Modelling, Simulation and Analysis of the Thyristor-Controlled Series Capacitor (TCSC)

Bhakti S Nitve
Assistant Professor
Department of Electrical and Electronics Engineering
MMEC Belagavi
Corresponding Author's Email: *bhakti.nitve@gmail.com*

Abstract

The analysis presents the study of TCSC device on Simulink. TCSC is one of the important members of FACTS family that is rapidly increasingly and is applied for long transmission lines by the utilities in modern power systems to improve the power quality of the system. It can have various roles in the operation and control of power systems, such as scheduling power flow; decreasing unsymmetrical components; reducing net loss; providing voltage support; limiting short-circuit currents; mitigating sub synchronous resonance; damping the power oscillation and enhancing transient stability control of power systems, procedures are used to compensate dynamically the detrimental effect of nonlinear loads. The compensation process should be carried out without important alteration of the signal quality along with some benefits like reduction of losses in distribution lines, harmonic content minimization and power factor improvement.

The simulation results demonstrate the performance of the system for TCSC FACTS device in improving the power profile and thereby voltage stability of the same. All simulations have been carried out in MATLAB/SIMULINK environment.

Keywords: *FACTS, Series Compensator, TCSC, Thyristor, MATLAB*

I. INTRODUCTION

Electrical networks are interconnected to different generating stations and load centers according to the existing plan. But load demands on the system are not constant. With the increase of industrial growth and domestic load, more power is consumed by the different loads. To fulfill the load demand, either electrical system network to be re-evaluated or the power carrying capability of the transmission line to be increased. Economic point of view, modification or alteration of electric network is costly. Thus aim is to increase the power carrying capability of transmission line.

To maintain both dynamic and steady state operation, the new technology i.e FACTS (Flexible AC Transmission System) is used which is a power electronics based system. Its main role is to enhance controllability and power transfer capability in ac systems. It uses switching power electronics to control power flow in the range of few tens to a few hundreds of megawatts. The various FACTS controller govern the operation of transmission system by providing series impedance, shunt impedance, line current, voltage, phase angle and damping of oscillations at various frequencies below the rated frequency. Thus use of FACTS technology increases the power carrying capability of existing transmission network which is more economical. The series compensation is an economic method of improving power transmission capability of the lines. Series compensation will increase power transmission capability, improve system stability, reduce system losses, improve voltage profile of the lines, optimize power flow between parallel lines. [4]

Thyristor-controlled series capacitors (TCSC) is also a type of series compensator, can provide many benefits for a power system including controlling power flow in the line, damping power oscillations, and mitigating subsynchronous resonance. The TCSC concept is that it uses an extremely simple main circuit. The capacitor is inserted directly in series with the transmission line and the thyristor-controlled inductor is mounted directly in parallel with the capacitor. Thus no interfacing equipment for e.g. high voltage transformers is required. This makes TCSC much more economic than some other competing FACTS technologies. Thus it makes TCSC simple and easy to understand the operation. [2][3]

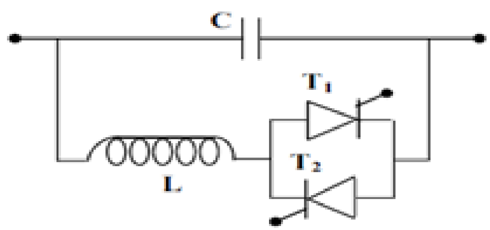

Fig1: a simple diagram of TCSC

II. PHYSICAL MODEL OF TCSC

The TCSC consists of the series-compensating capacitor shunted by a thyristor-controlled reactor (TCR) [2] [3] [11]

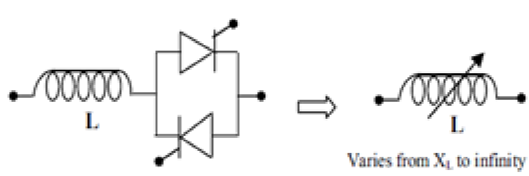

Fig2: Equivalent circuit of TCR

The impedance of the reactor XL is sufficiently smaller than that of the capacitor impedance Xc is taken. By varying the delay angle or firing angle (α) of TCR, the inductive impedance of TCR can be varied. Thus TCSC can provide variable capacitance by means of canceling the effective capacitance by the TCR. Therefore, the steady state impedance of TCSC is simply that of the parallel LC circuit, consisting of fixed capacitive impedance Xc and variable inductive impedance XL. The effective impedance of the TCSC is given by

$$X_T(\alpha) = \frac{X_c X_L(\alpha)}{X_L(\alpha) - Xc} \qquad \text{.......... (1)}$$

Where XL(α) is the variable impedance of TCR that is

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha} \qquad \text{.......... (2)}$$

for $X_L \leq X_L(\alpha) \leq \infty$ where $X_L = \omega L$

and α is the delay angle measured from the crest of the capacitor voltage or the zero crossing of the line current. Effective TCSC reactance XTCSC with respect to alpha (α) is [10]

$$X_{TCSC} = -X_C + C_1\left(2(\pi-\alpha) + \sin[2(\pi-\alpha)]\right) - C_2 \cos^2(\pi-\alpha)\left(\varpi \tan[\varpi(\pi-\alpha)] - \tan(\pi-\alpha)\right)$$

(3)

Where

$$C_1 = \frac{X_C + X_{LC}}{\pi},$$

$$C_2 = \frac{4X_{LC}^2}{X_L \pi},$$

$$X_{LC} = \frac{X_C X_L}{X_C - X_L},$$

$$\varpi = \left(\frac{X_C}{X_L}\right)^{1/2}$$

where X_L=ωL and α is the delay angle measured from the crest of the capacitor voltage or the zero crossing of the line current.

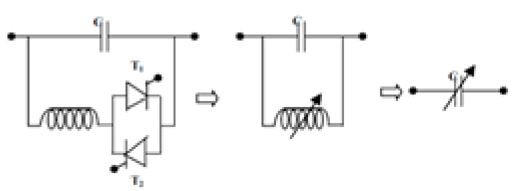

Fig3: Equivalent circuit of TCSC

The TCSC behaves as a tunable parallel LC-circuit to the line current. As the impedance of the controlled reactor $X_L(\alpha)$ is varied from its maximum (infinity) toward its minimum (ωL) i.e. when α varies from 900 to 00, then TCSC increases its minimum capacitive impedance $X_{T(\min)} = X_c = 1/\omega C$, until parallel resonance occurs at $X_c = X_L(\alpha)$ and $X_T(\alpha)$ approaches to it maximum value X_T(max)=infinite. If we decrease $X_L(\alpha)$ further, the $X_T(\alpha)$ becomes inductive and approaches to its minimum value of $X_T(\min)=X_cX_L/(X_L-X_c)$ at $\alpha=0^0$. i.e the effect of capacitor is bypassed by TCR.

Angle α has two limiting value

(1) One for inductive $\alpha_{L(\lim)}$ and

(2) One for capacitive $\alpha_{C(\lim)}$.

The TCSC has two operating ranges around its internal circuit resonance:

(1) One is the $\alpha_{C(\lim)} \leq \alpha \leq \pi/2$ range, where $X_T(\alpha)$ is capacitive

(2) The other is the $0 \leq \alpha \leq \alpha_{L(\lim)}$ range, where $X_T(\alpha)$ is inductive.

III. MODES OF OPERATION OF TCSC

There are three modes of operation of TCSC depending upon the firing angle of the pulses fed to the thyristor.[10][11][12]

(a)Thyristor-blocked mode:

In this mode of operation, the current through the TCR is zero and the TCSC function as a capacitive reactance Xc .It is known as the waiting mode. The firing pulses to the thyristor valves are blocked. The thyristors turn off as soon as the current through them reaches a zero crossing. The TCSC module is thus reduced to a fixed-series capacitor. The net TCSC reactance is capacitive.

(b)Thyristor-bypassed mode:

In this mode, the thyristor valves are fired with no delay and the TCSC has small inductive impedance. The thyristors are made to fully conduct with a conduction angle of 1800. Gate pulses are applied as soon as the voltage across the thyristors reaches zero and becomes positive results in a continuous sinusoidal of flow current through the thyristor valves thyristor valves are fired with no delay. TCSC has small inductive impedance. Also known as the thyristor-switched-reactor (TSR) mode employed for control purposes and also for initiating certain protective functions.

(c)Thyristor- phase controlled mode (partially conducting thyristor (capacitive-vernier) and the partially conducting thyristor (inductive-vernier) mode):

In this mode the value of the firing angle determines the direction of the current through the TCR and the capacitor, enabling the TCSC to work as either a capacitive or an inductive reactance. In this mode, the thyristor firing mechanism is controlled to vary the amount of effective reactance connected to the system .It allows the TCSC to behave either as a continuously controllable capacitive reactance or as a continuously controllable inductive reactance. It is achieved by varying the thyristor-pair firing angle in an appropriate range a smooth transition from the capacitive to inductive mode is not permitted because of the resonant region between the two modes. In capacitive-vernier-control mode the thyristors are fired when the capacitor voltage and capacitor current have opposite polarity. In inductive-vernier mode, the TCSC can be operated by having a high level of thyristor conduction. Direction of the circulating current is reversed and the controller presents net inductive impedance.

IV. PRACTICAL TCSC CIRCUIT

Practical TCSC circuit has various protection elements including MOV, circuit breaker in series with an inductor. TCSC module with different protective elements is as shown below [10] [11] [12].

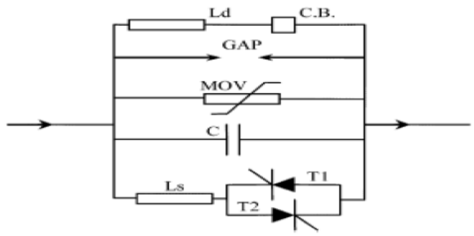

Fig4: Practical circuit of TCSC

Basically, it comprises a series capacitor, in parallel with a Thyristor Controlled Reactor (TCR), Ls. A Metal Oxide Varistor (MOV), essentially a nonlinear resistor, is connected across the series capacitor to prevent the occurrence of high capacitor over voltages. Not only does the MOV limit the voltage across the capacitor, but it allows the capacitor to remain in the circuit even during fault conditions and helps improve the transient stability. A circuit breaker is also installed across the TCSC module to bypass it if a severe fault or equipment malfunction occurs. A current limiting inductor, Ld is incorporated in the circuit to restrict both the magnitude and the frequency of the capacitor current during the capacitor bypass operation.

V. SIMULATIONS ON M – FILE FOR ANALYSING THE ACTIVE AND REACTIVE POWER FLOW CONTROL BY TCSC

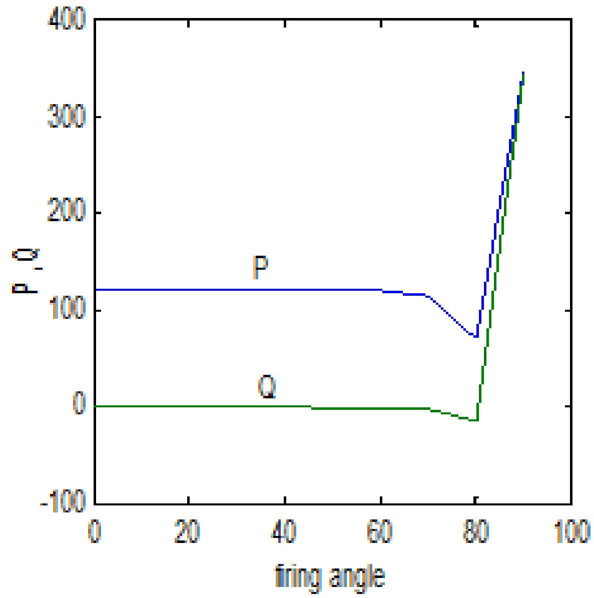

Fig5: Active power and reactive power VS firing angle

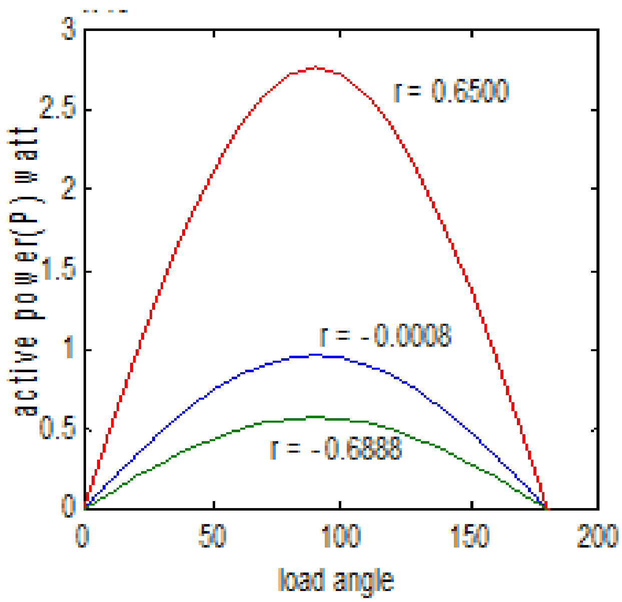

Fig6: Active power VS load angle

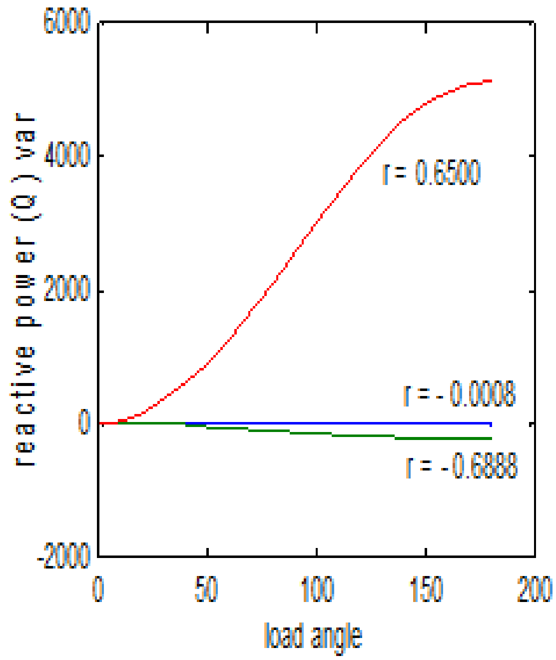

Fig7: Reactive power VS load angle

Output of the result shows that the compensating coefficient 'r' is having both inductive and capacitive compensation value & this varies according to the firing angle. From the analysis it is clear that height of load angle curve increases with the more capacitive reactance of TCSC. But the height of the load angle curve decrease with more inductive reactance of TCSC [1][11] .

Similarly the reactive power curve for capacitive compensation is positive and reactive power curve for inductive compensation is negative.

Also both active and reactive power decreases with the increase of firing angle up to certain value where the reactance of TCSC is inductive. At 900 of firing angle the reactance of TCSC becomes capacitive and both active and reactive power increases.

VI. SIMULATION OF TCSC CIRCUIT USING MATLAB

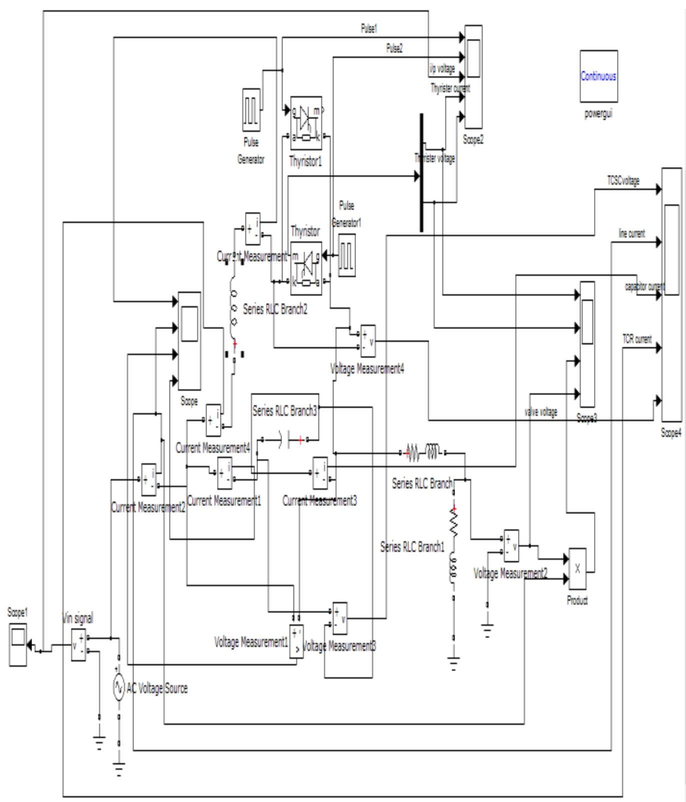

Fig. 8 Simulink model of TCSC device

Here in MATLAB various blocks are all interconnected to make an open loop TCSC Simulink model which is connected in series with the single source transmission line. Fig 8 shows the Simulink model of open loop TCSC device connected in series with the single source transmission line system. For analyzing the Thyristor Current, Thyristor Voltage, firing angle pulse is given through pulse generator. To analysis about capacitive mode of TCSC apply the pulse in the region of vernier capacitive region [12]. This gives the analysis of waveforms of capacitor voltage, line current, thyristor current and capacitor current of TCSC as shown in fig 10. Simulation results of Thyristor current, Thyristor voltage, o/p power, o/p voltage when Delay of pulser1=0.0275s and delay of pulser2=0.0375s i.e. $\alpha=135^o$ and 315^o

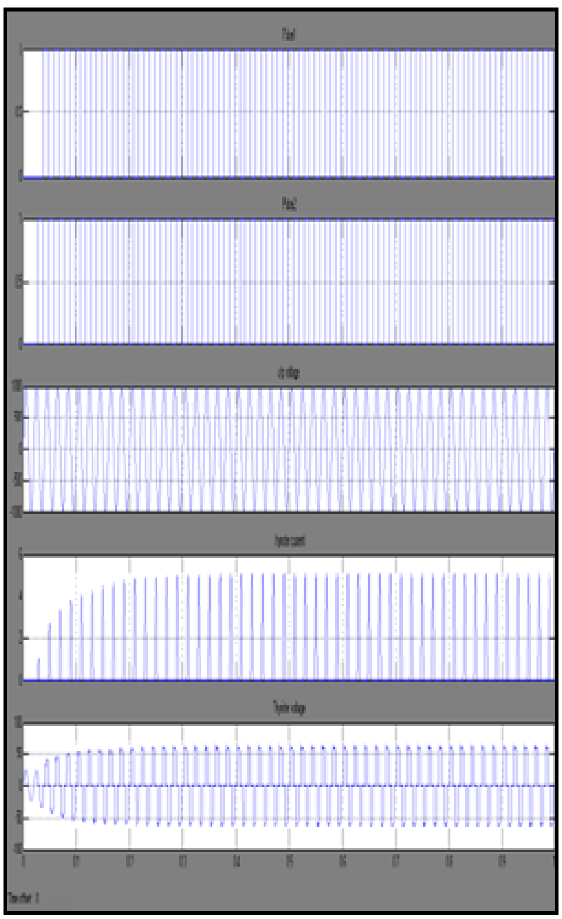

Fig.9: Pulse1, Pulse2, Input Voltage, Thyristor current, Thyristor voltage[12]

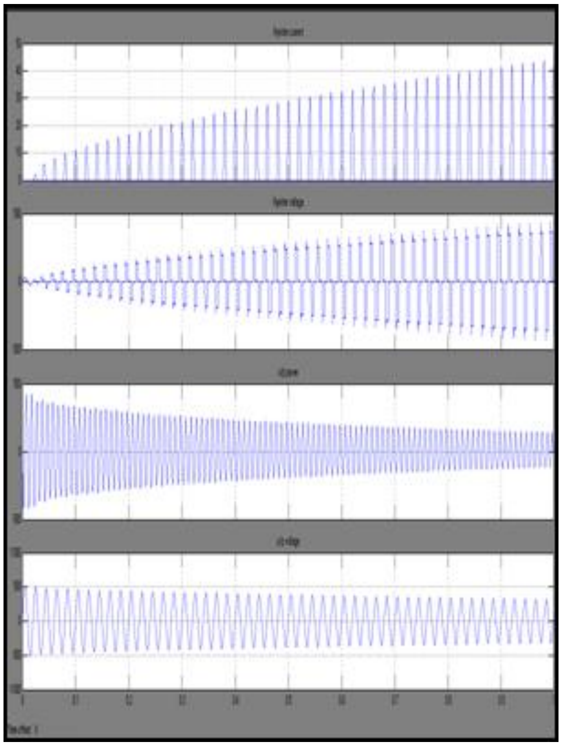

Fig10: Thyristor current, Thyristor voltage, Thyristor output power and output voltage

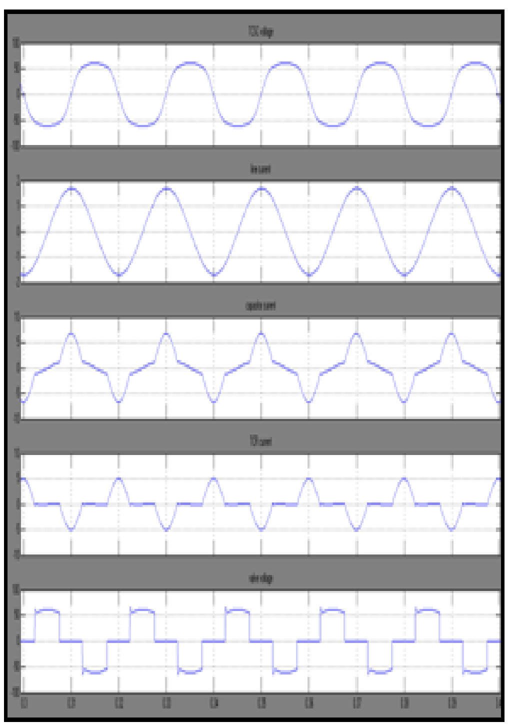

Fig11: TCSC waveforms in the capacitive mode of operation TCSC voltage, line current, capacitor current, TCR current, valve voltage [10] [12]

VII. SIMULATION OF CORRELATION OF TCSC IN POWER SYSTEMS

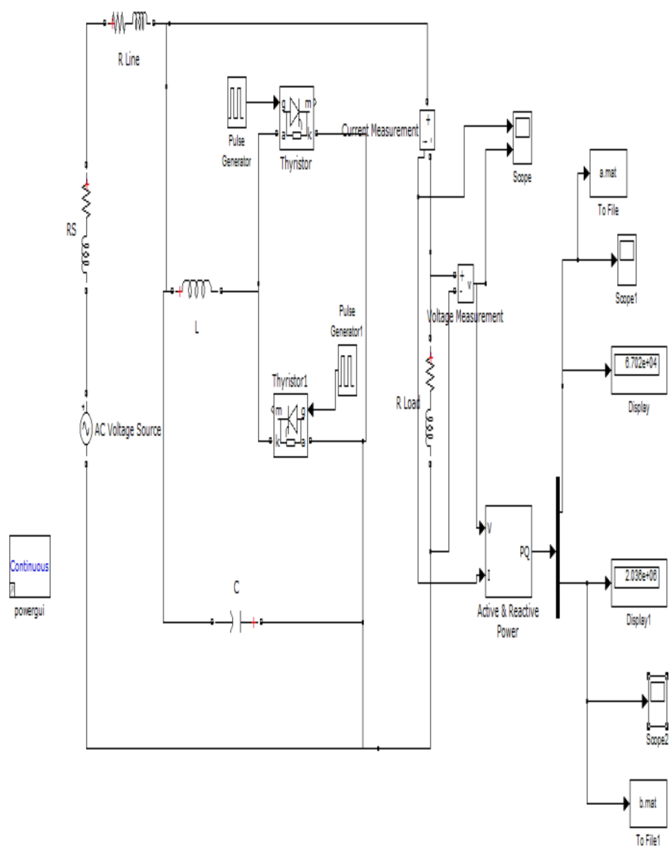

Fig.9: Simulation of Correlation of TCSC in Power Systems

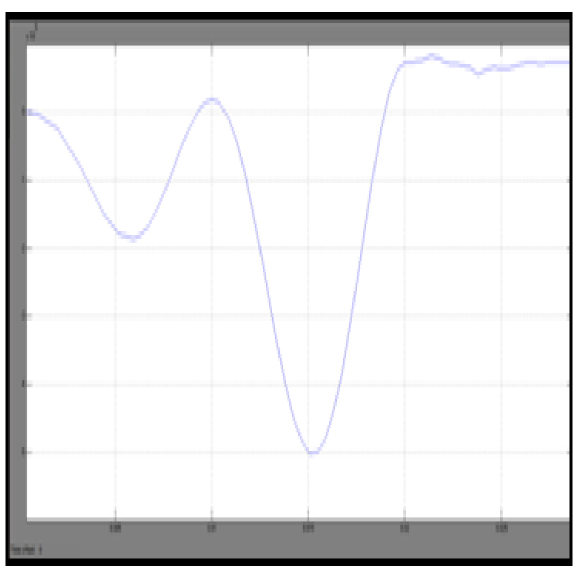

Fig.10:Real Power with TCSC Compensation

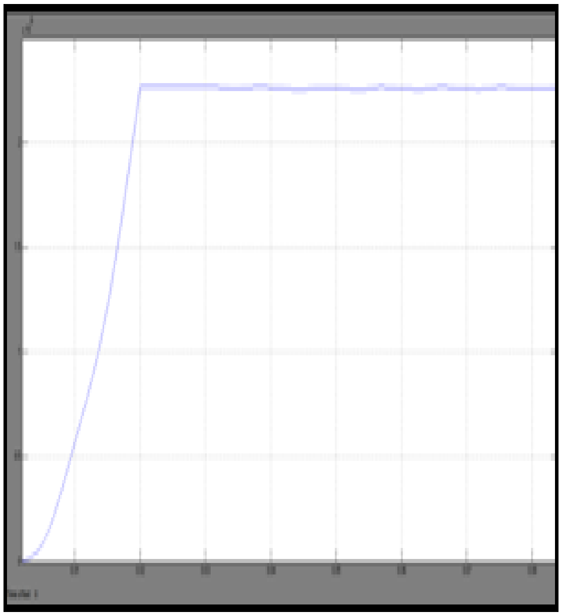

Fig.12: Reactive Power with TCSC Compensation

Table: 1

Capacitance (µF)	**Real Power** (MW)	**Reactive power** (MVAR)
50	0.712	1.88
100	0.721	1.91
150	0.723	1.95
200	0.751	2.01
250	0.783	2.05
300	0.789	2.11
350	0.791	2.15
400	0.798	2.23
450	0.811	2.31
500	0.824	2.35

Simulation results of Transmission line with TCSC compensation for different values of Capacitor. As the value of Capacitance increases the flow of Real and Reactive powers also increases.[5]

CONCLUSION

This paper is to analyze the actual behavior of the TCSC FACTS device. The main purpose of this paper is to lay a strong foundation on TCSC and precisely explained about the operation, characteristic curve and modes of operation of TCSC and to simulate the TCSC FACTS controller. The simulation model was analysed for different modes of operation, waveforms at different points and at different operating condition. Correlation of TCSC in power systems is seen. The results obtained were in consistence with the results from standard text[10] and reference paper[12][5].

REFERENCES

1) Hadi Saddat, "Power System Analysis (MATLAB concept)", Tata McGraw-Hill, Edition,2002.

2) Muhammad H. Rashid, "Power Electronics (concept of Flexible AC Transmission Systems)", Pearson Education-3rd Edition,2004.

3) Narain G. Hingorani / Laszlo Gyugyi, "Understanding FACTS", IEEE press, 1st Indian Edition,2001.

4) IJ Nagrath / DP Kothari, "Power System Engineering (concept of series and shunt compensation)", Tata McGraw-Hill,2003.

5) Mr. B. Ashok Kumar, Mr. P. Rajendra Bhanu Teja, "Exemplary Design and Correlation of FACTS Devices in Power Systems",pp.86-101, Issue 3, Vol.5, ISSN 2249-6149, September 2013.

6) S. Meikandasivam1, Rajesh Kumar Nema2, and Shailendra Kumar Jain3, Selection of TCSC Parameters: Capacitor and inductor, IEEE, 2011.

7) E Acha / VG Agelidis / T J E Miller, "Power Electronic Control in Electrical Systems", Newnes Power Engineering Series,Ist Indian Edition,2006.

8) Geng Juncheng; Tong Luyuan; Ge Jun; Wang Zhonghong; "Mathematical model for describing characteristics of TCSC",

Power System Technology, 2002. Proceedings. PowerCon 2002. Volume 3, 13-17 Oct. 2002 Page(s):1498 – 1502.

9) Abdel-Moamen, M.A.; Narayana Prasad Padhy, "Power flow control and transmission loss minimization model with TCSC for practical power networks", Power Engineering Society General Meeting, 2003, Volume 2, 13-17 July 2003.

10) R. Mohan Mathur, Rajiv K. Varma; "Thyristor-Based FACTS Controllers For Electrical Transmission Systems", A John Wiley & Sons, Inc. Publication, 2002.

11) Bijoy Kumar Sahoo and Narendra Kumar, "Power Flow Control Using TCSC", M.Tech dissertation, Dept. of Electrical Engineering, Delhi college of Engineering, 2005-2006.

12) Kusum Arora, S.K. Agarwal, Narendra kumar, Dharam Vir," Simulation Aspects of Thyristor Controlled Series Compensator in Power System", Vol. 3, Issue 4 (April. 2013), ||V1 || PP 17-26

