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Analysis of Power Flow Control in Power System using Thyristor controlled series capacitor Device (TCSC): A Review

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Abstract— **The world's electric power supply systems are widely interconnected. We need these interconnections because, apart from delivery, the purpose of the transmission network is to pool power plants and load centre in order to minimize the total power generation capacity and fuel cost. Today's power system demand have been increase with loads, it is more difficult to provide stability and control. In this paper analysis of power flow control in power system using Thyristor controlled series compensation and performance of TCSC is given. FACTS technology new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. In this paper the study of TCSC with capacitive and Inductive mode of operation and applications, advantages of FACTS. Thyristor controlled series compensation consist of series capacitor shunted by back to back thyristor. By changing the firing angle of this back to back thyristor possible to vary the reactance of the TCSC as per TCSC characteristics. This compensation controls the transmission line reactance to improve the real power flow. TCSC in capacitive region power flow increasing and in capacitive region power flow decreases.**

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

I. Introduction

Electricity is an everyday as it was an essential part of our life and need to get electricity to the consumer in reliable and specified quality. Transmission of electricity in the interconnected cooperating electricity system is steadily increasing due to increasing growth in consumption and electricity generation. World-wide transmission systems are undergoing continuous changes and restructuring. They are becoming more heavily loaded. The transmission systems must be flexible to react to more diversified generation and load patterns. The three control parameters such as voltage magnitudes, phase angle and line reactance Governs flow of power in the transmission system. Considering a symmetrical lossless transmission line of Fig. 1 between two areas, the power flow P in the transmission line can be expressed as:

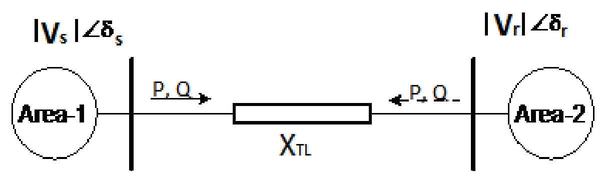

Fig. 1: Symmetrical two area lossless transmission line

The power flow *P* in the transmission line as.

$$P = \frac{|V_s| \cdot |V_r|}{X_{TL}} \sin(\delta_s - \delta_r)$$

Whereas |Vs| & |Vr| are the sending end and receiving end voltage magnitudes and (δs – δr) 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 magnitudes, phase angle or line reactance, power flow in the transmission line can be governed effectively and system can be operated reliably and securely. By improving the sending end or receiving end voltage profile (|Vs| & |Vr|), both real and reactive power flow of the transmission line can be enhanced. The absolute magnitude of _sending-end' and _receiving-end' voltages governs the reactive power flow in the transmission line. If |Vs| > |Vr|, then reactive power flows from sending end to receiving end side i.e., from area-1 to area-2 as shown in Fig. 1 and vice versa. The Real Power flow, on the other hand is governed by the phase angles difference (δs – δr) between sending end and receiving end voltages in the transmission Line. If the difference between the phase angles (δs – δr) are large and positive, then real power flow in the transmission line is large and power flows in the direction from area-1 to area-2 as shown in Fig. 1 The power flow is vice versa for negative value of phase angle difference. Apart from the phase angle difference of the voltages, the real power flow in transmission line is also inversely proportional to transmission

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line reactance XTL and thus can be improved by compensating inherent line reactance partially. These three parameters to improve power flow in the transmission line. The real and reactive power (P and Q) Flow at the receiving end bus as shown in equation 1.1 and 1.2

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

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

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

II. INTRODUCTION OF FLEXIBLE AC TRANSMISSION SYSTEM (FACTS) & CONTROLLERTYLE AND FONTS

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. 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

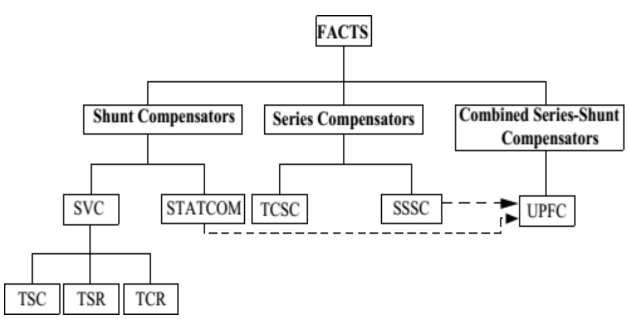

Fig.2. Classification of FACTS controllers.

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. In addition, SSSC regulates the phase angle of the transmission system. The Unified Power Flow Controller (UPFC) is the only device which can be employed to govern all three parameters of given transmission line, however cost and complexity is an important issue.

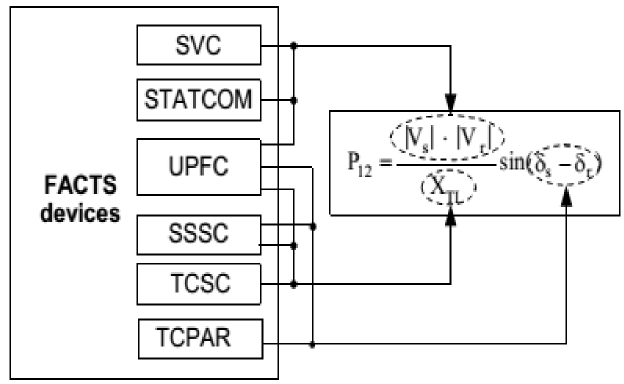

Fig. 3:Representation of different type's controllers controlled different parameters of transmission line.

The basic applications and advantages of FACTS devices are:

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

III. TCSC AND POWER FLOW CONTROL

FACTS controllers are incorporated in power systems. Significant device from the group FACTS is a TCSC, TCSC is a second generation of the Flexible AC transmission system device. This is applicable to solving many problems in power system. TSCS consists of a series capacitor bank shunted by a Thyristor Controlled Reactor in order to provide a smoothly variable series capacitive reactance TCSC controller can be used to control the power flow in transmission line, increase the transmission limit or can greatly enhance the stability of the network and also provide the continuous variable and impedance. The main principles of the TCSC concept are Two; firstly, to provide electromechanical damping between large electrical systems by changing the reactance of a specific interconnecting power line. Secondly the TCSC will change its apparent impedance for sub-synchronous frequencies. Such that a prospective sub synchronous resonance is avoided. A Basic TCSC Configuration and equivalent circuit of Thyristor

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controlled series compensation are show in figures.

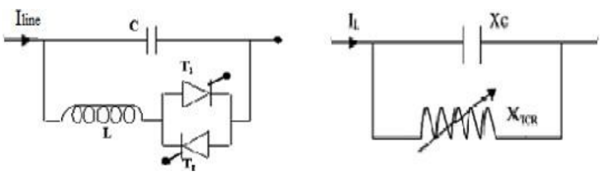
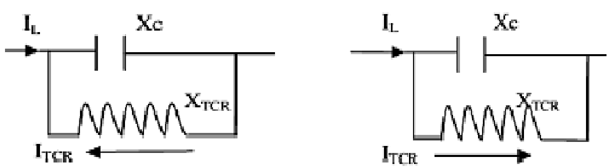


Fig. 3: Basic TCSC Configuration and Equivalent Circuit of TCSC

In figure.3 Shown capacitor C parallel with a thyristor controlled reactor L as shown in equivalent circuit of TCSC. TCSC commonly used in two modes that is Capacitive mode (XL<XC) and inductive mode (XL>XC) are shown in figure. In this mode TCSC is used dynamically, It Consist of three components as capacitor banks C, bypass inductor L and bidirectional thyristors T1 and T2. The firing angles of the thyristors are controlled to adjust the TCSC reactance in a system control algorithm, normally in response to some system parameter variations. However, a practical TCSC module also includes protective equipment normally installed with series capacitors, as shown in Figure 3



(a) Capacitive mode (b) Inductive Mode

Figure.4 A basic two mode of Thyristor controlled series compensator.

TCSC is a series FACT device available for application in AC line of voltage up to 500 KV. In Figure.3 Shown equivalent circuit of the TCSC model as a capacitance in parallel with a variable inductor.

The impedance of TCSC (Z_{TCSC}) $Z_{TCSC} = (-jXc)\ (jX_{TCR}) / j(X_{TCR}-X_C)$ $Z_{TCSC}= (-JXc) / (1-Xc/ X_{TCR})$

The current through the TCR (ITCSC) is given by

$$ITCSC = (-jXc)\ IL / j(XTCR - Xc)$$

$$ITCSC = IL / (1 – XTCR / Xc)$$

Since the losses are neglected, the impedance of TCSC is purely reactive. The capacitive reactance of TCSC is obtained from figure 9.

$$XTCSC = Xc / (1 – Xc / XTCR)$$

IV. MODES OF TCSC

There are essentially three modes of TCSC operation. These are illustrated in Figure below

1. Bypassed Thyristor mode:-
2. Blocked Thyristor Mode (Waiting Mode):-
3. Partially Conducting Thyristor or Vernier Mode: -

Capacitive and Inductive Vernier Mode

1. ***Bypassed Thyristor Mode: -*** In this bypassed mode, the thyristors are made to fully conduct with a conduction angle of 180^0. The susceptance of the reactor is greater than capacitor. Gate pulses are applied as soon as the voltage across the thyristors reaches zero and becomes positive, resulting in a continuous sinusoidal of flow current through the reactor and thyristor valves. The TCSC module behaves like a parallel combination of capacitor and inductor. This mode is employed for protection of capacitor against overvoltage.

2. ***Blocked Thyristor Mode: -*** This mode also known as the waiting mode. In this mode no current pass through the thyristor valves and firing pulses to the thyristor valves is blocked. If the thyristors are conducting and a blocking command is given, 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, and the net TCSC reactance is capacitive. The reactance of TCSC and Fixed capacitor is similar.

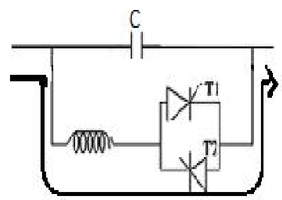


Fig:-Bypass Mode

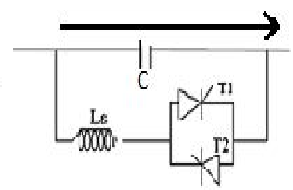


Fig:-Blocked Mode

3. ***Partially Conducting Thyristor or Vernier Mode:*** - In this mode thyristor valves are operated by two gate pulses in the two region i.e capacitive region and inductive region. This mode 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. However, a smooth transition from the capacitive to inductive mode is not permitted because of the resonant region between the two modes. The loop current increases the voltage across the FC, is constrained in the range $\alpha_{min} \leq \alpha \leq 180^0$. This constraint provides a continuous vernier control of the TCSC module reactance. The loop current increases as α is decreased from 180^0 to α_{min}. Another variant is the inductive vernier mode, in which the TCSC can be operated by having a high level of thyristor conduction. In this mode, the direction of the circulating current is reversed and the controller presents a net inductive impedance Based on the three modes of thyristor valve operation.

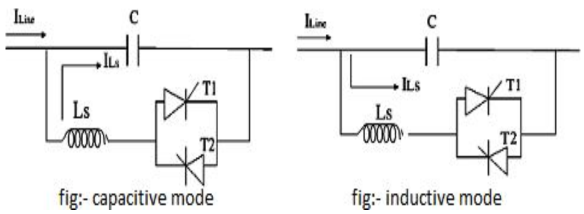


Fig. 5: A partially conducting Mode of Thyristor controlled series compensation

V. OPERATIONS OF TCSC

The basic operation of TCSC can be easily explained from circuit analysis. It consists of a series compensating capacitor shunted by a Thyristor controlled reactor (TCR). TCR is a variable inductive reactor XL shown in figure. Controlled by firing angle α. Here variation of XL with Respect to is α given by

$$XL(\alpha) = XL\frac{\pi}{\pi - 2\alpha - \sin 2\alpha}$$

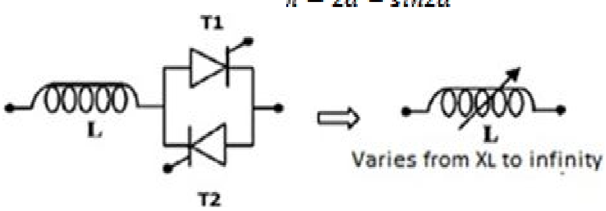


Fig.6: Equivalent circuit of TCR

For the range of 0 to 900 of α, $X_L(\alpha)$ start vary from actual reactance XL to infinity. This controlled reactor is connected across the series capacitor, so that the variable capacitive reactance shown in figure 18 is possible across the TCSC to modify the transmission line impedance. Effective TCSC reactance XTCSC with respect to firing angle alpha (α) is

$$X_{TCSC}(\alpha) = -Xc + C1[\,2(\pi-\alpha) + \sin 2(\pi-\alpha)\,] - C2[\cos^2(\pi-\alpha)\,\overline{W}\tan\{\overline{W}(\pi-\alpha)\}] - \tan(\pi-\alpha)$$

Where

$$X_{LC} = \frac{Xc\,X_L}{Xc - X_L},\quad C_1 = \frac{Xc+XL}{\pi},\quad C_2 = 4\,X^2Lc/\,\pi\,X_I$$

$$\overline{W} = \sqrt{Xc\,/XL}$$

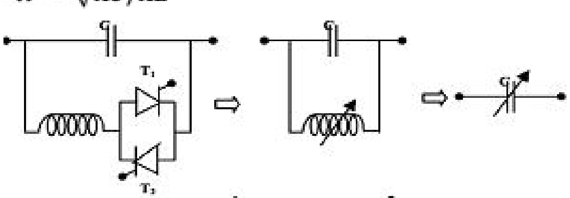


Fig.7: Equivalent circuit of TCSC

The impedance characteristics curve of a TCSC device is shown in Figure. 8 that is drawn between effective reactance of TCSC and firing angle α

Impedance characteristics of TCSC shows, both capacitive and inductive region are possible through varying firing angle (α) as follows:

1. 900 < α < αLlim Inductive region.
2. αLlim < α < αClim Capacitive region.
3. αClim < α < 1800 Resonance region.

While the maximum and minimum value of firing angles should be selected in such a way as to avoid the TCSC operating in high impedance region (at resonance) which results in high voltage drop across the TCSC.

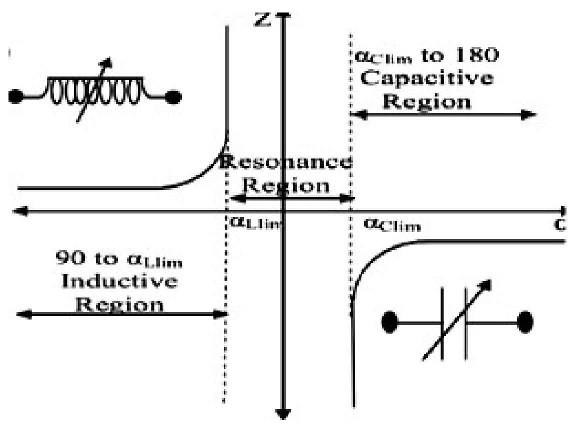


Fig.8: Impedance versus firing angle Characteristics of a TCSC

VI. CONCLUSION

In this paper, the used of TCSC in power flow control between two ends of the transmission line to maintain the voltage magnitude, phase angle and line impedance. 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 TCSC can be operated in generally two modes as inductive and capacitive mode. 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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