CHAPTER 4

FACTS CONTROLLERS FOR OPTIMIZATION OF POWER SYSTEM

4.1 INTRODUCTION

Flexible AC Transmission System (FACTS) controllers have been used in power systems with the objective of improving system performance. Due to the environmental, right-of-way and cost problems in both bundled and unbundled power systems, many transmission lines have been forced to operate at almost their full capacities worldwide. FACTS controllers are used to enhance the static performances like increased loading, congestion management, reduced system loss, economic operation, etc., and dynamic performances like increased stability limits, damping of power system oscillation, etc. For better utilization of the existing power system, it is imperative to install FACTS devices. FACTS devices can control the parameters of the transmission lines, i.e. line impedances, terminal voltages and voltage angles in a fast and effective way. FACTS devices provide proven technical solutions to address these new operating challenges being presented in power system.

FACTS controllers can be divided into four categories based on their connection in the network.
• Shunt Controllers
• Series Controllers
• Combined Series – Series Controllers
• Combined series – Shunt Controllers

Among the FACTS devices Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC) and Unified Power Flow Controller (UPFC) are considered for the proposed work.

Static Var Compensator (SVC) provides fast acting dynamic reactive power compensation for voltage stability enhancement. SVC helps to maintain a bus voltage at a desired value during load variations. It also dampens power swings and reduces system losses by optimized reactive power control.

Thyristor Controlled Series Capacitor (TCSC) is connected in series with the line conductors to compensate for the inductive reactance of the line. It can be operated in both capacitive and inductive mode. In capacitive mode it reduces the transfer reactance between the buses at which the line is connected, thus, increasing the maximum power that can be transmitted and reducing the effective active and reactive power losses. It is also contributed for better voltage profile and reactive power control.

SVC (Shunt controller) provides voltage support at critical buses in the system and TCSC (Series Controller) regulate power flow in critical lines (Dussan Povh et al 2000). Both voltage and power flow are controlled by the combined series and shunt controller (UPFC). The UPFC is capable of
providing active and reactive power control, as well as adaptive voltage magnitude control and it regulates all the three variables simultaneously or any combination of them, provided no operating limits are violated. From the operational point of view, the UPFC may act as a SVC or as a TCSC or as a phase shift controller. The versatility afforded by the UPFC makes it a prime contender to provide many of the control functions required to solve a wide range of dynamic and steady state problems encountered in electrical power networks.

4.2 STATIC VAR COMPENSATOR (SVC)

A shunt connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current, so as to maintain or control specific parameter of the electrical power system (typically bus voltage). Figures 4.1(a) and 4.1(b) show the functional diagram and equivalent circuit of SVC.

Static Var Compensators are used to provide rapid control of voltages (Yakout Mansour et al 1994 and Abdelaziz Laifa et al 2009) at weak points in electrical power systems. SVCs are also used to provide system stabilization in case of insufficient damped inter area oscillations and improve the quality of power system. SVCs should be controlled in order to provide rapid and continuous reactive power during steady state and dynamic condition. The application in power system is to keep the bus voltages within the permissible values under varying load conditions and improve voltage stability.
The SVC provides an excellent source of rapidly controllable reactive shunt compensation for dynamic voltage control through its utilization of high-speed thyristor switching/controlled reactive devices.

An SVC is typically made up of the following major components:

- Coupling transformer
- Thyristor valves
-Reactors and
- Capacitors (often tuned for harmonic filtering)
In general, the two thyristor valve controlled/switched concepts used with SVCs are the Thyristor Controlled Reactor (TCR) and the Thyristor Switched Capacitor (TSC). The TSC provides a “stepped” response and the TCR provides a “smooth” or continuously variable susceptance.

An SVC is a controlled shunt susceptance ($B_{svc}$) as defined by the SVC control settings that injects reactive power ($Q_{svc}$) into the system based on the square of its terminal voltage.

If the high voltage bus begins to fall below its set point range, the SVC will inject reactive power into the system (within its controlled limits), thereby increasing the bus voltage back to its desired voltage level. If the bus voltage increases, the SVC will inject less (or TCR will absorb more) reactive power (within its controlled limits) and the result will be to achieve the desired bus voltage.

The model considers SVC as shunt connected variable susceptance. If the real power consumed by the SVC is assumed to be zero then,

\[ P_{svc} = 0 \]
\[ Q_{svc} = -V^2 B_{svc} \]  \hspace{1cm} (4.1)

where $V$ is the bus voltage magnitude. The reactive power $Q_{svc}$ of SVC is varied between -100MVAR to +100MVAR. Here SVC is modeled as reactive source added at a load bus to optimize the power system.

4.3 THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

Thyristor Controlled Series Capacitor (TCSC) is a second generation FACTS controller, which controls the effective line reactance by connecting a variable reactance in series with line. It is a capacitive/inductive
reactance compensator which consists of a series capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitive/ inductive reactance. This characteristic meets the demands of modern power systems that must be operated flexibly and react quickly. Functional diagram of TCSC is shown in Figure 4.2.

![Figure 4.2 Functional Diagram of TCSC](image)

A TCSC is typically made up of the following major components:

- A series compensating capacitor (C)
- Bypass inductor (L)
- Back to back thyristors (SW)

The degree of TCSC compensation is controlled by the size of capacitor C. Thyristors are used to transform the equivalent impedance of TCSC which fulfills the need in improving the stability (Alberto Del Rosso et al 2000 and Benabid et al 2007), increasing the transmission capability, restraining hypo-synchronization resonance etc.
The basic idea behind power flow control with the TCSC is to decrease or increase the overall lines effective series transmission impedance, by adding a capacitive or inductive reactive correspondingly. In capacitive mode TCSC reduces the transfer reactance between the buses at which the line is connected and increases the maximum power that can be transmitted. The TCSC is modeled as variable impedance, where the equivalent reactance of line $X_{ij}$ is defined as (Benabid et al 2008):

$$X_{ij} = X_{\text{Line}} + X_{\text{TCSC}}$$

(4.2)

The level of the applied compensation of the TCSC usually varies between 20% inductive and 80% capacitive.

$$-0.8X_{\text{Line}} \leq X_{\text{TCSC}} \leq 0.2X_{\text{Line}}$$

(4.3)

where, $X_{\text{Line}}$ - Reactance of transmission line

$X_{\text{TCSC}}$ - Reactance of Thyristor Controlled Series Capacitor

The impedance of the line $i-j$ is assumed to be $R+jX$. If $s$ is defined as the TCSC compensation ratio ($s = X_C / X_L$) and TCSC is installed in the line $i-j$ then the impedance of the line $i-j$ changes to $R+jX(1-s)$. Therefore the admittance matrix of the power systems becomes a function of the TCSC compensation ratio $s$. Now the line reactance of the transmission line also depends on the value of TCSC compensation ratio $s$. The main advantage from breaking up the TCSC reactance in segments is that the total effective TCSC reactance can achieve a wider range of values. In this work, TCSC is modeled as variable reactance inserted in the line to optimize the power system.
4.4 UNIFIED POWER FLOW CONTROLLER (UPFC)

UPFC is a combination of static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) which are coupled via a common dc link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control the transmission line voltage, impedance and angle or, alternatively, the real and reactive power flow in the line (Sreekanth Reddy Donapati et al 2008 and Seyed Abbass Taher et al 2009). Figure 4.3 shows the General Scheme of UPFC.

![Figure 4.3 General UPFC Scheme](image-url)
The UPFC may also provide independently controllable shunt and series reactive compensations. In this work UPFC is modeled as combination of SVC (for shunt compensation) at a load bus and TCSC (for series compensation) in the line connected to the same bus to optimize the power system.

The FACTS devices constraints are given as follows (Saravanan et al 2007):

For series compensation (TCSC):

i) \[-0.8X_L \leq X_{TCSC} \leq 0.2 X_L \text{ p.u.} \] (4.4)

For shunt compensation (SVC):

ii) \[-100 \text{MVAR} \leq Q_{svc} \leq 100 \text{MVAR} \] (4.5)

For both series and shunt compensations (UPFC):

iii) Eqn (4.4) and (4.5) for UPFC. (4.6)

where \( X_{TCSC} \) – Reactance added to the line by placing TCSC
\( X_L \) – Reactance of the line where TCSC is located
\( Q_{svc} \) - Reactive power injected at the bus by placing SVC

Among the FACTS devices, UPFC is able to compensate reactive power and control active and reactive power flows of a transmission line simultaneously.
4.5 CONCLUSION

Brief modeling of FACTS controllers such as SVC, TCSC and UPFC are discussed. Static Var Compensator (SVC) is provided for fast acting dynamic reactive compensation for voltage stability enhancement. It dampens power swings and reduces system losses by optimized reactive power control. TCSC is connected in series with the line conductors to compensate for the inductive reactance of the line. It also contributes for better voltage profile and reactive power control. Unified Power Flow Controller (UPFC) is the combined series and shunt controller and can control both voltage and power flow. The versatility afforded by the UPFC makes it a prime contender to provide many of the control functions required to solve a wide range of dynamic and steady state problems encountered in electrical power networks. In this work, SVC, TCSC and UPFC are placed to achieve optimized real power loss.