FOR REDUCE SUB-SYNCHRONOUS RESONANCE TORQUE BY USING TCSC

Shrikant patel[1], N.K.Singh[2], Tushar kumar[3]
Department of Electrical Engineering, Scope College of Engineering
Bhopal,(M.P.)
Emil:Shrikantcseb@gmail.com[1], Dannyk0809@gmail.com[2], Tusharkumar1729@gmail.com[3]

Abstract

Series capacitive compensation is the most economical way to enhance transmission capacity and to improve transient stability of transmission grids. However one of the impeding factors for the widespread use of series capacitive compensation is the potential risk of sub-synchronous resonance (SSR). In this paper, SSR phenomenon is studied with IEEE second benchmark model & a complete model of TCSC is used for damping of SSR Torques. TCSC is one of the FACTS devices which can be utilized to perform flexible series compensation and damping of SSR Torques.

The analysis of SSR is carried out by using eigen value analysis and results are validated by using MATLAB/SIMULATION software.

Keywords: Series Capacitive Compensation, Sub synchronous resonance, FACTS, TCSC, Eigen Values

I. INTRODUCTION

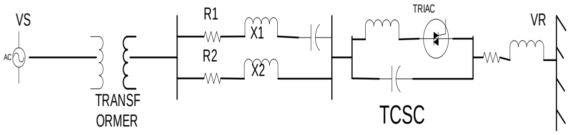
Series capacitive compensation in long transmission lines is an important way to improve power transfer capability, to improve system stability, to reduces system losses, to improve voltage profile of the lines and to optimize power flow between parallel lines. However when this technique is applied together with a steam T-G it may lead to Sub-synchronous resonance phenomenon. It means that the interaction between the electrical oscillation modes of the series compensated network and the mechanical oscillations modes of the T-G set may generate oscillating torsional torques which may result in the failure of the T-G shaft. Sub-synchronous resonance is addressed in three categories (i) Induction Generator effect, (ii) Torsional Interactions, (iii) Torque amplification. The first two types are caused by a steady state disturbance, while the third is excited by transient disturbance. FACTS devices have the flexibility of controlling both real and reactive power which could provided an excellent capability for improving power system dynamics. TCSC is a FACTS device proposed for enhancing power transfer, improving transient Stability, damping power oscillations, and mitigating sub-synchronous resonance torques [1-2].

Many countermeasures to sub-synchronous resonance problem have been reported in the literature [3]. However sub-synchronous resonance control through FACTs controller is gaining importance. Based on the above considerations, this paper focused the attention on control of sub-synchronous resonance torques with FACTS controller such as TCSC. SSR analysis with and without TCSC is proposed. SSR analysis with TCSC uses constant angle control method. This paper attempts to highlight the effectiveness of TCSC control in stabilizing the critical torsional mode in addition to the enhancement of power transfer capability [4].

II. POWER SYSTEM MODELING

The analysis of SSR phenomena requires a detailed modeling of overall electrical system comprising of synchronous machine, excitation system, power system stabilizer, AC network, TCSC and mechanical system.

The system considered is a modified IEEE second benchmark model. The complete electromechanical system is represented in fig.1.



(a) Electrical System

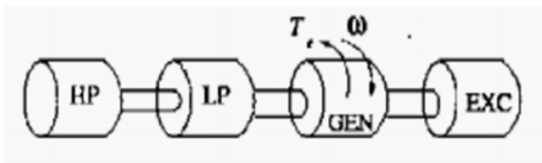


Fig. 1 (a) Electrical system of IEEE second benchmark model with TCSC (b) Four mass mechanical system.

The modeling of the electromechanical system comprising the synchronous generator, the mass-spring mechanical system, the excitation system, power system stabilizer, torsional filter, the transmission line containing the series capacitor and TCSC along with PI Controller. The combined system equations are linearized to carryout the Eigen value analysis [5].

III. SSR ANALYSIS

The SSR phenomenon involves energy exchange between mechanical and electrical systems. Therefore the details representation of both electromechanical dynamics of the generating units and the electromagnetic dynamics of the transmission network is required for the analysis of SSR. There are several methods available for the study of SSR. In this paper, Eigen value analysis method is used to study SSR. The equations of the individual masses of the shaft can be developed considering the rotors of the generators and the turbines. Equation (1) gives set of equations of mechanical and electrical quantities. This equation consists of input torque, output torque, damping torque and accelerating torque.

$$M_i\delta_i + d_{ii}\delta_i + \sum_{j=i-1}^{i+1}\left[d_{if}\left(\delta_i-\delta_j\right)+k_{ij}\left(\delta_i-\delta_j\right)\right]=T_{mi}-T_{ei}$$

(3)

where [M] is a diagonal matrix, consisting of inertia of all masses, [D] and [K] are tri-diagonal symmetric matrix consisting of damping co-efficient and spring co-efficient of the various mass sections. [Tm] and [Te] are the N-vectors of mechanical and electrical torques. [Te] has only one non-zero element corresponding to generator rotor. Now if

$$X = \left[\delta_1\delta_2\delta_3\delta_4\delta_5\delta_1\delta_2\delta_3\delta_4\delta_5\right]^t \quad (4)$$

From eq. (4) it can be written as:

$$\delta_i = M[M][M]^{-1}[D]\delta_i - [M]^{-1}[K]\delta_i + [M]^{-1}[T_{mi} - T_{ei}]$$

(5)

$$\therefore X = [A]X + [B]u \quad (6)$$

Equation (8) gives set of equations of the torsional mode of the turbine–generator mechanical system in the state space form, [6], where [A] is the state-coefficient matrix of the turbine–generator mechanical system and u is the forcing torque vector. The eigen values or the natural torsional modes of the shaft system are calculated from [A] matrix of the state variable model.

The SSR analysis is carried out based on the following initial operating conditions and assumptions

1. The generators deliver 1.0 p.u. power to the transmission system.
2. The input mechanical power to the turbine is assumed constant.
3. Compensation level provided by the series capacitor is set at 56% of the line reactance X_{L2}.
4. For transient simulation, a step decrease of 10% mechanical input torque applied at 1 sec. and removed at 1.5 sec.

A. Case-I Without TCSC

In this study, the series capacitors provide 56% compensation of the line reactance $X_{L2.}$ The Eigen values of the system matrix [A] are obtained which gives information concerning all the modes of oscillations along with their respective frequencies. Table I shows that mode 1 is unstable**.** This is also verified by transient simulation of the system using MATLAB-SIMULINK [7]. The response of the system obtained with transient simulation is shown in Fig. [6] and [7]

TABLE I
Eigen values of the system without TCSC

Modes	Eigen Value
0	-3.399000+j9.654000
1	0.380600+j155.250000
2	-0.045000+j203.450000
3	-0.049400+j321.180000
Network Mode	-15.415000+j5.020000
Network Mode	-15.605000+j598.960000

B. Case-II With TCSC

IV. MODELING OF TCSC

A TCSC consist of a capacitor in parallel with an inductor that is connected to a pair of opposite-poled thyristors. No interfacing equipment like high voltage transformer is required By using firing angle of the thyristors, the inductance reactance is varied, which in turns changes the effective impedance of the TCSC. The TCSC is modeled as a voltage source using equivalent impedance at fundamental frequency in each phase. The TCSC can operate in capacitive or inductive mode.

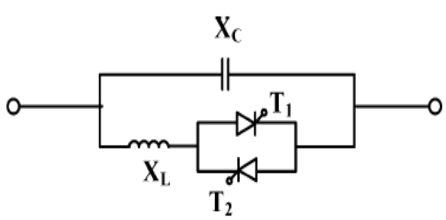


Fig.2. Model of TCSC

The equivalent TCSC reactance is given by

$$X_{TCSC} = X_C - \frac{X_C^2}{X_C - X_L}\,\frac{2\beta + Sin2\beta}{\Pi} \quad (8)$$

Where β = angle of advance (before the forward voltage becomes zero)= π – α, α is the firing angle of the thyristor.

CONTROL CIRCUIT OF TCSC

The TCSC controller model consists of second order feedback filter, PI-controller, series compensator and a transport delay model. The TCSC voltage feedback control is used. The continuous model includes the first order delay given by time constant T_{d1}. Additional lag is introduced represented by the delay filter with T_{d2} Simulation results demonstrate improvement in the response with the introduction of this delay elements. The second order filter with V_C reduces harmonic on the feedback signal [8-9].

The stability of the system is analyzed through eigen value techniques and it is noted that the TCSC controller stabilizes critical torsional mode 1 at the specified operating point [10]. To validated the results obtained by the eigen value analysis, transient simulation is carried out using MATLAB – SIMULINK. The simulation results are shown in Fig. 8 and 9.

TABLE II
Eigen values of the system with TCSC

Modes	Eigen Value
0	-2.165800±j2.356980
1	-0.386700±j147.580000
2	-0.019500±j201.355400
3	-0.047500±j305.020000
Network Mode	-15.024550±j149.856200
Network Mode	-15.220000±j523.325800

I. SIMULINK IMPLEMENTATION

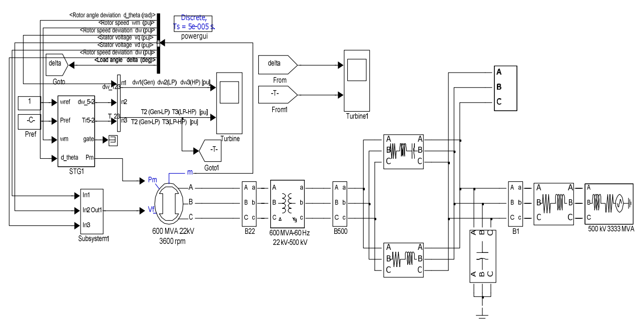


Fig.3. Simulink modeling with TCSC

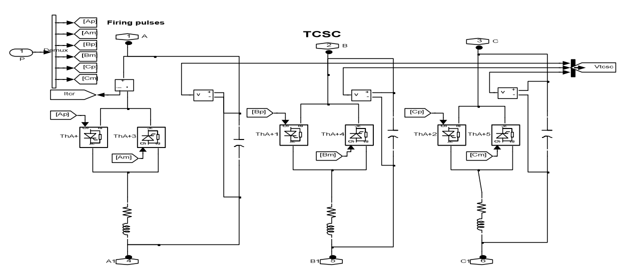


Fig.4. Simulink modeling subsystem of TCSC

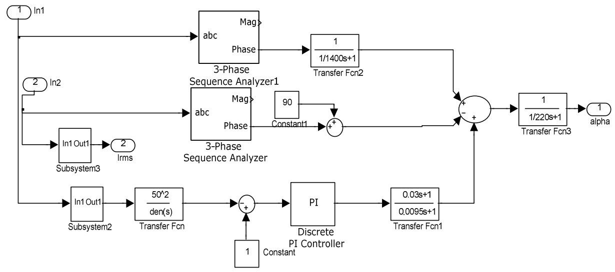
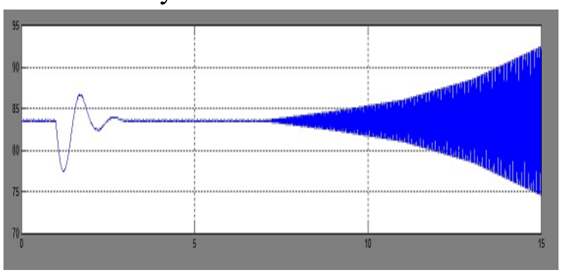


Fig.5. Simulink modeling subsystem of TCSC firing unit controller

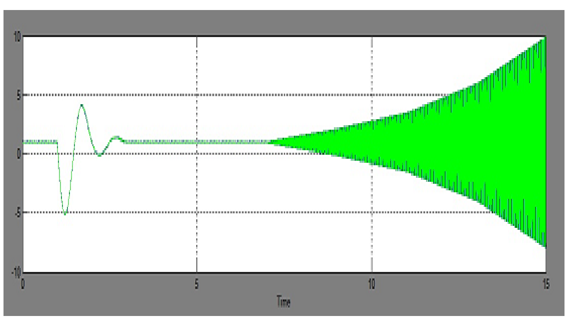
V. RESULT

Case-I Simulation results of electro mechanical system without TCSC



Time (Sec)

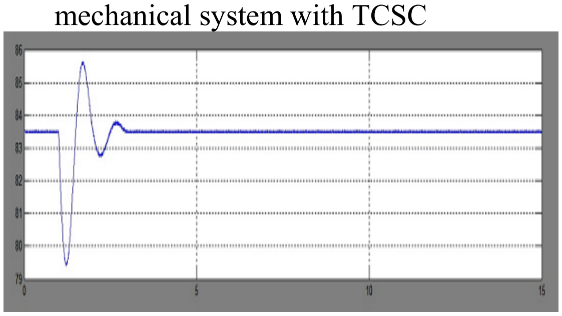
Fig.-6. The variations of rotor angle (δ) in degrees Vs Time in seconds



Time (Sec)

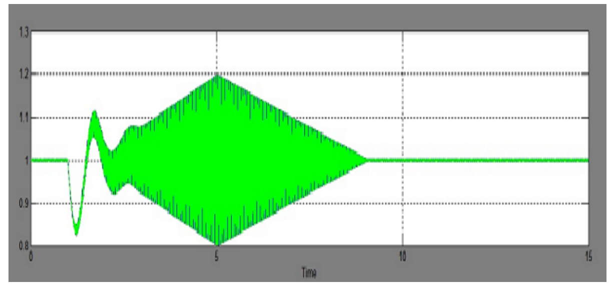
Fig.-7. The variations of SSR torque LP-GEN in p.u.Vs Time in seconds

A. Case-II Simulation results of electro mechanical system with TCSC



Time (Sec)

Fig.-8. The variations of rotor angle (δ) in degrees Vs Time in seconds



Time (Sec)

Fig.-9. The variations of SSR torque LP-GEN in p.u.Vs Time in seconds

VI. CONCLUSION

The analysis and damping of sub-synchronous resonance torques of the electromechanically system has been studied in this paper. The eigenvalue techniques and MATLAB-SIMULINK has been adopted for the purpose of analysis. The analysis of basic electromechanical system shows that the without TCSC, mode 1 is unstable at the specified operating point. The TCSC is provided at the receiving end of the transmission line control by TCSC controller. When TCSC is controlled by PI-controller, the critical torsional mode 1 is stabilized with good stability margin. However, method for further improvement in the stability margin of the other torsional modes needs to be investigated.

VII. REFERENCES

[1]. K.R. Padiyar, “Analysis Of Sub-synchronous Resosnance In Power Systems”, *Kluwer academic publishers*, 1999

[2]. IEEE committee report “A bibliography for the study of sub-synchronous resonance between rotating machine and power system” *IEEE trans. Power apparatus and system*, vol. PAS-95, No. 3, PP 216-218, Jan/Feb. 1976.

[3]. Nadia Yousif, Majid Al-Dabbagh, “Subsynchronous Resonance Damping in Interconnected Power Systems”. *IEEE Transaction on Power Apparatus & System*, 2009.

[4]. B. K. Keshavan and Nagesh Prabhu , “Damping of Subsynchronous Oscillations Using STATCOM -A FACTS Controller”, *lntematlonal Conference on Power System Technology - POWERCON Singapore*, 21-24 November 2004

[5]. Dr. Narendra Kumar , Sanjiv Kumar and Vipin Jain , "Damping Subsynchronous Oscillations in power System using Shunt and series Connected FACTS Controllers" *IEEE; Transaction on Power System* ,2010.

[6]. B.S. Umare, J.B. Helonde, J.P. Modak, and Sonali Renkey "Application of gate controlled series capacitor (GCSC) for reducing stresses due to sub-synchronous resonance in turbine generator shaft" *IEEE Proce*., 2010.

[7]. N. Kakimoto and A. Phongphanphanee, "Sunsynchronous resonance damping controlof thyristor-controlled series capacitor", *IEEE Transactions on Power Delivery*, vol. 18, no. 3, pp 1051-1059, July 2003.

[8]. G.N. Pillai and D. Jovcic "SSR Analysis with a new analytical model of the thyristor controlled series capacitor" *IEEE 15th PSCC, Liege* 22-26 August, 2005.

[9]. H.S.Y. Sastry, and NageshPrabhu "Damping of subsynchronous oscillations through FACTS controller" *Proceding 14thnational convention of electrical engineers on modern trends in the transmission system,* 10-12 December, IIT Kanpur, India, 1998.

[10]. Mohamad Hosseini Abardeh and Javed Sadeh, "Effect's of TCSC Parameters and Control Structure on Damping of Sub-Synchronous Resonance" *4th International power engineering and optimisation,* 2010.