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Modeling & Simulation Study of TCSC based Damping Controller for Power System

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Abstract:- **Flexible AC Transmission System (FACTS) technology comes into effect to overcome the power system existing problem and allows the industries to better utilize the existing transmission and generation reserves with relatively low investment to enhance the power system performance. Moreover, the current trend of deregulated electricity market also favours the FACTS controllers in many ways. FACTS controllers are group of power electronics controllers expected to modernize the power transmission and distribution system, enhance power system performance, improve quality of supply and also provide an optimal utilization of the existing resources. Thyristor Controlled Series Compensator (TCSC) is widely recognized as an effective and economical means to enhance power system stability. Change in value of reactance of the TCSC also affects the stability of the system. In this paper Load flow study has been carried out without compensation and with compensation that is with TCSC alone and then with TCSC & fixed capacitor at different loading of system to obtain the initial conditions of the system. After the initial operating conditions were computed, the detailed linearised state space models has been designed for a single machine infinite bus (SMIB) environment.**

INTRODUCTION

In present context of power scenario, series and static shunt compensation in power transmission system is attracting more and more attentions on account of several reasons. In the coming days conductor and line installations costs are expected to increase and the right of way problem is bound to be proved a bottleneck in construction of transmission lines. Squeezing more active power out of existing lines by means of series compensation can be than a more immediate and compelling alternative. Series compensation uses passive capacitor banks as the main component to provide reactive power and to recapture synchronism immediately at fault clearing. Adding control means to the fixed capacitor permits a variation of the inserted capacitor reactance, physically or virtually, so that the degree of compensation can be controlled. The compensation provide fast dynamic reactive power support, increase loading capability of line, allowing line to carry more active power and reduce reactive power flows. For the optimization of transmission corridors the power transfer has become great importance. Therefore, the FACTS technology is an attractive and best option for increasing system operation flexibility.

One important FACTS component is the TCSC which allows rapid and continuous changes of the transmission line impedance Z and is increasingly applied by the utilities in modern power system with long transmission line and is widely recognized as an effective and economical means to solve the power system problem. The TCSC operation has been focused on two aspects: (1) dynamics of TCSC, called device study and (2) contribution of the TCSC to power system operation and control, called system study. To avoid the linkage these two studies are usually undertaken separately. The effective reactance X_{TCSC} (α) of TCSC operates in three region, inductive region, capacitive region and resonance region. Detailed characteristics of TCSC, in which parameters such as capacitance, inductance, firing angle, input current and parameters of Metal Oxidized Varistor (MOV) are involved.

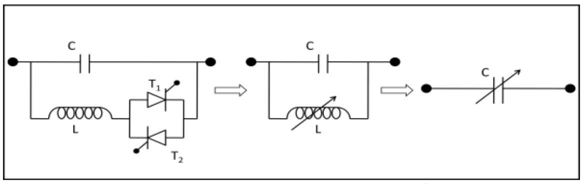


Figure.1. Equivalent Circuit of Tcsc

Methods:

The first step of controller design is load flow study and it is very important and powerful tool for power system analysis in planning stages and to calculate the initial condition of system. The models are required to be as simple and should retain all significant steady state dynamic characteristics. The new and comprehensive idea in which the state variable is the TCSC's firing angle, which is combined with the nodal voltage magnitudes and angles of the entire network in a single frame-of-reference for a unified iterative solution through the Newton-Raphson method[1]. And a suitable linear continuous TCSC model in state space is derived [2]. In this paper a complete closed loop model is verified in the time and frequency domain. Modeling of Single Machine Infinite Bus (SMIB) & Multi Machine Infinite Bus (MMIB) along with initial condition calculation have been discussed [3, 4, 5].

3. Operating Principle of 'SMIB'

The system is chosen to analysis the system performance e.g. load flow calculation, oscillation generation in generator, electrical power output at different companion of line reactance by means of fixed capacitor & TCSC. A single machine connected to an infinite bus through line reactance is widely used for performance of alternator & power transfer at different system parameters For the calculation of power angle delta, rotor speed & corresponding electrical power output model based on Phillips & Hefron is used. It has also being used for designing & tuning the power system stabilizers. Although the model is the liner model yet it is sufficient for study of low frequency oscillations & stability of power system.

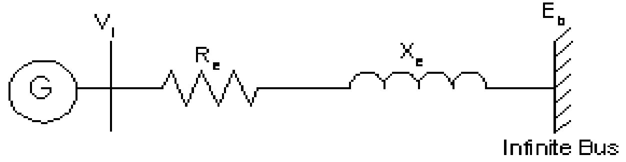


Figure.2. Single Line Diagram Of Smib

3.1 Modelling of SMIB

The equations of acceleration are as follows

$$p\,\Delta\,\omega_r = \frac{1}{2H}(T_m - T_e - K\,D\Delta\,\omega_r) \tag{3.1}$$

$$p\delta = \omega_b \Delta\omega_r \tag{3.2}$$

$$\text{Where} \quad \omega_b = 2\pi f_0 \tag{3.3}$$

$$x_e = x_{tl} + x_t \tag{3.4}$$

$$pE`_q = \frac{1}{T'_{do}}[-\,E_{fd} + E_q` + (x_d - x_d`) \tag{3.5}$$

$$V_d = \frac{x_q E_b \sin\delta}{x_q + x_e} \tag{3.6}$$

$$V_q = \frac{x_d` E_b \cos\delta + x_e x E_q`}{x'_d + x_e} \tag{3.7}$$

$$i_d = \frac{Eq` - V_q}{x'_d} \tag{3.8}$$

$$i_q = \frac{V_d}{x_q} \tag{3.9}$$

$$pE_{fd} = -\frac{E_{fd}}{T_A} + \frac{K_A}{T_A}(V_{ref} - V_t) \tag{3.10}$$

$$P_e = E_q` i_q + (x_q - x_d`)\, i_d\, i_q \tag{3.11}$$

3.2 Load flow study & Calculation of initial conditions

$$x_e = x_{tl} + x_t \tag{3.12}$$

$$\bar{E} = V_t e^{j\theta} + (R_a + j\,x_q)\, I_t \tag{3.13}$$

$$I_t = (V_t - E_b)/Z_e \tag{3.14}$$

$$(i_{d0} + i_{q0}) = I_t * e^{-j(\delta_0 - \frac{\pi}{2})} \tag{3.15}$$

$$(V_{do} + V_{q0}) = V_t\, e^{j\theta} * e^{-j(\delta_0 - \frac{\pi}{2})} \tag{3.16}$$

3.3 Formulation of State Matrix

$$E_{fdo} = E'_{qo} + (x_d - x'_d) \tag{3.24}$$

$$V_{ref} = V_t + \frac{E_{fdo}}{K_A} \tag{3.25}$$

$$P_m = E'_{q0} i_{q0} + (x_q - x'_d)\, i_{d0} i_{q0} \tag{3.26}$$

$$\Delta = R_e^2 + (xe + xq)\,(xe + x'd) \tag{3.27}$$

$$K_3 = \frac{\Delta}{\Delta + (xd + x'd)(xe + xq)}$$

$$K_4 = \frac{E_{b0}\,(x_d - x'_d)(x_e + x_q)\sin\delta 0 - R_e \cos\delta 0}{\Delta} \tag{3.29}$$

$$K_{2A} = i_{q0}\,\Delta - i_{q0}\,(x'_d - x_q)(x_q + x_e) \tag{3.30}$$

$$K_{2B} = -\,R_e\,(x'_d - x_q)\, i_{d0} + R_e\, E'_{q0} \tag{3.31}$$

$$K_2 = \frac{K_{2A} + K_{2B}}{\Delta} \tag{3.32}$$

$$K_{1A} = i_{q0}\, E_{b0}\,(x'_d - x_q)\,(x_q + x_e)\sin\delta_0 - R_e\cos\delta_0 \tag{3.33}$$

$$K_{1B} = E_{b0}\{i_{d0}(x'_d - x_q) - E'_{q0}\}\{(x'_d + x_e)\cos\delta_0 + R_e\sin\delta_0\} \tag{3.34}$$

$$K_1 = \frac{-(K_{1A} + K_{1B})}{\Delta} \tag{3.35}$$

$$K_6 = \frac{1}{\Delta V_t}\{V_{d0}\, x_q\, R_e - V_{q0}\, x'_d\,(x_q + x_e)\} + V_{q0} \tag{3.36}$$

$$A_{11} = -\frac{1}{K_3 T'_{do}} \tag{3.37}$$

$$K_5A = V_{do} x_q\{R_e\, E_{bo}\sin\delta_0 + (x'_d + x_e)E_{b0}\cos\delta_0\} \tag{3.38}$$

$$K_5B = V_{q0}\, x'_d\{R_e\, E_{b0}\cos\delta_0 - E_{b0}(x_e + x_q)\sin\delta_0\} \tag{3.39}$$

$$K_5 = \frac{K_{5A} + K_{5B}}{\Delta V_t} \tag{3.40}$$

$$A_{12} = -\,\frac{K_4}{T'_{do}} \tag{3.41}$$

$$A_{13} = 0\,,\; A_{14} = \frac{1}{T'_{do}} \tag{3.42}$$

$$A_{15} = 0;\; A_{21} = 0, \quad A_{44} = -\,\frac{1}{T_A}$$

$$B_{11} = 0;\; B_{21} = 0;\; B_{31} = 0$$

(3.47)

$$B_{41} = \frac{K_A}{T_A}$$

4. FIXED SERIES COMPENSATED SINGLE MACHINE INFINITE BUS SYSTEM

Series capacitors is a powerful and economic tool for many power transmission system applications and has many important characteristics.

(1)Increase the power transfer capability of existing transmission systems. (2)Provide fast dynamic reactive power support and voltage control. (3)Reduce financial costs and environmental impact by possible deferral of new transmission lines. (4)Increase the loading capability of lines to their thermal capabilities, including short term and seasonal demands.

5. THYRISTOR CONTROLLED SERIES CAPACITOR

The series capacitor is a good method to increase transmission line capability and reduces the net series impedance but it is a slow method due to its slow switching time and large discrete segments of mechanical switching devices, therefore, Thyristor Controlled Series Compensator (TCSC) and Thyristor Switched Series Compensator (TSSC) are used with rapid and continuous control of line and continuous range of flexible results. TCSC is expected to be applied in transmission line to achieve a number of benefits. The main benefits of TCSCs are increased energy transfer, dampening of power oscillations and control of line power flow. In this system capacitive reactance of the circuit is varied by providing a reactor across the capacitor unit, which is controlled by power thyristor valves. The load carrying capacity of line is controlled and varied by changing the line reactance through thyristor-controlled reactor (TCR).

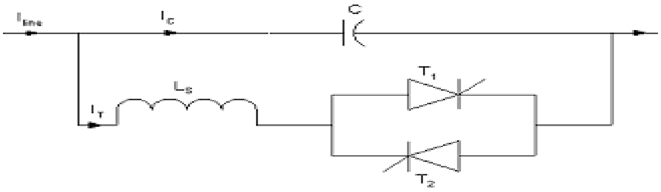


Figure. 3. Basic Tcsc Module

The main circuit of TCSC consist of four components, i.e., capacitor banks C, bypass inductor L, bidirectional thyristors SCR's and a MOV. The firing angles of the thyristors are controlled to adjust the TCSC reactance in accordance with a system control algorithm, normally in response to the system voltage.

TCSC provides variable-series compensation is simply to increase the fundamental-frequency voltage across a fixed capacitor in a series compensated line through appropriate variation of firing angle α. This enhanced voltage changes the effective value of the series capacitive-reactance. The equivalent impedance is,

$Z_{eq} = (-j/\omega C) \parallel (j\,\omega L) = -j/(\omega C - 1/\omega L)$

If $\omega C - \frac{1}{\omega L} > 0$ or $\omega L > \frac{1}{\omega C}$, the reactance of fixed capacitor is less than that of the parallel connected variable reactor and this combination provides a variable capacitive reactance.

For the smooth operation of system the TCSC can operate in a three different modes

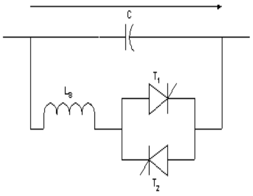


Figure.4. By Passed Thyristor Mode

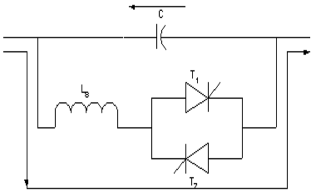


Figure.5. Blocked Thyristor Mode

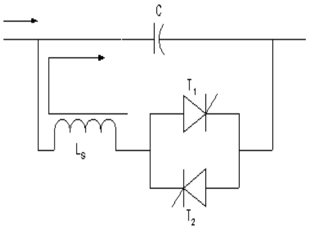


Figure.6. Partially Thyristor Conducting Mode

Description of TCSC Controller

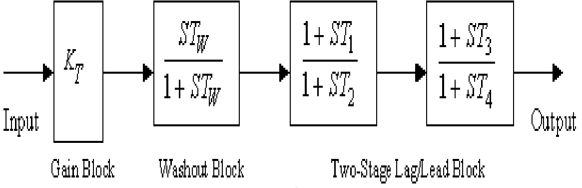


Figure. 7. Structure Of The Tcsc Controller

The commonly used lead-lag structure as in above FIGUREure is used as TCSC controller. It consists of a gain block with Gain K_T, a signal wash out block and two stage phase compensation block. The phase compensation block provides the appropriate phase-lead characteristic for the compensation of phase lag between input & output signal. The washout block serves as a high pass filter enough to allow signals associated with oscillations in input signal to pass without change. The input signal to the TCSC controller is speed deviation $\Delta\omega$ & output signal is the deviation in the conduction angle $\Delta\sigma$. For a optimum control by TCSC for enhancing the power transfer & to avoid system instability during fault, the TCSC controller designed by taking suitable values of K_T, T_w, T_1, T_2, T_3, T_4. The value of washout time constant T_w may be in the range of 1-20 sec. The effective TCSC reactance is

$$X_{TCSC}(\alpha) = \frac{V_{CF}}{I_m} = -X_c + \frac{X_C^2}{X_{C-}\,X_P}\,\frac{2\beta + sin 2\beta}{\pi} + \frac{4X_C^2}{(X_C - X_{P)}}\,cos^2\beta\left(\frac{k\ tan\ k\beta - tan\ \beta}{л(k^2-1)}\right)$$

where

$$\alpha = \pi - \frac{\sigma}{2}$$

and $\sigma = \sigma_0 + \Delta\sigma$

σ_0 is the value of initial conduction angle and $\Delta\sigma$ is the output of TCSC controller and hence during the fault the change in rotor angle changes the output i.e. deviation in conduction angle $\Delta\sigma$ and this value of $\Delta\sigma$ changes the value of $X_{TCSC}(\alpha)$ as desired by the system.

6. TCSC & FIXED SERIES COMPENSATED SINGLE MACHINE INFINITE BUS SYSTEM

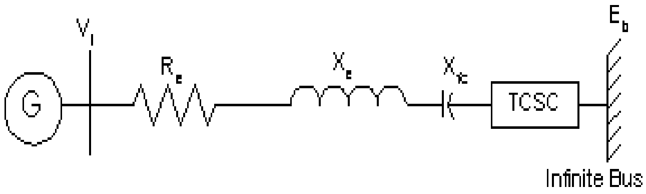


Figure.8. Tcsc & Fixed Series Compensated Single Machine Infinite Bus System

A single machine connected to an infinite bus in series with TCSC & fixed series capacitor is chosen to analysis the system performance with TCSC & fixed capacitor e.g. load flow calculation, oscillation generation in generator, electrical power output at different companion of line reactance by means of TCSC. Fixed series capacitor reduces the value of capacitor in TCSC or reduces the overall size of TCSC resulted in the saving of cost.

Load Flow Study & Initial Value Calculation

$x_e = x_{tl} + x_t + x_{TCSC} - x_{fc}$ (7.13)
$S = P + jQ$ (7.14)
$Ze = \sqrt{r_e^2 + x_e^2}$ (7.15)
Angle $V_t = \theta = E_{babs}/(1 - S^* Z_e)$ (7.16)
$\bar{E} = V_t e^{j\theta} + (R_a + j\,x_q)\,I_t$ (7.17)
$\angle E = \delta_0$, $I_t = (V_t - E_b)/Z_e$ (7.18)
$I_t = e^{\,j(\delta_0 - \frac{\pi}{2})}(i_{d0} + i_{q0})$ (7.19)
or $(i_{d0} + i_{q0}) = It^* e^{-j(\delta_0 - \frac{\pi}{2})}$ (7.20)
i_{d0} = real part i_{q0} = imaginary part
$(V_{do} + V_{q0}) = V_t e^{j\theta} * e^{-j(\delta_0 - \frac{\pi}{2})}$ (7.21)
V_{d0}= real part V_{q0} = imaginary part
$E_{bd} = E_{b0} \sin \delta_0$ (7.22)

$$E_{bq}= E_{bo}\cos\delta_0 \qquad (7.23)$$

$$E_{b0} = \surd\,(E_{b0}\sin\delta_0)^2 + (E_{bo}\cos\delta_0)^2 \qquad (7.24)$$

7. SIMULATION STUDIES AND RESULTS

Load flow study has been carried out without compensation and with compensation that is with TCSC alone and then with TCSC & fixed capacitor at 90%, 100%, 110% & 120% loading of system to obtain the initial conditions of the system. Load flow results at different loadings along with Eigen value analysis have been presented. Eigen value analysis has been carried out to ensure the stability of the system.

Table.1.

Load flow results of SMIB system at 90%, 110% loading without any compensation.

At 90 % loading

$V_t\angle\theta$	$I_t\angle\theta$	δ_0
1∠30.09	0.67∠20.23	50.37

Eigen Value	Damping	Freq. (rad./s)
-1.28e+001 ± 2.28e+001i	4.88e-001	2.62e+001
1.05e-001 ± 6.08e+000i	-1.74e-002	6.08e+000

At 110 % loading

$V_t\angle\theta$	$I_t\angle\theta$	δ_0
1∠35.31	0.78∠22.04	57.65

Eigen Value	Damping	Freq. (rad./s)
-1.28e+001 ± 2.26e+001i 1.46e-001± 6.09e+000i	4.93e-001 -2.40e-002	2.60e+001 6.09e+000

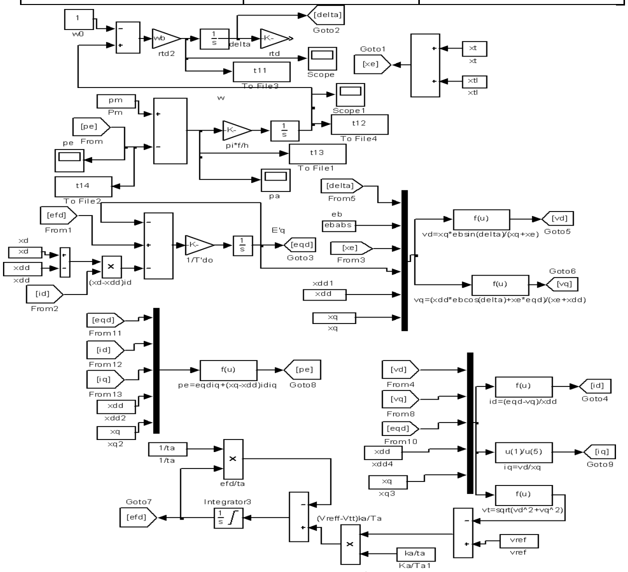


Figure.9. Simulation Model Of Smib Without Fault

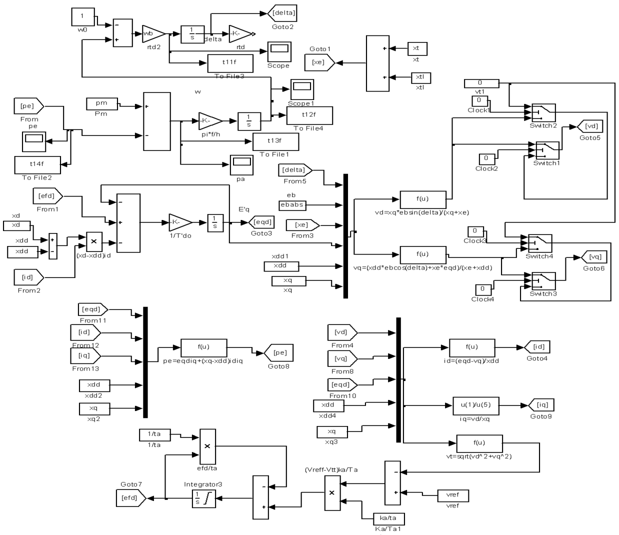


Figure.10. Simulation Model Of Smib With Fault

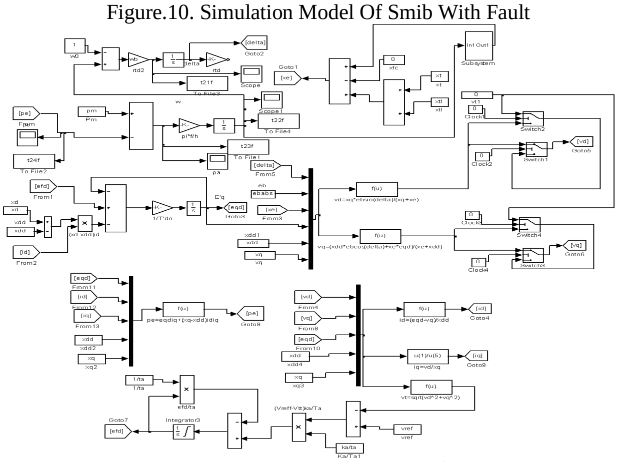


Figure.11.smib with TCSC with fault

Table 2.

Eigen value analysis of SMIB system with TCSC at 90 % loading

Eigen Value	Damping	Freq. (rad./s)
-1.28e+001 ± 3.20+001i 7.73e-002± 6.96e+000i	3.70e-001 -1.11e-002	3.45e+001 6.96e+000

$V_t\angle\theta$	$I_t\angle\theta$	δ_0
1∠23.15	0.75∠18.37	46.43

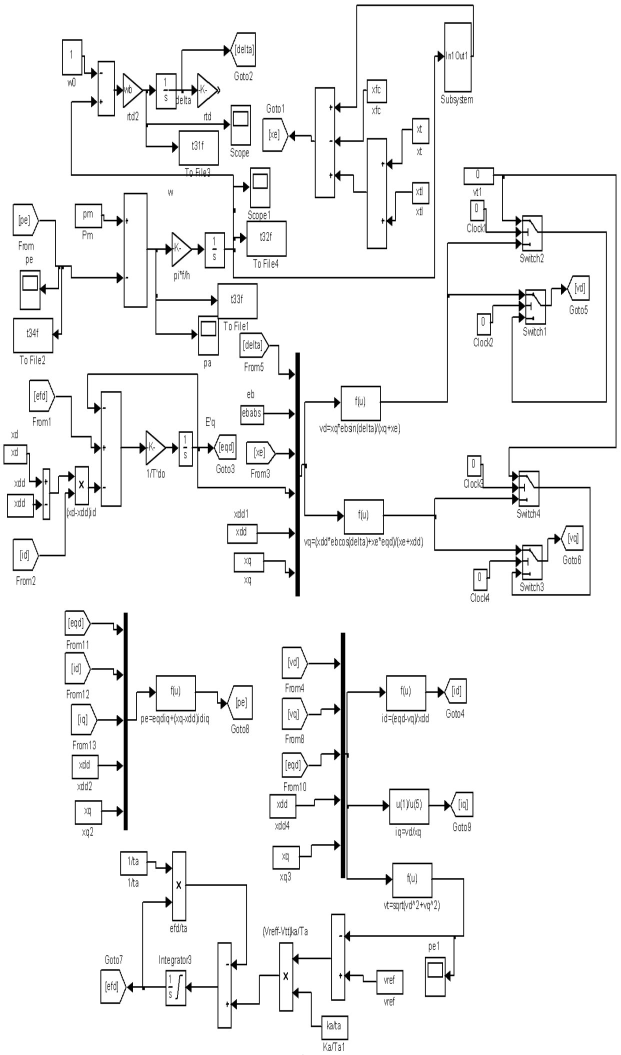


Figure.12. Simulink Model Of Smib With Tcsc & Fc With Fault

Table.3.
Eigen value analysis of SMIB system with TCSC and FC at 90% loading

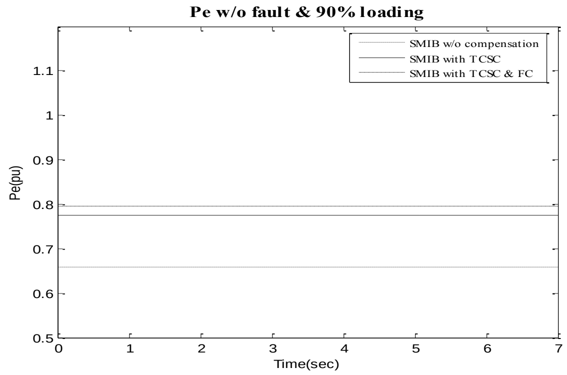
$V_t\angle\theta$	$I_t\angle\theta$	δ_0
1∠21.31	0.77∠18.04	45.40

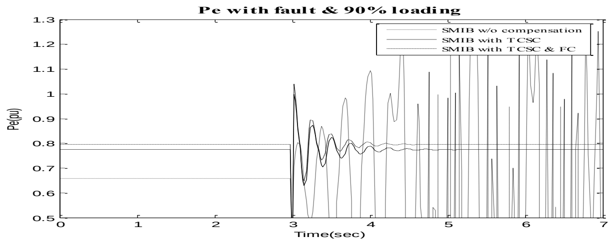
Eigen Value	Damping	Freq. (rad./s)
-1.29e+001 ± 2.03+001i 1.64-001± 7.15e+000i	5.35-001 -2.30-002	2.40+001 7.15e+000

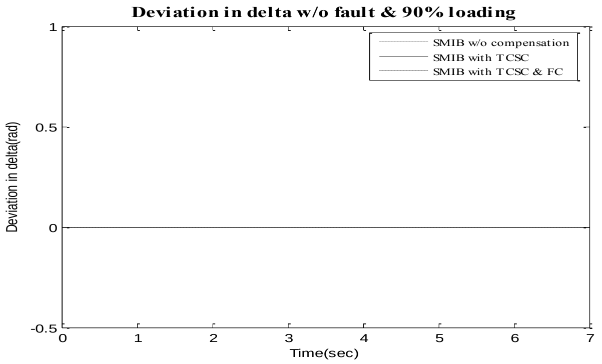
Table .4.
Cumulative Comparison of results 90 % Loading

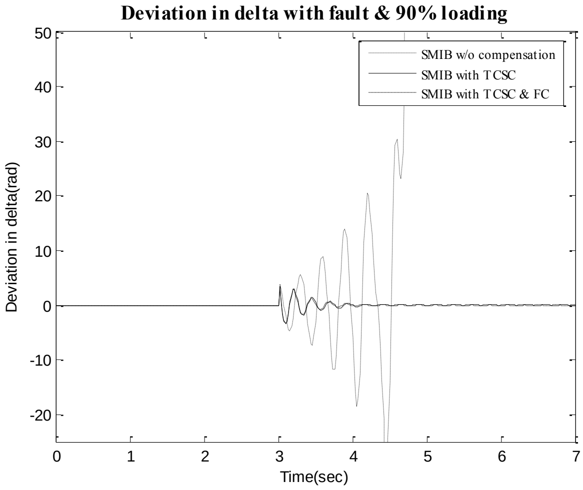
Items	SMIB without any compensation	SMIB with TCSC	SMIB with TCSC & FC
$V_t\angle\theta$	1∠30.09	1∠23.15	1∠21.31
$I_t\angle\theta$	0.67∠20.23	0.75∠18.37	0.77∠18.04
δ_0	50.37	46.43	45.40
Eigen value	-1.28e+001 ± 2.28e+001i 1.05e-001 ± 6.08e+000i	-1.28e+001 ± 3.20e+001i 7.73e-002± 6.96e+000i	-1.29e+001 ± 2.03e+001i 1.64e-001± 7.15e+000i
Damping	4.88e-001 -1.74e-002	3.70e-001 -1.11e-002	5.35e-001 -2.30e-002
Freq. (rad/s)	2.62e+001 6.08e+000	3.45e+001 6.96e+000	2.40e+001 7.15e+000

8. SIMULATIONS & RESULTS









CONCLUSION

After the initial operating conditions were computed, the detailed linearised state space models of a single machine infinite bus (SMIB) system incorporating a TCSC alone and then with TCSC & fixed capacitor has been developed to design the TCSC damping controller in a single machine infinite bus (SMIB) environment.

Eigen value analysis has been carried out to ensure the stability of the system.

For this purpose, a five cycle, self-clearing fault has been considered at the generator terminal and the performance of the controller was found to be satisfactory for damping the low frequency oscillations.

REFERENCES:

[1] C.L. Wadhwa, “ Electrical Power System”
[2] B.R. Gupta, “Power System Analysis & Design”
[3] Dragan Jovcic, “Analytical Modeling of TCSC Dynamics”, IEEE Transactions on power delivery, vol. 20, no. 2, april 2005
[4] Peter W. Sauwr & M.A. Pai, “ Power System Dynamics and stability”
[5] Yao-nan-Yu, “Electric Power System Dynamics” P. Kundur, “ Power System Stability and control”
[6] S. Meikandasivam, Rajesh Kumar Nema, and Shailendra Kumar Jain, “Selection of TCSC Parameters: Capacitor and Inductor”, IEEE 2011
[7] Benjamin C. Kuo, “ Automatic control system
[8] Vasundhara Mahajan, Department of Electrical Engineering, M P Christian College of Engineering & Technology Bhilai, Chattisgarh, INDIA -“Thyristor Controlled Series Compensator”.
[9] S.K. Pillai, “ A First Course on Electrical Drives”
[10] G.K. Dubey, SR Doradla, A Joshi & RMK Sinha - Thyristorised Power Controllers
[11] Alberto D. Del Rosso, Member, IEEE, Claudio A. Cañizares, “A Study of TCSC Controller Design for Power System Stability Improvement”, IEEE transactions on power systems, vol. 18, no. 4, November 2003
[12] MD Singh & KB Khanchandani, “Power Electronics”
[13] John Kueck -Lecture notes (2004) on economic benefits of synchronous condensers and FACTS
[14] Narain G. Hingorani, Laszlo Gyugyi (2000) “FACTS Concepts and Technology of Flexible AC Transmission Systems” IEEE Press Text Book
[15] P. Y. Wang and X. X. Zhou, “Influence of the Transient Processes of TCSC and MOV on Power System Stability,” IEEE transactions on power systems, vol. 15, no 2, May 2000
[16] John J. Paserba (M), Nicholas W. Miller (SM), Einar V. Larsen (F), Richard J. Piwko (SM), “A thyristor controlled series compensation model for power system stability analysis,” IEEE Transactions on Power Delivery, Vol. 10, No. 3, July 1995
[17] Preeti singh, mrs.Lini mathew, prof. S. Chatterji , “ MATLAB based simulation of TCSC FACTS controller”, proceedings of 2nd national conference on challenges & opportunities in information technology, March 29, 2008
[18] Scott G. Helbing & G.G Karady, “ Investigation of an advanced form of series compensation,” IEEE transaction on power delivery, vol.9, no.2, April 1994
[19] B.H. Li, Q.H. Wu,, D.R. Turner, P.Y. Wang, X.X. Zhou, “Modelling of TCSC dynamics for control and analysis of power system stability,” Electrical Power and Energy Systems,22 43–49, 2000
[20] C. R. Fuerte-Esquivel, E. Acha, and H. Ambriz-Pbrez , “A Thyristor Controlled Series Compensator Model for the Power Flow Solution of Practical Power Networks,” IEEE transactions on power systems, vol. 15, no 1, February 2000