Chapter 1

Introduction

1.1 General

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. For example, it may be cheaper to locate a thermal power station at pithead instead of transporting coal to load centres. Hydropower is generally available in remote areas. A nuclear plant may be located at a place away from urban areas. Thus, a grid of transmission lines operating at high or extra high voltages is required to transmit power from the generating stations to the load centres.

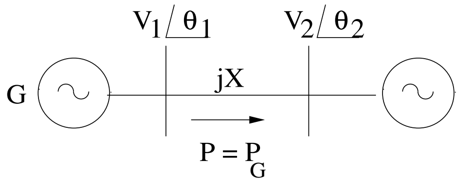
In addition to transmission lines that carry power from the sources to loads, modern power systems are also highly interconnected for economic reasons. The interconnected systems benefit by (a) exploiting load diversity (b) sharing of generation reserves and (c) economy gained from the use of large efficient units without sacrificing reliability. However, there is also a downside to ac system interconnection – the security can be adversely affected as the disturbances initiated in a particular area can spread and propagate over the entire system resulting in major blackouts caused by cascading outages.

1.2 Basics of Power Transmission Networks

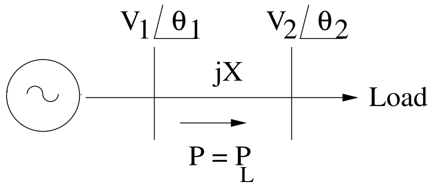
A large majority of power transmission lines are AC lines operating at different voltages (10 kV to 800 kV). The distribution networks generally operate below 100 kV while the bulk power is transmitted at higher voltages. The lines operating at different voltages are connected through transformers which operate at high efficiency. Traditionally, AC lines have no provision for the control of power flow. The mechanically operated circuit breakers (CB) are meant for protection against faults (caused by flashovers due to overvoltages on the lines or reduced clearances to ground). A CB is rated for a limited number of open and close operations at a time and cannot be used for power flow control. (unlike a high power electronic switch such as thyristor, GTO, IGBT, IGCT, etc.). Fortunately, ac lines have inherent power flow control as the power flow is determined by the power at the sending end or receiving end. For example, consider a trasmission line connecting a generating station to a load centre in Fig.1.1(a). Assuming the line to be lossless and ignoring the line charging, the power flow (P) is given by

$$P = \frac{V_1 V_2}{X} \sin(\theta_1 - \theta_2) \tag{1.1}$$

where X is the series line reactance. Assuming V_1 and V_2 to be held constants (through voltage regulators at the two ends), the power injected by the power station determines the flow of power in the line. The difference in the bus angles is automatically adjusted to enable $P = P_G$ (Note that usually there could be more than one line transmitting power from a generating station to a load centre). If one or more lines trip, the output of the power station may have to be reduced by tripping generators, so as to avoid overloading the remaining lines in operation.



(a) A line transmitting power from a generating station



(b) A line supplying power to a load

Figure 1.1: A transmission line carrying power

Fig. 1.1(b) shows another situation where a line supplies power to a load located at bus (2). Here also the eq. (1.1) applies but the power flow in the line is determined by the load supplied. The essential difference between the two situations is that in Fig. 1.1(a), the load centre is modelled as an infinite bus which can absorb (theoretically) any amount of power supplied to it from the generating station. This model of the load centre assumes that the generation available at the load centre is much higher than the power supplied from the remote power station (obviously, the total load supplied at the load centre is equal to the net generation available at that bus).

The reliability of the power supply at a load bus can be improved by arranging two (or more) sources of power as shown in Fig. 1.2. Here, P_1 is the output of $G1$ while P_2 is the output of $G2$ (Note that we are neglecting losses as before). However, the tripping of any one line will reduce the availability of power at the load bus. This problem can be overcome by providing a line (shown dotted in Fig. 1.2) to interconnect the two power stations. Note that this results in the creation of a mesh in the transmission network. This improves the system reliability, as tripping of any one line does not result in curtailment of the load. However, in steady state, P_1 can be higher or lower than P_{G1} (the output of G1). The actual power flows in the 3 lines forming a mesh are determined by Kirchhoff's Voltage Law (KVL). In general, the addition of an (interconnecting) line can result in increase of power flow in a line (while decreasing the power flow in some other line). This is an interesting feature of AC transmission lines and not usually well understood (in the context of restructuring). In general, it can be stated that in an uncontrolled AC transmission network with loops (to improve system reliability), the power flows in individual lines are determined by KVL and do not follow the requirements of the contracts (between energy producers and customers). In other words, it is almost impossible to ensure that the power flow between two nodes follows a predetermined path. This is only feasible in radial networks (with no loops), but the reliability is adversely affected as even a single outage can result in load curtailment. Consider two power systems, each with a single power station meeting its own local load, interconnected by a tie line as shown in Fig. 1.3(a). In this case, the power flow in the tie line (P) in steady state is determined by the mismatch between the generation and load in the individual areas. Under dynamic conditions, this power flow is determined from the equivalent circuit shown in Fig. 1.3(b). If the capacity of the tie is small compared to the size (generation) of the two areas, the angles δ_1 and δ_2 are not affected much by the tie line power flow. Thus, power flow in AC tie is generally uncontrolled and it becomes essential to trip the tie during a disturbance, either to protect the tie line or preserve system security.

In comparison with a AC transmission line, the power flow in a HVDC line in controlled and regulated. However, HVDC converter stations are expensive and HVDC option is used primarily for (a) long distance bulk power transmission (b) interconnection of asynchronous systems and (c) underwater (submarine) transmission. The application of HVDC transmission (using thyristor converters) is also constrained by the problem of commutation failures affecting operation of multiterminal or multi-feed HVDC systems. This implies that HVDC links are primarily used for point-to-point transmission of power and asynchronous interconnection (using Back to Back (BTB) links).

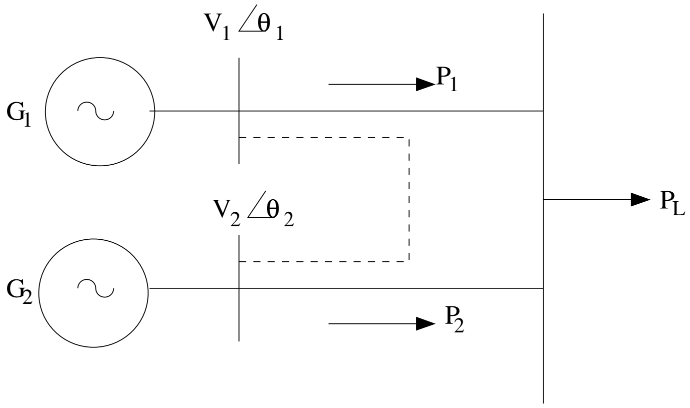
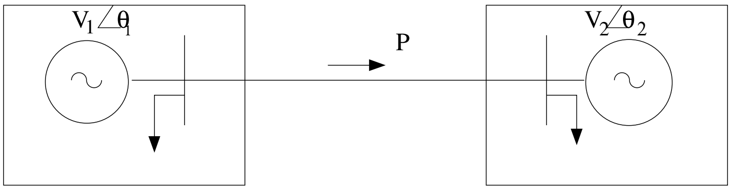
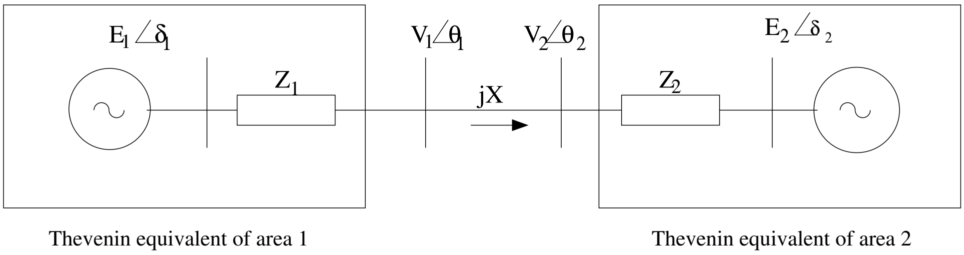


Figure 1.2: Two generating stations supplying a load



(a)Single line diagram



(b)Equivalent circuit

Figure 1.3: Two areas connected by a tie line

1.3 Control of Power Flow in AC Transmission Line

We may like to control the power flow in a AC transmission line to (a) enhance power transfer capacity and or (b) to change power flow under dynamic conditions (subjected to disturbances such as sudden increase in load, line trip or generator outage) to ensure system stability and security. The stability can be affected by growing low frequency, power oscillations (due to generator rotor swings), loss of synchronism and voltage collapse caused by major disturbances.

From eq. (1.1), we have the maximum power ($P_{\max}$) transmitted over a line as

$$P_{\max} = \frac{V_1 V_2}{X} \sin \delta_{\max} \tag{1.2}$$

where $\delta_{\max}$ (30°–40°) is selected depending on the stability margins and the stiffness of the terminal buses to which the line is connected. For line lengths exceeding a limit, $P_{\max}$ is less than the thermal limit on the power transfer determined by the current carrying capacity of the conductors (Note this is also a function of the ambient temperature). As the line length increases, X increases in a linear fashion and $P_{\max}$ reduces as shown in Fig. 1.4.

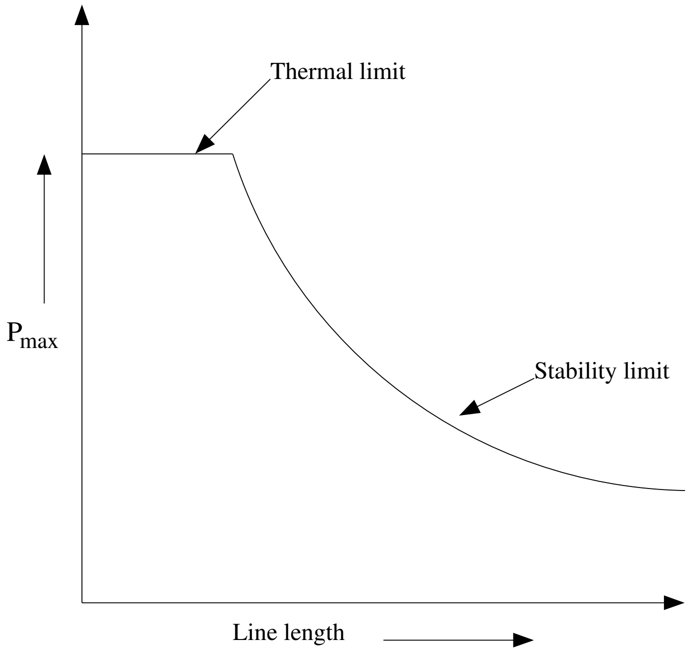


Figure 1.4: Power transfer capacity as a function of line length

The series compensation using series connected capacitors increases $P_{\max}$ as the compensated value of the series reactance (X_c) is given by

$$X_c = X(1 - k_{se}) \tag{1.3}$$

where k_{se} is the degree of series compensation. The maximum value of k_{se} that can be used depends on several factors including the resistance of the conductors. Typically k_{se} does not exceed 0.7.

Fixed series capacitors have been used since a long time for increasing power transfer in long lines. They are also most economical solutions for this purpose. However, the control of series compensation using thyristor switches has been introduced only 10–15 years ago for fast power flow control. The use of Thyristor Controlled Reactors (TCR) in parallel with fixed capacitors for the control of X_c, also helps in overcoming a major problem of Subsynchronous Resonance (SSR) that causes instability of torsional modes when series compensated lines are used to transmit power from turbogenerators in steam power stations.

In tie lines of short lengths, the power flow can be controlled by introducing Phase Shifting Transformer (PST) which has a complex turns ratio with magnitude of unity. The power flow in a lossless transmission line with an ideal PST (see Fig. 1.5) is given by

$$P = \frac{V_1 V_2}{X} \sin(\theta \pm \phi) \tag{1.4}$$

where $\theta = \theta_1 - \theta_2$.

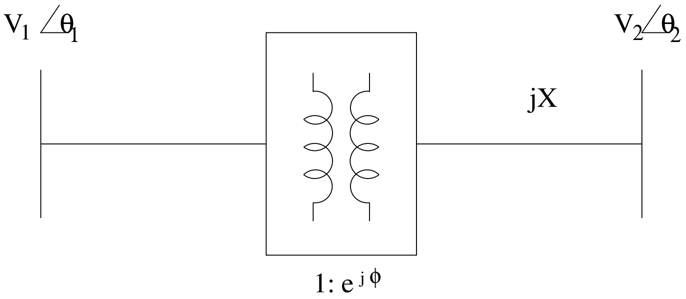


Figure 1.5: A lossless line with an ideal PST

Again, manually controlled PST is not fast enough under dynamic conditions. Thyristor switches can ensure fast control over discrete (or continuous) values of ϕ, depending on the configuration of PST used. $P_{\max}$ can also be increased by controlling (regulating) the receiving end voltage of the AC line. When a generator supplies a unity power factor load (see Fig. 1.1(b)), the maximum power occurs when the load resistance is equal to the line reactance. It is to be noted that V_2 varies with the load and can be expressed as

$$V_2 = V_1 \cos(\theta_1 - \theta_2) \tag{1.5}$$

Substituting (1.5) in (1.1) gives

$$P = \frac{V_1^2 \sin[2(\theta_1 - \theta_2)]}{2X} \tag{1.6}$$

By providing dynamic reactive power support at bus (2) as shown in Fig. (1.6), it is possible to regulate the bus voltage magnitude. The reactive

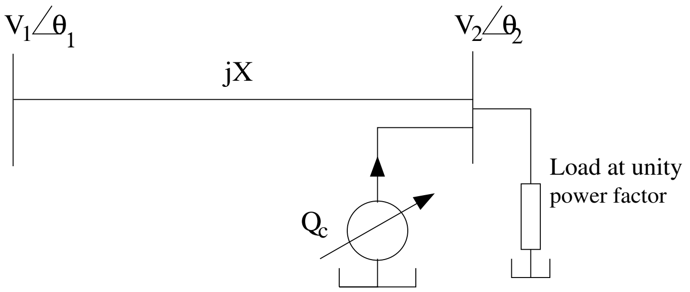


Figure 1.6: Transmission line compensated by controllable reactive power source at receiving end

power (Q_C) that has to be injected is given by

$$Q_C = \frac{V_2^2 - V_1 V_2 \cos(\theta_1 - \theta_2)}{X} \tag{1.7}$$

Comparing eq. (1.6) with (1.1), it can be seen that the maximum power transfer can be doubled just by providing dynamic reactive power support at the receiving end of the transmission line. This is in addition to the voltage support at the sending end. It is to be noted that while steady state voltage support can be provided by mechanically switched capacitors, the dynamic voltage support requires synchronous condenser or a power electronic controller such as Static Var Compensator (SVC) or STATic synchronous COMpensator (STATCOM).

1.4 Flexible AC Transmission System Controllers

1.4.1 General Description

The large interconnected transmission networks (made up of predominantly overhead transmission lines) are susceptible to faults caused by lightning discharges and decrease in insulation clearances by undergrowth. The power flow in a transmission line is determined by Kirchhoff's laws for a specified power injections (both active and reactive) at various nodes. While the loads in a power system vary by the time of the day in general, they are also subject to variations caused by the weather (ambient temperature) and other unpredictable factors. The generation pattern in a deregulated environment also tends to be variable (and hence less predictable). Thus, the power flow in a transmission line can vary even under normal, steady state conditions. The occurrence of a contingency (due to the tripping of a line, generator) can result in a sudden increase/decrease in the power flow. This can result in overloading of some lines and consequent threat to system security.

A major disturbance can also result in the swinging of generator rotors which contribute to power swings in transmission lines. It is possible that the system is subjected to transient instability and cascading outages as individual components (lines and generators) trip due to the action of protective relays. If the system is operating close to the boundary of the small signal stability region, even a small disturbance can lead to large power swings and blackouts.

The increase in the loading of the transmission lines sometimes can lead to voltage collapse due to the shortage of reactive power delivered at the load centres. This is due to the increased consumption of the reactive power in the transmission network and the characteristics of the load (such as induction motors supplying constant torque).

The factors mentioned in the previous paragraphs point to the problems faced in maintaining economic and secure operation of large interconnected systems. The problems are eased if sufficient margins (in power transfer) can be maintained. This is not feasible due to the difficulties in the expansion of the transmission network caused by economic and environmental reasons. The required safe operating margin can be substantially reduced by the introduction of fast dynamic control over reactive and active power by high power electronic controllers. This can make the AC transmission network 'flexible' to adapt to the changing conditions caused by contingencies and load variations. Flexible AC Transmission System (FACTS) is defined as 'Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability' [1,2]. The FACTS controller is defined as 'a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters'.

The FACTS controllers can be classified as

1. Shunt connected controllers
2. Series connected controllers
3. Combined series-series controllers
4. Combined shunt-series controllers

Depending on the power electronic devices used in the control, the FACTS controllers can be classified as

(A) Variable impedance type
(B) Voltage Source Converter (VSC) – based.

The variable impedance type controllers include:

(i) Static Var Compensator (SVC), (shunt connected)

(ii) Thyrister Controlled Series Capacitor or compensator (TCSC), (series connected)

(iii) Thyristor Controlled Phase Shifting Transformer (TCPST) of Static PST (combined shunt and series)

The VSC based FACTS controllers are:

(i) Static synchronous Compensator (STATCOM) (shunt connected)

(ii) Static Synchronous Series Compensator (SSSC) (series connected)

(iii) Interline Power Flow Controller (IPFC) (combined series-series)

(iv) Unified Power Flow Controller (UPFC) (combined shunt-series)

Some of the special purpose FACTS controllers are

(a) Thyristor Controller Braking Resistor (TCBR)

(b) Thyristor Controlled Voltage Limiter (TCVL)

(c) Thyristor Controlled Voltage Regulator (TCVR)

(d) Interphase Power Controller (IPC)

(e) NGH-SSR damping

The FACTS controllers based on VSC have several advantages over the variable impedance type. For example, a STATCOM is much more compact than a SVC for similar rating and is technically superior. It can supply required reactive current even at low values of the bus voltage and can be designed to have in built short term overload capability. Also, a STATCOM can supply active power if it has an energy source or large energy storage at its DC terminals.

The only drawback with VSC based controllers is the requirement of using self commutating power semiconductor devices such as Gate Turn-off (GTO) thyristors, Insulated Gate Bipolar Transistors (IGBT), Integrated Gate Commutated Thyristors (IGCT). Thyristors do not have this capability and cannot be used although they are available in higher voltage ratings and tend to be cheaper with reduced losses. However, the technical advantages with VSC based controllers coupled will emerging power semiconductor devices using silicon carbide technology are expected to lead to the wide spread use of VSC based controllers in future.

It is interesting to note that while SVC was the first FACTS controllers (which utilized the thyristor valves developed in connection with HVDC line commutated convertors) several new FACTS controller based on VSC have been developed. This has led to the introduction of VSC in HVDC transmission for ratings up to 300 MW.

1.4.2 Voltage Source Converter Based Controllers - An Introduction

This section is aimed at giving a brief introduction to the VSC based controller. The individual controllers are discussed in detail in the following chapters (6-8). The schematic diagram of a STATCOM is shown in Fig. 1.7 while that of a SSSC is shown in Fig.1.8. The diagram of a UPFC is shown in Fig. 1.9.

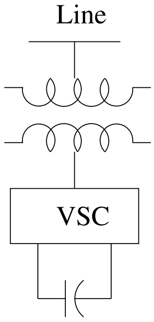


Figure 1.7: Shunt connected STATCOM

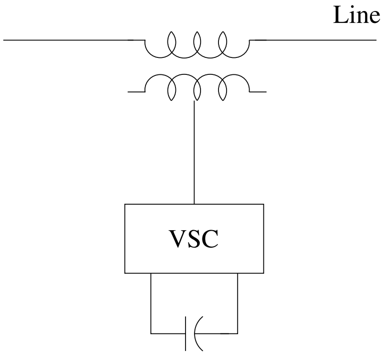


Figure 1.8: Series connected SSSC

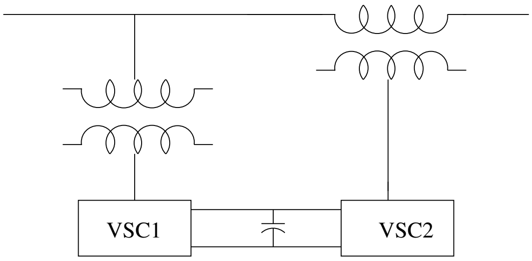


Figure 1.9: Unified power flow controller

A six pulse Voltage Source Converter (VSC) is shown in Fig. 1.10. By suitable control, the phase and the magnitude of the AC voltage injected by the VSC can be controlled. The Phase Lock Loop (PLL) ensures that the sinusoidal component of the injected voltage is synchronized (matching in frequency and required phase angle) with the voltage of the AC bus to which VSC is connected through an inductor. Often, the leakage impedance of the interconnecting transformer serves as the inductive impedance that has to separate the sinusoidal bus voltage and the voltage injected by the VSC (which contains harmonics). The injection of harmonic voltages can be minimized by multipulse (12, 24 or 48), and/or multilevel convertors. At low power levels, it is feasible to provide pulse width modulation (PWM) to control the magnitude of the fundamental component of the injected voltage. The high voltage IGBT devices can be switched up to 2 kHz and high frequency of sinusoidal modulation enables the use of simple L-C (low pass) filters to reduce harmonic components.

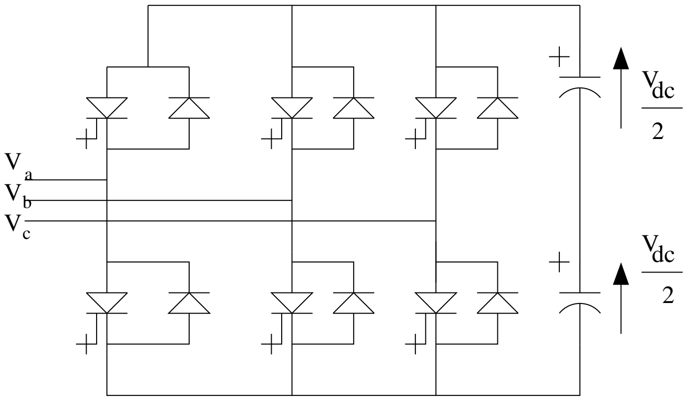


Figure 1.10: A three phase, six pulse VSC

The operation of a VSC can be explained with reference to a single phase (half-wave) convertor shown in Fig. 1.11. This can represent one leg of the 3 phase VSC.

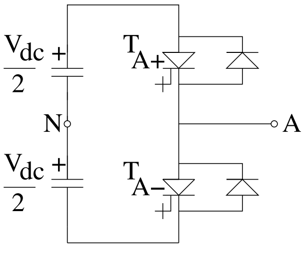


Figure 1.11: A single phase half wave converter

T_{A+} and T_{A-} are controllable switches which can be switched on or off at controllable instants in a cycle. The diodes ensure that the current can flow in both directions in the DC capacitor. The switches T_{A+} and T_{A-} work in complementary fashion – only one of them is on while the other is off. If the switch is turned on only once during a cycle, this is called as the square-wave switching scheme with each switch conducting for 180° in a cycle. The peak value of the fundamental component (V_{AN1}) is given by

$$V_{AN1} = \frac{4}{\pi}\left(\frac{V_{dc}}{2}\right) = 1.273\left(\frac{V_{dc}}{2}\right) \tag{1.8}$$

The waveform contains odd harmonics with the magnitudes

$$V_{ANh} = \frac{V_{AN1}}{h}, \quad h = 3, 5, 7, \ldots \tag{1.9}$$

It is to be noted that in the square wave switching scheme, only the phase angle of the voltage injected by the VSC can be controlled (and not the magnitude). It will be shown in chapter 6 that in a three phase converter with 3 legs the triplen harmonics will disappear such that the non-zero harmonic order (h) is given by

$$h = 6n \pm 1, \quad n = 1, 2, \ldots \tag{1.10}$$

Increasing the pulse number from six to twelve has the effect of eliminating the harmonics corresponding to odd values of n.

The introduction of PWM has the effect of controlling the magnitude of the fundamental component of the injected voltage by the VSC. For this case, the waveform of the voltage v_{AN} is shown in Fig. 1.12. Using sinusoidal modulation (with triangular carrier wave), the peak value of the injected sinusoidal voltage can be expressed as

$$V_{AN1} = m\left(\frac{V_{dc}}{2}\right), \quad 0 < m \leq 1 \tag{1.11}$$

where m is called the modulation index.

The maximum modulation index can be achieved with space vector modulation and is given by [10]

$$m_{\max} = \frac{2}{\sqrt{3}} = 1.1547 \tag{1.12}$$

It is to be noted that the modulation index (m) and the phase angle (α) are controlled to regulate the injected current by the shunt connected VSC. Neglecting losses, a STATCOM can only inject reactive current in

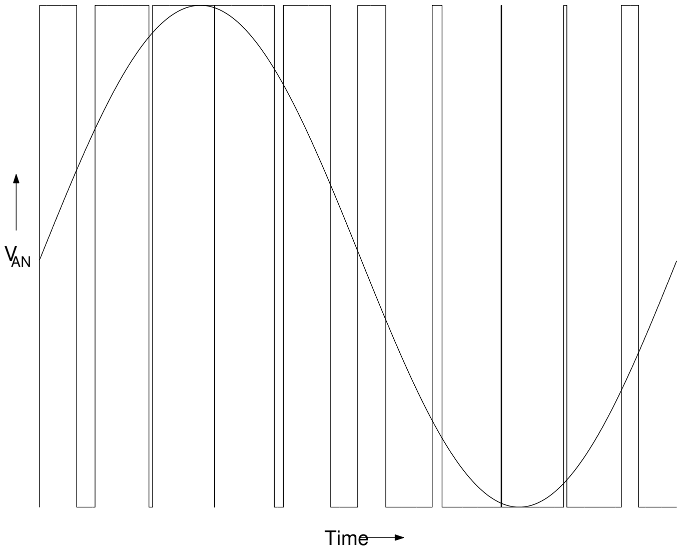


Figure 1.12: Waveform of v_{AN} and the fundamental component

steady state. The reactive current reference can be controlled to regulate the bus voltage. In a similar fashion the reactive voltage injected by a lossless SSSC can be controlled to regulate the power flow in a line within limits. The combination of a STATCOM and a SSSC, in which the STATCOM feeds (or absorbs) power on the DC side to SSSC, can be used to regulate both active and reactive power flow in a line (subject to the constraints imposed by the ratings of the converters in addition to the limits on bus voltages).

1.4.3 A General Equivalent Circuit for FACTS Controllers

The UPFC (shown in Fig. 1.9) is the most versatile FACTS controller with 3 control variables (the magnitude and phase angle of the series injected voltage in addition to the reactive current drawn by the shunt connected VSC). The equivalent circuit of a UPFC on a single phase basis is shown in Fig. 1.13. The current i is drawn by the shunt connected VSC while the voltage e is injected by the series connected VSC. Neglecting harmonics, both the quantities can be represented by phasors I and E.

Neglecting power losses in the UPFC, the following constraint equation applies.

$$Re[V_1 I^*] = Re[E I_2^*] \tag{1.13}$$

Assuming that $\hat{V}_1 = V_1 e^{j\theta_1}$, $\hat{I}_2 = I_2 e^{j\phi_2}$, $\hat{I}$ and $\hat{E}$ can be expressed as

$$\hat{I} \;=\; (I_p - jI_r)e^{j\theta_1} \tag{1.14}$$

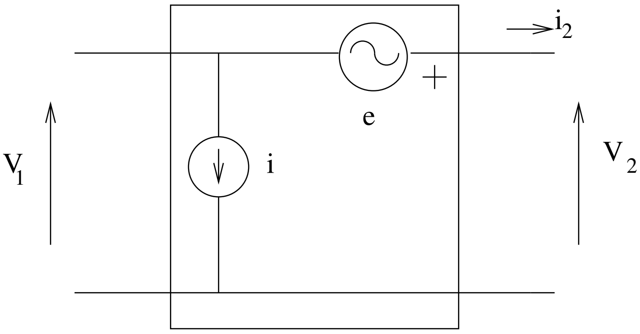


Figure 1.13: An equivalent circuit for UPFC

$$\hat{E} \quad = \quad (V_p + jV_r)e^{j\phi_2} \tag{1.15}$$

where I_p and I_r are 'real' and 'reactive' components of the current drawn by the shunt connected VSC. Similarly V_p and V_r and the 'real' and 'reactive' voltages injected by the series connected VSC. Positive I_p and V_p indicate positive 'real' (active) power flowing into the shunt connected VSC and flowing out of the series connected VSC. The positive values of I_r and V_r indicate reactive power drawn by the shunt convertor and supplied by the series converter. These conventions will be used throughout this book.

Using eqs (1.14) and (1.15), (1.13) can be expressed as

$$V_1 I_p = I_2 V_p \tag{1.16}$$

The remaining shunt and series connected FACTS controllers can be viewed as special cases of a UPFC. For example in a SVC,

$$V_p = 0, V_r = 0, I_p = 0, I_r = -B_{SVC} V_1, \tag{1.17}$$

There are 3 constraint equations and one control variable (B_{SVC}) in a SVC. In a STATCOM, I_r is the control variable. Table 1.1 gives the constraint equations and control variables for all the FACTS controllers. Note that in a STATCOM or SSSC with an energy source at the DC terminals, there are 2 control variables as I_p or V_p is non-zero.

1.4.4 Benefits with the Application of FACTS Controllers

Primarily, the FACTS controllers provide voltage support at critical buses in the system (with shunt connected controllers) and regulate power flow in critical lines (with series connected controllers). Both voltage and power flow are controlled by the combined series and shunt controller (UPFC). The power electronic control is quite fast and this enables regulation both

Table 1.1: Constraint Equations and Control Variables for FACTS Controllers.

Controller	Constraint Equations	Control Variable(s)
SVC	$V_p = 0,\ V_r = 0,\ I_p = 0$ $I_r = -B_{SVC}V_1$	B_{SVC}
TCSC	$I_p = 0,\ I_r = 0,\ V_p = 0$ $V_r = X_{TCSC}I_2$	X_{TCSC}
SPST (TCPAR)	$\hat{E} = V_1(e^{j\phi} - 1) \simeq jV_1\phi$ $V_1 I_p = V_p I_2,\ V_1 I_r = I_2 V_r$	ϕ
STATCOM	$V_p = 0,\ V_r = 0,\ I_p = 0$	I_r
STATCOM with energy source	$V_p = 0,\ V_r = 0$	$I_p,\ I_r$
SSSC	$I_p = 0,\ I_r = 0,\ V_p = 0$	V_r
SSSC with energy source	$I_p = 0,\ I_r = 0$	$V_p,\ V_r$

under steady state and dynamic conditions (when the system is subjected to disturbances). The benefits due to FACTS controllers are listed below.

1. They contribute to optimal system operation by reducing power losses and improving voltage profile.
2. The power flow in critical lines can be enhanced as the operating margins can be reduced due to fast controllability. In general, the power carrying capacity of lines can be increased to values upto the thermal limits (imposed by current carrying capacity of the conductors).
3. The transient stability limit is increased thereby improving dynamic security of the system and reducing the incidence of blackouts caused by cascading outages.
4. The steady state or small signal stability region can be increased by providing auxiliary stabilizing controllers to damp low frequency oscillations.
5. FACTS controllers such as TCSC can counter the problem of Subsynchronous Resonance (SSR) experienced with fixed series capacitors connected in lines evacuating power from thermal power stations (with turbogenerators).
6. The problem of voltage fluctuations and in particular, dynamic overvoltages can be overcome by FACTS controllers.

The capital investment and the operating costs (essentially the cost of power losses and maintenance) are offset against the benefits provided by the FACTS controllers and the 'payback period' is generally used as an index in the planning. The major issues in the deployment of FACTS controllers are (a) the location (b) ratings (continuous and short term) and (c) control strategies required for the optimal utilization. Here, both steady-state and dynamic operating conditions have to be considered. Several systems studies involving power flow, stability, short circuit analysis are required to prepare the specifications. The design and testing of the control and protection equipment is based on Real Time Digital Simulator (RTDS) or physical simulators.

It is to be noted that a series connected FACTS controller (such as TCSC) can control power flow not only in the line in which it is connected, but also in the parallel paths (depending on the control strategies). This will be explained in chapter 4.

1.5 Application of FACTS Controllers in Distribution Systems

Although the concept of FACTS was developed originally for transmission network; this has been extended since last 10 years for improvement of Power Quality (PQ) in distribution systems operating at low or medium voltages.

In the early days, the power quality referred primarily to the continuity of power supply at acceptable voltage and frequency. However, the prolific increase in the use of computers, microprocessors and power electronic systems has resulted in power quality issues involving transient disturbances in voltage magnitude, waveform and frequency. The nonlinear loads not only cause PQ problems but are also very sensitive to the voltage deviations.

In the modern context, PQ problem is defined as "Any problem manifested in voltage, current or frequency deviations that result in failure or misoperation of customer equipment" [5].

The PQ problems are categorized as follows

1. Transients
   (a) Impulsive
   (b) Oscillatory
2. Short-duration and Long-duration variations
   (a) Interruptions

    (b) Sag (dip)
    (c) Swell

3. Voltage unbalance
4. Waveform distortion
    (a) DC offset
    (b) Harmonics
    (c) Interharmonics
    (d) Notching
    (e) Noise
5. Voltage Flicker
6. Power frequency variations

More details about these problems are discussed in chapter 12.

Hingorani [7] was the first to propose FACTS controllers for improving PQ. He termed them as Custom Power Devices (CPD). These are based on VSC and are of 3 types given below.

1. Shunt connected Distribution STATCOM (DSTATCOM)
2. Series connected Dynamic Voltage Restorer (DVR)
3. Combined shunt and series, Unified Power Quality Conditioner (UPQC).

The DVR is similar to SSSC while UPQC is similar to UPFC. In spite of the similarities, the control strategies are quite different for improving PQ. A major difference involves the injection of harmonic currents and voltages to isolate the source from the load. For example, a DVR can work as a harmonic isolator to prevent the harmonics in the source voltage reaching the load in addition to balancing the voltages and providing voltage regulation. A UPQC can be considered as the combination of DSTATCOM and DVR. A DSTATCOM is utilized to eliminate the harmonics from the source currents and also balance them in addition to providing reactive power compensation (to improve power factor or regulate the load bus voltage).

The terminology is yet to be standardized. The term ‘active filters’ or ‘power conditioners’ is also employed to describe the custom power devices. ABB terms DSTATCOM as ‘SVC light’. Irrespective of the name, the trend is to increasingly apply VSC based compensators for power quality improvement.

References and Bibliography

1. N.G. Hingorani, "Flexible AC transmission". IEEE Spectrum, v. 30, n. 4, pp. 40-44, 1993.
2. N.G. Hingorani and L Gyugyi, **Understanding FACTS - Concepts and Technology of Flexible AC Transmission Systems**, IEEE Press, New York, 2000.
3. Y.H. Song and A.T. Johns, Eds., **Flexible AC Transmission Systems (FACTS)**, IEE Press, London, 1999.
4. R.M. Mathur and R.K. Varma, **Thyristor-Based FACTS Controller for Electrical Transmission Systems**, IEEE Press and Wiley Interscience, New York, 2002.
5. R.C. Dugan, M.F. McGranaghan and H.W. Beaty, **Electrical Power Systems Quality**, McGraw-Hill, New York, 1996.
6. A. Ghosh and G. Ledwich, **Power Quality Enhancement Using Custom Power Devices** , Kluwer Academic Publishers, Boston, 2002.
7. N.G. Hingorani, "Introducing Custom Power", IEEE Spectrum, v. 32, n. 6, pp. 41–48, 1995.
8. K.R. Padiyar and A.M. Kulkarni, "Flexible AC transmission systems: A status review", Sādhanā, v. 22, Part 6, pp. 781–796, December 1997.
9. H. Akagi, "New trends in active filters for power conditioning", IEEE Trans., Ind. Appl., v. 32, pp. 1312–1322, 1996.
10. H.W. Van Der Broeck, H.C. Skudelny and G.V. Stanke, "Analysis and realization of a pulsewidth modulator based on voltage space vectors", IEEE Trans., Ind. Appl., v. 24, n. 1, pp. 142–150, 1988.