CSC Use for Power Flow Control in the Electrical Power System- A Review

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Abstract:

Today's power system demand have been increase with loads, it is more difficult to provide stability and control. Power electronic controllers for a flexible ac transmission system (FACTS) can offer a greater control of power flow, secure loading of power system. In this paper deals with possibilities of the thyristor controlled series capacitor (TCSC) to control power flows in interconnected power systems. The main goal is to describe the working principle of TCSC and its possible use in the transmission system and advantages and disadvantages of using of such equipment in the electric power system. FACTS technology new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. A TCSC is a one of series FACTS device. The real and reactive power flow in the transmission line can be controlled by changing the magnitude and phase angle of the injected voltage produced by the series converter. In this paper discusses that used a TCSC to improving the real and reactive power flow of the power systems.

Keywords — Flexible AC Transmission System (FACTS), Power Flow Control, TCSC**.**

I. INTRODUCTION

Last year, the top notch of electric power has become huger for electric utilities and clients. Power is a regularly as it was a fundamental piece of our life and have to get power to the purchaser in dependable and determined quality. Transmission of power in the interconnected coordinating power framework is consistently expanding because of expanding development in utilization and power age. Utility and client side aggravations bring about terminal voltage changes, drifters, and waveform mutilations on the electric lattice that at long last gives an issue in power quality. Power Quality (PQ) alludes to "keeping up with the waveforms of voltages and flows as sinusoidal at appraised recurrence and greatness" Recently power frameworks keeping up with power quality turned out to be most significant issue because of the presentation of hardware's with power electronic gadgets which are more delicate to control quality issues. Overall transmission frameworks are going through consistent changes and rebuilding. They are turning out to be all the more intensely stacked. The transmission frameworks should be adaptable to respond to more broadened age and burden designs. The three control boundaries, for example, voltage sizes, phase angle and line reactance Governs flow of force in the transmission system. Considering a balanced lossless transmission line of Fig. 1 between two regions, the power flow P in the transmission line can be communicated as:

Whereas $|V_s|$ & $|V_r|$ are the sending end and receiving end voltage magnitudes and $(\delta s - \delta r)$ are phase angle between the two ends. Considering resistance and susceptance as negligible, XTL is defined as reactance of the transmission line.

Either by controlling voltage sizes, phase angle or line reactance, power flow in the transmission line can be represented adequately and system can be worked dependably and safely. By further developing the sending end or getting end voltage profile ($|V_s|$ and $|V_r|$), both genuine and responsive power flow of the transmission line can be upgraded. The outright greatness of ‗sending-end' and ‗receiving-end' voltages administers the responsive power flow in the transmission line. In the event that $|V_s| > |V_r|$, then, at that point, receptive power flows from sending end to getting end side i.e., from region 1 to region 2 as displayed in Fig. 1 as well as the other way around. The Real Power flow, then again is represented by the phase points distinction $(\delta s - \delta r)$ between sending end and getting end voltages in the transmission Line. In the event that the distinction between the phase points $(\delta s - \delta r)$ are enormous and positive, then, at that point, genuine power flow in the transmission line is huge and power flows toward the path from region 1 to region 2 as displayed in Fig. 1 The power flow is the other way around for negative worth of phase point distinction. the genuine power flow in transmission line is additionally conversely relative to transmission line reactance XTL and subsequently can be improved by repaying innate line reactance somewhat. These three boundaries to further develop power flow in the transmission line. The power (P and Q) at the less than desirable end Bus as displayed in condition 1.1 and 1.2

$$\text{Active Power} \quad P = \frac{Vs\,Vr\,Sin\,(\delta s - \delta r)}{XTL} = \frac{V^2\,Sin\delta}{XTL} \qquad \cdots (1.1)$$

$$\text{Reactive Power} \quad Q = \frac{VsVr\,[1 - Cos(\delta s - \delta r)]}{XTL} = \frac{V^2(1 - cos\delta)}{XTL} \qquad \cdots (1.2)$$

$$\delta = \delta s - \delta r \qquad \cdots (1.3)$$

II. INTRODUCTION OF FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

Flexible Alternating Current Transmission System (FACTS) devices are widely incorporated in electrical power systems in order to control the system parameters such as; power flow,

transmission line impedances, voltage magnitude and phase angle of the bus. Thereby, FACTS are embedded for improving the voltage profile, minimizing the active and reactive power losses, increasing the system loadability and enhancing power system security and stability. FACTS can be divided into shunt, series, and combined shunt-series devices. The popular shunt devices are Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM). Besides the series devices are Thyristor Controlled Series Capacitor (TCSC), Static Synchronous Series Compensator (SSSC), and Short Circuit Current Limiting (SCCL). While the combined shunt-series devices are such as Unified Power Flow Controller (UPFC), Interline Power Flow Controller (IPFC), and Generalized Unified Power Flow Controller (GUPFC) [3]. In addition, FACTS can be categorized based on the power electronic devices that have been used in them such as variable impedance controllers' devices and Voltage Source Converter (VSC) devices.

Flexible AC Transmission system technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. FACTS has number of benefits, such as greater power flow control, increased secure loading of existing transmission lines, damping of power oscillations, less environmental impact and potentially less cost than most alternative techniques of transmission system reinforcement. The FACTS devices are certainly an improvement over the conventional methods as they are fast and control these parameters efficiently to manage power flow effectively in transmission system. These opportunities arise through the ability of FACTS Controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle, and the damping of oscillations at various frequencies below the rated frequency. In general, FACTs controller may divided into four categories as shown in figure. 2

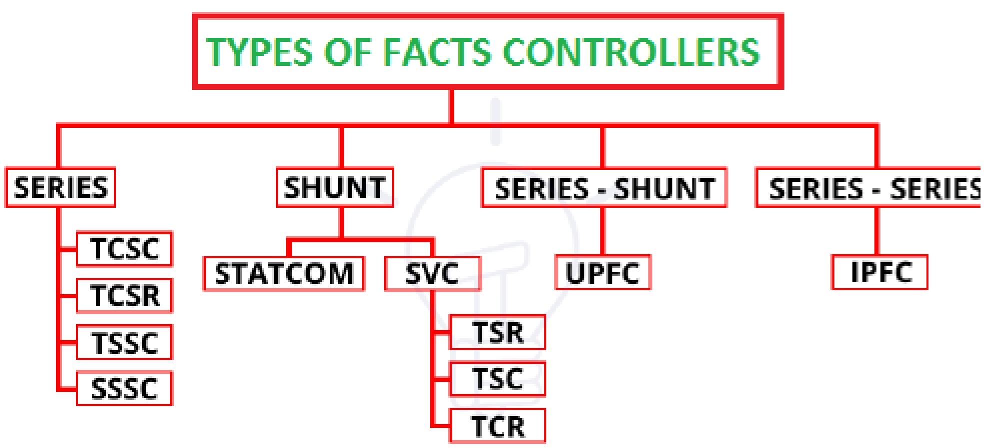
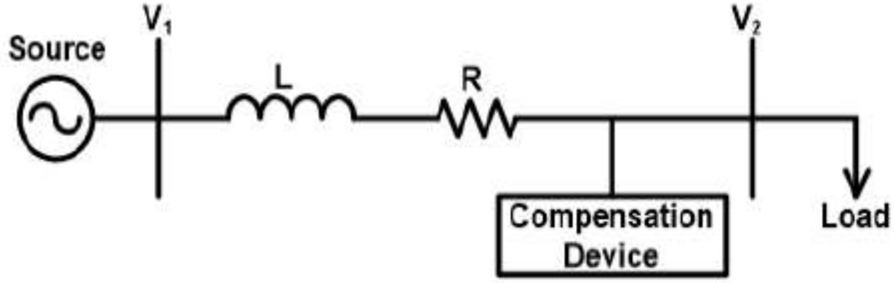


Fig.1. Classification of FACTS controllers

Series Controller

In series compensation, the FACTS devices are connected in series with the power system network. Series Controllers consist of capacitors or reactors which introduce voltage in series with the line. They are variable impedance devices. Their major task is to reduce the inductivity of the transmission line. They supply or consume variable reactive power. Examples of series controllers are SSSC, TCSC, TSSC, etc.



The power transfer capacity of a transmission line without using compensation device-

$$P = \frac{V1V1}{XL} \sin \delta$$

Where,
V1 = Sending end voltage
V2 = Receiving end voltage
XL = Inductive reactance of transmission line
δ = Phase angle between V1 and V2
P = Power transferred per phase
Now, we connect a capacitor in series with the transmission line. The capacitive reactance of this capacitor is XC. So, the total reactance is XL-XC. So, with a compensation device, the power transfer capacity is given by;

$$P' = \frac{V1V1}{XL - XC} \sin \delta$$

$$\frac{P}{P'} = \frac{1}{1 - \frac{XC}{XL}}$$

$$\frac{P}{P'} = \frac{1}{1 - k}$$

$$k = \frac{XC}{XL}$$

The factor k is known as the compensation factor or degree of compensation. Generally, the value of k is lies between 0.4 to 0.7. Let's assume the value of k is 0.5.

$$\frac{P}{P'} = \frac{1}{1 - 0.5} = \frac{1}{0.5} = 2$$

$$P' = 2P$$

Hence, it is clear that, if we use the series compensation devices, approximately 50% more power can be transfer. By using the series capacitor, the angle between voltage and current (δ) is less compared to the uncompensated line. The lower value of δ will give better system stability. Hence, for the same amount of power transfer and the same value of sending end and receiving end, the compensated line will give better stability compared to the uncompensated line.

Shunt Compensation

Shunt controllers consist of variable impedance devices like capacitors or reactors which introduce current in series with the line. Their major task is to reduce the capacitive of the transmission line. The injected current is in phase with the line voltage. Examples of shunt controllers are STATCOM, TSR, TSC, SVC.

Each FACTS device can individually or collectively control. The Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM) improve the power flow of the transmission line by increasing the voltage profile at the point of connection. The Thyristor Controlled Series Compensator (TCSC) and Static Series Synchronous Compensator (SSSC) is series compensator switch Compensator. The transmission line reactance to improve the real power flow.

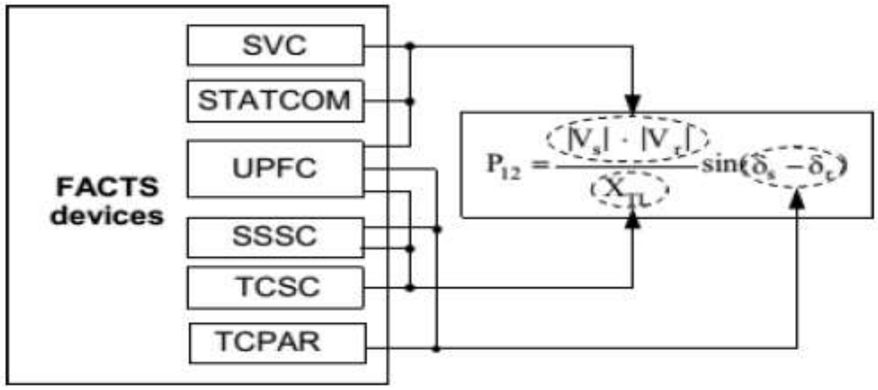


Fig. 2:Representation of different type's controllers controlled different parameters of transmission line.

The basic applications and advantages of FACTS devices are:
1. Reduce system losses
2. Enhance power system stability
3. Power quality improvement.
4. Power flow control
5. Reactive power compensation
6. Voltage control
7. Increased system security and reliability
8. Rapid, continuous control of the
transmission line reactance
9. Flicker mitigation Power conditioning
10. Optimizing load sharing between parallel circuits

III. TCSC AND POWER FLOW CONTROL

TCSC has been used for many years to control power flow. The basic configuration of TCSC is shown in Fig. 3. TCSC consists of three main components; bypass inductor (L), capacitor banks (C), and two antiparallel Thyristor T1 and T2. The TCSC reactance can be adjusted according to the firing angle (a) of the Thyristor to control the active power flow of the connected line. However, this device can be represented as a variable reactance (XTCSC) as shown in Fig. 4.'

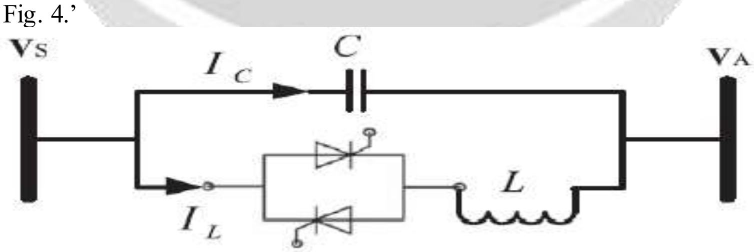


Fig.3. TCSC Configuration

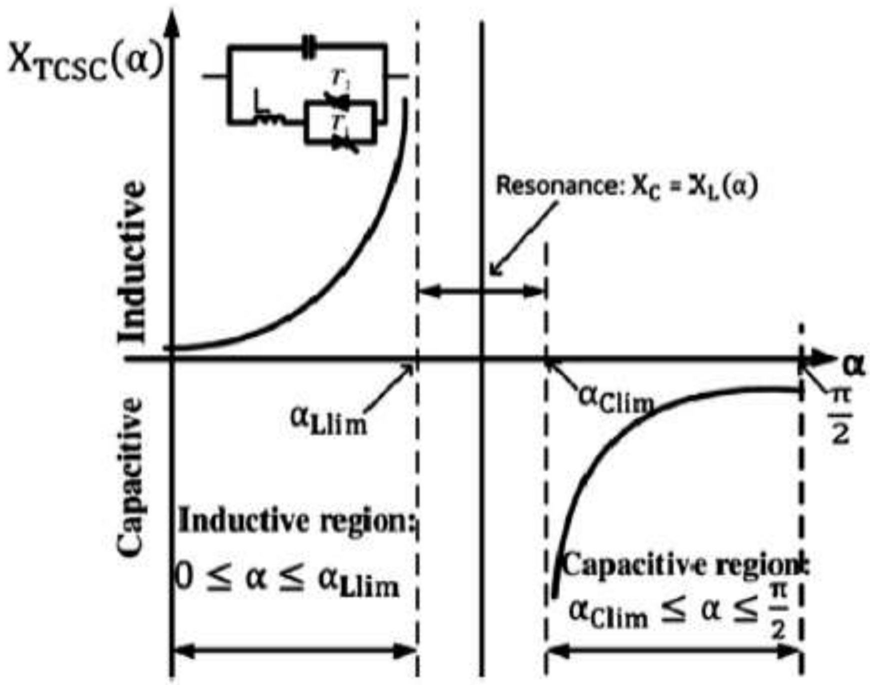


Fig.4. XTCSC characteristic curve

The effective inductive reactance of the TCR branch is varied between a minimum value of jXTCRmin=jXL =jwoL and a maximum of jXTCR =00. The minimum value of TCR inductive reactance XTCRmin is obtained when a=90° and the maximum value is obtained when a= 180° and TCR is open circuited. The net reactance XTCSC of TCSC is a parallel combination of –jXc of the capacitor and jXTCR the effective reactance, which is a function of the delay angle a as given by equations (1) and (2).

$$X_{TCSC} = \frac{iX_{TCR}(-iX_C)}{iX_{TCR} - iX_C} \text{.......................(1)}$$

The TCR's effective reactance jXTCR is related to delay angle α as

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

If, XTCR>Xc, the reactance ofthe FC is less than that of the parallel-connected variable reactor and the net TCSC reactance XTCSC is capacitive.
If XTCR= Xc, a resonance develops that results in an infinitecapacitive impedance-an obviously unacceptable condition. If, XTCR<Xc, the net TCSC reactance is inductive.
The variation of TCSC reactance XTCSC with delay angle α is shown in Fig.3. In practice, TCSC cannot be operated near the resonance region because during this time the device voltage and current will be very high and TCSC offers a high impedance. Thus, reactance characteristics of TCSC shows, operation in both capacitive and inductive regions through variation of firing angle α. Table.l shows the region of operation ofTCSC for different firing angles.

Table 1. Region of operation for different firing angles

Range of firing angle (α)	Region
90< α < αL lim	Inductive region
α C lim< α < 180	Capacitive region
α L lim< α < α C lim	Resonance region

IV. OPERATING PRINCIPLE OF TCSC

A TCSC is a series-controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. From the system viewpoint, the principle of variable-series compensation is simply to increase the fundamental-frequency voltage across a Fixed Capacitor (FC) in a series compensated line through appropriate variation of the firing angle, α. This enhanced voltage changes the effective value of the series capacitive reactance. A simple understanding of TCSC functioning can be obtained by analyzing the behavior of a variable inductor connected in parallel with an FC. The maximum voltage and current limits are design values for which the thyristor valve, the reactor and capacitor banks are rated to meet specific application requirements. The characteristics of TCSC. α is the delay angle measured from the crest of the capacitor voltage or equivalently, the zero crossing of the line current. Therefore, with the usual TCSC arrangement in which the impedance of the TCR reactor XL is smaller than that of the capacitor, XC, the TCSC has two operating ranges around its internal circuit resonance.
The total impedance of TCSC could be changed by TCR. Current flowing through the reactor iL (∝) can be continuously controlled from maximum to 0 by control of firing angle. While considering harmonic progress of voltage on reactor: $U(t)= Um.\cos wt$,

Model of TCSC in MATLAB
Model of TCSC is shown in Fig. 4 and consists of the following blocks:

1. Module of TCSC,
2. Control System,
3. Firing Unit.

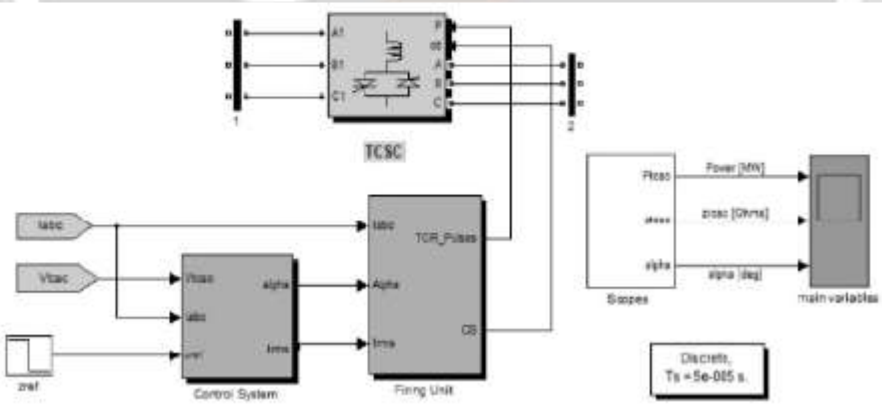


Fig.5. Model of TCSC

V. THE OPERATING MODES OF TCSC
TCSC is used to decrease or increase overall effective series transmission impedance from sending end to the receiving end so as to control the transmission of power and the current in the reactor can be controlled from zero to maximum by the method of firing delay angle. Closure of the thyristor valve is delayed w.r.t. peak of the applied voltage in each half cycle thus duration of the current conduction interval is controlled. There are three modes of operation of TCSC depending upon the firing angle of the pulses fed to the thyristor.
1) Thyristor blocked mode
2) Thyristor bypassed mode
3) Vernier operating mode

1) THYRISTOR BLOCKED OPERATING MODE:

When the thyristor valve is not triggered and the TCSC is operating in blocking mode. In this mode, the TCSC performs like a fixed series capacitor.

2) THYRISTOR BYPASS OPERATING MODE:

In bypass mode the thyristor valve is triggered continuously and the valve stays conducting all the time; so the TCSC behaves like a parallel connection of the series capacitor with the inductor, Ls in the thyristor valve branch. In this mode, the resulting voltage in the steady state across the TCSC is inductive and the valve current is somewhat bigger than the line current due to the current generation in the capacitor bank. For practical TCSC's with ratio (XL/XC) between 0.1 to 0.3 ranges, the capacitor voltage at a given line current is much lower in bypass than in blocking mode. Therefore, the bypass mode is utilized as a
means to reduce the capacitor stress during faults.

3) VERNIER OPERATING MODE:

In Vernier control the TCSC dynamics are varied continuously by controlling the firing angle. The firing angle is possible from 0o to 90o for each half cycle when it is generated from the zero crossing of the line current hence divided into two parts:

1) Capacitive Boost mode
2) Inductive Boost Mode

1) CAPACITIVE BOOST MODE:

In capacitive boost mode a trigger pulse is supplied to the thyristor having forward voltage just before the capacitor voltage crosses the zero line, so a capacitor discharge current pulse will circulate through the parallel inductive branch. The discharge current pulse adds to the line current through the capacitor and causes a capacitor voltage that adds to the voltage caused by the line current. The capacitor peak voltage thus will be increased in proportion to the charge that passes through the thyristor branch. The fundamental voltage also increases almost proportionally to the charge. From the system point of view, this mode inserts capacitors to the line up to nearly three times the fixed capacitor. This is the normal operating mode of TCSC.

2) INDUCTIVE BOOST MODE:

In inductive boost mode the circulating current in the TCSC thyristor branch is bigger than the line current. In this mode, large thyristor currents result and further the capacitor voltage waveform is very much distorted from its sinusoidal shape. The peak voltage appears close to the turn on. The poor waveform and the high valve stress make the inductive boost mode less attractive for steady state operation.

VI. CONCLUSIONS

In this paper, the used of TCSC in power flow control between two ends of the transmission line to maintain the Power flow of the transmission line. The study of Series compensation TCSC device to controlling the power flow through the transmission line by changing the effective reactance of the system. The various FACTS controller with its classification. The advantages of FACTS devices in power system and various operating modes of TCSC are specified. This paper work can be extended in future for TCSC modelling and simulation with a number of bus system for controlling the power flow.

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