Abstract—In a modern day’s power system have been growing due to increase of demand and loads, it’s getting more and more difficult to provide stability and control. Reactive power control is the basic requirement for maintaining the voltage levels thereby the stability of the interconnected power system. Voltage variations can be stabilized and controlled by providing required reactive power. These low voltages may also reduce the power transfer through the transmission lines and may lead to Instability Hence FACTS Controllers are widely used in Interconnected Power Systems to control the voltage levels within the tolerable limits. FACTS Controllers are used to enhance controllability and increase power transfer capability. Among the FACTS devices, the TCSC controller has given the best results in terms of performance and flexibility. In this paper an overview to general type of FACTS controller and performance of TCSC is given. TCSC are used to improve power handling capability and reduce line losses in power systems. An additional feature of TCSC is its dynamic performance of power oscillation damping by varying the power flow in accordance with power oscillations. This behavior can be used to improve the stability of the system following a disturbance. In this paper, stability of the power system is improved using TCSC.

Index Terms—FACTS, Thyristor Controlled Series Capacitor, Reactive Power Control, Stability, Power System.

I. INTRODUCTION

Electric energy is an essential ingredient for the industrial and all round development of any country. It is a coveted form of energy, because it can be generated centrally in bulk and transmitted economically over long distances. Further, for domestic and industrial applications it can be adapted easily and efficiently. The per capita consumption of electrical energy is a reliable indicator of a country’s state of development. The basic structure of a power system is as shown in Fig.1.1 and the main components of electric power system are Generating stations, transmission lines and the distribution systems. Generating stations and a distribution systems are connected through transmission lines, which is also connect one power system (grid, area) to another. A distribution system connects all the loads in a particular area to the transmission lines. Modern power systems are designed to operate efficiently to supply power on demand to various load centres with high reliability. The generating stations are often located at distant locations for economic, environmental and safety reasons. In addition to transmission lines that carry power from the sources to loads, modern power systems are also highly interconnected for economic reasons.

![Fig. 1.1 power system basic structure](image)

The benefits of interconnected system are:

i. Exploiting load diversity
ii. Sharing of generation reserves
iii. Economy gained from the use of large efficient units without sacrificing reliability.

In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. Now, more than ever, advanced technologies are vital for the reliable and secure operation of power systems. To attain both operational reliability and financial profitability, it has become clear that more efficient utilization and control of the existing transmission system infrastructure is required. Better utilization of the existing power system is provided through the application of advanced control technologies recent development of power electronics introduces the employ of FACTS controllers in power systems. FACTS controllers are capable of controlling the network condition in a very fast manner and this feature of FACTS can be oppressed to improve the voltage stability, and steady state and transient stabilities of a complex power system. This allows increased utilization of existing network closer to its thermal loading capacity, and thus avoiding the need to construct new transmission lines. The well known FACTS devices are namely SVC, STATCOM, TCSC, SSSC and UPFC.

Flexible AC transmission systems devices are one of the recent propositions to assuage such situations by controlling the power flow along the transmission lines and improving power oscillations damping. The use of these controllers increases the flexibility of the operation by providing more options to the power system operators. Amongst the available FACTS [3] devices for transient stability enhancement, the TCSC is the most versatile one. The TCSC is a series FACTS device which allows rapid and continuous changes of the...
transmission line impedance. It has great application and potential in accurately regulating the power flow on a transmission line.

II. THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

For TCSC is one of the most important and best known FACTS devices, which has been in use for many years to increase line power transfer as well as to enhance system stability. The TCSC consists of three main components: capacitor bank C, bypass inductor L, and bidirectional thyristors SCR1 and SCR2. The firing angles of the thyristors are controlled to adjust the TCSC reactance in accordance with a system control algorithm, normally in response to some system parameter variations. When the thyristors are fired, the TCSC can be mathematically described as follows:

\[ i_c = \frac{dv}{dt} \]
\[ v = L \frac{di_L}{dt} \]
\[ i_s = i_c + i_L \]

where \( i_c \) and \( i_L \) are the instantaneous values of the currents in the capacitor banks and inductor, respectively; \( i_s \) the instantaneous current of the controlled transmission line; \( v \) is the instantaneous voltage across the TCSC.

![Fig 2.1: TCSC Configuration](image)

The current in the reactor can be from maximum (thyristor valve closed) to zero (thyristor valve open) by method of firing delay angle control. It means that the closure of thyristor value is delayed wrt the peak of applied voltage in each half cycle and thus the duration of current conduction intervals is controlled. A voltage \( 'v' \) is applied and their vector current is given by \( il(\alpha) \) at zero angle delay (switch fully closed) and at an arbitrary angle ‘\( \alpha \)’ delay angle.

2.2 Advantages of TCR in FACT

1. Accuracy of compensation – Very good
2. Control flexibility – Very good
3. Reactive power capacity – Lagging or leading indirect
4. Control – Continuous
5. Response Time - Fast, 0.5 to 0.2 cycles
6. Harmonics - Very high (Large size filters are needed)
7. Losses - Good but increase in lagging mode
8. Phase balancing ability- Good

III. MODELLING OF TCSC

There are basically two reasons for which we opted to use tcsc for power flow studies, they are –

1. Electromechanical damping : It provides electromechanical damping between large interconnected electrical systems by changing the reactance of any specific power line that connects them.
2. Avoiding SSR : TCSC changes its apparent impedance (as the line current confronts) for sub-synchronous frequencies such that any sub synchronous resonance is avoided.

TCSC module consists of a fixed series capacitor (FC) in parallel with a thyristor controlled reactor (TCR). The TCR is formed by a reactor in series with a bi-directional thyristor valve that is fired with a phase angle \( \alpha \) ranging between 90° and 180° with respect to the capacitor voltage.

In a TCSC, two main operational blocks can be clearly identified:-

1) External control
2) Internal control

External control directly relies on measured systems variables to define the reference for the internal control, which is usually the value of the controller reactance.

Internal control provide appropriate gate drive signals for the thyristor valve to produce the desired compensating reactance.

Hence, the external control is the one that defines the functional operation of the controller.

The external control may be comprised of different control loops depending on the control objectives. Additional functions for stability improvement, such as damping controls, may be included in the internal control. In the diagram given below \( X_m \) is the stability control modulation reactance value, as determined by the stability or dynamic control loop, and \( Xeo \) denotes the TCSC steady state reactance. The sum of these two values yields \( X'm \), which is the final value of the reactance ordered by the external control block. This signal is put through a first-order lag to represent the natural response of the device and the delay introduced by the internal control, which yields the equivalent capacitive reactance \( X'e \) of the TCSC.

2.1 Characteristics of TCR:

Tcr can be used as a better series compensator which is effective in load flow control and short circuit limitations. It’s because of Tcr advantages another another concept of Advanced Series Compensation of Tcr has been developed and commercialized. Tcr consists of a fixed (mainly air core) reactor of inductance L and a bidirectional thyristor value.

![Fig 2.2: Single Machine Infinite Bus Power System with TCSC](image)
model, it is possible to directly represent some of the actual TCSC internal control blocks associated with the firing angle control, as opposed to just modeling them with a first order lag function. Nevertheless, since the relationship between angle $\alpha$ and the equivalent fundamental frequency impedance $X_e$ is a unique-valued function, the TCSC is modeled here as a variable capacitive reactance within the operating region defined by the limits imposed by the firing angle $\alpha$. Thus, $X_{\text{min}} \leq X_e \leq X_{\text{max}}$, with $X_{\text{max}} = X_e(\alpha_{\text{min}})$ and $X_{\text{min}} = X_e(180 \text{ deg}) = X_C$, where $X_C$ is the reactance of the TCSC capacitor. The controller is assumed to operate only in the capacitive region, i.e. $\alpha_{\text{min}} > \alpha_{\text{r}}$, where $\alpha_{\text{r}}$ corresponds to the resonant point, as the inductive region associated with $90^\circ < \alpha < \alpha_{\text{r}}$ induces high harmonics that cannot be properly modeled in stability studies.

Equations used in the power flow implementation using TCSC:

$$\delta_1 = \omega_0 \Delta \omega_1$$
$$\delta_2 = \omega_0 \Delta \omega_2$$
$$\omega_1 = p_{m1} - p_{e1}$$
$$\omega_2 = p_{m2} - p_{e2}$$

**Fig 3.1:** TCSC model for stability studies

**Fig 3.2:** The transfer function of stability control loop

Transfer function obtained:

$$u = K_T (\frac{s T_W}{1+s T_W})(\frac{1+s T_1}{1+s T_2})(\frac{1+s T_3}{1+s T_4})$$

where, $u$ and $y$ are the TCSC controller output and input signals, respectively. In this structure, $T_w$ is usually prespecified and is taken as 10 s. Also, two similar lag-lead compensators are assumed so that $T_1=T_3$ and $T_2=T_4$. The controller gain $K_T$ and time constants $T_1$ and $T_2$ are to be determined.

**IV. SIMULATION & RESULTS**

The simulation system of power system with and without TCSC is validated by simulation of the circuit in MATLAB/SIMULINK environment. A TCSC is placed on 80 km long transmission line, to improve power transfer & stability. Without the TCSC the stability of the system is not proper. The TCSC consists of a fixed capacitor and a parallel Thyristor Controlled Reactor (TCR) in each phase. The nominal compensation is 75%, i.e. using only the capacitors (firing angle of 90deg).

The TCSC can operate in capacitive or inductive mode. The capacitive mode is achieved with firing angles 69-90deg. The impedance is lowest at 90deg, and therefore power transfer increases as the firing angle is reduced. In capacitive mode the range for impedance values is approximately 120-136 Ohm. Comparing with the stability with an uncompensated line, TCSC enables significant improvement in power system stability.

To change the operating mode (inductive/capacitive/manual) use the toggle switch in the control block dialog. The inductive mode corresponds to the firing angles 0-49deg, and the lowest impedance is at 0deg. In the inductive operating mode, the range of impedances is 19-60 Ohm, which corresponds to 100-85 MW range of power transfer level. The inductive mode reduces power transfer over the line.

When TCSC operates in the constant impedance mode it uses voltage and current feedback for calculating the TCSC impedance. The reference impedance indirectly determines the power level, although an automatic power control mode could also be introduced.

The inductive mode also employs a phase lead compensator. Each controller further includes an adaptive control loop to improve performance over a wide operating range. The controller gain scheduling compensates for the gain changes in the system, caused by the variations in the impedance.

The firing circuit uses three single-phase PLL units for synchronization with the line current. Line current is used for synchronization, rather than line voltage, since the TCSC voltage can vary widely during the operation.

**Figure 4.1:** Modelling of Power System with TCSC
As shown in figure 4.4, the power system is without tcsc. The active and reactive power slightly increase from 0 to 2.8 & 1.8 MW respectively. After $t = 0.2$ sec the power become reduce due to synchronization of complete system up to $t = 0.3$ sec. From $t = 0.3$ sec the powers comes in previous state but there is some instability and fluctuation in the power system.

Similarly as shown in figure 4.5, the power system with tcsc. the active and reactive power slightly increase from 0 to 2.8 & 1.8 MW respectively. After $t = 0.2$ sec the power become reduce due to synchronization of complete system up to $t = 0.3$ sec. From $t = 0.3$ sec the powers comes in previous state without any fluctuation and power system is in stable condition.
V. CONCLUSION

This paper provides a detailed analysis of some of the fundamental aspects of proper TCSC controller design. The proposed method is implemented using MATLAB software. The limitations of using linear control techniques for controller design are discussed at length and illustrated in detail by studying the effect of large disturbances in a realistic power system network. A detailed analysis of TCSC control performance for improving power system stability. TCSC with his composition and capabilities allows widely using in power system. It can be used also for damping of active power oscillations, improve dynamic and voltage stability, eliminating SSR and other. In this paper, optimal placement and sizing of TCSC device has been proposed for improving and controlling the power flows in the network can help to increase the power flows in heavily loaded lines. TCSC controller shows the effectiveness of TCSC in controlling active and reactive power through the transmission line. The comparison of simulations of with and without TCSC in power system networks shows the TCSC controller enhances stability of power system. For large interconnected systems it is essential.

REFERENCES


BIOGRAPHY

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