# CHAPTER 3

# FLEXIBLE AC TRANSMISSION SYSTEMS

## 3.1 GENERAL

Flexible alternating-current transmission systems (FACTS) is a recent technological development in electrical power systems. It uses the great many advances achieved in high-current, high-power semiconductor device technology, digital control and signals conditioning. Many of the ideas upon which the foundation of FACTS rests evolved over a period of many decades. Nevertheless, FACTS, an integrated philosophy, is a novel concept that was brought to fruition during the 1980s at the Electric Power Research Institute, the utility arm of North American utilities (Hingorani and Laszio Gyugyi 2000). From the power systems engineering perspective, the wealth of experience gained with the commissioning and operation of high-voltage direct-current (HVDC) links and static VAR compensator (SVC) systems, over many decades, in many parts of the globe, may have provided the driving force for searching deeper into the use of emerging power electronic equipment and techniques, as a means of alleviating long-standing operational problems in both high-voltage transmission and low-voltage distribution systems.

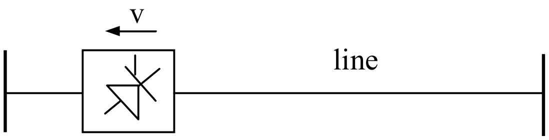
FACTS looks at ways of capitalizing on the many break through taking place in the area of high-voltage and high current power electronics, aiming at increasing the control of power flows in the high voltage side of the network during both steady-state and transient conditions. The new reality of making the power network electronically controllable has started to alter the way power plant equipments are designed and built as well as the thinking and procedures that go into the planning and operation of transmission and distribution networks. These developments may also affect the way energy transactions are conducted, as high-speed control of the path of the energy flow is now feasible. Owing to many economical and technical benefits it promised, FACTS received the uninstinctive support of electrical equipment manufacturers, utilities, and research organizations around the world (Zhang et al 2006).

Several kinds of FACTS controllers have been commissioned in various parts of the world. The most popular are: load tap changers, phase-angle regulators, static VAR compensators (SVC), thyristor-controlled series compensators (TCSC), inter-phase power controllers (IPC), static compensators (STATCOM), and unified power flow controllers (UPFC). They can be classified into four categories as indicated in Figure 3.1.

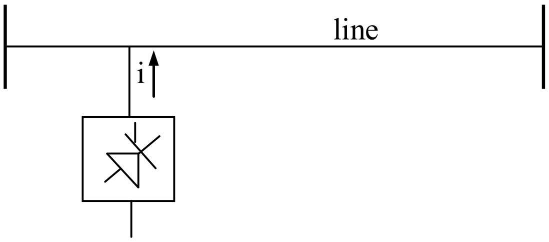
- **Series Controllers**: The series controller, as shown in Figure 3.1 (a). Could be variable impedance, such as capacitor, reactor, etc., or a power electronics based variable source of main frequency, sub synchronous and harmonic frequencies to serve the desired need. In principle, all series controllers inject voltage in series with the line. Even variable impedance multiplied by the current flow through it, represents an injected series voltage in the line. As long as the voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well.
- **Shunt Controllers**: The shunt Controllers, as shown in Figure 3.1(b), may be variable impedance, variable source, or a combination of these. In principle, all shunt Controllers inject current into the system at the point of connection. Even

variable shunt impedance connected to the line voltage causes a variable current flow and hence represents injection of current into the line. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well.

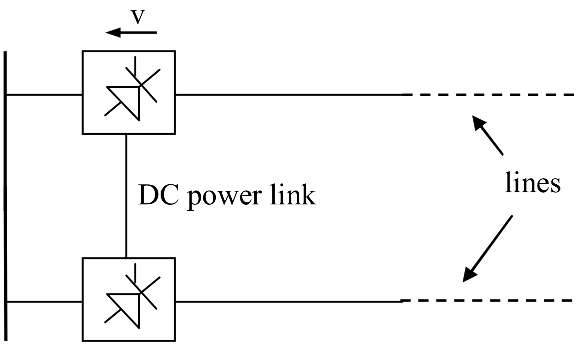
- **Combined series-series Controllers**: This could be a combination of separate series controllers, which are controlled in a coordinated manner, in a multiline transmission system, or it could be a unified controller, in which series controllers provide independent series reactive power compensation for each line but also transfer real power among the lines via the power link. The real power transfer capability of the unified series-series controller, referred to as Interline Power Flow Controller, makes it possible to balance both the real and reactive power flow in the lines and thereby maximize the utilization of the transmission system. It is to be noted that the term "unified" here means that the dc terminals of all controller converters are all connected together for real power transfer.
- **Combined series-shunt Controllers**: This could be a combination of separate shunt and series controllers, which are controlled in a coordinated manner or a UPFC with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with the shunt part of the controller and voltage in series in the line with the series part of the controller. However, when the shunt and series controllers are unified, there can be a real power exchange between the series and shunt controllers via the power link.



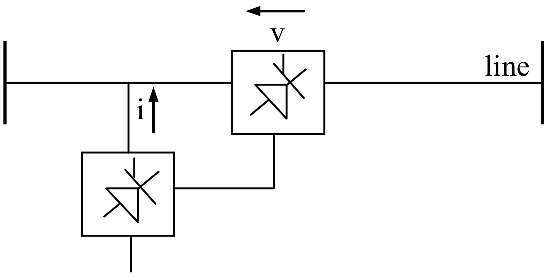
(a) Series Controllers



(b) Shunt Controllers



(c) Series and Series Controllers



(d) Series and Shunt Controllers

**Figure 3.1 Basic Type of FACTS devices**

## 3.2 STATIC VAR COMPENSATOR

SVC is a general term for a thyristor-controlled or thyristor-switched reactor, and/or thyristor-switched capacitor or combination as shown in Figure. 3.2. From an operational point of view, the SVC behaves like a shunt-connected variable reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the AC network. So it is extensively used for fast reactive power and voltage regulation support. In power flow analysis, the total susceptance of the SVC may be taken as a variable and additional voltage or reactive power control equation should be included. The firing angle control of the thyristor enables the SVC to have almost instantaneous speed of response. Based on the operation of SVC it can be configured as variable shunt susceptance model and firing- angle model. Moreover, a compound transformer and SVC model based on the SVC firing-angle representation is also available.

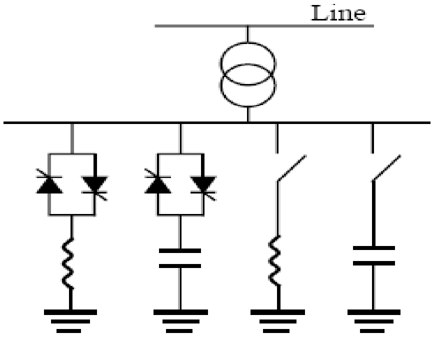


**Figure 3.2 Static VAR Compensator**

Figure.3.3 shows the steady-state and dynamic voltage-current characteristics of the SVC. In the active control range, current/susceptance and reactive power is varied to regulate voltage according to a slope (droop) characteristic. The slope value depends on the desired voltage regulation, the desired sharing of reactive power production between various sources, and other needs of the system. The slope is typically 1-5%. At the capacitive limit, the SVC becomes a shunt capacitor. At the inductive limit, the SVC becomes a shunt reactor (the current or reactive power may also be limited). Figure 3.4 gives the V-Q characteristics of the SVC.

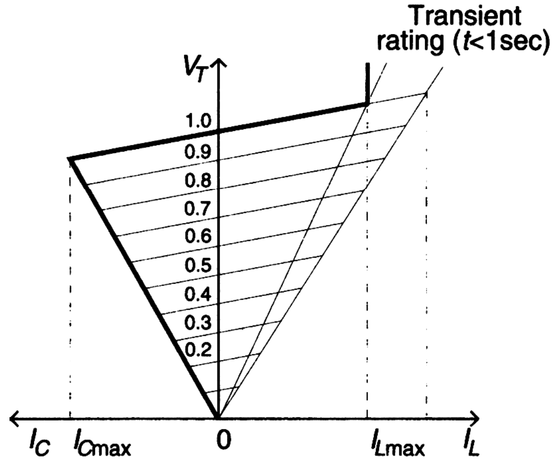


Figure 3.3 V-I Characteristics of SVC

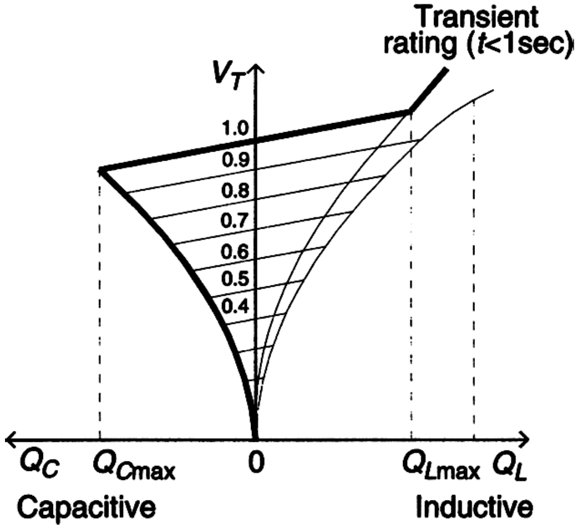


Figure 3.4 V-Q Characteristics of SVC

### 3.2.1 Shunt Variable Susceptance Model

The susceptance model represents the SVC as an adjustable susceptance connected to the high-voltage bus with susceptance. This model assumes a fixed voltage at the SVC's terminal bus when operating within the limits. Therefore, it is similar to a PV bus. Figure 3.5 shows the shunt susceptance model and current drawn by the SVC is

$$I_{SVC} = jB_{SVC}V_K \tag{3.1}$$

and the reactive power drawn by the SVC, which is also the reactive power injected at bus k, is

$$Q_{SVC} = Q_K = -V_K^2 B_{SVC} \tag{3.2}$$

$$B^i{}_{SVC} = B_{SVC}^{(i-1)} + \left(\frac{\Delta B_{SVC}}{B_{SVC}}\right)^{(i)} B_{SVC}^{(i-1)} \tag{3.3}$$

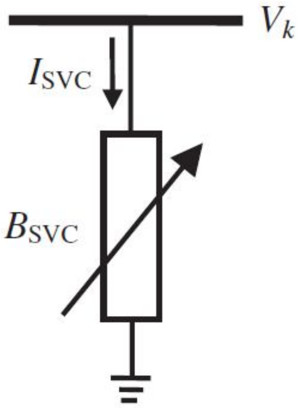


Figure 3.5 Susceptance model of SVC

### 3.2.2 Firing angle model of SVC

SVC firing angle model is shown in Figure 3.6. The equivalent reactance $X_{SVC}$, which is function of a changing firing angle $\alpha$ , is made up of the parallel combination of a thyristor controlled reactor (TCR) equivalent admittance and a fixed capacitive reactance. This model provides information on the SVC firing angle required to achieve a given level of compensation.

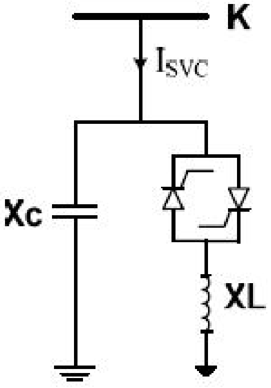


**Figure 3.6 Firing angle model of SVC**

The reactive power drawn by the SVC, which is also the reactive power injected at bus k, is

$$Q_K = \frac{-V_K^2}{X_C X_L}\left\{X_L - \frac{X_C}{\pi}[2(\pi - \alpha_{SVC}) + \sin(2\alpha_{SVC})]\right\} \tag{3.4}$$

the SVC variable firing angle $\alpha_{SVC}$ is given by equation (3.5) at the end of $i_{th}$ iteration as

$$\alpha^{(i)}{}_{SVC} = \alpha^{(i-1)}{}_{SVC} + \Delta\alpha^{(i)}{}_{SVC} \tag{3.5}$$

## 3.3 THYRISTOR CONTROLLED SERIES COMPENSATOR

TCSC is a typical series FACTS device comprising a thyristor controlled reactor across a series capacitor, which is used to vary the reactance of the transmission line. It reduces the electrical length of the compensated transmission line. The TCSC may be a single, large unit, or may consist of several equal or different-sized smaller capacitors in order to achieve a superior performance. Figure 3.7 shows the layout of one phase of TCSC. Since TCSC works through the transmission system directly, it is much more effective than the shunt FACTS devices in the application of power flow control and power system oscillation damping control (de Souza et al 1997; Lof et al 1992).

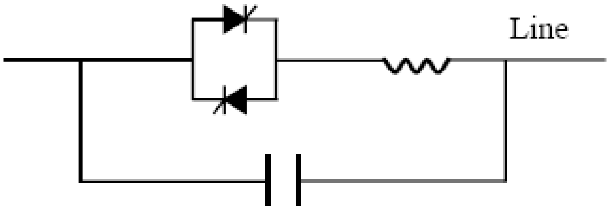


**Figure 3.7 Thyristor Controlled Series Compensator**

### 3.3.1 Variable Series Impedance Power Flow Model

The TCSC power flow model presented in this section is based on the simple concept of a variable series reactance, the value of which is adjusted automatically to constrain the power flow across the branch to a specified value. The amount of reactance is determined efficiently using Newton's method. The changing reactance $X_{TCSC}$, shown in Figures 3.8(a) and (b), represents the equivalent reactance of all the series-connected modules making up the TCSC, when operating in either the inductive or the capacitive regions.

**Figure 3.8 Thyrister controlled series compensator equivalent circuit (a) Inductive and (b) capacitive operative region**

### 3.3.2 Static modelling of TCSC

The model of a transmission line with a TCSC connected between bus-*i* and bus-*j* is shown in Figure 3.9. In steady state, the TCSC can be considered as a static reactance $-jx_c$. The change in the line flow due to series capacitance can be represented as a line without series capacitance with additional power (complex) injections at the receiving $S_{jc}$ and sending $S_{ic}$ ends as shown in Figure 3.10. The real power injections due to series capacitor at bus-i $P_{ic}$ and bus $-jP_{jc}$ and can be written as

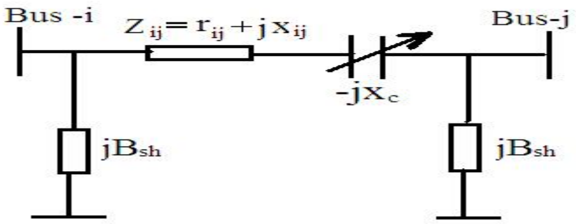


**Figure 3.9 Static modelling of TCSC**

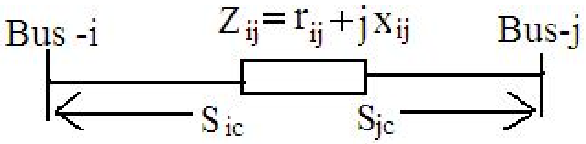


**Figure 3.10 Injection modelling of TCSC**

$$P_{ic} = V_i^2 \Delta G_{ij} - V_i V_j \left[ \Delta G_{ij} \cos \delta_{ij} + \Delta B_{ij} \sin \delta_{ij} \right] \tag{3.6}$$

$$P_{jc} = V_j^2 \Delta G_{ij} - V_i V_j \left[ \Delta G_{ij} \cos \delta_{ij} - \Delta B_{ij} \sin \delta_{ij} \right] \tag{3.7}$$

Where $$\Delta G_{ij} = \frac{x_c r_{ij} \left( x_c - 2x_{ij} \right)}{\left( r_{ij}^2 - x_{ij}^2 \right)\left( r_{ij}^2 + \left( x_{ij} - x_c \right)^2 \right)} \tag{3.8}$$

$$\Delta B_{ij} = \frac{- x_c \left( r^2{}_{ij} - x_{ij}^2 + x_c x_{ij} \right)}{\left( r_{ij}^2 - x_{ij}^2 \right)\left( r_{ij}^2 + \left( x_{ij} - x_c \right)^2 \right)} \tag{3.9}$$

## 3.4 STATCOM

STATCOM may be one of the popular FACTS-devices, among the converter based FACTS-devices which has many installations in electric utilities worldwide. Considering the practical applications of the STATCOM in power systems, it is of importance and interest to investigate the possible multi-control functions of the STATCOM as well as model these functions in power system steady state operation and control, such that the various control capabilities can be fully employed, and the benefits of applications of the STATCOM may be fully realized under nine modes of operations.

A STATCOM is usually used to control transmission voltage by reactive power shunt compensation. Typically, a STATCOM consists of a coupling transformer, an inverter and a DC capacitor, which is shown in Figure 3.11. For such an arrangement, in ideal steady state analysis, it can be assumed that the active power exchange between the AC system and the STATCOM can be neglected, and only the reactive power can be exchanged between them. Based on the operating principle of the STATCOM, the equivalent circuit can be derived, which is given in Figure 3.12. The STATCOM can be equivalently represented by a controllable fundamental frequency positive sequence voltage source $V_{sh}$. In principle, the STATCOM output voltage can be regulated such that the reactive power of the STATCOM can be changed.

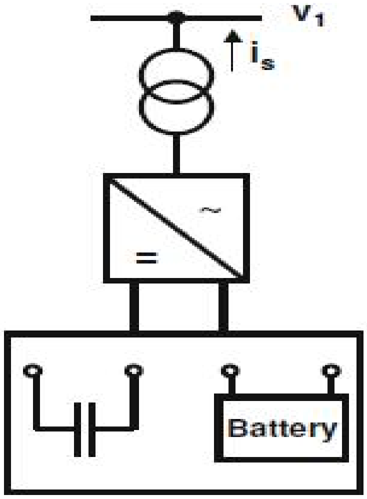


**Figure 3.11 Static synchronous Compensator**

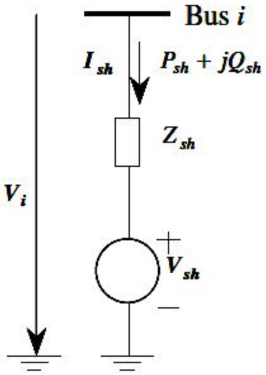


**Figure 3.12 Static synchronous Compensator Equivalent circuit**

According to the equivalent circuit of the STATCOM shown in Figure 3.12, suppose $V_{sh} = V_{sh}\angle\theta_{sh}, V_i = V_j\angle\theta_i$, then the power flow constraints of the STATCOM are:

$$P_{sh} = V_i^2 G_{sh} + V_i V_{sh}\left(G_{sh}\cos\left(\theta_i - \theta_{sh}\right) + B_{sh}\sin\left(\theta_i - \theta_{sh}\right)\right) \quad (3.10)$$

$$Q_{sh} = V_i^2 B_{sh} + V_i V_{sh}\left(G_{sh}\sin\left(\theta_i - \theta_{sh}\right) + B_{sh}\cos\left(\theta_i - \theta_{sh}\right)\right) \quad (3.11)$$

In the practical applications of a STATCOM, it may be used for controlling one of the following parameters:

- Voltage magnitude of the local bus, to which the STATCOM is connected.
- Reactive power injection to the local bus, to which the STATCOM is connected.
- Impedance of the STATCOM.
- Current magnitude of the STATCOM while the current $I_{sh}$ leads the voltage injection $V_{sh}$ by 90.
- Current magnitude of the STATCOM, while the current $I_{sh}$ lags the voltage injection $V_{sh}$ by 90.
- Voltage injection.
- Voltage magnitude at a remote bus.

## 3.5 STATIC SYNCHRONOUS SERIES COMPENSATOR

A multi-control functional model of the SSSC, which can be used for steady state controlling of the following parameters, (a) the active power flow of the transmission line, (b) the reactive power flow the transmission line, (c) the bus voltage, and (d) the impedance of the transmission line. Usually it consists of a coupling transformer, an inverter and a capacitor, as shown in Figure. 3.13, the SSSC is series connected with a transmission line through the coupling transformer.

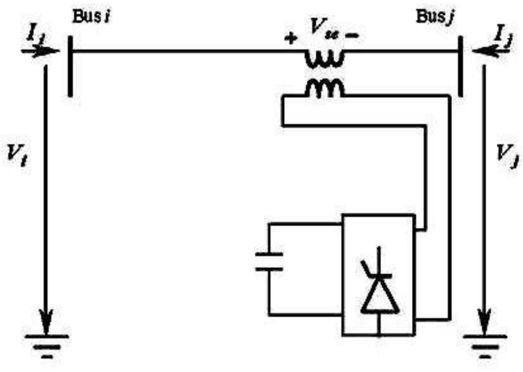


**Figure 3.13 Static Synchronous Series Compensator**

It is assumed here that the transmission line is series connected via the SSSC bus *j*. The active and reactive power flows of the SSSC branch *i-j* entering the bus *j* are equal to the sending end active and reactive power flows of the transmission line, respectively. In principle, the SSSC can generate and insert a series voltage, which can be regulated to change the impedance (more precisely reactance) of the transmission line. In this way, the power flow of the transmission line or the voltage of the bus, which the SSSC is connected with, can be controlled.

An equivalent circuit of SSSC is as shown in Figure. 3.14 can be derived based on the operation principle of the SSSC. In the equivalent, the SSSC is represented by a voltage source $V_{se}$ *in* series with transformer impedance. In the practical operation of the SSSC, $V_{se}$ can be regulated to control the power flow of line *i-j* or the voltage at bus *i* or *j*.

In the equivalent circuit, $V_{se} = V_{se}\angle\theta_{se}$ , $V_i = V_i\angle\theta_i$ $V_j = V_j\angle\theta_j$, then the bus power flow constraints of the SSSC are:

$$\begin{aligned} P_{ij} &= V_i^2 G_{ii} - V_i V_j \left(G_{ij}\cos(\theta_{ij}) + B_{ij}\sin(\theta_{ij})\right) \\ &- V_i V_{se}\left(G_{ij}\cos(\theta_i - \theta_{se}) + B_{ij}\sin(\theta_i - \theta_{se})\right) \end{aligned} \tag{3.12}$$

$$\begin{aligned} Q_{ij} &= -V_i^2 B_{ii} - V_i V_j \left(G_{ij}\sin(\theta_{ij}) - B_{ij}\cos(\theta_{ij})\right) \\ &- V_i V_{se}\left(G_{ij}\sin(\theta_i - \theta_{se}) - B_{ij}\cos(\theta_i - \theta_{se})\right) \end{aligned} \tag{3.13}$$

$$\begin{aligned} P_{ji} &= V_j^2 G_{jj} - V_i V_j \left(G_{ij}\cos(\theta_{ji}) + B_{ij}\sin(\theta_{ji})\right) \\ &+ V_j V_{se}\left(G_{ij}\cos(\theta_j - \theta_{se}) + B_{ij}\sin(\theta_j - \theta_{se})\right) \end{aligned} \tag{3.14}$$

$$\begin{aligned} Q_{ji} &= -V_j^2 B_{jj} - V_i V_j \left(G_{ij}\sin(\theta_{ji}) - B_{ij}\cos(\theta_{ji})\right) \\ &+ V_j V_{se}\left(G_{ij}\sin(\theta_j - \theta_{se}) - B_{ij}\cos(\theta_j - \theta_{se})\right) \end{aligned} \tag{3.15}$$

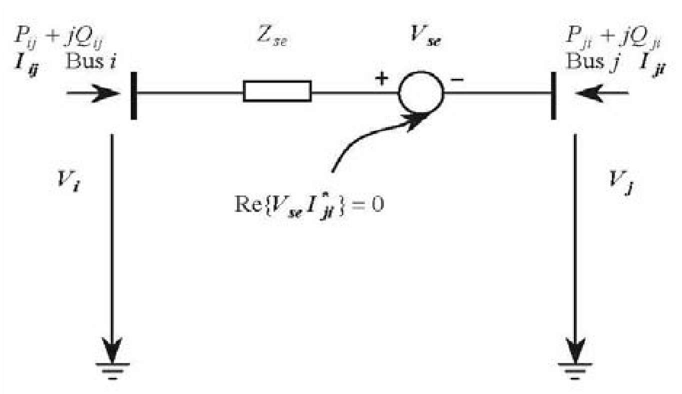


**Figure 3.14 Equivalent circuit of SSSC**

## 3.6 UNIFIED POWER FLOW CONTROLLER

The UPFC is the most powerful and versatile FACTS controller for the regulation of voltage and power flow in a transmission line. A simplified schematic representation of the UPFC is given in Figure 3.15. It consists of two VSCs one shunt connected and the other series connected. The two converters exchange real power flow between the two converters. The active power can be either absorbed or supplied by the series connected converter.

The shunt connected converter not only provides the necessary real power required, but also the reactive current injected at the converter bus. It allows simultaneous control of active power flow, reactive power flow, and voltage magnitude at its terminals. Alternatively, the controller may be set to control one or more of these parameters in any combination or to control none of them.

UPFC was proposed for real time and dynamic compensation of AC transmission systems, providing the necessary functional flexibility required to solve many of the problems facing the utility industry. It is the most powerful and versatile FACTS controller for the regulation of voltage and power flow in a transmission line. A simplified schematic representation of the UPFC is given in Figure 3.15 and its equivalent circuit is shown in Figure 3.16. It consists of two VSCs one shunt connected and the other series connected. The two converters exchange real power flow between the two converters. The active power can be either absorbed or supplied by the series connected converter. The shunt connected converter not only provides the necessary real power required, but also the reactive current injected at the converter bus. It allows simultaneous control of active power flow, reactive power flow, and voltage magnitude at its terminals. Alternatively, the controller may be set to control one or more of these parameters in any combination or to control none of them.

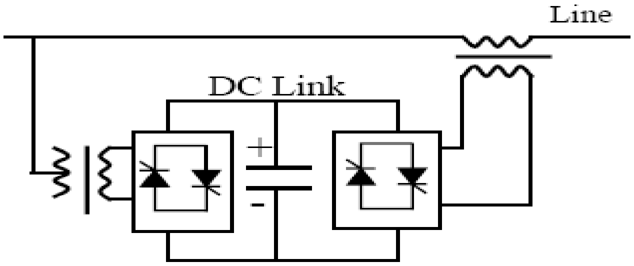


**Figure 3.15 Unified Power Flow Controller**

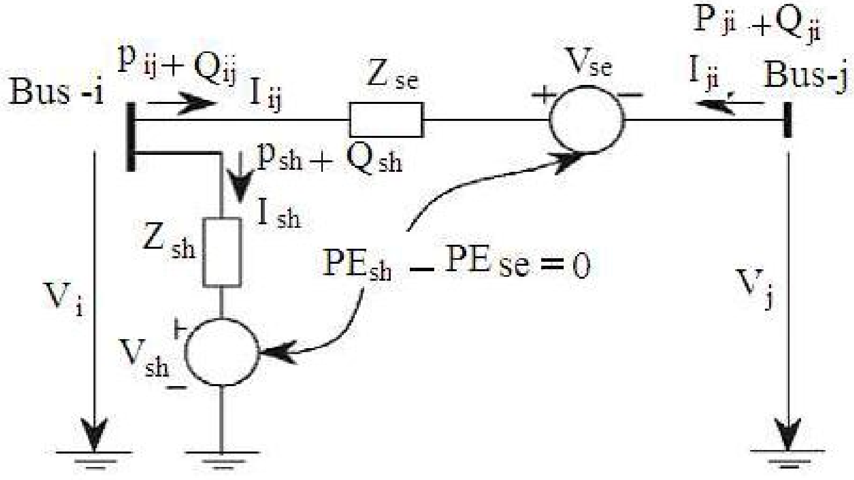


**Figure 3.16 Equivalent circuit of Unified Power Flow Controller**

The two voltage source converters of the UPFC, connected through a D.C link can be modelled as two ideal voltage sources, one connected in series and the other in shunt between the two buses. The output of the series voltage source $V_{se}$ and $\theta_{se}$ are controllable magnitude and angle between the limits $V_{se}$max ≤ $V_{se} \leq V_{se}$ min and 0 ≤ $\theta_{se} \leq 2\pi$ respectively and of the shunt voltage source is $V_{sh}$ and $\theta_{se}$ controllable between the limits $V_{sh}$max ≤ $V_{sh}$ ≤ $V_{sh}$ min and 0 ≤ $\theta_{se} \leq 2\pi$. $Z_{se}$ and $Z_{sh}$ are the impedances of the two coupling transformer one connected in series and other in shunt between the line and the UPFC. For the series and shunt sources the power equations of UPFC can be written.

The converter output voltage (magnitude and angle) is used to control the mode of power flow and voltage at the nodes as follows:

The bus voltage magnitude can be controlled by injecting a voltage $V_{se}$ in phase or anti phase as shown in the Figure 3.17 ($\theta_{se}$ is in phase/anti phase with the nodal voltage angle $\theta_K$)

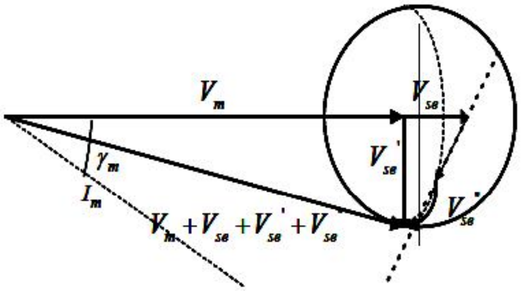


**Figure 3.17 simultaneous control of voltage, impedance and angle**

$$P_{sh} = V_i^2 G_{sh} - V_i V_{sh} \left( G_{sh} \cos(\theta_i - \theta_{sh}) + B_{sh} \sin(\theta_i - \theta_{sh}) \right) \tag{3.16}$$

$$Q_{sh} = -V_i^2 B_{sh} - V_i V_{sh} \left( G_{sh} \sin(\theta_i - \theta_{sh}) - B_{sh} \cos(\theta_i - \theta_{sh}) \right) \tag{3.17}$$

$$\begin{aligned} P_{ij} &= V_i^2 G_{ij} - V_i V_j \left( G_{ij} \cos(\theta_{ij}) + B_{ij} \sin(\theta_{ij}) \right) \\ &- V_i V_{se} \left( G_{ij} \cos(\theta_i - \theta_{se}) + B_{ij} \sin(\theta_i - \theta_{se}) \right) \end{aligned} \tag{3.18}$$

$$\begin{aligned} Q_{ij} &= -V_i^2 B_{ij} - V_i V_j \left( G_{ij} \sin(\theta_{ij}) - B_{ij} \cos(\theta_{ij}) \right) \\ &- V_i V_{se} \left( G_{ij} \sin(\theta_i - \theta_{se}) - B_{ij} \cos(\theta_i - \theta_{se}) \right) \end{aligned} \tag{3.19}$$

$$\begin{aligned} P_{ji} &= V_j^2 G_{ij} - V_i V_j \left( G_{ij} \cos(\theta_{ji}) + B_{ij} \sin(\theta_{ji}) \right) \\ &+ V_j V_{se} \left( G_{ij} \cos(\theta_j - \theta_{se}) + B_{ij} \sin(\theta_j - \theta_{se}) \right) \end{aligned} \tag{3.20}$$

$$\begin{aligned} Q_{ji} &= -V_j^2 B_{ij} - V_i V_j \left( G_{ij} \sin(\theta_{ji}) - B_{ij} \cos(\theta_{ji}) \right) \\ &+ V_j V_{se} \left( G_{ij} \sin(\theta_j - \theta_{se}) - B_{ij} \cos(\theta_j - \theta_{se}) \right) \end{aligned} \tag{3.21}$$

## 3.7 INTERLINE POWER FLOW CONTROLLER

A series-series FACTS device called Interline Power Flow Controller (IPFC) which can increase power transfer capability and maximize the use of the existing transmission network is shown in Figure 3.18. The salient features of the IPFC are its convertibility and expandability, which are becoming increasingly important as electric utilities are being transformed into highly competitive marketplaces. The functional convertibility enables the IPFC to adapt to changing system operating requirements and changing power flow patterns. The expandability of the IPFC is that a number of voltage-source converters coupled with a common DC bus can be operated. Additional compatible converter or converters can be connected to the common DC bus to expand the functional capabilities of the IPFC. The convertibility and expandability of the CSC enables it to be operated in various configurations. In principle, with an extra shunt converter, a Generalized Unified Power Flow Controller (GUPFC), which requires at least three converters, can be configured the IPFC and GUPFC are significantly extended to control power flows of multi-lines or a sub-network beyond that achievable by the UPFC or SSSC or STATCOM.

In principle, with at least two converters, an IPFC can be configured. With at least three converters, a GUPFC can be configured. The IPFC and GUPFC will work under practical operating inequality constraints in power flow.

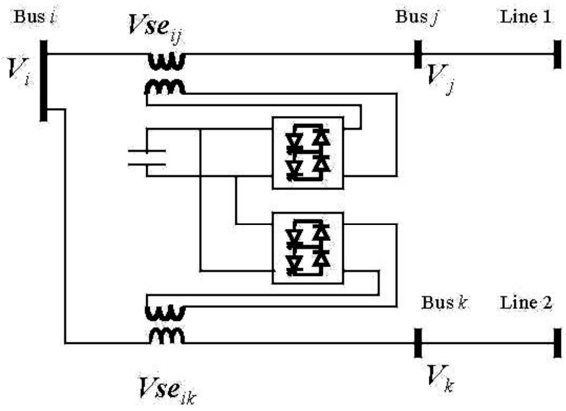


**Figure 3.18 Inter Line Power Flow Controller**

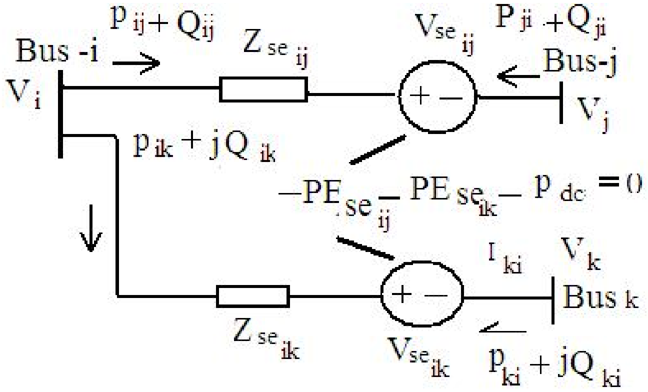


**Figure 3.19 Equivalent circuit of IPFC**

An equivalent circuit of the IPFC with two controllable series injected voltage sources is shown in Figure. 3.19. The real power can be exchanged between or among the series converters via the common DC link while the sum of the real power exchange should be zero. Suppose in Figure 3.19 the series transformer impedance is $Z_{se}in$, and the controllable injected voltage source is $V_{se}in = V_{se}in\angle\theta_{se}in$ (n = *j, k*). Active and reactive power flows of the FACTS branches leaving buses *i, j, k* are given by:

$$\begin{aligned} P_{in} &= V_i^2 G_{in} - V_i V_n \left( G_{in} \cos(\theta_{in}) + B_{in} \sin(\theta_{in}) \right) \\ &\quad - V_i V_{se_{in}} \left( G_{in} \cos\left(\theta_i - \theta_{se_{in}}\right) + B_{in} \sin\left(\theta_i - \theta_{se_{in}}\right) \right) \end{aligned} \tag{3.22}$$

$$\begin{aligned} Q_{in} &= -V_i^2 B_{in} - V_i V_n \left( G_{in} \sin(\theta_{in}) - B_{in} \cos(\theta_{in}) \right) \\ &\quad - V_i V_{se_{in}} \left( G_{in} \sin\left(\theta_i - \theta_{se_{in}}\right) - B_{in} \cos\left(\theta_i - \theta_{se_{in}}\right) \right) \end{aligned} \tag{3.23}$$

$$\begin{aligned} P_{ni} &= V_n^2 G_{in} - V_i V_n \left( G_{in} \cos(\theta_n - \theta_i) + B_{in} \sin(\theta_n - \theta_i) \right) \\ &\quad + V_n V_{se_{in}} \left( G_{in} \cos\left(\theta_n - \theta_{se_{in}}\right) + B_{in} \sin\left(\theta_n - \theta_{se_{in}}\right) \right) \end{aligned} \tag{3.24}$$

$$\begin{aligned} Q_{ni} &= -V_n^2 B_{nn} - V_i V_n \left( G_{in} \sin(\theta_n - \theta_i) - B_{in} \cos(\theta_n - \theta_i) \right) \\ &\quad + V_n V_{se_{in}} \left( G_{in} \sin\left(\theta_n - \theta_{se_{in}}\right) - B_{in} \cos\left(\theta_n - \theta_{se_{in}}\right) \right) \end{aligned} \tag{3.25}$$

## 3.8 POSSIBLE BENEFITS

The FACTS devices enable the transmission system to obtain one or more of the following benefits

- Control of power flow as ordered. This is the main function of FACTS devices. The use of power flow control may be to follow a contract, meet the utilities' own needs, ensure optimum power flow, ride through emergency conditions, or a combination of them.

- Increase utilization of lowest cost generation. One of the principle reasons for transmission interconnections is to utilize the lowest cost generation. When this cannot be done, it follows that there is not enough cost-effective transmission capacity. Cost-effective enhancement of capacity will therefore allow increased use of lowest cost generation.

- Dynamic stability enhancement. The additional function includes the transient stability improvement, power oscillation damping and voltage stability control.
- Increase the loading capability of lines to their thermal capabilities, including short term and seasonal demands.
- Provide secure tie-line connections to neighboring utilities and regions thereby decreasing overall generation reserve requirements on both sides.
- Upgrade of transmission lines.
- Reduce reactive power flows, thus allowing the lines to carry more active power.
- Loop flow control.
- Keeping of contractual power exchanges with balanced reactive Power.
- Compensation of consumers and improvement of power quality especially with huge demand fluctuations like industrial machines, metal melting plants, railway or underground train systems.

## 3.9 SUMMARY

An introduction to FACTS devices and their classifications have been outlined. The modelling of SVC, TCSC and UPFC has been narrated besides highlighting the possible benefits of the FACTS devices.