INFLUENCE OF TCSC IN AN INTERCONNECTED POWER SYSTEMS-MODELLING, ANALYSIS AND INTERFACING

Nirav Patel[1], Chanakya Bhatt[2], Shailesh Modi[3]
[1]PG student, [2]Assistant professor
[1,2]Department of Electrical Engineering, Nirma University, Ahmedabad, Gujarat,
[3]Manager at ERDA, Vadodara
Email: [1] 14meee15@nirmauni.ac.in, [2] chanaykya.bhatt@nirmauni.ac.in, [3]shailesh.modi@erda.org

Abstract
In the last two decades, power demand has increased enormously and at the same time expansion of power generation and transmission has been severely limited due to limited resources. In the existing power system; many transmission lines are heavily loaded and stability of the system becomes unstable. Hence in order to reduce the heavy loading of transmission lines and to maintain the stability of the system di erent alternative solution like FACTS (Flexible AC transmission systems) devices have been used. There are various FACTS devices out of which, use of TCSC (Thyristor controlled series capacitor) has been increased in last one decade. TCSC is a series control device which is applied on the ac transmission in order to acquire smooth control of series reactance and direct control of power flow. As incorporation of TCSC in the transmission line provides number of benefits like it emphasizes on enhancement of dynamic and transient stability and its control, it also diminishing the damping of SSR (sub synchronous resonance) and loop flow. In this paper main focus is to analyse TCSC behaviour in inductive and capacitive mode by doing its simulation in MATLAB R2014a software.
Keywords— TCSC, FACTS, SSR, loop flows, power flow control, heavy loading.

I. INTRODUCTION

Series capacitive and inductive compensation is very efficient technique to increase and to cut the power transfer capability of a transmission line respectively. In early 90's fixed series capacitors had been used for increase the real power transfer capacity of transmission line by cancelling a part of the inherent inductive reactance. If 70% line inherent inductive reactance is cancelled, then it can be said that 70% compensation is there in line and hence degree of series compensation (K) is 70%. More than 70% compensation will increase a risk of sub synchronous resonance problem in the power system. So typically, up to 70% of compensation is done for transmission line compensation. Risk of sub synchronous resonance (SSR) problem is higher in series capacitive compensation technique than inductive compensation technique [4, 5, 7].

Because of fixed series compensation technique which was used in early 90's, two sub synchronous problems were occurred in the year 1970s, at the Mojave in southern Nevada, and further as a consequence of SSR shaft of generator was damaged and that shaft damage had taken months to be repaired. Hence later in 1981 NGH damping technique for series compensators was given by N.G. Hingorani, and it is named as thyristor controlled series capacitor (TCSC) by which SSR mitigation became easy. In 1999 the world's first TCSC was installed for the purpose of SSR mitigation in 400 kV grid which is located in Sweden. [4, 5].

Due to capacitor and inductor parallel combination in TCSC device it has been observed that there is a possibility of parallel resonance problem apart from series and sub synchronous resonance problem. Hence it is required to select the value of inductor and capacitor in such a way that parallel and series resonance problem can be minimised significantly. The main benefit of using TCSC is that it offers only single resonance point in its working region which is in between 90° to 180° of firing angle. For further analysis, this paper starts with basic description of TCSC device and its reactance vs. firing angle characteristic curve. Kanpur – Ballabhgarh TCSC project is taken as a case study, section II, illustrates the operation of TCSC along with few mathematical equations which is used to calculate the TCSC reactance at different firing angle. Section III illustrates a reactance vs. firing angle characteristics curve of a TCSC device and it also describes the range of inductance and capacitance region. Section IV, V discusses the modelling of TCSC simulation circuit & simulation results and analyses of the power transfers on transmission line for different values of firing angle α.

II. OPERATION OF TCSC

Fig. 1 shows a schematic diagram of TCSC device which consists of a two anti-parallel thyristor in series with one inductor (L) and this two combination is in parallel with one capacitor (C). The combination of inductor in series with two antiparallel thyristor is also called as thyristor controlled reactor (TCR). TCR is a variable inductive reactor ((α)) tuned at firing angle α, as shown in Fig. 2.

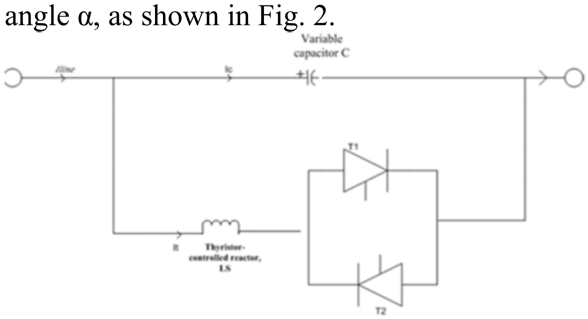

Fig. 1 TCSC device schematic diagram.

The variation of $XL$with respect to α can be given as

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha} \quad (1)$$

Here, $X_C = \frac{1}{2\pi f c}$ and $X_L = 2\pi fl$ (2)

For the variation of α from 0 to 90, the inductive reactance (α) varies from actual reactance ( ) to infinity. This thyristor controlled reactor is connected in parallel with series capacitor, so that the variable capacitive reactance XC (α), is possible across the TCSC which modify the transmission line impedance. Effective TCSC reactance $XTCSC$ with respect to alpha (α) can be given as [9, 10]

$$X_{TS(\alpha)} = -X_C + b_1(2(\pi - \alpha) + \sin(2(\pi - \alpha))) - b_2 \cos^2(\pi - \alpha)(\omega \tan(\omega(\pi - \alpha)) - \tan(\pi - \alpha)) \quad (3)$$

Where,

$$b_1 = \frac{X_c + X_{LC}}{\pi} \quad (4)$$

$$b_2 = 4\ \frac{X_{LC}^2}{X_L\,\pi} \quad (5)$$

$$X_{LC} = \frac{X_c X_L}{X_c - X_L} \quad (6)$$

$\omega = \sqrt{\frac{X_C}{X_L}}$ and it should not be more than 3. (7)

Degree of series compensation (K) is a ratio of effective reactance of TCSC [$SC(\alpha)$] to net reactance of transmission line [XTL]. And hence K is given in mathematical form as

K = $XT(\alpha)/XTL$ *100, 0 < K < 1 (8)

While choosing the value of K, it should be keep in mind that compensation should not be more than 70% in order to avoid the sub synchronous resonance in transmission line [4, 5].

III. REACTANCE CHARACTERISTIC

Fig. 2 shows the characteristics curve of TCSC device. It is drawn between effective reactance of TCSC $XTCSC$ and firing angle α. The effective reactance (XT(α)) of TCSC operates in three region, inductive region, resonance region, capacitive region. In inductive region XL starts increasing from 90° to infinity (parallel resonance condition, XL (α) =), and decreasing from infinity to capacitive reactance XC for capacitive region. Between this two regions resonance region is exits, where resonance occurs [1].

TABLE I
COMPARISION BETWEEN RANGE OF FIRING ANGLE (α) AND OPERATING REGION OF TCSC

Range of firing angle (α)	**Operating Region**
$\alpha = 90^{\circ} \le \alpha \le \alpha_{L(lim)}$	Inductive region
$\alpha_L(lim) \le \alpha \le \alpha_C(lim)$	Resonance region
$\alpha_{C(lim)} \le \alpha \le \alpha = 180^{\circ}$	Capacitive region

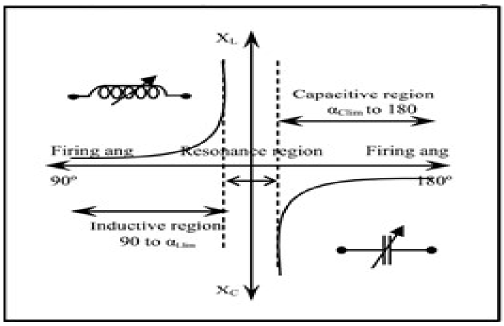

Fig. 2 Characteristic curve of Firing angle vs. Reactance

IV. MODELING OF TCSC SIMULATION CIRCUIT

Fig. shows MATLAB/SIMULINK model with TCSC for open loop controlled system. SIMULINK is used to model, analyse and simulate dynamic systems using block diagrams.

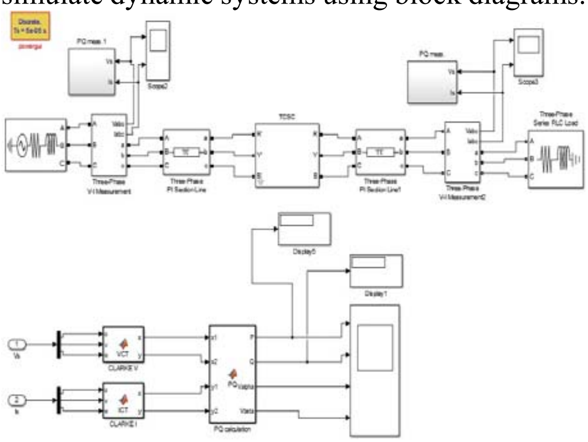

Fig. 3 Simulink model of TCSC (open loop)

Fig. 4 Shows MATLAB/SIMULINK model with TCSC for close loop controlled system. In close loop controlled system reference reactance $Xref$ value can be set by two ways: 1. By scheduling controller in such a way that it will completely based on the power flow specification in the transmission line. 2. By manual control in response to an order from an energy control centre. $Vtcsc$ and $Itcsc$ is the TCSC voltage and current respectively.

TCSC reactance's desired magnitude is $Xdes$that is implemented after a finite delay caused by the firing controls and the natural response of the TCSC. This finite delay can be modelled by a lag circuit and it is having a time constant which is denoted as, $Ttcsc$, and its value typically lies in between 15-21 ms. The final $XTCSC$ is added to the $Xfixed$ which is reactance of FC component of the installed TCSC.

The final reactance vary equation is given below,

$Xref$ = XTL - $XTCSC(\alpha)$

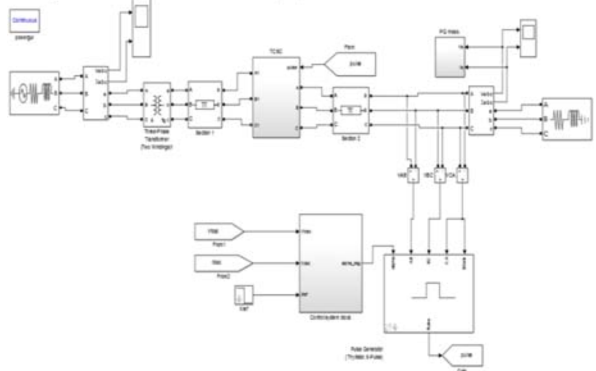

Fig.4 Simulink model of TCSC (close loop)

V. SIMULATION RESULTS

Table II shows comparison of firing angle (α) with TCSC reactance and TCSC reactance for different firing angle can be calculated by equation (3).

TABLE II

COMPARISION BETWEEN FIRING ANGLE (α) AND TCSC REACTANCE

Firing angle (α)	TCSC reactance ($XTCSC$)
$XTCSC$(90°)	∞ Ω
$XTCSC$(130°)	3.95 Ω
$XTCSC$(140°)	4.11 Ω
$XTCSC$(180°)	-10.4 Ω

Fig. 4 and Fig. 5 shows the real power flow in transmission line when system is not connected with TCSC device. The value of real power flow at sending end and receiving end bus are 415.86 MW and 414.41 MW respectively.

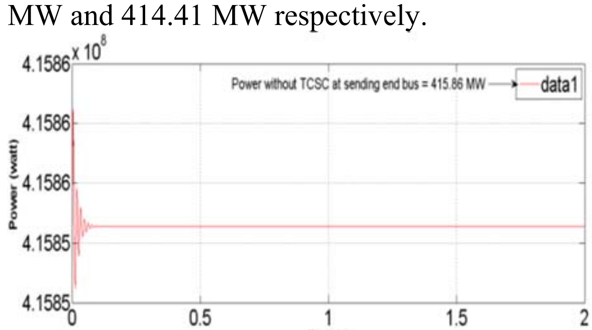

Fig. 4 Real power flow without TCSC at sending end bus

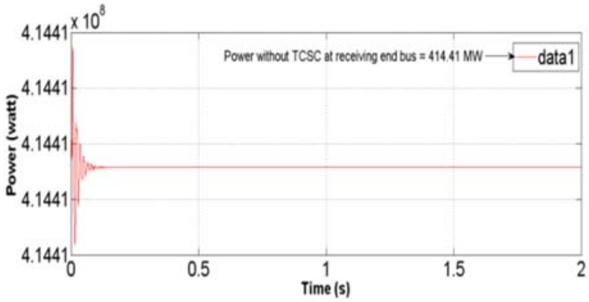

Fig. 5 Real power flow without TCSC at receiving end bus

Fig. 6 and Fig. 7 shows active power flows at α = 90° and α = 130° respectively. As α = 90° to 130° is inductive mode and in inductive mode region power will decrease. The value of real power at α = 90° is 394.14 MW and at α = 130° it is 402.73MW.

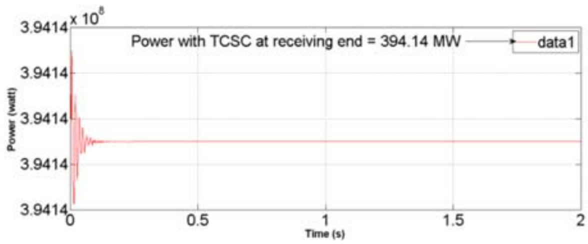

Fig .6 Real power flow with TCSC at α = 90°

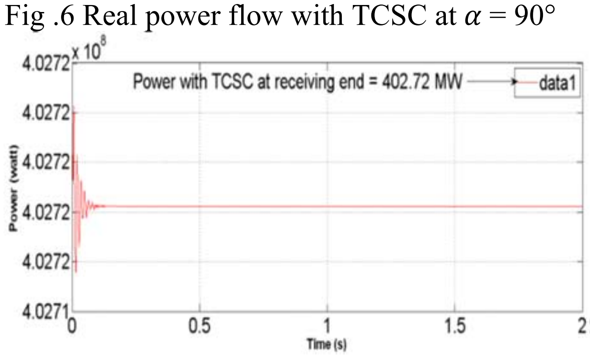

Fig. 7 Real power flow with TCSC at α = 130°

Fig. 8 and Fig. 9 shows active power flows at α = 140° and α = 180° respectively. As α = 140° to 180° is capacitive mode and in capacitive mode region power will increase. The value of real power at α = 140° is 426.90 MW and at α = 180° it is 435.07 MW.

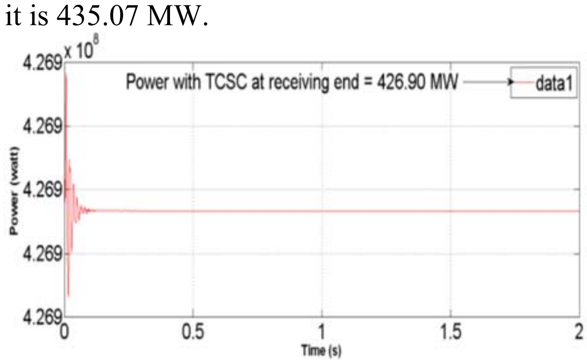

Fig. 8 Real power flow with TCSC at α = 140°

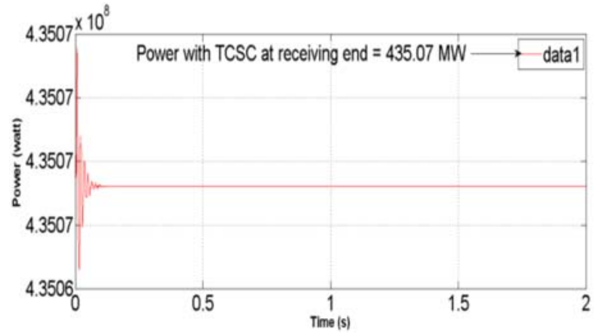

FIG. 9 Real power flow with TCSC at α = 180°

TABLE III
REAL POWER FLOW P (MW) IN TRANSMISSION LINE AT VARIOUS FIRING ANGLE WHEN ONLY TCSC IS CONNECTED

		Firing Angle α			
Power	**Without TCSC**	**90°**	**130°**	**140°**	**180°**
P (MW)	414.40	394.14	402.72	426.90	435.07

Here it can be observed from Table III that power is increasing from inductive (α = 90° to130°) to capacitive (α = 140° to180°) mode. Without connecting TCSC in series with the transmission line real power transfer is 414.40 MW and with connecting TCSC in series with the transmission line real power transfer in MW at α = 90°, 130°, 140°, 180° is 394.14, 402.72, 426.90, and 435.07 respectively.

VI. CONCLUSION

This paper describes information about the operation of TCSC, reactance characteristic, operating modes of TCSC. In this paper Kanpur–Ballabhgarh transmission line case has been taken and further simulated to know the power transfer over line. Possible real power flows on the transmission line with connected TCSC is tabulated in both capacitive mode (which is in between − 140° to 180°) and inductive mode (which is in between − 90° to 130°) of TCSC for different values of ‘α’ and it can be seen that power is decreasing in inductive mode and power is increasing in capacitive mode.

The main focus is to selecting the value of firing angle (α) according to the requirement of power demand on each side. Above study is done by considering the degree of series compensation (7.92%), but here few effects and parameters are not considered and it is fixed capacitor effect on power transfer, thermal loading effect of the transmission line, maximum allowable current limit and loop current limit of TCSC etc.

REFERENCES

[1] Meikandasivam, s., rajesh kumar nema, and shailendra kumar jain. ”selection of tcsc parameters: Capacitor and inductor.” power electronics (iicpe), 2010 india international conference on. ieee, 2011.

[2] Harikrishna, m., jitendra kumar, and premalata jena. ”detection of operational mode of tcsc using positive sequence technique.” power systems conference (npsc), 2014 eighteenth national. ieee, 2014.

[3] Meikandasivam, s., rajesh kumar nema, and shailendra kumar jain. ”performance of installed tcsc projects.” power electronics (iicpe), 2010 india international conference on. ieee, 2011.

[4] Mathur, r. mohan, and Rajiv k. varma. Thyristor-based facts controllers for electrical transmission systems. John Wiley and sons, 2002.

[5] N. G. Hingorani and L. Gyugyi, Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems, IEEE Press,

[6] Vatsal J. Patel, C. B. Bhatt, “Simulation and Analysis for Real and Reactive Power Control with Series Type FACT Controller”, International Journal of Emerging Technology and Advanced Engineering, Volume2, ISSUE 3, March 2012.

[7] S. Meikandasivam, Rajesh Kumar Nema and Shailendra Kumar Jain,
“Behavioral Study of TCSC Device-A mat lab/Simulink Implementation”, World Academy of Science, Engineering and Technology 45, 2008.

[8] Arthur R. Bergen Vijay Vittal, “Power System Analysis”, Second Edition, Pearson Education Asia, pp 528-529.

[9] 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”, TEEE Transactions on Power Systems. vol. 15, no. 1, pp. 58- 64, February 2000.

[10] L. F. W. de Souza, E. H. Watanabe, J. E. R. Alves, and L. A. S. Pilotto, “Thyristor and Gate Controlled Series Capacitors Comparison of Components Rating”, IEEE, 2003, pp: 2542-2547.

APPENDIX

The parameters of transmission line network is (situated in between Kanpur – Ballabhgarh):
Voltage at both ends: 400 kV line to line rms,
Frequency = 50 Hz
Length of line: 400 km
Maximum sustainable current of line $Imax$ = 1200 A. Three Phase PI Section Line no.1 and no.2 parameter ratings are:
Positive sequence parameters:
L = 1.044 mH/km,
C = 0.036758 μF/km,
R = 0.0032 Ω/km, Zero sequence parameters:
R = 0.2986 Ω/km,
L = 0.259 mH/km,
C = 9 nF/km,
According to parameters the line series impedance is given by
Z = 0.0032+j0.32798
Three-Phase Series RL Load
Active power P = 400 MW, Reactive power Q = 300 Mvar,
Configuration Y (grounded)
Capacitor: C = 306 μF, TCR: L = 4.4 mH
Percentage of compensation can be = ( ) *100 = 7.9272 %