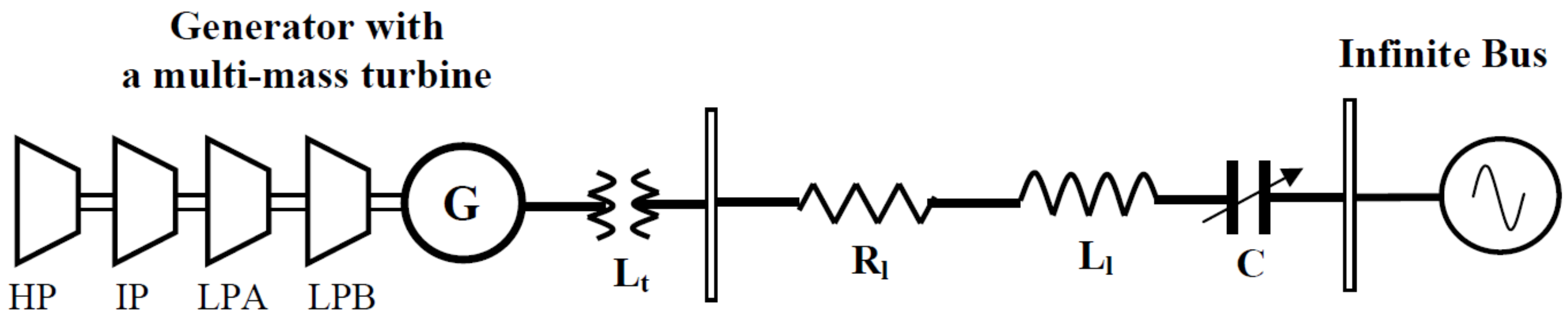
Introduction to TGSSR

- Applications
  - All other sub-synchronous frequency interactions in power systems (Interactions of FACTS devices, Network resonances etc.)
  - Controller tuning and sub-synchronous damping controller design.
  - Analysis of Eigen properties to determine the locations for damping controllers.

Introduction to TG*SSR*

- Largest System Analyzed
  - Manitoba Hydro System
    - More than 400 buses
    - About 100 current injection devices
    - Bipoles 1, 2 and 3 (proposed)
    - About 5000 state variables

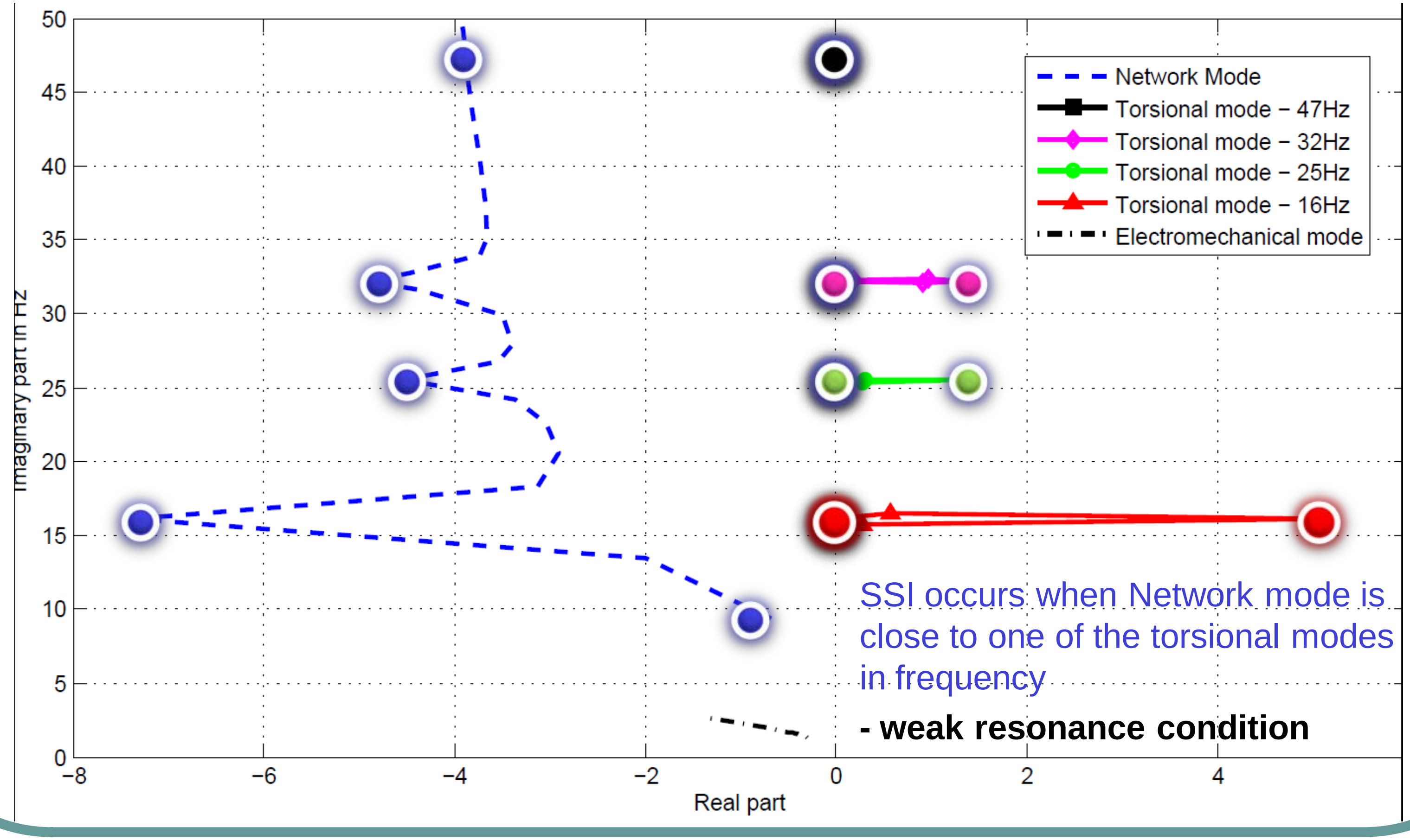
Applications – Generator-Series Cap SSR



- Series cap – generator electrical resonance (self excitation)
- Network (series cap-gen) interaction with torsional oscillations.

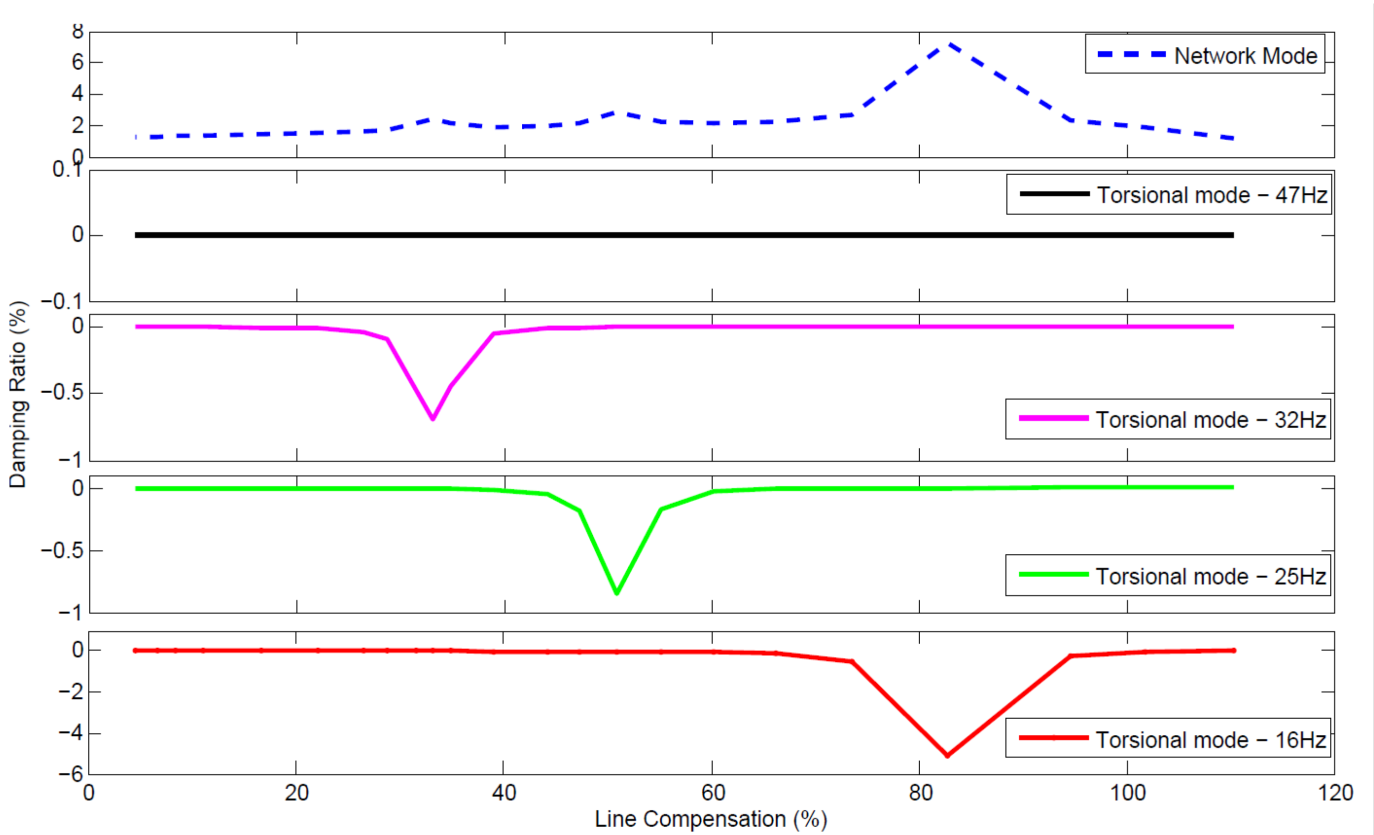
Applications – Generator-Series Cap SSR

- A network mode interacts with a torsional mode.



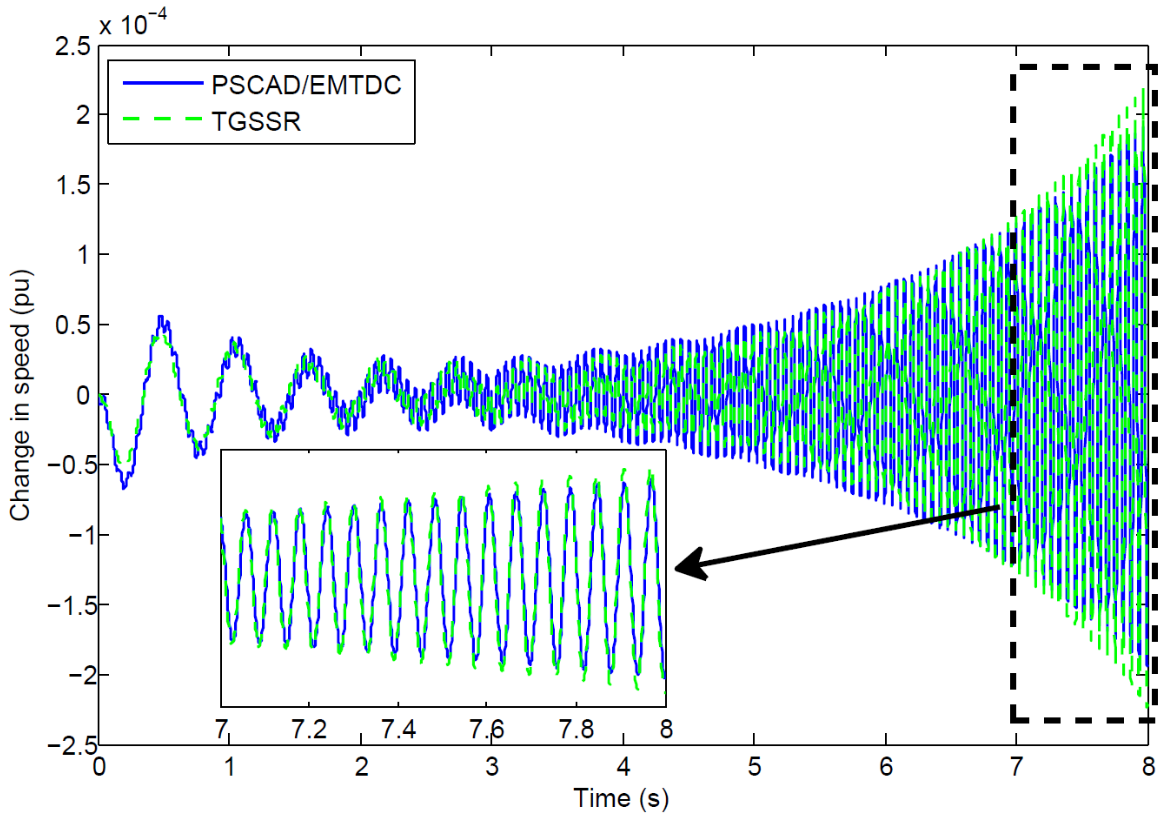
Applications – Generator-Series Cap SSR

- A network mode interacts with a torsional mode.

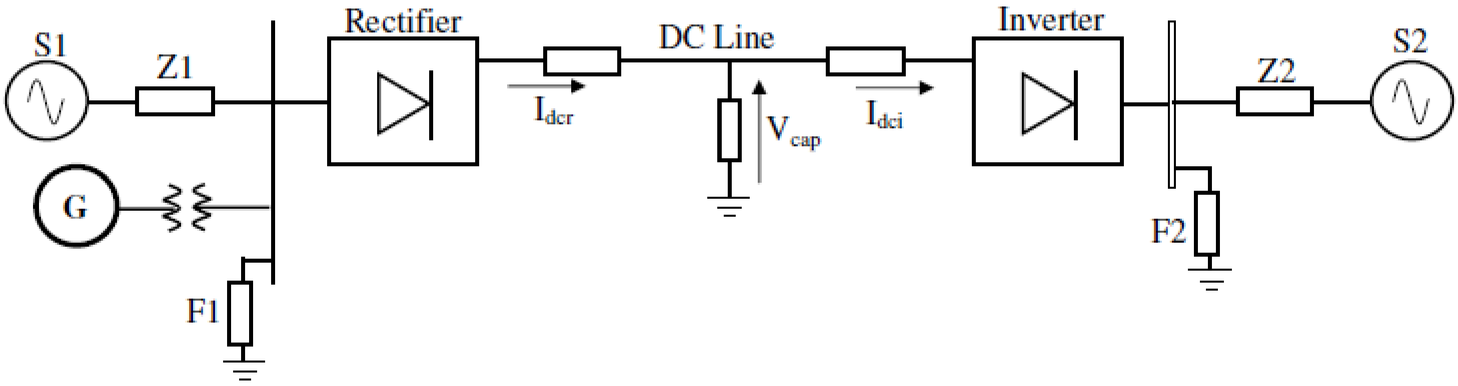


Applications – Generator-Series Cap SSR

- When Network mode is close to 16 Hz torsional mode.



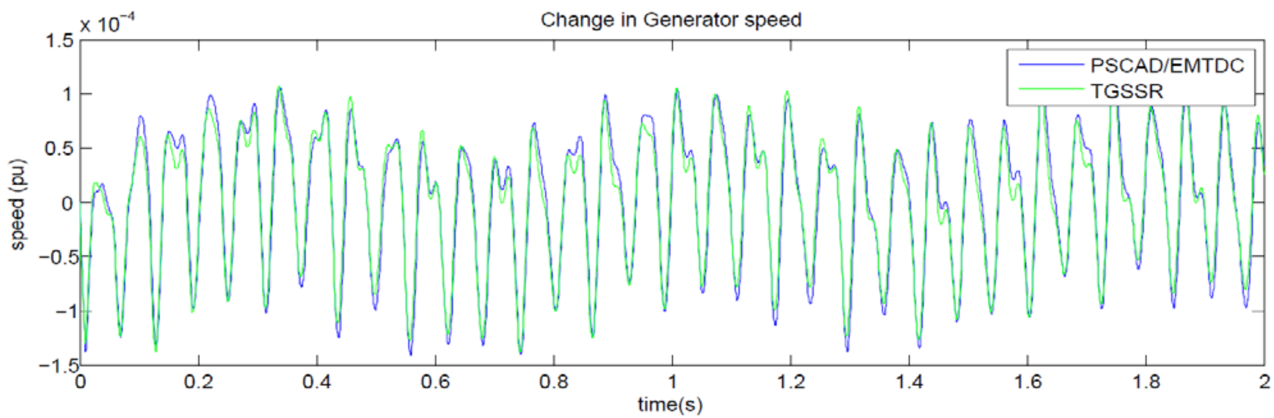
Applications – Generator-HVDC Torsional Interactions

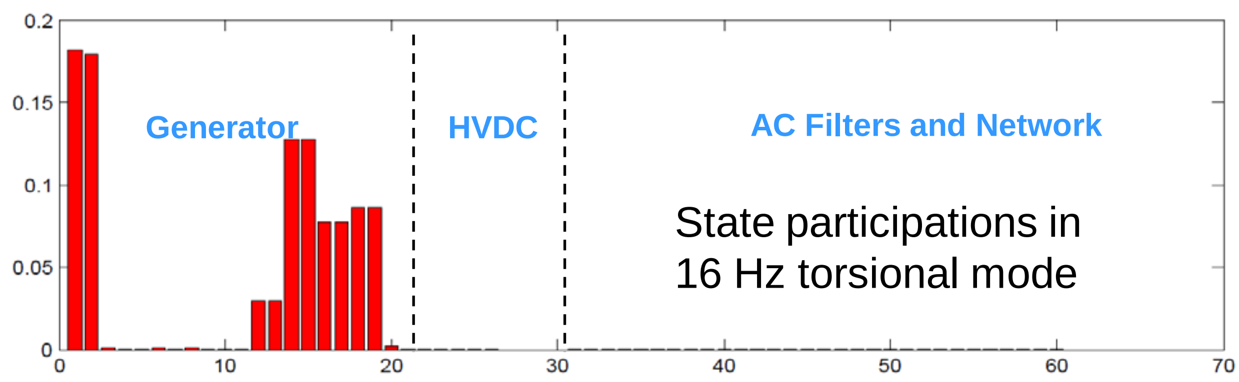


- Torsional interactions occur when there is a lightly damped oscillatory mode in the HVDC system close to one of the torsional modes – **weak resonance condition**

Applications – Generator-HVDC Torsional Interactions

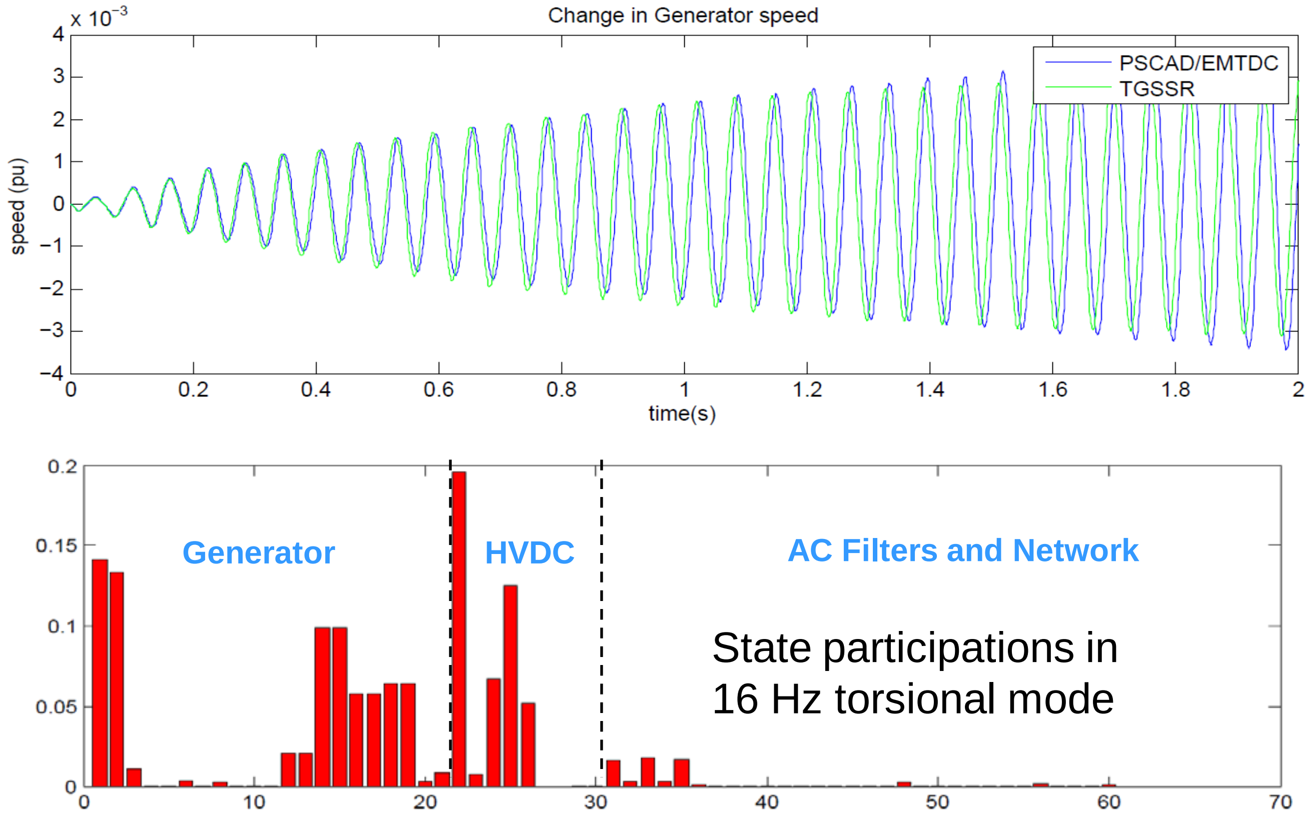
- Under normal operating conditions





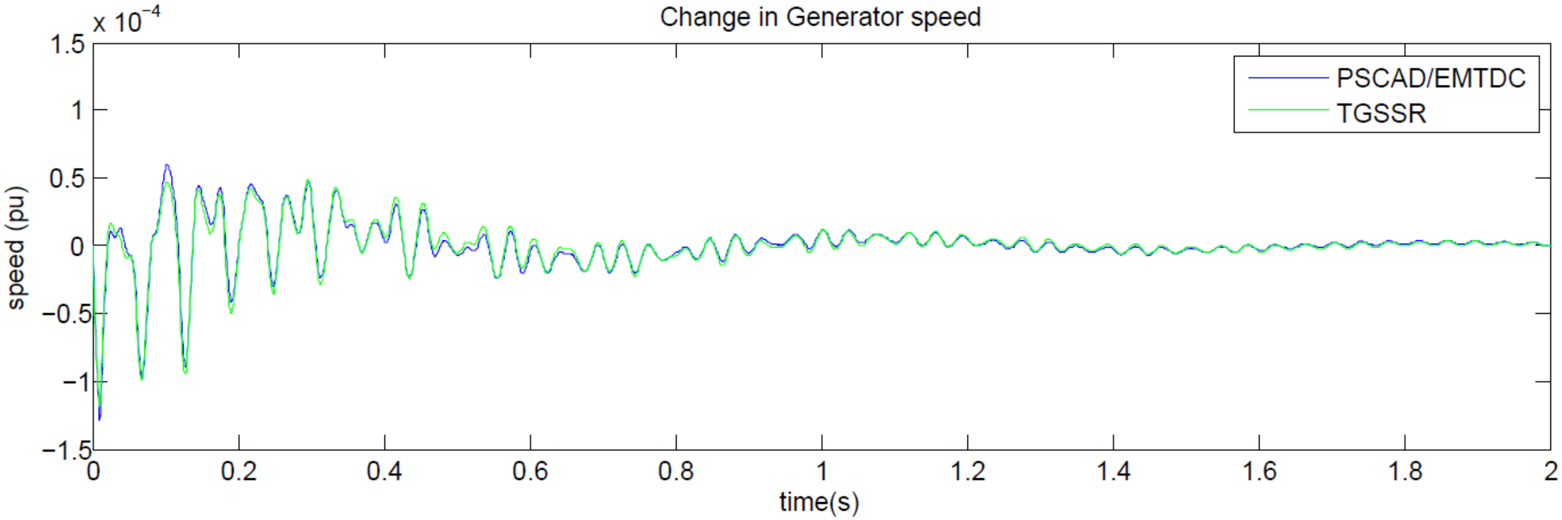
Applications – Generator-HVDC Torsional Interactions

- Current controller gains were adjusted to create a oscillatory mode close to 16 Hz.

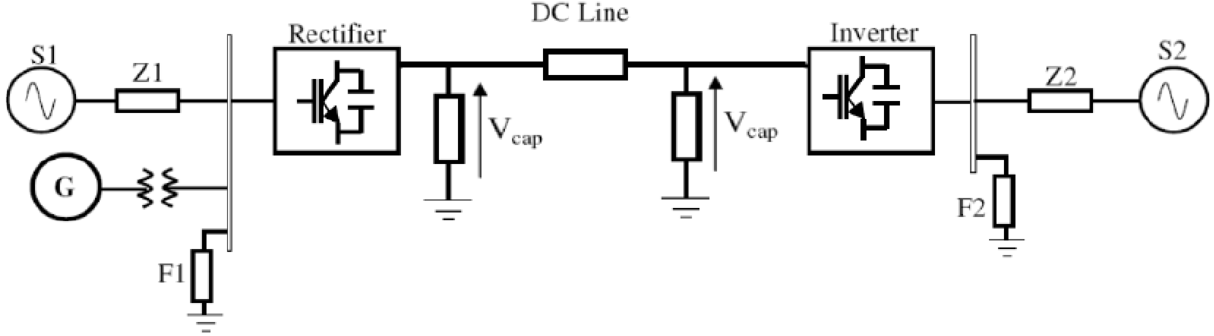


Applications – Generator-HVDC Torsional Interactions

- Sub-synchronous Damping Controller (SSDC) Design
  - The torsional modes of nearby generators can be controlled through a damping controller added to HVDC controllers.
  - Current controller is the most effective location.

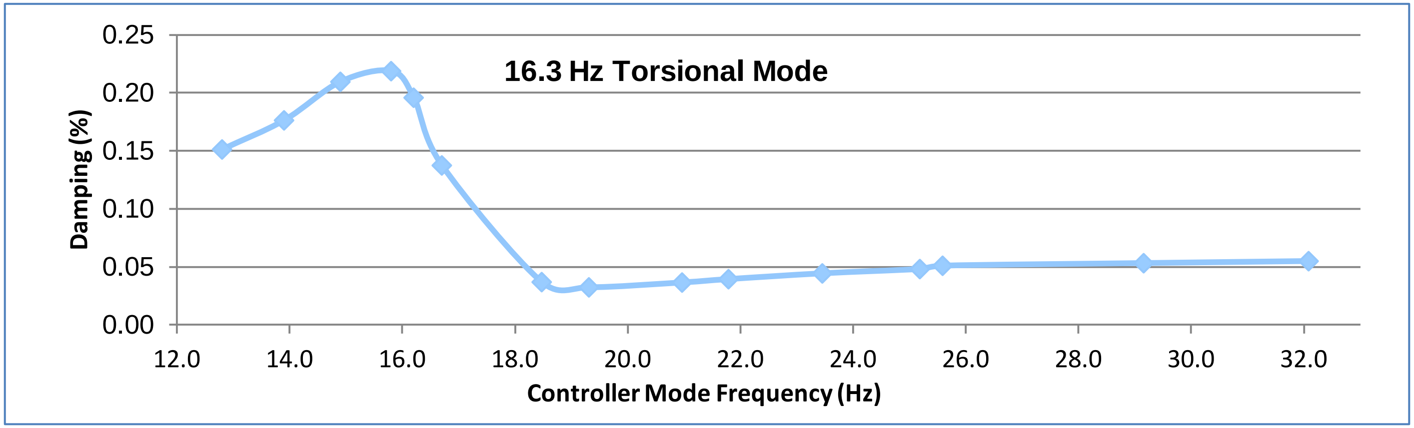


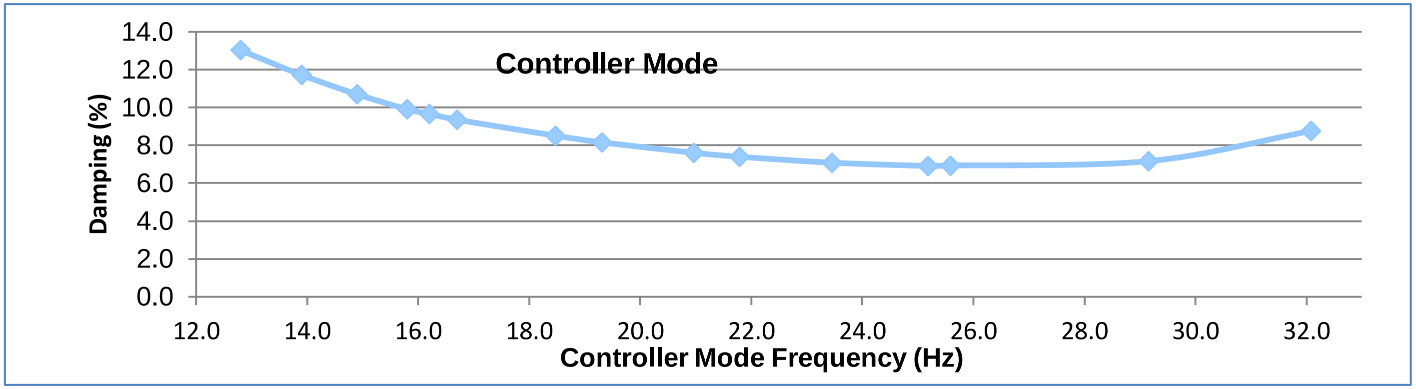
Applications – Generator-VSC Torsional Interactions



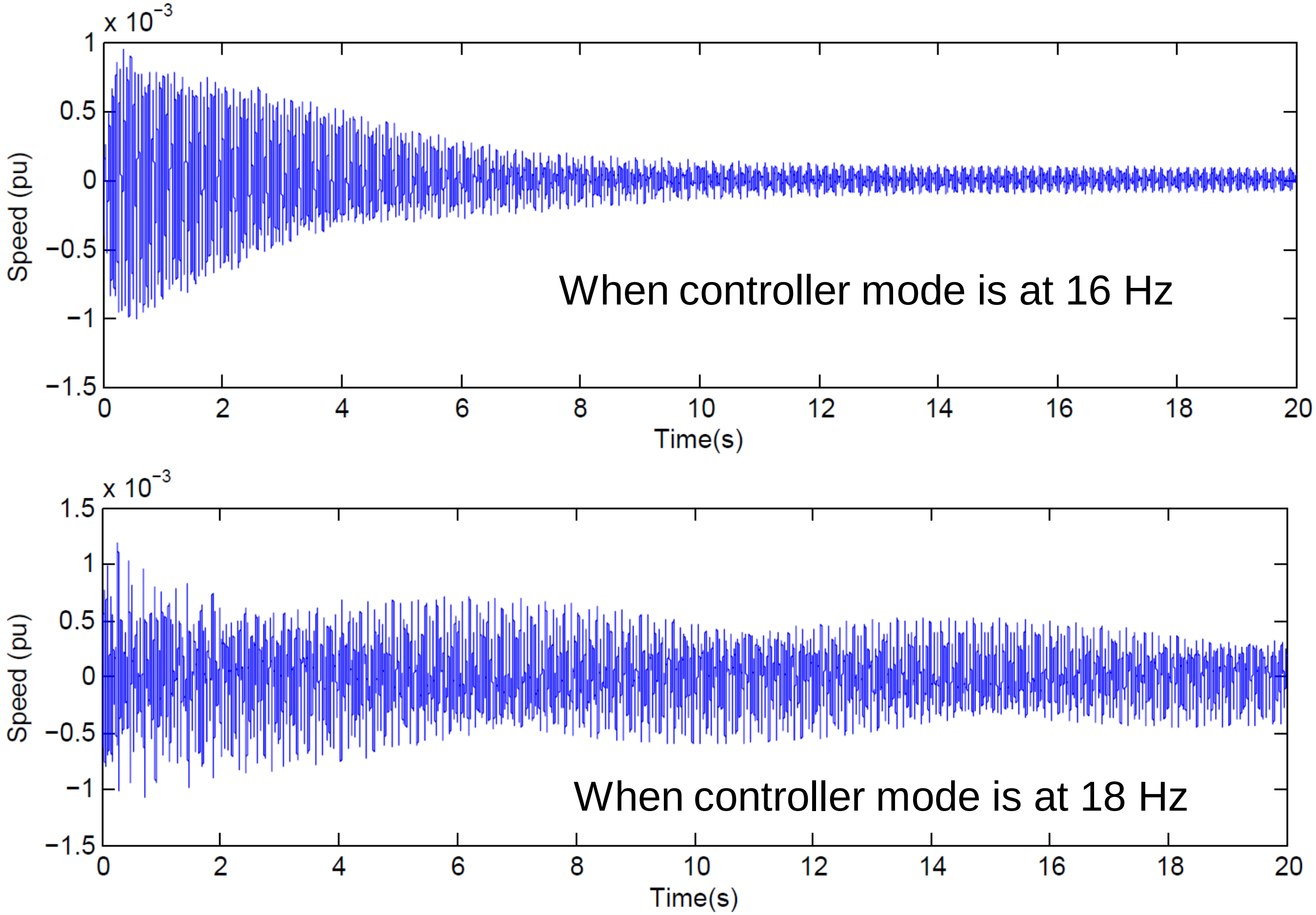
- It is believed that VSC systems provide positive damping to the torsional modes of nearby generators.
- Our analysis showed that this is not always correct.

Applications – Generator-VSC Torsional Interactions

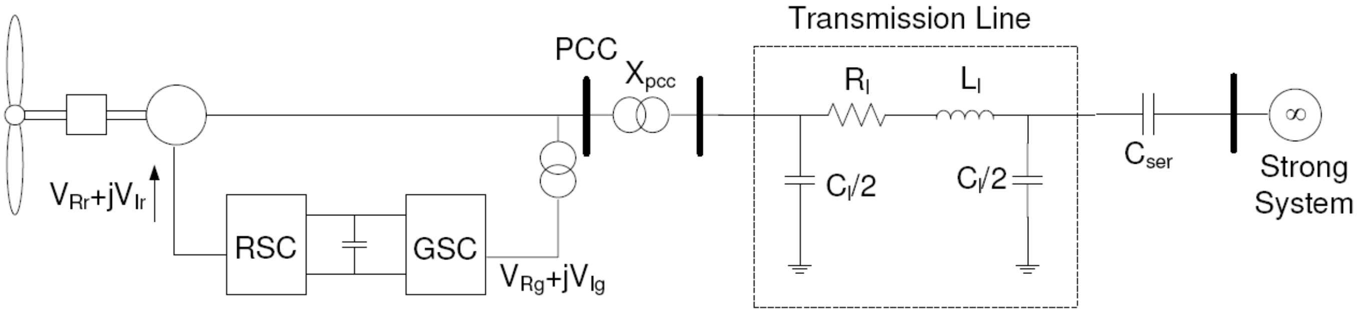




Applications – Generator-VSC Torsional Interactions



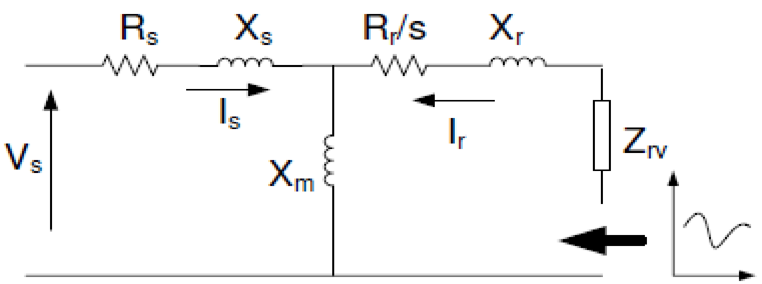
Applications – Wind Generator – Series Cap SSR

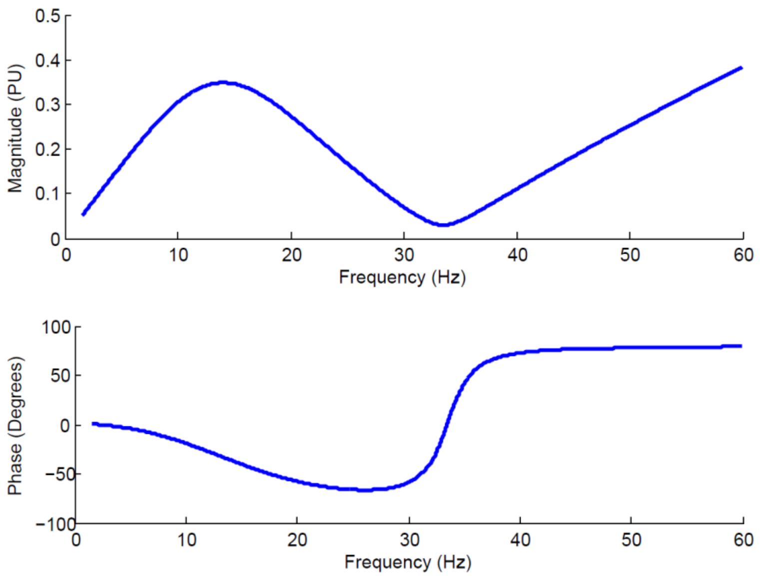


- Torsional oscillations are in low frequency range (<5Hz) – not possible to have torsional interactions.
- The problem is identified as a Sub-Synchronous Resonance in the electrical system.

Applications – Wind Generator – Series Cap SSR

- Frequency scans with equivalent circuit (change in slip is calculated for each frequency)



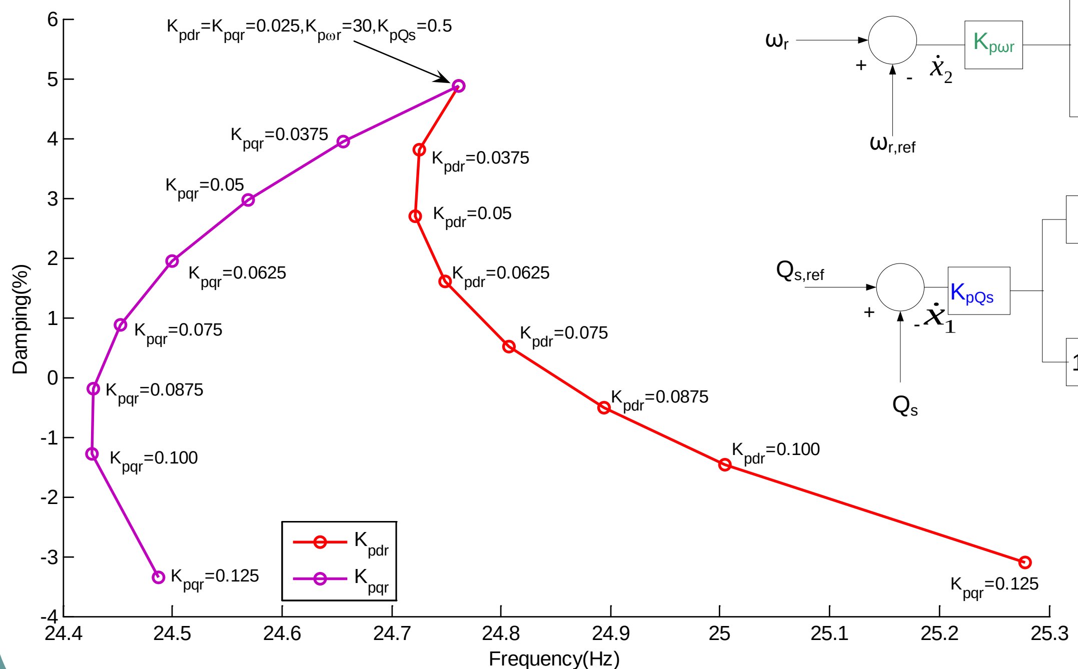


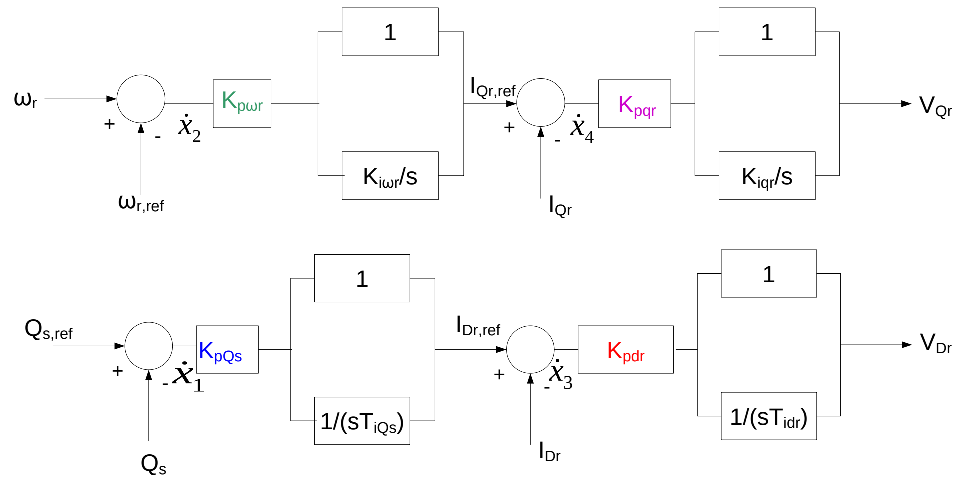
- Analysis shows sub-synchronous resonance (stable).
- Self excitation according to conventional definition is not present.

Dynamic behaviour of controllers and rotor voltage is not included.

Applications – Wind Generator – Series Cap SSR

- Damping of resonance is very sensitive to the rotor side converter controllers.





Small signal analysis shows an electrical resonance in which the damping can be controlled through the rotor side converter controllers.

Applicability in Modern Power Systems

- A new era of power systems
  - Most of the HVAC lines are series compensated.
  - A large percentage of wind generation.
  - Wide usage of HVDC and DC grids.
  - Involvements of FACTS devices are high.
- Possibilities of having sub-synchronous frequency interactions are high.
- A systematic approach using time domain simulations and small signal stability is essential to identify and solve these problems.

Publications

1. Chandana Karawita, D.H.R. Suriyaarachchi and U.D. Annakkage , "A Case Study on the Vulnerability of VSC HVDC Systems for Sub-synchronous Interactions with Generator-Turbine Units", CIGRE SCB4 Colloquium 2011, Brisbane, Australia, October 2011
2. D.H.R. Suriyaarachchi, U.D. Annakkage and Chandana Karawita, A Procedure to Study Sub-synchronous Interactions of Wind Integrated Power Systems, submitted to review, ", IEEE Transactions on Power Systems.
3. D. H. R. Suriyaarachchi, U. D. Annakkage, C. Karawita, D. Kell, R. Mendis, and R. Chopra, "Application of an SVC to Damp Sub-synchronous Interaction between Wind Farms and Series Compensated Transmission Lines, Accepted to present in IEEE PES meeting, 2012
4. Chandana Karawita, U. D. Annakkage, "A Hybrid Network Model for Small Signal Stability Analysis of Power Systems", IEEE Transactions on Power Systems, Vol.25, No. 1, Feb. 2010
5. Chandana Karawita, U. D. Annakkage, "Multi-In-Feed HVDC Interaction Studies Using Small Signal Stability Assessment", IEEE Transactions on Power Delivery, Vol.24, No. 2, April 2009
6. Chandana Karawita, U. D. Annakkage, "Control Block Diagram Representation of an HVDC System for Sub-Synchronous Frequency Interaction Studies" The 9th International Conference on AC and DC Power Transmission, Oct 2010.
7. Chandana Karawita, U. D. Annakkage, "HVDC-Generator Torsional Interaction Studies Using A Linearized Model with Dynamic Network Representation", International Conference on Power Systems Transients (IPST), June 3-6 2009, Kyoto, Japan

Questions