# Implementation of TCSC on a Transmission Line Model to analyse the variation in Power Transfer Capability

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## Abstract—

*The FACTS controllers clearly enhance power system performance, improve quality of supply and also provide an optimal utilization of the existing resources. This paper discusses the development of a Thyristor Controlled Series Capacitor (TCSC) with open loop control system. The TCSC circuit and characteristics are discussed in brief. Next the determination of TCSC parameters is discussed. With these parameters the capacitive mode of operation of TCSC is simulated and implemented on a power system model with 300 km long transmission line. MATLAB R2006b software had been used as the simulation tool. Results of simulation made are discussed. Significant enhancement in the power transfer capability of transmission line is observed with the inclusion of TCSC in the model.*

## Keywords:

**FACTS, TCSC, power quality, firing angle**

## 1. Introduction:

### Facts Definition:

A **Flexible Alternating Current Transmission System** (FACTS) is a system comprised of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronics -based device.

FACTS is defined by the IEEE as "a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability."

## TCSC:

Thyristor Controlled Series Capacitor (TCSC) is a Flexible AC Transmission Systems (FACTS) device. It has proven to be an excellent solution in controlling the power flow, especially over long transmission lines where the power angle control at either end of the line are constrained. The TCSC can also be used for damping power oscillations and mitigating subsynchronous resonance.

## 2. Fundamentals:

Series compensation has been utilized for many years with excellent results in AC power transmission in a number of countries all over the world. The usefulness of the concept can be demonstrated by well-known expressions relating to active power transfer and voltages.

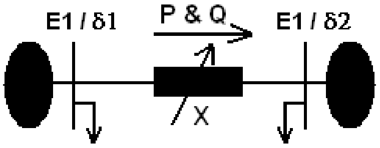



**Fig. – 1**

**Series Compensation**

$$P = \frac{E_1 \cdot E_2 \sin\delta}{X}$$ …………..(1)

$$V = f(P,Q)$$ …………(2)

Here, in fig.1, E1 and E2 denote the voltages at either end of the interconnection, whereas δ denotes the angular difference of the voltages (E1&E2). X is the reactance of the transmission circuit, while P and Q denote the active and reactive power flow.

From (1) it is evident that the flow of active power can be increased by decreasing the effective series reactance of the line. Similarly it is demonstrated that by introducing a capacitive reactance in the denominator of (1), it is possible to achieve a decrease of the angular separation with power transmission capability unaffected, i.e. an increase of the angular stability of the link.

FACTS devices are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines. Different FACTS devices in the power system are Static Var Compensators (SVC's), Thyristor controlled series compensators (TCSCs), STATCOMs, Unified Power Flow Controller (UPFC).

In this work, only TCSCs had been used for simulation, study and analysis.

## 3. Basic Structure of TCSC:

The basic structure of TCSC is shown in Fig.2. It is mainly constituted by four parts: series compensating capacitor C, bypass inductance L, bidirectional thyristor SCR and zinc oxide voltage limiter MOV.

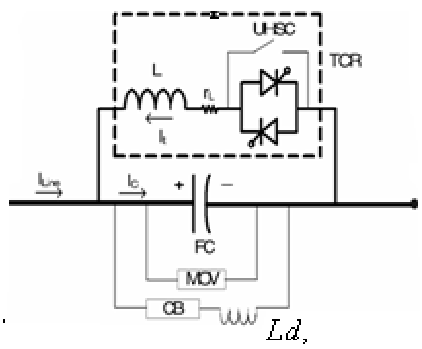



**Fig. 2 TCSC Module**

The degree of TCSC basic compensation is controlled by the capacity size of capacitor C. The main function of bypass inductance L is to reduce the short circuit current and the energy absorbed by MOV.

Bidirectional thyristor SCR is used to transform the equivalent impedance of TCSC which fulfill the needs in all kinds of power system condition, such as improving the stability, increasing the transmission capability, restraining hyposynchronization resonance and so on.

By controlling the trigger pulse, TCSC can transform the trigger angle of thyristor. Subsequently, the current value of inductance subcircuit which controlled by TCSC can be transformed, and then the total equivalent impedance will be changed continuously.

Generally, when the trigger angle is $145^{o}$ ~$180^{o}$ , the equivalent impedance of TCSC is appeared as capacitance. When the trigger angle is $90^{o}$ ~$140^{o}$ , the equivalent impedance of TCSC is appeared as inductance as which characteristic can restrict short circuit current during system failure. 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.

## 4. Effective reactance of TCSC:

The effective reactance of TCSC is given by equations (3) and (4). Equation (3) assumes that the capacitor voltage is free from harmonics and considers the only the TCR current harmonics.

$$X_{1TCSC} = \left( \frac{(X_{1TCR} \cdot X_C)}{j \cdot (X_{1TCR} \cdot X_C)} \right) \quad \text{........(3)}$$

$$X_{2TCSC} = -j \cdot X_C \left[ 1 + \frac{2}{\pi} \cdot \frac{\lambda^2}{\lambda^2 - 1} \left\{ \frac{2 \cdot \cos^2 \frac{\sigma}{2}}{\lambda^2 - 1} \cdot \left( \lambda \cdot \tan\left( \lambda \frac{\sigma}{2} \right) - \tan\left( \frac{\sigma}{2} \right) \right) - \left( \frac{\sigma}{2} \right) - \frac{\sin(\sigma)}{2} \right\} \right]$$

..........(4)

where ,

$$X_{1TCR} = j \cdot \omega \cdot L \cdot \left[ \frac{\pi}{\sigma - \sin(\sigma)} \right] \quad \text{.........(5)}$$

$$\lambda = \frac{\omega_0}{\omega_N} \quad \text{.......(6)}$$

$$\omega_0 = \frac{1}{\sqrt{L \cdot C}} \quad \text{.......(7)}$$

In the above equations, σ is the conduction angle, L is the inductance of the TCR inductor, C is the capacitance of the fixed capacitor, $\omega_N$ is power system frequency in radians per second and $\omega_0$ is the resonant frequency of the TCSC circuit. Fig. 3 shows the reactance characteristics of TCSC.

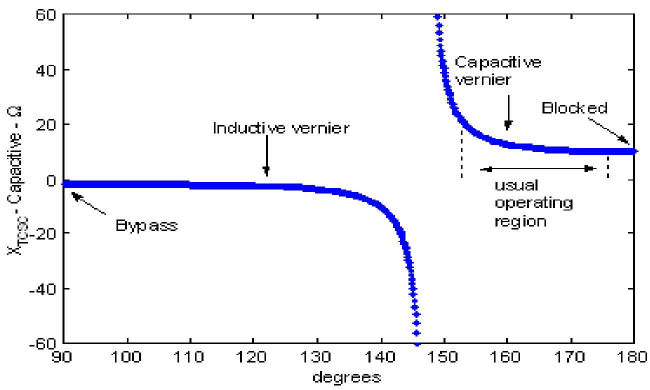


**Fig.-3. Reactance Characteristics of TCSC**

# 5. Simulation of transmission Line with TCSC:

## 5.1 Description of the system model:

A 735 kV, 300 km line is used to transmit power from bus B1 (735 kV equivalent system) to bus B2 where RL load (P=1000MW and Q= 10e3 var) is connected. In order to simplify, only one phase of the system has been represented.

The nominal compensation is 75%, i.e. using only the capacitors (firing angle of 90deg). The natural oscillatory frequency of the TCSC is 150.6 Hz, which is 2.51 times the fundamental frequency

From the simulated model, system performance characteristics had been analysed without a TCSC and with a TCSC is connected at mid point of the transmission line.

## 5.2 The simulated model:

It is shown in fig. 4 below.

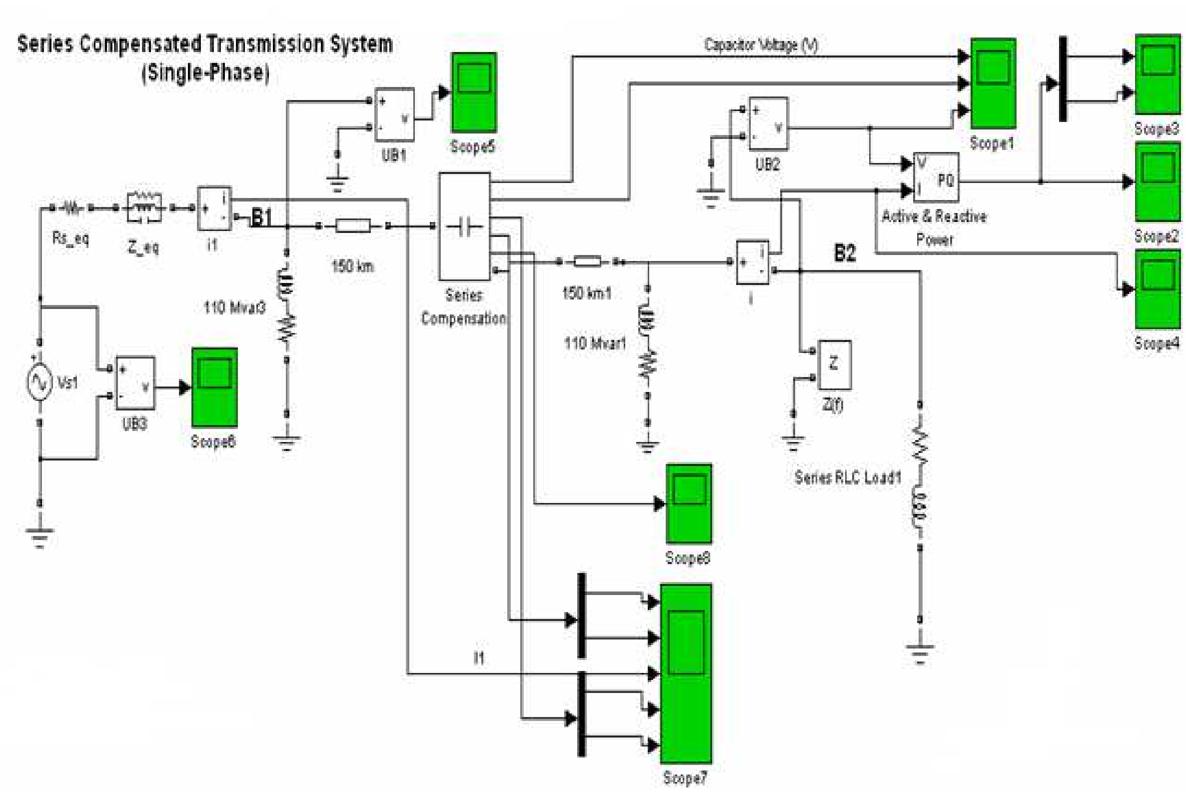



Fig.-4. Simulation of TCSC (on transmission system)

## **5.3 System** Parameters**:**

Transmission Line Inductive Reactance $(X_L) = 98\Omega$

**TCSC Parameters:**

Capacitor (C) = 36 $\mu F$

Inductor (L) = 31 mH

Resonance Factor (λ) = 2.5

Capacitive Reactance $(X_C)$ = 73.5 Ω

Inductive Reactance $(X_L)$ = 11.76Ω

Natural Oscillation Frequency of (TCSC): $\omega_o = 946$ rad/sec.;

$$\frac{X_L}{X_C} = 0.16$$

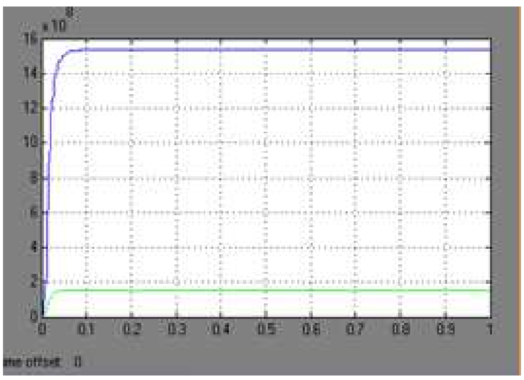
f = 150.6 Hz

To observe the power transfer capability of transmission line after using series compensation technique i.e.TCSC in capacitive mode, it was necessary to keep delay angle (firing angle, α) of thyristors between $145^0$ to $180^0$ . With different values of α, the simulations were made. Results with α = $146^o$ has been discussed below.

### **Simulation with firing angle, α = 146º :**

Started the simulation and observed the waveforms. At 75% compensation and firing angle, α =$146^o$ power transfer is 1540MW. Observed the corresponding TCSC Voltage, Capacitor current (Ic),VB1 (Voltage at B1),VB2(Voltage at B2), TCR current and line current on five scopes**.**

Waveforms are shown in figure -5 (a), (b), (c), (d) and (e)



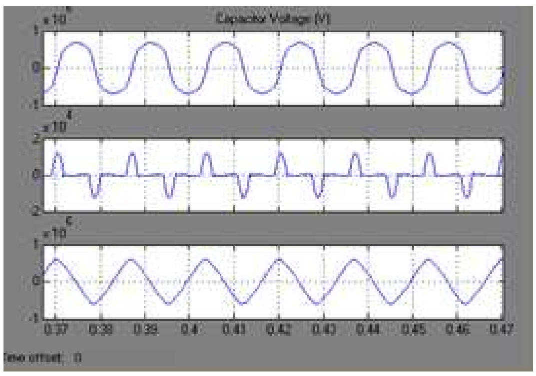
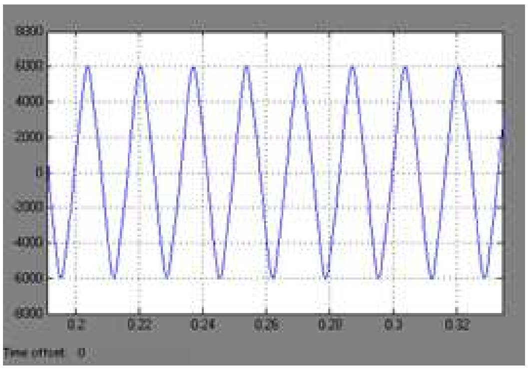
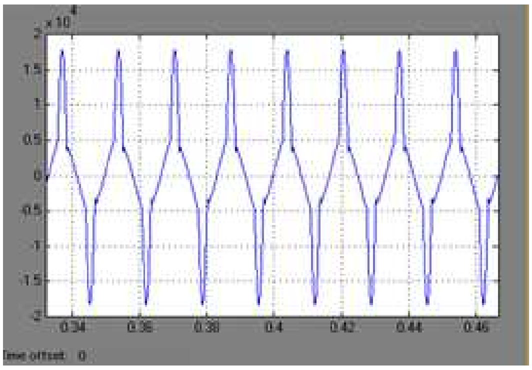


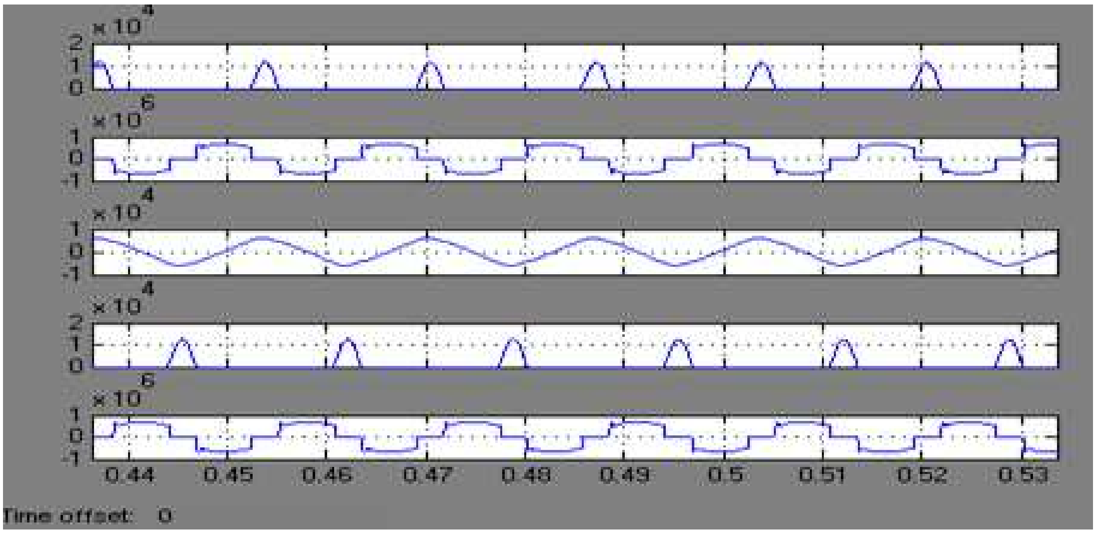
**Fig.-5. (a) Active, reactive Power at α=146º (b) Vc, Itcr & voltage at B2 at α=146º**




**(C) Line current ($I_L$) at B2)**

**(d) Capacitor current(Ic)**




**(e) Waveforms of $I_{ak1}$, $V_{ak1}$ , Iline ,$I_{ak2}$ & $V_{ak2}$**

In the model considered (Fig.4), TCSC is operated in capacitive mode keeping firing angle(delay angle) α = $146^0$ the corresponding Active/Reactive power ,capacitor voltage , capacitor current ,TCR current and current at node B2 are given below.

Active power (P) = 1540 MW

Reactive Power(Q) = 150 MVAR

Capacitor voltage (V) = 650 KV

Capacitor current(Ic) = 18 KV

TCR current = 10 KA

Line current (B2) = 6 KA

## 6. Conclusion:

It is observed that with the inclusion of TCSC, power transfer capacity increased to 1540 MW. The same power was only 685 MW without any compensation. In simulations, with different firing angles, power level had been varied and the corresponding change in reactive power is also observed.

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