Damping of Sub-Synchronous Resonance by placing Thyristor Controlled Series Compensators (TCSC)

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Motivation

- Series compensation is a popular solution for improving the power transfer capability of existing transmission lines
- Fixed Series Compensators (FSC) can cause Sub Synchronous Resonance (SSR)
- In a network with multiple series capacitors, there can be many sub-synchronous oscillatory modes which can excite different torsional modes of nearby generators
- This paper shows that multiple torsional mode instabilities can be mitigated by placing the TCSC at the right location

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What is Sub-Synchronous Resonance?

- SSR occurs when the generator electrical and/or the mechanical system interacts with the network at one or more natural frequencies of the system below the synchronous frequency[1].
- In a series compensated network, there can be amplitude modulated currents following a disturbance, which contains the following frequency components:
  - Sub-synchronous component : $\boldsymbol{\omega_n}$ (Network resonant frequency)
  - Super-synchronous component : $\boldsymbol{2\omega_0-\omega_n}$ (ω_0: synchronous frequency)

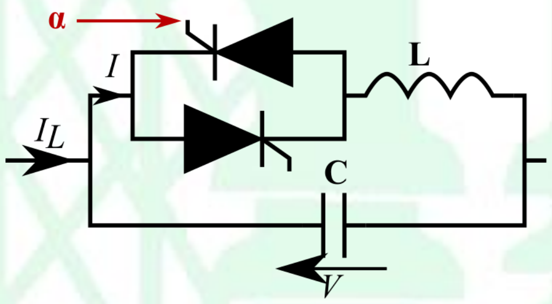
SSR

- Interactions with the generator electrical system
  Induction Generator Effect (IGE)
- Interactions with the generator mechanical system
  Torsional Interactions (TI), Torque Amplification (TA)

[1] "Proposed Terms and Definitions for Sub-synchronous Oscillation", IEEE Trans. Power Apparatus and Systems, vol. PAS-99, pp. 506-511, March/April 1980

Thyristor Controlled Series Compensators

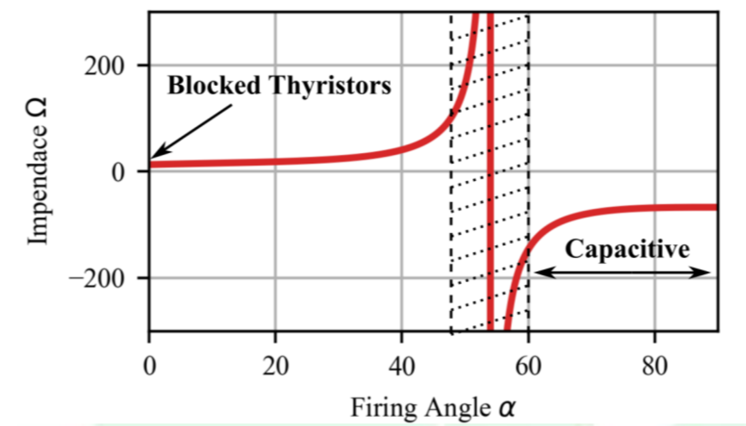
- TCSC is a parallel combination of a FSC, and a Thyristor Controlled Reactor (TCR) fired at a firing angle ‘α’ (ranges from 0^0 to 90^0 with respect to zero crossings of the line current ‘I_L’)
- TCSC will appear as a variable inductor or a variable capacitor depending on the firing angle
- A TCSC can be designed based on three parameters



1. Level of TCSC: $X_{FSC} + X_{TCSC} = X_{C,TOT}$

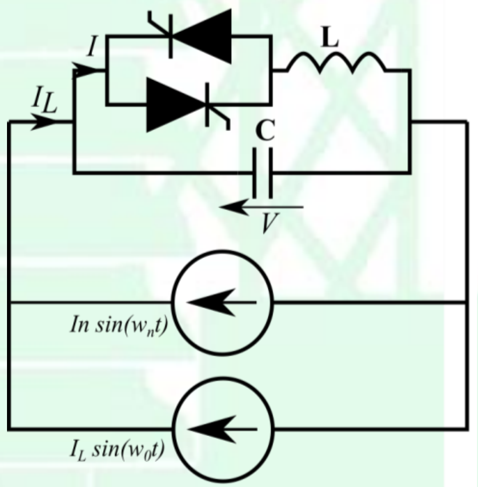
2. Boost Factor: $K_b = \frac{X_{TCSC}}{X_C}$ $\quad 1 \leq K_b \leq 3$

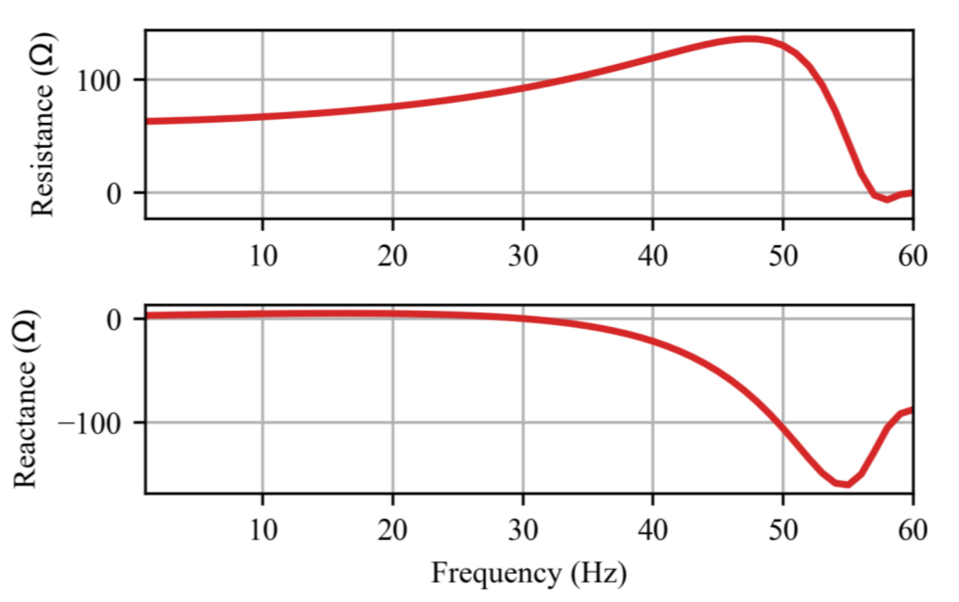
3. Characteristic Factor: $\lambda = \frac{\omega_N}{\omega_0} = \sqrt{\frac{X_C}{X_L}}$ $\quad 2 \leq \lambda \leq 4$



Frequency Response of a TCSC

- Frequency response of a TCSC designed to provide a capacitive impedance (X_{TCSC}) of 87.5 Ω at Kb=1.3 and λ=2.5.

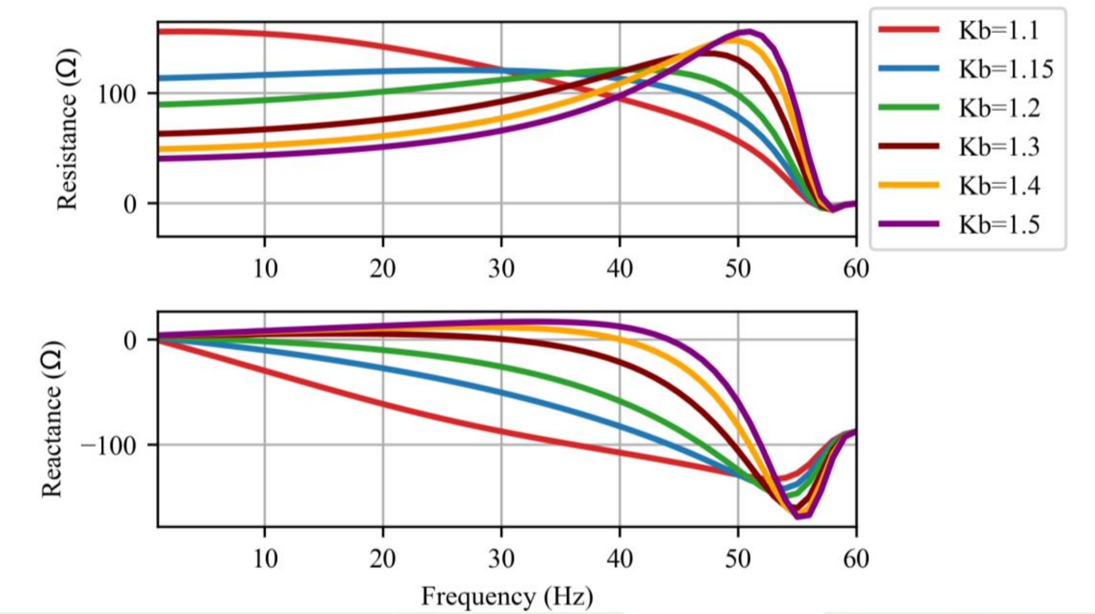




- TCSC presents a resistance at sub-synchronous frequencies and acts as an inductor in the frequency range from 1-30Hz

Frequency Response of a TCSC Cont.

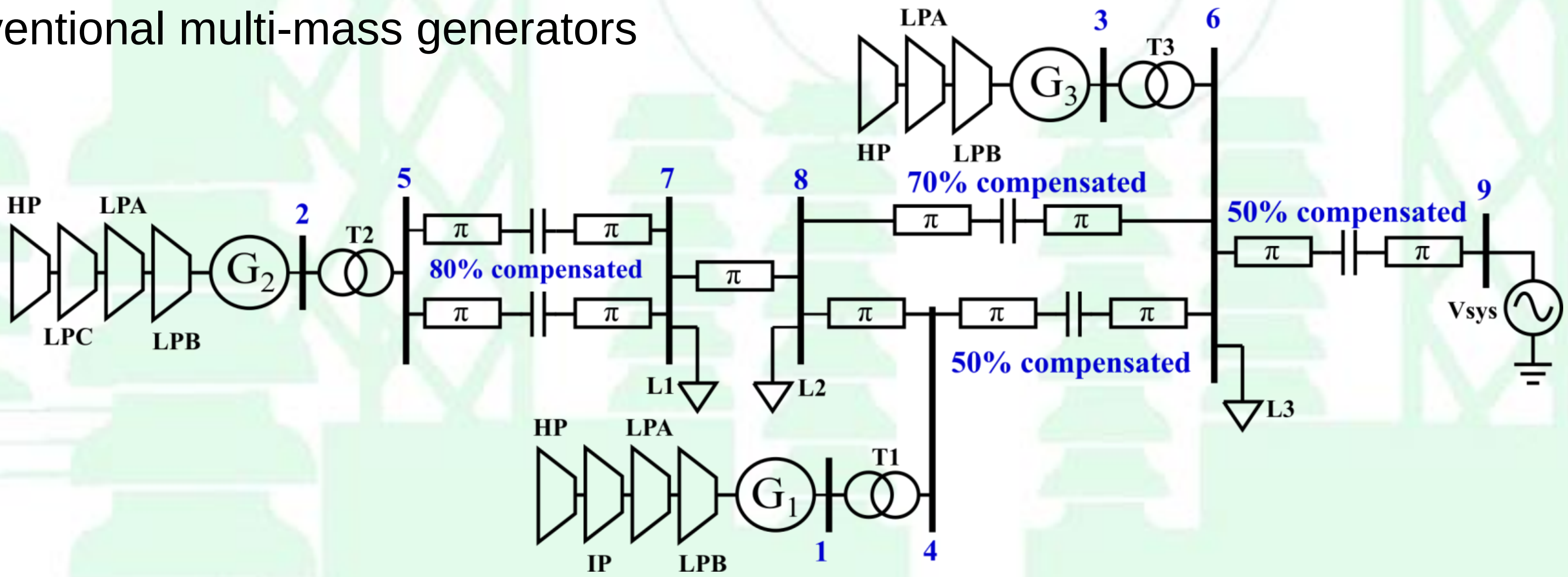
- Impedance characteristics of TCSCs designed for different boost factors to provide the same capacitive impedance (87.5 Ω) at respective boost factors is shown below.



- TCSC behaves more like a capacitor at sub-synchronous frequencies at low boost factors, even though it adds a high resistance to the network.

Test System

- A transmission network of radial nature is formed with five series compensated lines and three conventional multi-mass generators



- Two scenarios are obtained with different mechanical damping at multi-mass modules

	Mechanical damping of multi-masses at G1	Mechanical damping of multi-masses at G2	Mechanical damping of multi-masses at G3
Case 1:	0.05	2	2
Case 2:	0.3	0.3	0.3

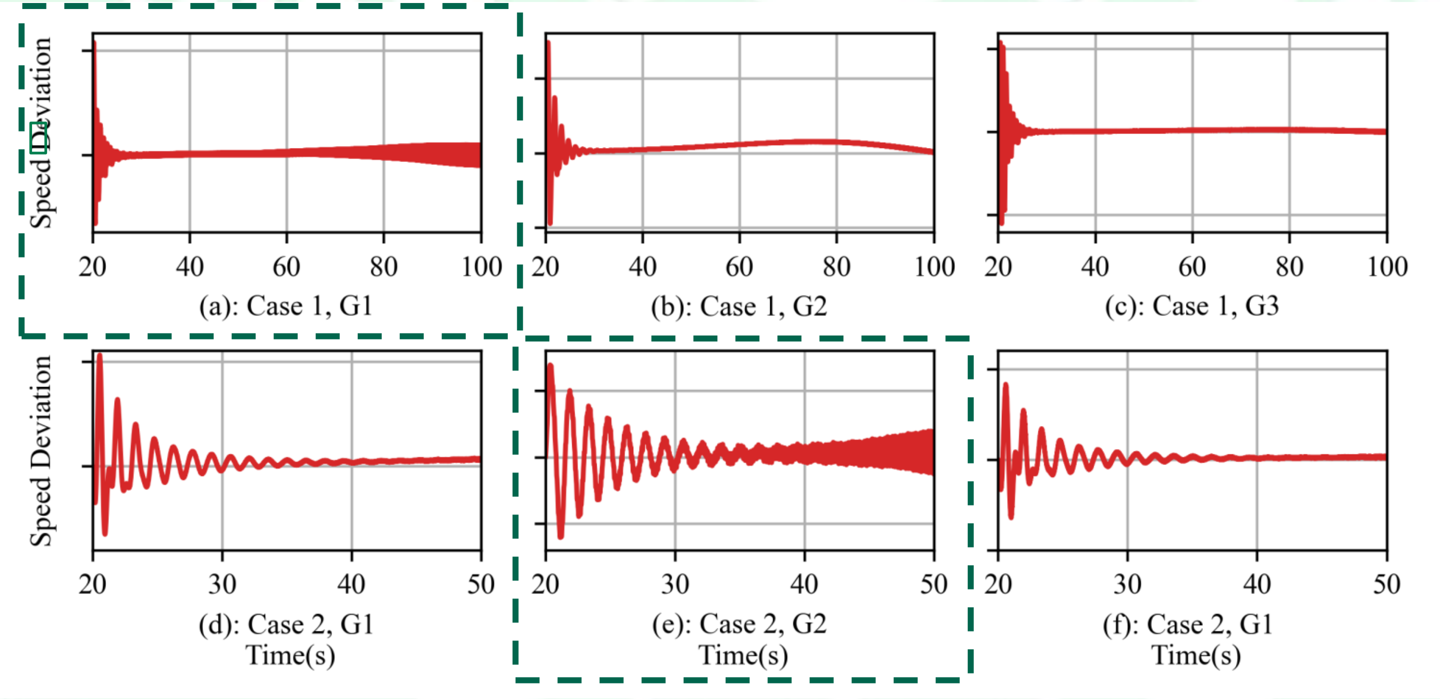
Eigen Value analysis of the Test network

- Network is linearized around the operating point and small signal stability is assessed for each case (Network modes are expressed in rotor reference frame)

	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)
Network Modes	43.61	2.17		
	34.11	6.46		
	20.75	8.34		
	16.35	14.52		
	6.51	43.51		
	Case 1		**Case 2**	
Generator 1 Torsional modes	**16.13**	**-0.0158**	16.13	0.175
	25.46	0.038	25.46	0.285
	32.23	**-0.037**	32.23	0.004
	47.45	0.03	47.45	0.182
Generator 2 Torsional modes	8.31	0.84	8.31	0.133
	15.23	0.31	**15.23**	**-0.048**
	20.25	0.0886	**20.25**	**-0.094**
	22.73	0.155	22.73	0.079
Generator 3 Torsional modes	23.64	1.61	23.64	0.24
	29.67	0.735	29.67	0.22
	52.73	0.5	52.74	0.15

EMT simulation results of the Test network

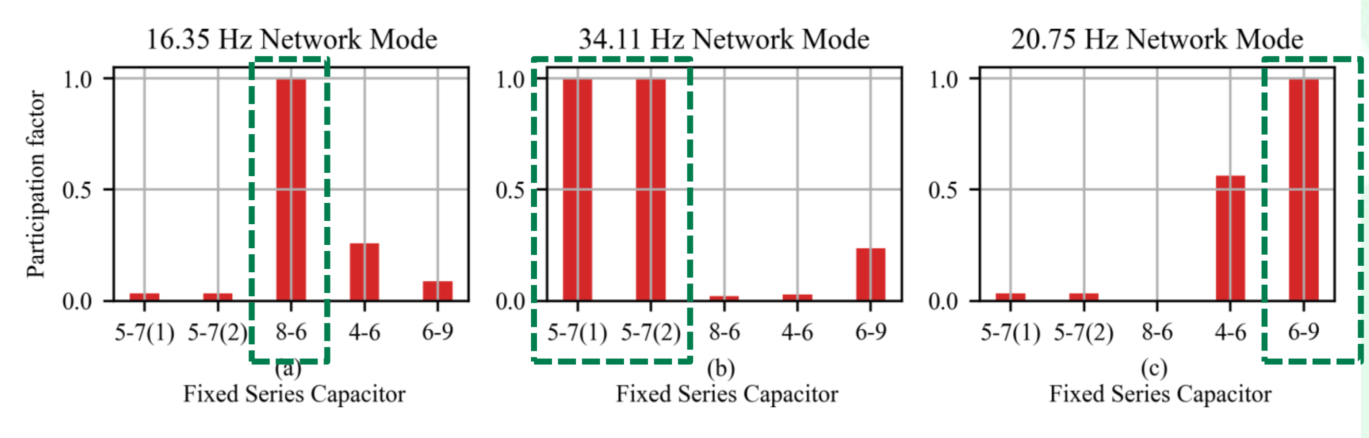
- Generator speed deviations obtained for the two cases following a small disturbance of 5% increment to the generator excitation voltage for 100ms



Damping of SSR with TCSC

Identifying critical network modes

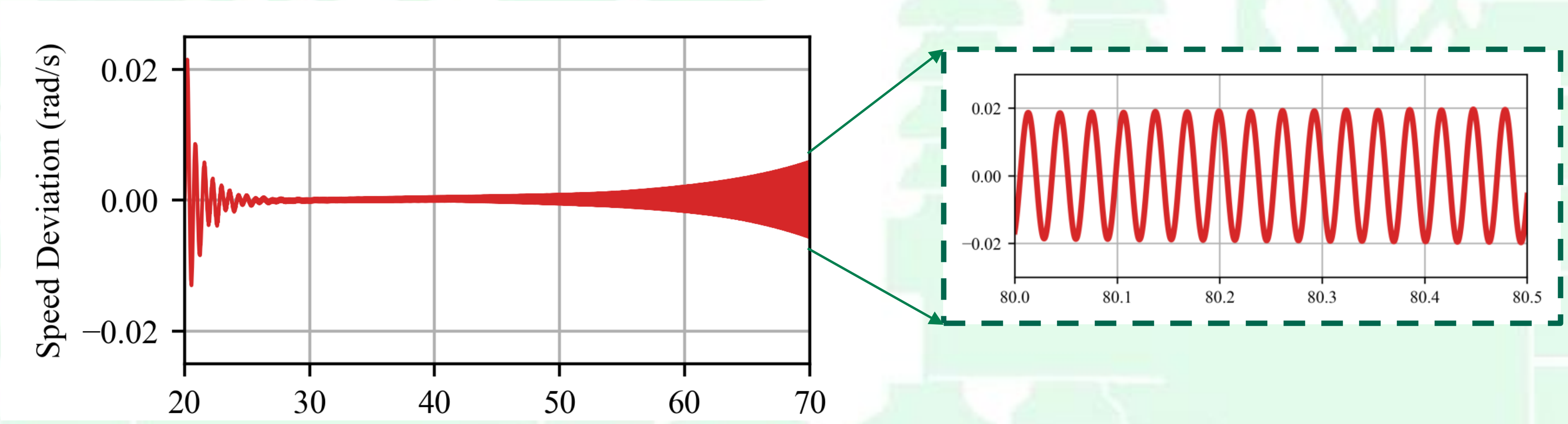
- There are three network modes which destabilize the torsional modes of generator 1 & 2.
- Participation of series capacitors to these network modes:



	Unstable torsional modes		Critical network modes		Corresponding FSC
	Frequency	Damping (%)	Frequency	Damping (%)	
Case 1	16.13	-0.0158	16.35	14.52	Branch 8-6
	32.23	-0.037	34.11	6.46	Branch 5-7
Case 2	15.23	-0.048	16.35	14.52	Branch 8-6
	20.25	-0.094	20.75	8.34	Branch 6-9

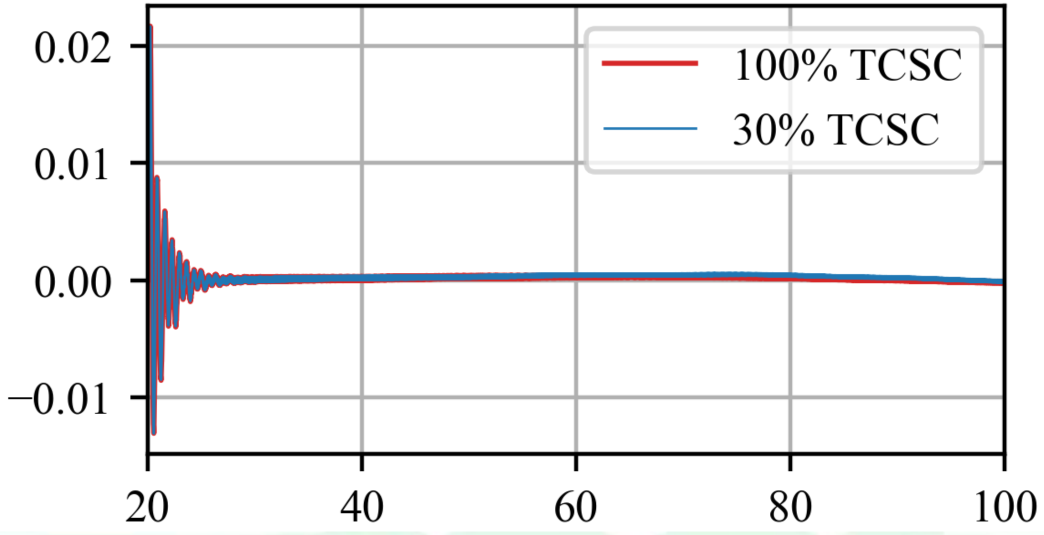
Replacing the FSC with TCSC in Case 1

- FSC in branch 8-6 is replaced fully with a TCSC designed to provide the same impedance as that of the FSC at a boost factor (Kb) of 1.3 and λ of 2.5.
- Even though the 16Hz torsional mode is well damped, growing 32 Hz torsional oscillation is observed



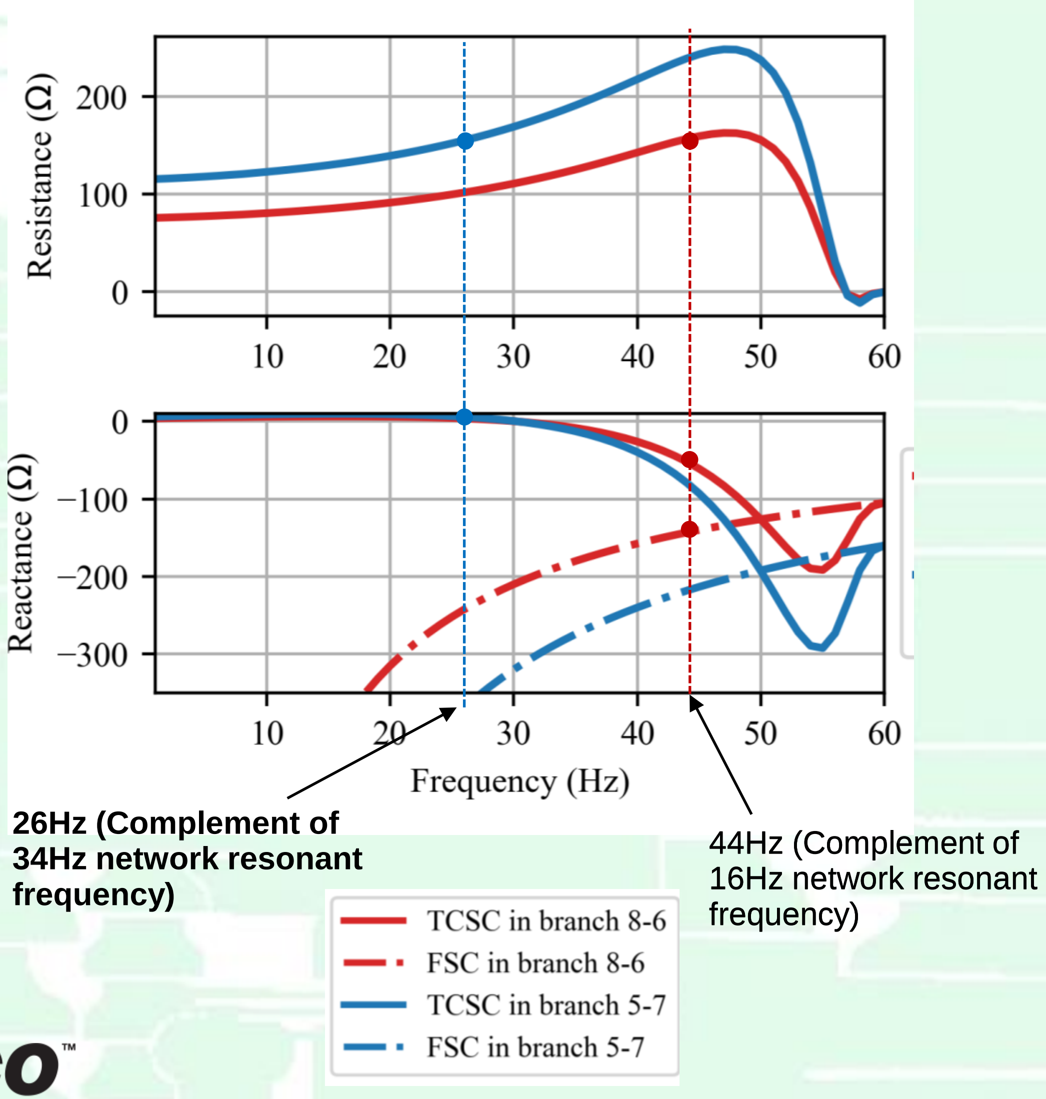
Replacing the FSC with TCSC in Case 1

- When the FSC in one of the branches from 5-7 is replaced fully with a TCSC (designed to produce the same impedance as the FSC at Kb=1.3 and λ of 2.5), both the 16Hz and 32 Hz torsional oscillations are well damped
- A TCSC level of 30% is adequate to damp the unstable torsional oscillations



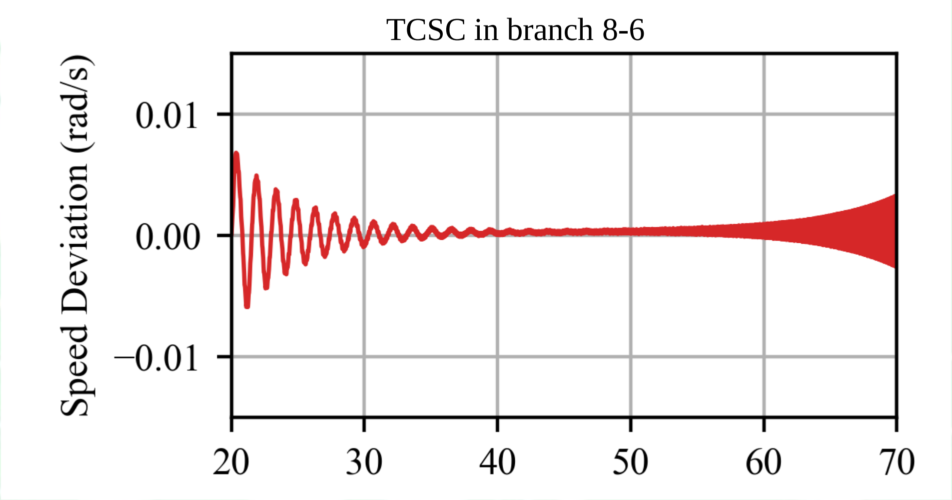
Replacing the FSC with TCSC in Case 1

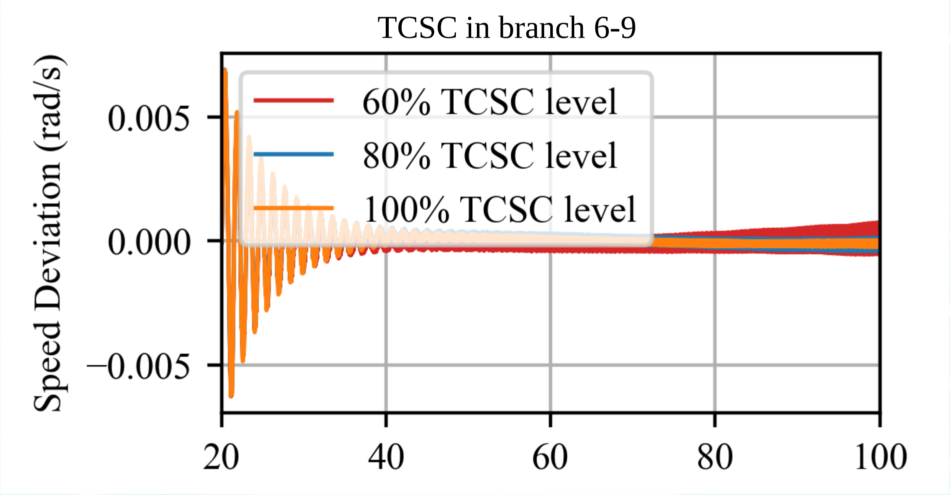
- Frequency response of the two TCSCs placed in branches 8-6 & 5-7 (to damp 16Hz and 32 Hz torsional modes respectively) is compared against the FSC impedance at the same frequency.
- Replacing the FSC which relates to the most unstable torsional mode with a TCSC (fully or partially) is more likely to damp other unstable torsional modes due to the resistance it adds to the circuit.



Replacing the FSC with a TCSC in Case 2

- Replacing the FSC which contributes the most to the 16Hz network mode is not sufficient to damp the 20Hz torsional mode in case 2
- Replacing the FSC in branch 6-9 fully with a TCSC avoids torsional interactions at both frequencies
- A minimum TCSC level of 80% is sufficient to damp the two torsional modes





Conclusions

- A test network is developed to demonstrate multiple torsional mode instabilities due to multiple series resonances in the network
- The inherent damping capability of the TCSC at sub-synchronous frequencies is purely utilized to damp SSR without any additional controllers.
- It is shown that replacing the FSC which relates to the most unstable torsional mode can improve the damping of other unstable torsional modes.
- However, if replacing the chosen FSC does not avoid other torsional instabilities in any case, replacing the FSC which relates to the next most unstable torsional mode may be considered. Furthermore, use of a SSDC may also be advantageous

THANK YOU!