International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Implementation of Thyristor Control Series Capacitor (TCSC) for Power Flow Enhancement in Matlab /Simulink

Mohammad Zohaib khattak[1], Muhammad Iftikhar Khan[2]

[1] PG Student, Department of Electrical Engineering, University of Engineering and Technology Peshawar, Pakistan

[2]Assistant Professor, Department of Electrical Engineering, University of Engineering and Technology Peshawar, Pakistan

Abstract: ***This paper presents the case study for power flow enhancement. The Scenario is, 132Kv DI Khan grid station have three transmission lines on which it takes power from the two power houses. The circuits named here as circuit 1, 2 and 3.Two circuits (1 and 2) from KAPCO side while the other circuit 3 from Chashma hydel power station. The load on circuit 1 and circuit 2 is usually less as compared with circuit of chashma side due to the circuit lengths. The power flow on circuit 1 & 2 is enhanced with the help of device known as Thyristor Control Series Capacitor (TCSC). TCSC is a series connected family member of Flexible AC Transmission System (FACTS). The benefits of TCSC includes power flow control, damp out power oscillations, mitigate subsyncronous resonance etc. The complete system is modeled in matlab/ Simulink.***

Keywords: FACTS, TCSC device, Resonance Point, Simulink Model

1. Introduction

Generally, the equation of power flow is given by $P=(V_s.V_r/X)\ \sin\boldsymbol{\delta}$, where V_s for sending end voltage, V_r receiving end voltage, X for series reactance, $\boldsymbol{\delta}$ is the angle difference. If we changed series reactance X, then it is possible to increase or decrease the active power flow on the line. In practice fixed capacitive compensation is used to decrease net series inductive reactance X, and thus increase power flow on the transmission line. The fixed capacitive compensation has a problem of subsyncronous resonance. This problem can be solved if TCSC is used. TCSC is among one such different number of methods for applying a dynamically-controllable compensating reactance.

As here focus is on case study of transmission line constraint, the existing scenario is given below. In figure1,132 kv DI khan grid is feeding from three incoming circuits, circuit 1& 2 from KAPCO power house while circuit 3 from Chasma power house. Maximum load is recorded on circuit 3 while the rest of two circuits have less load due to which circuit 3 tripped off in over loading. The DI khan grid is further connected to other grids that are not shown in figure1. Due to this less load on circuit 1 and Circuit 2, extra force load shedding is carried out in connected grids of DI khan. The loading position of the circuits is given below in table 1. So if the load on circuit 1 and circuit 2 is increased as these circuits have capability to take load, the extra forced load shedding can be minimized up to some extent. In short, this paper focuses the application of TCSC for the enhancement of power flow on circuit 1 and circuit 2. The operation of TCSC device and reactance characteristics curve are described in section II. Where section III discusses about analysis of 132 kv DI khan circuits for different firing angles.

Table 1: DI khan circuits loading status

SNO	Name of I/C circuits	Max capacity of circuit in Amp	Max load received in Amp	Load in MW
1	Circuit 1	400	240	48
2	Circuit 2	400	150	30
3	Circuit 3	400	400	80

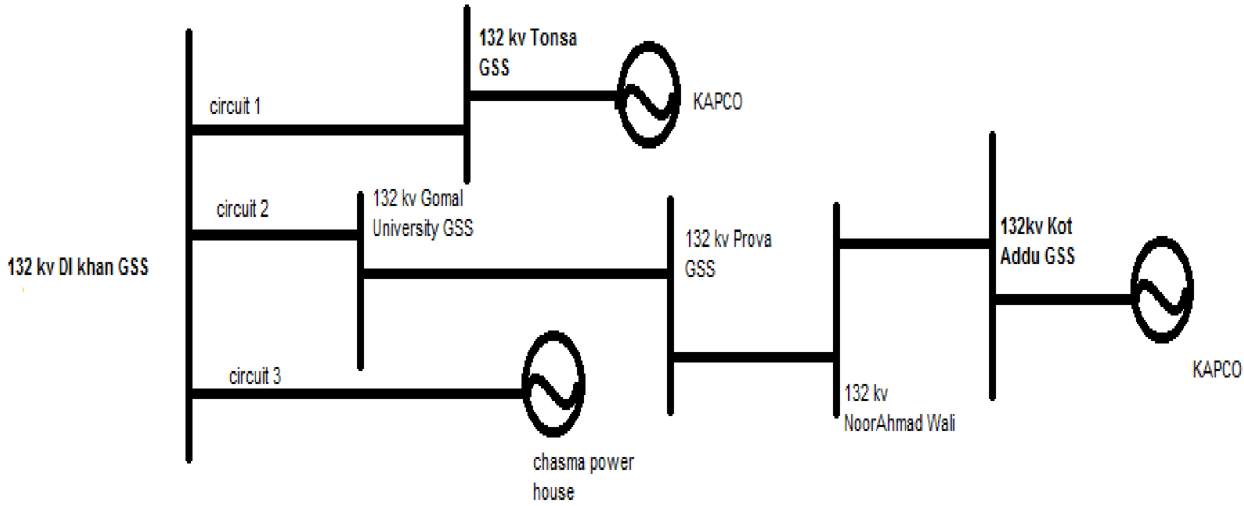

Figure 1: single line diagram of DI khan and connected grids

2. Thyristor Controlled Series Capacitor (TCSC)

The TCSC consist of a capacitor with a fixed value of capacitance connected in series with the transmission line. Thyristor controlled reactance (TCR), which consist of an inductor and a pair of back-to back thyristors, is connected in parallel to this capacitor as shown in figure 2.

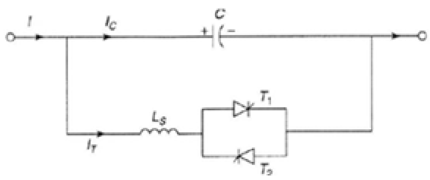

Figure 2 Basic Thyristor- Controlled Series Capacitor Scheme

The antiparallel thyristors in series with an inductor with the inductance L function as a variable inductance. Phase-control is used to change the delay angle α. The variable inductive reactance is given as

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin\alpha} \qquad X_L \le X_L(\alpha) \le \infty$$

From the above equation it is clear that it depends up on α and as α changed, it change the value of reactance X_L (α). The TCSC behaves as a tunable parallel LC-circuit to the line current as shown below in figure 3. The only dissimilarity is that the voltage and current in *LC*-combination are pure sinusoidal where as in the TCSC it is not.

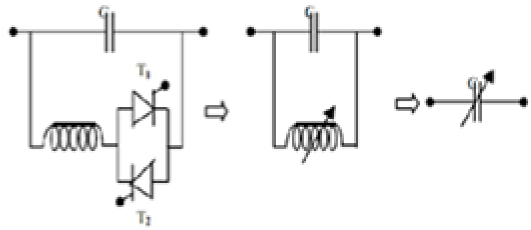

Figure 3 Equivalent circuit of TCSC

Any of the below two formulas can be used to calculate the effective reactance of the TCSC

$$X_{TCSC}(\alpha) = \frac{X_C . X_L(\alpha)}{X_L(\alpha) - X_C}$$

$$X_{TCSC}(\alpha) = -X_C + C_1(2(\pi-\alpha)+\sin(2(\pi-\alpha))) - C_2\cos^2(\pi-\alpha)(\omega\tan(\omega(\pi-\alpha))-\tan(\pi-\alpha))$$

Where

$$C_1 = \frac{X_C + X_{LC}}{\pi},\quad C_2 = \frac{4X_{LC}^2}{X_L},\quad X_{LC} = \frac{X_C X_L}{X_C - X_L},\quad \omega = \sqrt{X_C/X_L}$$

The effective reactance of TCSC operates in three regions which are shown below in figure 4.

1. Inductive region: - $0 \le \alpha \le \alpha_{Llim}$.
2. Capacitive region: - $\alpha_{Clim} \le \alpha \le 90$.
3. Resonance region: - $\alpha_{Llim} \le \alpha \le \alpha_{Clim}$

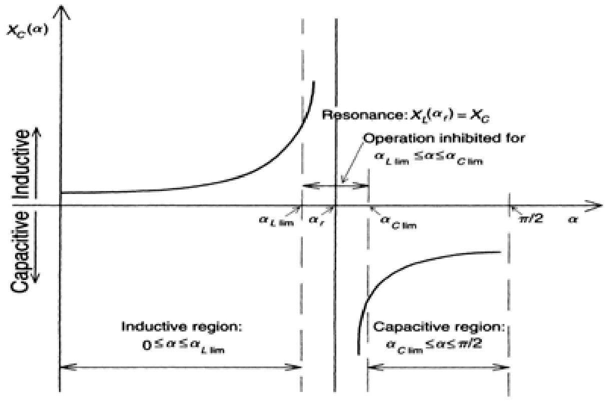

Figure 4

The impedance Vs delay angle or characteristic of the TCSC

TCSC have three modes of operation
1. By passed Thyristor mode
2. Block Thyristor mode
3. Partially conducting Thyristor or Vernier mode

Bypass mode is used for control purpose. This mode is and also used for initiating certain protective functions. The conduction angle of thyristor is 180°.

The other name of block thyristor mode is the *waiting* mode. In this mode thyristor valves are not fired as the firing pulses are blocked. In other words thyristors are off during the each period.

TCSC acts both as a continuously controllable capacitive reactance and as a continuously controllable inductive reactance in partially conducting thyristor or Vernier mode. This mode is achieved by changing the thyristor-pair delay (firing) angle in a proper range. As there is resonant region between the two modes therefor the smooth transition is not permitted from one mode to the other mode, i.e. from capacitive to inductive or vice versa. The TCSC shows large impedance at the resonance point due to which a significant voltage drops. Therefore, the TCSC is operated in such a manner to avoid the resonant region by installing limit on the firing angle. The different modes of operation of TCSC and their current direction are shown below in fig 5.

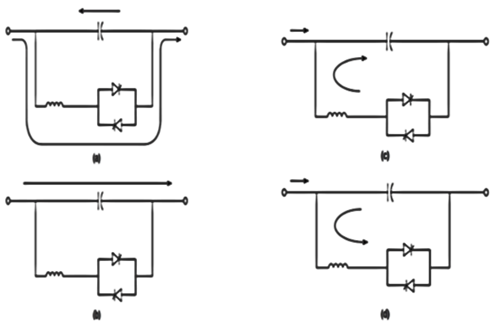

Figure 5 Different operating modes of a TCSC
(a) The Bypassed-Thyristor mode (b) The blocked Thyristor mode
(c) The partially conducting thyristor (capacitive-Vernier)
(d) (inductive–Vernier) mode

3. Choosing of Capacitor and Inductor Values

TCSC device which consist of capacitor and inductor & for choosing appropriate values of this capacitor and inductor it depends upon transmission line reactance and expected future demand. Degree of series compensation 'K' decide the capacitor value and it is normally up to 70% of line reactance, where K is given by

$$K = \frac{X_{tcsc}(\alpha)}{X} \qquad 0<K<1$$

Inductive reactance X_L should be sufficiently smaller than X_C for selection of Inductor value.

The capacitive and inductive operating regions depends on the factor '**ω**', where $\omega=\sqrt{Xc/X_L}$. To get one resonance point, then it is required to keep ω less than 3 i.e. $\omega=\sqrt{Xc/X_L}<3$. If ω greater than 3 than there are multi resonance point which decreased the operating range of TCSC. There is only capacitive region for $\omega < 1$. Thus $\omega \le 1$ is not permissible for getting both the effects of inductive and capacitive region in TCSC.

4. Matlab Simulink analysis of DI khan Circuit

As stated, a case study in the introduction part of this paper. To achieve the desired results that are to increase the power flow on circuit 1(Tonsa - DI khan) and circuit 2 (Prova - DI Khan), the TCSC along with control circuitry is designed in Matlab Simulink as shown in figure 6. The figure6 shows two voltage sources that are connected by means of transmission line and the TCSC is installed on this transmission line. The voltage source parameters are set according to Tonsa and DI khan grid for circuit 1and then for Prova and DI khan grid for circuit 2. Similarly transmission line parameters are set according to table 3. The figure 6 further shows the TCSC its control and firing unit blocks.

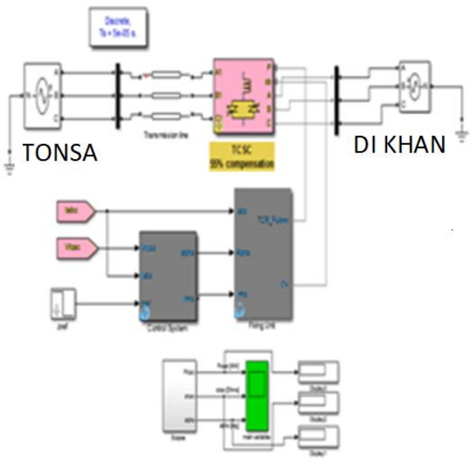

Figure 6 Matlab/ Simulink Design of TCSC for Circuit 1 and circuit 2

Table 2: Technical Data of Transmission Line

TCSC Parameters		
Circuits Names	Capacitor values	Inductor Values
Circuit 1	2.271226e^{-4}F	0.007751H
Circuit 2	1.916654e^{-4}F	0.0091870H

The TCSC block consists of a fixed value capacitor and parallel thyristor controlled reactor (TCR). The values of capacitor and inductor of TCSC are shown in table 2.

The control block consists of impedance measurement block and two PI controllers. To improve performance over a wide operating range each controller further includes an adaptive control loop. One PI controllers use for inductive operation and the other for capacitive operation. The PI controller keeps the output as desired. In TCSC capacitive or inductive mode of operation is used, but inductive mode is rarely used in practice. The operating mode can be switched from inductive to capacitive and vice versa by mean of toggle switch in the control block. The capacitive mode lies in the range of firing angle 68 – 90deg whereas firing range for inductive region is 0° to 49°. The resonance region for this TCSC is between 49° to 68°. So care must be taken while selecting firing angle to avoid resonance.

The firing unit block consist of synchronous phase lock loop (PLL) and square wave generator. The PLL is used for synchronization purpose. The PLL is in each phase of the circuit. From the firing unit the thyristor gate terminals are fired with the desired input alpha (firing angle).

When there is no TCSC on circuit-1 and circuit-2 the power flow transfer is about 48mw and 30mw respectively as shown in table 1. During the first 1 sec of simulation the TCSC is by passed and the load on the circuit 1 and 2 are 48 and 30 Mw respectively as shown in different simulation figures. According to figure 7, when the TCSC is fired at angle of 85°(initial alpha input 90° then it reduced to 85°) then power flow on the circuit increases. The power flow on circuit 1 increased from 48Mw to 72.8 Mw

Table 3: Technical Data of TCSC

The parameters of the model are as follows
Ideal Three-Phase Voltage Source
Line to-line voltage VLL = 132 kv,
Phase angle ö = 0°,5.00°,3.18°
Frequency f = 50 Hz,
Line resistance R = 0.0598Ohm/km,
Line inductance L = 0.827 mH/km,
Line capacity C = 0.018567F/km,
Line length b/w DI khan and Noor Ahmad Wally (circuit 1) = 120km DI khan and Prova section (circuit 2) = 80km

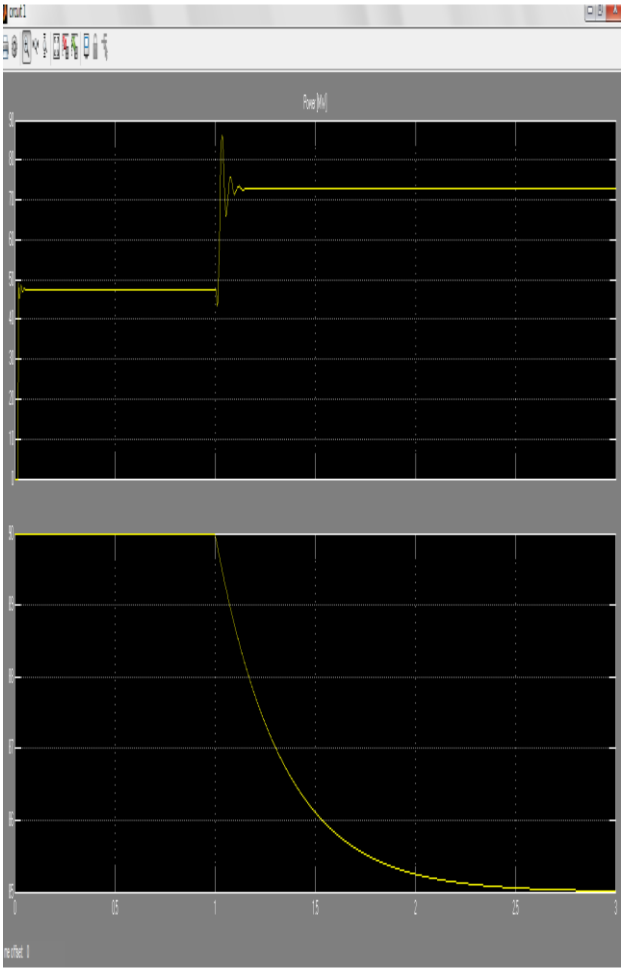

Figure 7: Circuit 1 active power flow vs firing angle (72.8Mw at alpha 85°)

When the firing angle is set to 75°, then power flow on circuit 1 increased to 73.80 Mw as shown below in figure 8

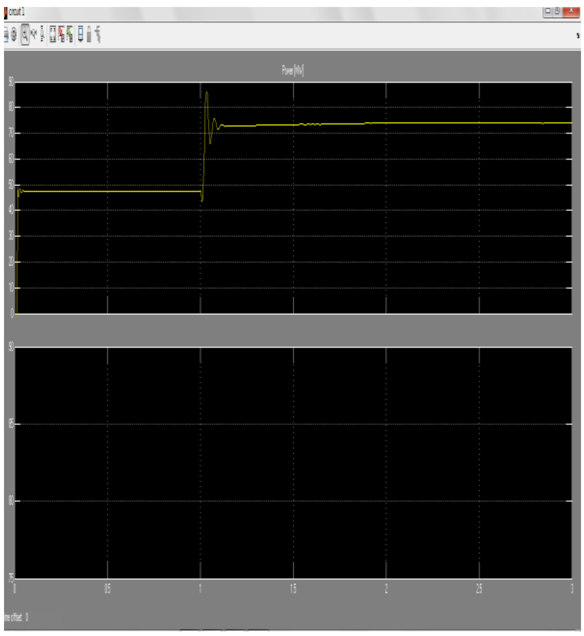

Figure 8: circuit 1 active power flow vs firing angle (73.80 Mw at alpha 75°)

The simulation of voltage and current at 132 kv DI khan grid station is shown in figure 9 below. The below figure 9 shows the enhancement of current for alpha 75°.Before 1sec, the current is round about 240 Amp and after the 1sec it increased up 370Amp.

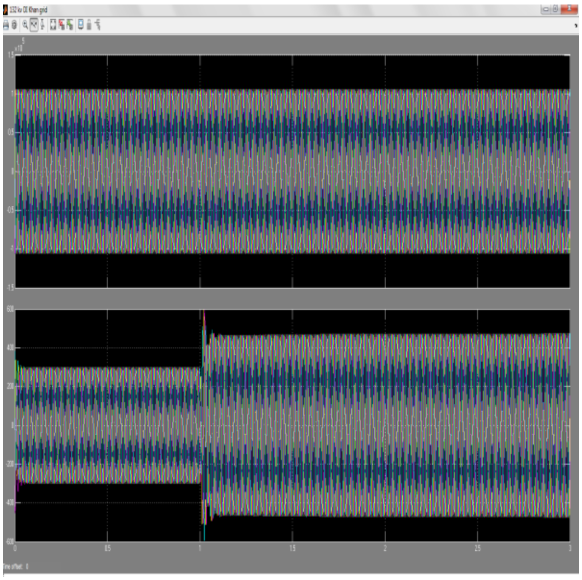

Figure 9: current vs firing angle (capacitive mode)

Similarly the simulation results of capacitive mode operation of the circuit 2 are given below in figure 10. Before 1sec the load on the circuit 2 is 30Mw, which is then enhanced to 60.75Mw when the thyristor fired at an angle of 75°

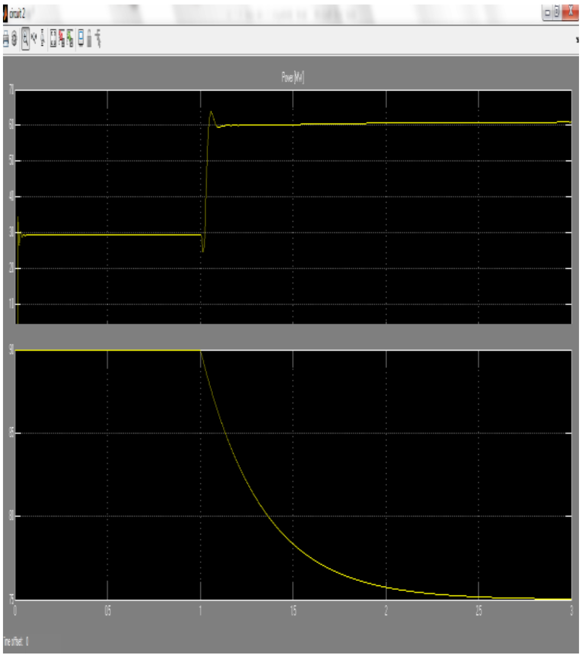

Figure 10: Circuit 2 (60.75Mw at alpha 75°)

The TCSC when used in inductive mode, the power flow on the circuit is decreased according to the alpha. In case of circuit 1 active power flow decreased to 30 Mw from 48Mw at alpha 30° as shown in figure 11(a) and 11(b).

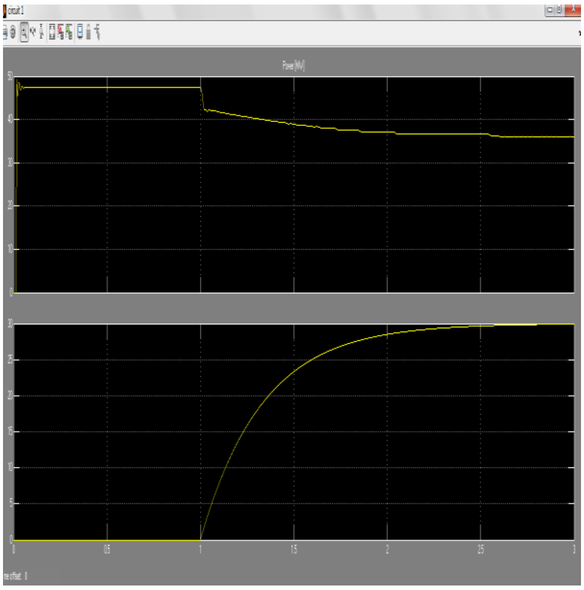

Figure 11: (a) inductive mode of TCSC (30Mw at alpha 30°)

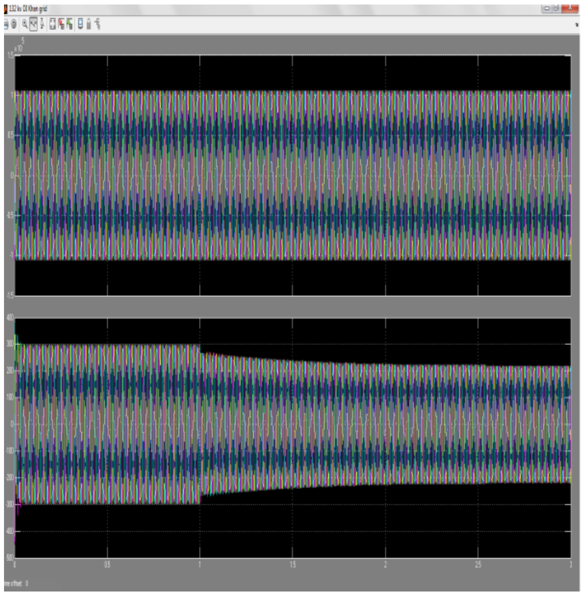

Figure 11: (b) current reductions in inductive mode

Similarly the inductive mode operation for circuit 2 the power flow decreased to16 Mw (alpha 35°) as shown below in figure 12(a) and 12(b).

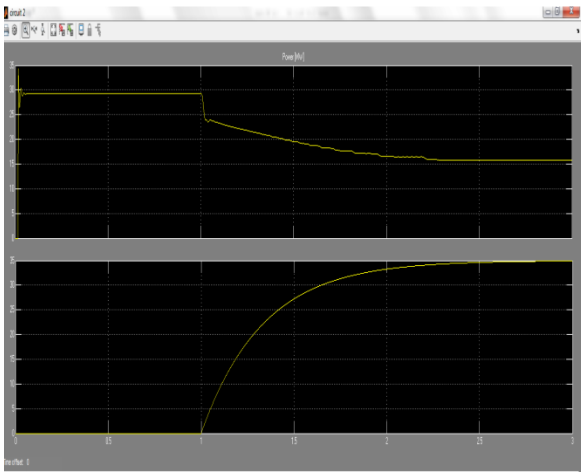

Figure 12 (a)

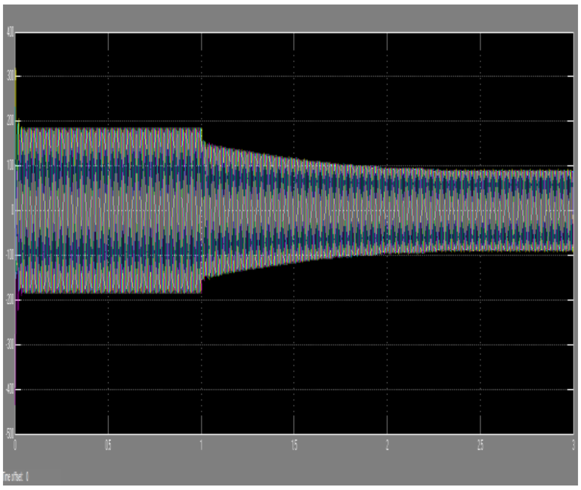

Figure 12 (b)

The overall effect of power flow on both the circuits i.e. with respect to firing angle of TCSC is shown in table 4

Table 4: Enhanced Power flow on circuit 1 and circuit 2

Name of circuit	Load without TCSC (MW)	Load (in Mw) with TCSC at different firing angles						
		capacitive region				Inductive region		
		85°	80°	75°	68°	40°	30°	10°
Circuit 1	48	72.85	73.15	73.8	77.2	23.01	35.01	41.01
Circuit 2	30	59.9	60	61.1	63	5	18	23.5
Total power Improved	78	132.75	133.15	134.9	140.2	….	….	….

5. Conclusion and Future Work

132 kv transmission line circuits of DI kan grid is analyzed in Mat lab/Simulink for power flow enhancement. The power flow of the circuit 1 and circuit 2 is enhanced and is showed in various graphs. From the table it is clear that with the use of TCSC the power flow increased from 78Mw to about 140Mw. Thus this increase in active power on the circuits is helpful in fulfilling the demand of the connected grids of the DI khan. So if the existing circuits have the capability to take load, so the use of TCSC is a one of the good solution rather than to build new transmission line. The results can be checked on other Facts devices for better improvement of power flow.

References

[1] S. Meikandasivam, Rajesh Kumar Nema, Shailendra Kumar Jain "*Behavioral Study of TCSC Device – A MatlaB/Simulink Implementation*" World Academy of Science, Engineering and Technology Vol: 2 2008-09-24

[2] John J. Paserba, *Fellow, IEEE "How FACTS Controllers Benefit AC Transmission Systems"*, IEEE 2003

[3] Preeti Singh, Mrs.Lini Mathew, Prof. S. Chatterji,N.I.T.T.T.R., Chandigarh. *"Matlab Based Simulation of TCSC FACTS Controller"* Proceedings of 2nd National Conference on Challenges & Opportunities in Information Technology (COIT-2008) RIMT-IET, MandiGobindgarh. March 29, 2008

[4] Thyristor-Based Facts Controllers For Electrical Transmission System R. Mohan Mathur, Rajiv K. Varma, A john wiley& sons, inc.public