4.5 Design of AC filters

1. Harmonic Distortion:

Harmonic Distortion is given by,

$$D = \frac{\sum_{n=2}^{m} I_n Z_n}{E_1} \times 100$$

where,

I_n – harmonic current injected

Z_n – harmonic impedance of the system

E_1 – fundamental component of line to neutral voltage

m – highest harmonic considered

Harmonic Distortion is also given by,

$$D_{RSS} = \frac{\left[\sum_{n=2}^{m} (I_n Z_n)^2\right]^{1/2}}{E_1} \times 100$$

2. Telephone Influence Factor (TIF):

An index of possible telephone interference and is given by,

$$TIF = \frac{\left[\sum_{n=2}^{m} (I_n Z_n F_n)^2\right]^{1/2}}{E_1}$$

where,

$F_n = 5\, n\, f_1\, p_n$

P_n is the c message weighting used by Bell Telephone Systems (BTS) and Edison Electric Institute (EEI) in USA. This weighting reflects the frequency dependent sensitivity of the human ear and has a maximum value at the frequency of 1000Hz.

3. Telephone Harmonic Form Factor (THFF):

It is similar to TIF and is given by,

$$F_n = (n\, f_1 / 800)\, W_n$$

where,

W_n – weight at the harmonic order n, defined by the Consultative Commission on Telephone and Telegraph Systems (CCITT).

TIF is used in USA.

THFF is popular in Europe.

4. IT Product:

In BTS-EEI system, there is another index called IT product and is defined by,

$$IT = \left[\sum_{n=2}^{m}(I_n F_n)^2\right]^{1/2}$$

Types of AC Filters

The various types of filters that are used are

1. Single Tuned Filter
2. Double Tuned Filter
3. High Pass Filter
   a) Second Order Filter
   b) C Type Filter

Single Tuned Filter

Single Tuned Filters are designed to filter out characteristic harmonics of single frequency.

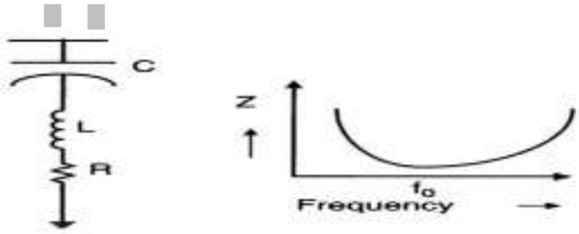


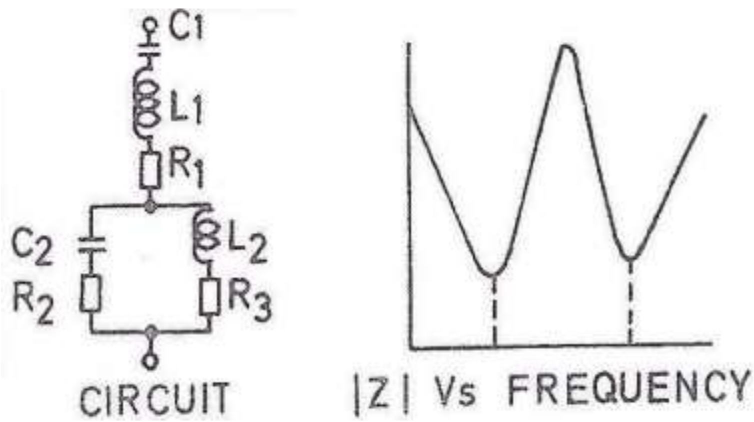
Figure 4.5.1 Single tuned filter

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page180]

Double Tuned Filter

The Double Tuned Filters are used to filter out two discrete frequencies, instead of using two Single Tuned Filters. Their main disadvantages are

i. only one inductor is subject to full line impulse voltage.



ii. power loss at the fundamental frequency is considerably reduced.

Second Order High Pass Filter

The Second Order High Pass Filters are designed to filter out higher harmonics.

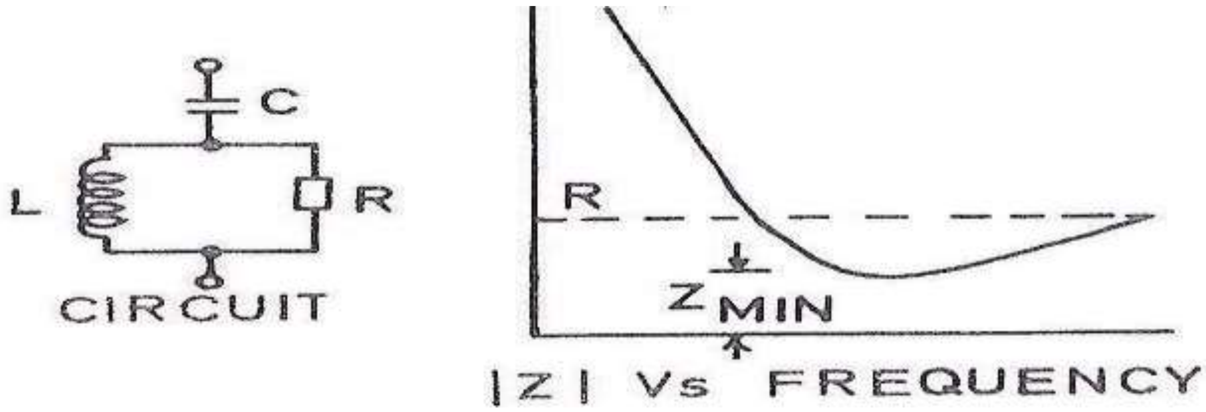


Figure 4.5.3 Second order high pass filter

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page180]

High Pass C Type Filter

The losses at the fundamental frequency can be reduced by using a C Type Filter where capacitor C_2 is in series with inductor L, which provides a low impedance path to the fundamental component of current.

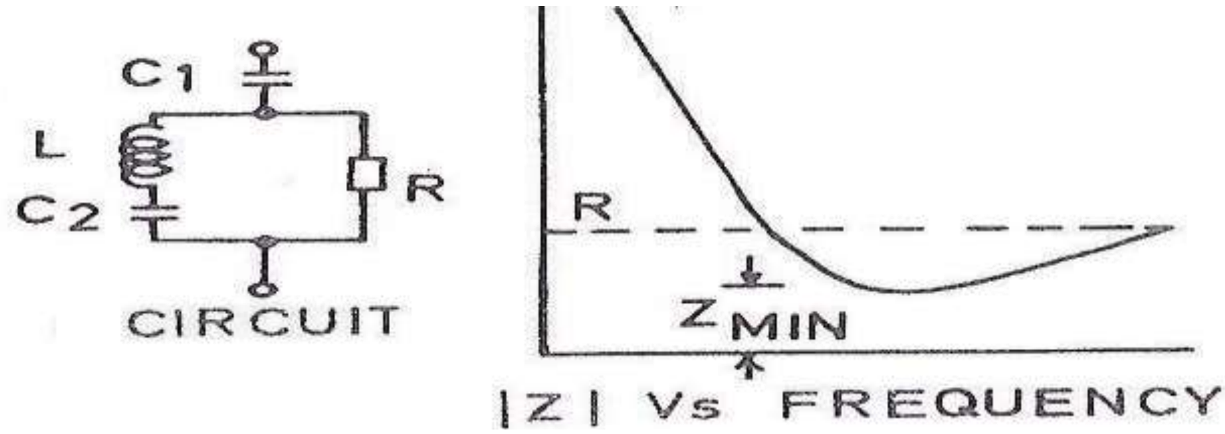


Figure 4.5.4 High pass C type filter

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page180]

A converter system with 12 pulse converters has Double Tuned (or two Single Tuned) Filter banks to filter out 11^{th} and 13^{th} harmonics and a High Pass Filter bank to filter the rest of harmonics. Sometimes a third harmonic filter may be used to filter the non-characteristic harmonics of the 3^{rd} order particularly with weak AC systems where some voltage unbalance is expected.

All filter branches appear capacitive at fundamental frequency and supply reactive power.

Design of Single Tuned Filter

The impedance Z_{Fh} of the single tuned filter at the harmonic order 'h' is given by

$$Z_{Fh} = R + j\left(h\omega L - \frac{1}{h\omega C}\right)$$

where ω is the fundamental frequency which can vary with the power system operating conditions.

A tuned filter is designed to filter a single harmonic of order h_r . If $h_r\omega=\omega_r$, then $Z_{Fh}=R=\frac{X_0}{Q}$ and is minimum.

Since ω is variable and there could be errors in the tuning($\omega_r \neq h_r\,\omega_n$ where ω_n is the nominal (rated) frequency), it is necessary to compute the impedance of the tuned filter as a function of the detuning parameter (δ) defined by

$$\delta = \frac{h_r\,\omega - \omega_r}{h_r\,\omega_n} = \frac{\omega}{\omega_n} - \frac{\omega_r}{h_r\,\omega_n}$$

Considering variations in the frequency (f), inductance (L) and capacitance (C),

$$\delta = 1 + \frac{\Delta f}{f_n} - \left[\left(1+\frac{\Delta L}{L_n}\right)\left(1+\frac{\Delta C}{C_n}\right)\right]^{1/2}$$

$$\delta = \frac{\Delta f}{f_n} + \frac{1}{2}\frac{\Delta L}{L_n} + \frac{1}{2}\frac{\Delta C}{C_n}$$

where L_n and C_n are the nominal values of L and C such that $h_r\omega_n=(L_nC_n)^{-1/2}$

The variation in C can be due to

(i) error in the initial setting of C

(ii) the variation in C due to the temperature dependence of the dielectric constant.

$$Z_{Fh} = R + jX_0\left(\frac{\omega}{\omega_n}\frac{L}{L_n} - \frac{\omega_n}{\omega}\frac{C_n}{C}\right)$$

where

$$X_0 = h_r\,\omega_n L_n = \frac{1}{h_r\,\omega_n C_n}$$

The single tuned filters are designed to filter out characteristic harmonics of single frequency. The harmonic current in the filter is given by

$$I_{Fh} = \frac{I_h |Z_{Sh}|}{|Z_{Sh} + Z_{Fh}|}$$

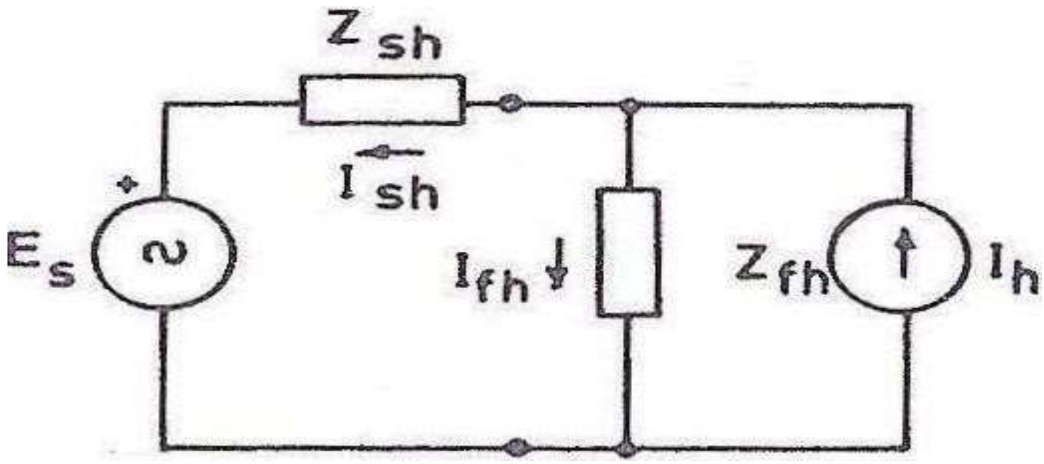


Figure 4.5.5 Equivalent circuit of harmonic current

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page184]

The harmonic voltage at the converter bus is

$$V_h = I_{Fh} |Z_{Fh}| = \frac{I_h}{|Y_{Fh} + Y_{Sh}|} = \frac{I_h}{|Y_h|}$$

The basic objective in designing the filter is to select the filter admittance Y_{Fh} in order to minimize V_h or satisfy the constraints on V_h . The problem of designing a filter is complicated by the uncertainty about the network admittance (Y_{Sh}). There are two possible representations of system impedance in the complex plane where

(a) impedance angle is limited

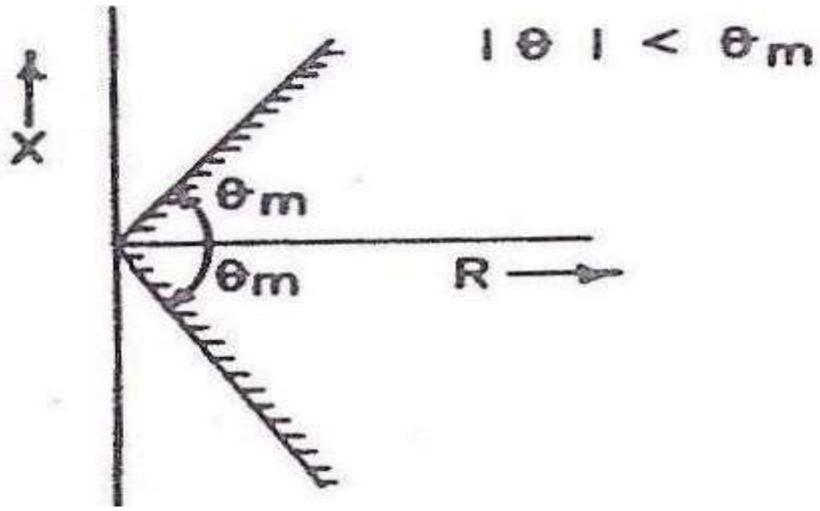


Figure 4.5.6 Network impedance characteristics : case 1

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page184]

This allows a simplified computation of the optimum value of Q. In computing the optimum value of Q, we need to minimize the maximum value of V_h . The optimum value of Q corresponds to the lowest value of the upper limit on V_h .

(b) the impedance is limited both in angle and impedance

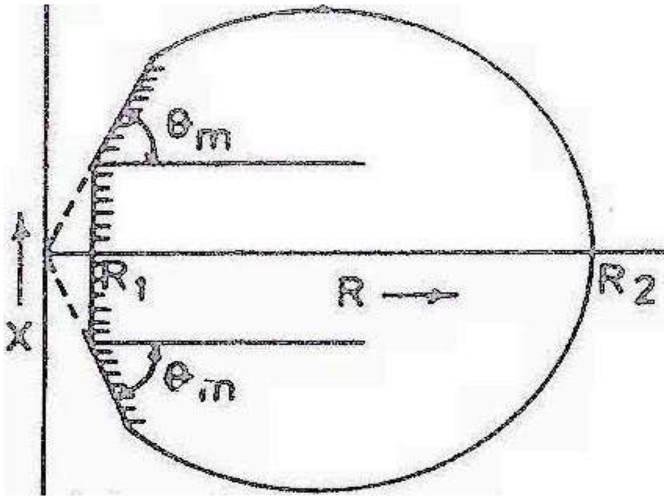


Figure 4.5.7 Network impedance characteristics : case 2

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page184]

The value of Y_h is reduced if the detuning parameter δ is maximum = δ_m . For a specified value δ_m and X_0 , the locus of the filter impedance as Q is varied is a semicircle in the 4th quadrant of the G-B plane as shown below.

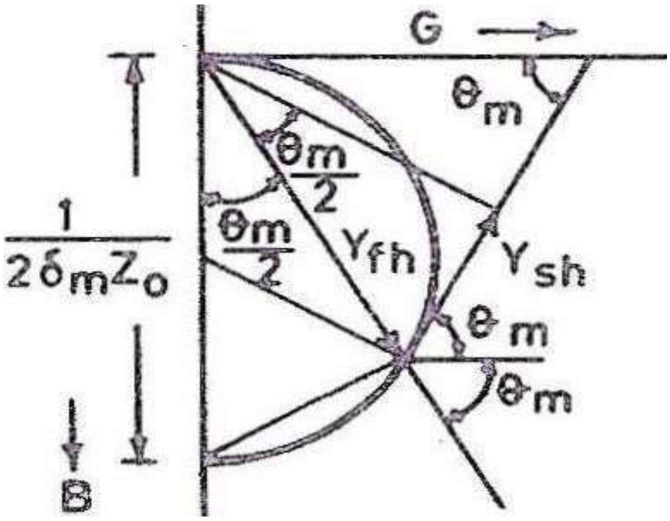


Figure 4.5.8 Load of filter and network admittance

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page185]

The optimum value of Q can be obtained from game-theoretic analysis. If one selects Y_{Fh} arbitrarily (the tip of Y_{Fh} lying along the semicircle), the network can select Y_{Sh} such that the vector Y_h is perpendicular to the vector Y_{Sh} and ensure Y_h is minimum.

To maximize the minimum magnitude of Y_h , it is necessary to have Y_{Sh} tangential to the circle. Thus, we select Y_{Fh} to maximize Y_h when the network tries to minimize it.

Design of High Pass Filter

For harmonic frequencies of order equal to or higher than 17, a common second order high pass filter is provided. By defining the following parameters

$$h_0\omega_1 = 1/\sqrt{LC}\ ,\ Z_0 = \sqrt{L/C}\ ,\sigma = R / Z_0$$

The following values can be chosen

$$0.5 < \sigma < 2$$

$$h_0 \leq \sqrt{2}\ h_{min}$$

where h_{min} is the smallest value of h to be handled by the filter. The choice of h_0 given above implies that the filter impedance at h_{min} has decreased approximately to the value of R.

The filter impedance is given by

$$Z_f = \frac{Z_0[\sigma + j(h_0 / h).(\sigma^2 - 1 - (\sigma h / h_0)^2)]}{1 + (\sigma h_0 / h)^2}$$

The reactive power supplied by the filter is

$$Q_f = (h_0 / (h_0^2 - 1)) . (V_1^2 / Z_0)$$

The filtering is improved if Q_f is increased and higher value of h_0 can be chosen. Hence, it is advantageous in designing high pass filter to exclude six pulse operation.

Protection of Filters

The filter is exposed to overvoltage during switching in and the magnitude of this overvoltage is a function of the short-circuit ratio (higher with low values of SCR) and the saturation characteristics of the converter transformer.

During switching in, the filter current (at filter frequencies) can have magnitudes ranging from 20 to 100 times the harmonic current in normal (steady-state) operation. The lower values for tuned filters and higher values are applicable to high pass filters. These overcurrents are taken into consideration in the mechanical design of reactor coils.

When filters are disconnected, their capacitors remain charged to the voltage at the instant of switching. The residual direct voltages can also occur on bus bars. To avoid, the capacitors may be discharged by short-circuiting devices or through converter transformers or by voltage transformers loaded with resistors.

4.4 Generation of harmonics

Electrical energy transmitted through AC transmission or DC transmission is to be delivered at the consumer's terminals at specified voltage level of constant magnitude without deviation from the ideal waveform.

An HVDC transmission system generates harmonic currents on the AC side and harmonic voltages on the DC side during operation. The harmonic currents generated at the AC bus of the converter get transmitted to the AC network and then cause the following adverse effects.

a) Heating of the equipments connected.
b) Instability of converter control.
c) Generates telephone and radio interference in adjacent communication lines, thereby inducing harmonic noise.
d) Harmonics can lead to generation of overvoltages due to resonance when filter circuits are employed.

An HVDC transmission system consists of a rectifier and an inverter whose operation generates harmonics on AC and DC side of the converter. The three distinct sources of harmonics in HVDC systems are

1) Transformer.
2) AC Generator.
3) Converter along with its control devices.

Transformer as source of harmonics

Transformers can be considered as source of harmonic voltages, which arise from magnetic distortion and magnetic saturation due to the presence of a DC component in its secondary. The magnitude of these harmonics depends upon the operating flux density. Converter transformers are usually operated at high flux densities than conventional 3-phase transformers, and therefore the possibility of generation of harmonics is more.

Although the waveform is usually good, an AC generator may be regarded as a source of balanced harmonics because of non-uniform distribution of flux on the armature windings.

The converter which forms the basic unit in HVDC transmission imposes changes of impedances in the current.

When hysteresis effect is considered, then the non-sinusoidal magnetizing current waveform is no longer symmetrical which is mainly caused by triple n harmonics and particularly the third harmonic. Thus, in order to maintain a reasonable sinusoidal voltage supply, it is necessary to supply a path for triple n harmonics which is achieved by the use of delta-connected windings.

Harmonics due to Converters

A 12-pulse connection consists of two 6-pulse groups. One group having Y-Y connected converter transformer with 1:1 turns ratio and the other group having Y-Δ converter transformer bank with 1:√3 turns ratio.

Generation of Harmonics

The harmonics which are generated are of two types.

(i) Characteristic harmonics.

(ii) Non- characteristic harmonics.

Characteristic Harmonics

The characteristic harmonics are harmonics which are always present even under ideal operation.

In the converter analysis, the DC current is assumed to be constant. But in AC current the harmonics exist which are of the order of

$$h = np \pm 1$$

and in DC current it is of the order of

$$h = np$$

where n is any integer and p is pulse number.

Neglecting overlap, primary currents of Y-Y and Y-Δ connection of the transformer are considered taking the origin symmetrical where

$$i = I_d \text{ for } -\pi/3 \le \omega t \le \pi/3$$

$$= 0 \text{ for } \pi/3 \le \omega t \le 2\pi/3 \text{ and } -\pi/3 \le \omega t \le -2\pi/3$$

$$= -I_d \text{ for } -2\pi/3 \le \omega t \le -\pi \text{ and } 2\pi/3 \le \omega t \le \pi$$

for Y-Y connection converter transformer

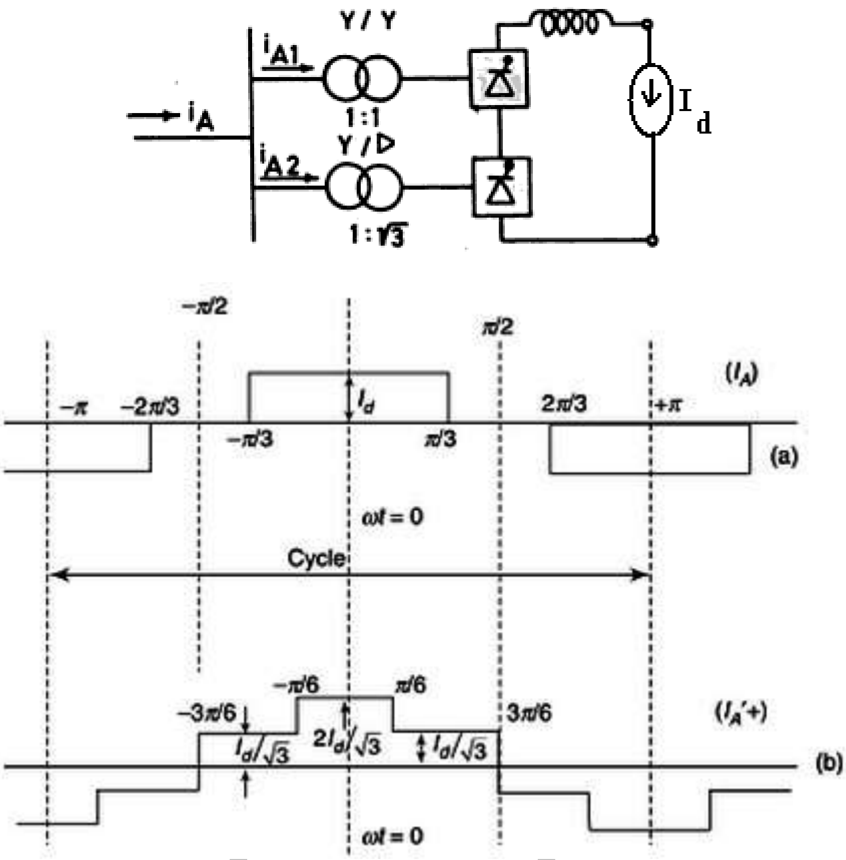


Figure 4.4.1 Phase current on primary side of Y-Y connection converter transformer

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page172]

For convenience, the ordinate axis (corresponding to ωt = 0) is chosen such that the waveform has even symmetry. So, generally, by fourier series

$$f(t) = \frac{1}{2}a_0 + \sum_{n=0}^{\infty} a_n \cos n\omega t + \sum_{n=0}^{\infty} b_n \sin n\omega t$$

As positive and negative half cycle cancel each other, so $a_0 = 0$ and as it is (waveform is) even symmetry, so $b_n = 0$ due to which f(t) becomes

$$f(t) = \sum_{n=0}^{\infty} a_n \cos n\omega t \,(or) \sum_{n} a_n \cos n\omega t$$

$$\text{Therefore, } i_{A_1} = \sum_{n} a_{n_1} \cos n\omega t$$

$$\text{where, } a_{n_1} = \frac{2}{T}\int_0^{PeriodOfConduction} f(t)\,dt$$

Here total time period is T = π and period of conduction is π/3

So,

$$a_{n_1} = 2\,X\,\frac{2}{\pi}\int_0^{\pi/3} I_d \cos n\omega t\, d(\omega t)$$

(Here as it is symmetry)

$$a_{n_1} = \frac{4I_d}{\pi}\int_0^{\pi/3} \cos n\omega t\, d(\omega t) = \frac{4I_d}{\pi}\left(\frac{\sin n\omega t}{n}\right)_0^{\pi/3}$$

$$a_{n_1} = \frac{4I_d}{n\pi}\left(\sin n\frac{\pi}{3}\right)$$

4.1 Reactive power requirements in steady state

To make transmission networks operate within desired voltage limits and methods of making up or taking away reactive power is called reactive-power control‖. The AC networks and the devices connected to them create associated time-varying electrical fields related to the applied voltage and as well as magnetic fields dependent on the current flow and they build up these fields store energy that is released when they collapse‖.

- Apart from the energy dissipation in resistive components, all energy-coupling devices (e.g.: motors and generators) operate based on their capacity to store and release energy.
- While the major means of control of reactive power and voltage is via the excitation systems of synchronous generators and devices may be deployed in a transmission network to maintain a good voltage profile in the system.
- The shunt connected devices like shunt capacitors or inductors or synchronous inductors may be fixed or switched (using circuit breaker).
- The **Vernier** or smooth control of reactive power is also possible by varying effective susceptance characteristics by use of power electronic devices. Example: Static Var Compensator (SVC)‖ and a Thyristor Controlled Reactor (TCR).

SOURCES OF REACTIVE POWER:

Most equipment connected to the electricity system will generate or absorb reactive power, but not all can be used economically to control voltage. Principally synchronous generators and specialised compensation equipment are used to set the voltage at particular points in the system, which elsewhere is determined by the reactive power flows.

Synchronous generators:

Synchronous machines can be made to generate or absorb reactive power depending upon the excitation (a form of generator control) applied. The output of synchronous machines is continuously variable over the operating range and automatic voltage regulators can be used to control the output so as to maintain a constant system voltage.

Synchronous compensators:

These are devices that can be connected to the system to adjust voltage levels. A capacitive compensator produces an electric field thereby generating reactive power whilst an inductive compensator produces a magnetic field to absorb reactive power. Compensation devices are available as either capacitive or inductive alone or as a hybrid to provide both generation and absorption of reactive power.

Transformers:

Transformers produce magnetic fields and therefore absorb reactive power. The heavier the current loading the higher the absorption.

Consumer Loads:

A typical load bus supplied by a power system is composed of a large number of devices. The composition changes depending on the day, season and weather conditions. The composite characteristics are normally such that a load bus absorbs reactive power. Both active and reactive powers of the composite loads Concepts of Reactive Power Control and Voltage Stability Methods in Power System Network vary due to voltage magnitudes. Loads at low-lagging power factors cause excessive voltage drops in the transmission network. Industrial consumers are charged for reactive power and this convinces them to improve the load power factor.

Underground cables-

They are always loaded below their natural loads, and hence generate reactive power under all operating conditions

Overhead lines-

Depending on the load current either absorb or supply reactive power. At loads below the natural load, the lines produce net reactive power; on the contrary, at loads above natural load lines absorb reactive power.

4.3 STATCOM

- The STATCOM (or SSC) is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system.
- It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals.
- Specifically, the STATCOM considered is a voltage-source converter that, from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer).
- The dc voltage is provided by an energy-storage capacitor and a STATCOM can improve power-system performance in such areas as the following:
  1. The dynamic voltage control in transmission and distribution systems;
  2. The power-oscillation damping in power-transmission systems;
  3. The transient stability;
  4. The voltage flicker control;
  5. The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

PRINCIPLE OF OPERATION

- A STATCOM is a controlled reactive-power source. It provides the desired reactive-power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage-source converter (VSC).
- A single-line STATCOM power circuit is shown in Fig.(a),where a VSC is connected to a utility bus through magnetic coupling.
- The exchange of reactive power between the converter and the ac system can be controlled by varying the amplitude of the 3-phase output voltage, *Es*, of the converter, as illustrated in Fig. (c).

- If the amplitude of the output voltage is increased above that of the utility bus voltage, *Et*, then a current flows through the reactance from the converter to the ac system and the converter generates capacitive-reactive power for the ac system.

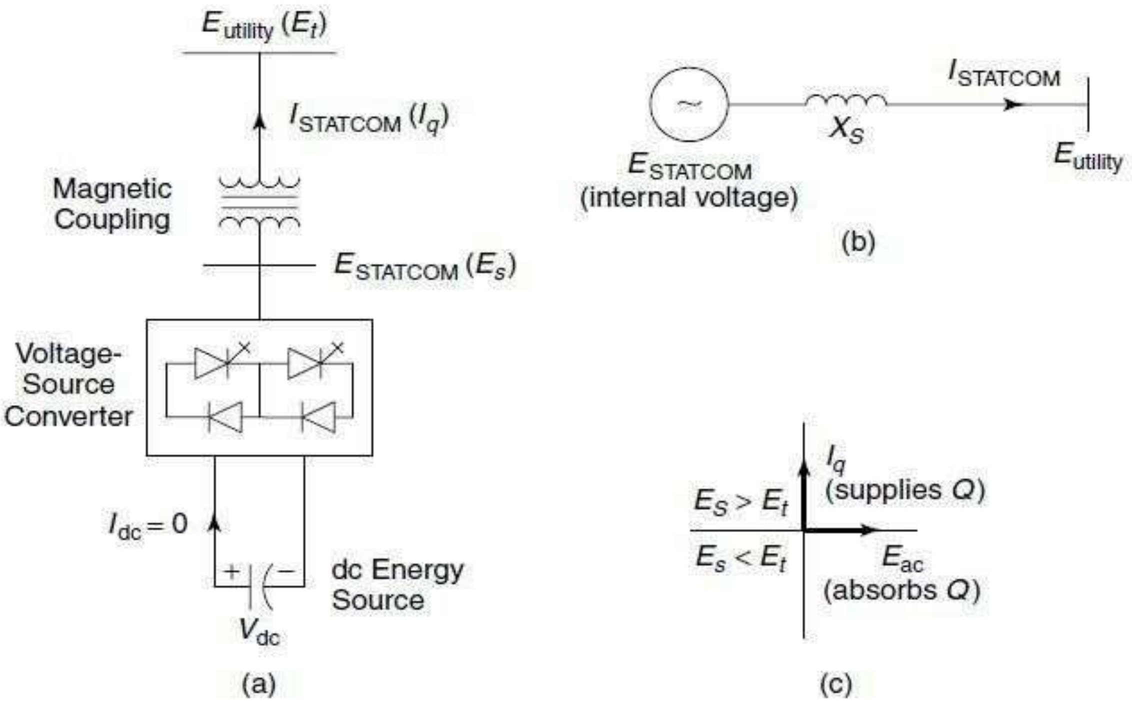


Figure 4.3.1 Schematic diagram of STATCOM

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page168]

- If the amplitude of the output voltage is decreased below the utility bus voltage, then the current flows from the ac system to the converter and the converter absorbs inductive-reactive power from the ac system.
- If the output voltage equals the ac system voltage, the reactive-power exchange becomes zero, in which case the STATCOM is said to be in a floating state.
- Adjusting the phase shift between the converter-output voltage and the ac system voltage can similarly control real-power exchange between the converter and the ac system. In other words, the converter can supply real power to the ac system from its dc energy storage if the converter-output voltage is made to lead the ac-system voltage.
- On the other hand, it can absorb real power from the ac system for the dc system if its voltage lags behind the ac-system voltage.
- A STATCOM provides the desired reactive power by exchanging theinstantaneous

reactive power among the phases of the ac system.

- The mechanism by which the converter internally generates and/ or absorbs the reactive power can be understood by considering the relationship between the output and input powers of the converter. The converter switches connect the dc- input circuit directly to the ac-output circuit. Thus the net instantaneous power at the acoutput terminals must always be equal to the net instantaneous power at the dc-input terminals (neglecting losses).
    - Assume that the converter is operated to supply reactive-output power. In this case, the real power provided by the dc source as input to the converter must be zero.
    - Furthermore, because the reactive power at zero frequency (dc) is by definition zero, the dc source supplies no reactive ower as input to the converter and thus clearly plays no part in the generation of reactive-output power by the converter.
    - Although reactive power is generated internally by the action of converter switches, a dc capacitor must still be connected across the input terminals of the converter.
    - The primary need for the capacitor is to provide a circulating-current path as well as a voltage source.
    - The magnitude of the capacitor is chosen so that the dc voltage across its terminals remains fairly constant to prevent it from contributing to the ripples in the dc current. The VSC-output voltage is in the form of a staircase wave into which smooth sinusoidal current from the ac system is drawn, resulting in slight fluctuations in the output power of the converter.
    - However, to not violate the instantaneous power-equality constraint at its input and output terminals, the converter must draw a fluctuating current from its dc source.
    - Depending on the converter configuration employed, it is possible to calculate the minimum capacitance required to meet the system requirements, such as ripple limits on the dc voltage and the rated-reactive power support needed by the ac system.
    - The VSC has the same rated-current capability when it operates with the

capacitive- or inductive-reactive current.

- The VSC may be a 2- level or 3-level type, depending on the required output power and voltage. A number of VSCs are combined in a multi-pulse connection to form the STATCOM.
- In the steady state, the VSCs operate with fundamental-frequency switching to minimize converter losses. However, during transient conditions caused by line faults, a pulse width–modulated (PWM) mode is used to prevent the fault currentfrom entering the VSCs. In this way, the STATCOM is able to withstand transients on the ac side without blocking.

VI characteristics of STATCOM

- A typical *V-I* characteristic of a STATCOM is depicted in Fig.
- The STATCOM can supply both the capacitive and the inductive compensation and is able to independently control its output current over the rated maximum capacitive or inductive range irrespective of the amount of ac-system voltage.
- The STATCOM can provide full capacitive-reactive power at any system voltage— even as low as 0.15 pu.

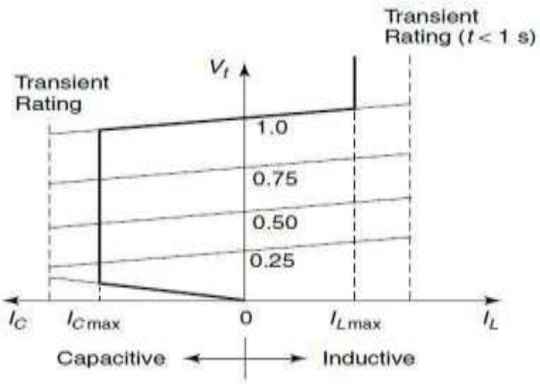


Figure 4.3.2 VI characteristics of STATCOM

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page169]

- The characteristic of a STATCOM reveals strength of this technology: that it is capable of yielding the full output of capacitive generation almost independently of the system voltage (constant-current output at lower voltages). This capability is particularly useful for situations in which the STATCOM is needed to support the system voltage during and after faults where voltage collapse would otherwise be a limiting factor.

Figure illustrates that the STATCOM has an increased transient rating in both the capacitive- and the inductive-operating regions.

The maximum attainable transient over current in the capacitive region is determined by the maximum current turn-off capability of the converter switches. In the inductive region, the converter switches are naturally commutated; therefore,

the transient-current rating of the STATCOM is limited by the maximum allowable junction temperature of the converter switches.

- In practice, the semiconductor switches of the converter are not lossless, so the energy stored in the dc capacitor is eventually used to meet the internal losses of the converter, and the dc capacitor voltage diminishes.
- However, when the STATCOM is used for reactive-power generation, the converter itself can keep the capacitor charged to the required voltage level. This task is accomplished by making the output voltages of the converter lag behind the ac-system voltages by a small angle (usually in the 0.18–0.28 range).
- In this way, the converter absorbs a small amount of real power from the ac system to meet its internal losses and keep the capacitor voltage at the desired level.
- The same mechanism can be used to increase or decrease the capacitor voltage and thus, the amplitude of the converter-output voltage to control the var generation or absorption.
- The reactive- and real-power exchange between the STATCOM and the ac system can be controlled independently of each other.
- Control coordination for obviating such interactions may be necessary if the FACTS and HVDC controllers are located within a distance of about three major

buses. Instabilities of harmonics (those ranging from the 2nd to the 5th) are likely to occur in power systems because of the amplification of harmonics in FACTS controller loops.

- Harmonic instabilities may also occur from synchronization or voltage-measurement systems, transformer energization, or transformer saturation caused by geomagnetic ally induced currents (GICs).

4.2 Static Var Compensator (SVC)

A SVC is an electrical device for providing fast acting reactive power on high-voltage electricity transmission networks. SVCs are part of the FACTS device family and regulating voltage and stabilizing the system. Unlike a synchronous condenser which is a rotating electrical machine a SVC has no significant moving parts and prior to the invention of the SVC power factor Compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks.

The SVC is an automated impedance matching device designed to bring the system closer to unity power factor.

SVCs are used in two main situations:

- Connected to the power system, to regulate the transmission voltage.
- Connected near large industrial loads, to improve power quality.

In transmission applications the SVC is used to regulate the grid voltage. If the power system‘s reactive load is capacitive (leading) the SVC will use thyristor controlled reactors to consume vars from the system lowering the system voltage. Under inductive (lagging) conditions the capacitor banks are automatically switched on thus providing a higher system voltage and by connecting the thyristor-controlled reactor which is continuously variable along with a capacitor bank step and the net result is continuously-variable leading or lagging power. In industrial applications SVCs are typically placed near high and rapidly varying loads such as arc furnaces where they can smooth flicker voltage.

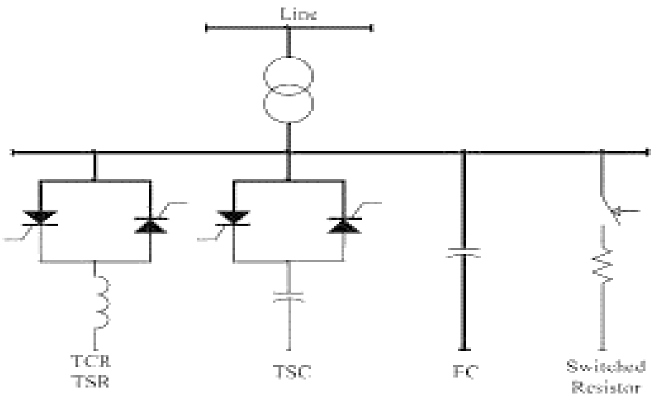


Figure 4.2.1 Schematic diagram of TCR, TSR, FC

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page164]

Description:

- The elements which may be used to make an SVC typically include
- Thyristor Controlled Reactor (TCR) where the reactor may be air or iron cored.
- Thyristor Switched Capacitor (TSC).
- Harmonic filter(s).
    - Mechanically switched capacitors or reactors.

Connection:

This reduces the size and number of components needed in the SVC although the conductors must be very large to handle high currents associated with the lower voltage.The dynamic nature of the SVC lies in the use of thyristors connected in series and inverse-parallel forming ―thyristor valves‖ and the disc-shaped semiconductors usually several inches in diameter are usually located indoors in a ―valve house‖.

Prevention of Voltage Stability

Voltage instability is caused by the inadequacy of the power system to supply the reactive-power demand of certain loads, such as induction motors. A drop in the load voltage leads to an increased demand for reactive power that, if not met by the power system, leads to a further decline in the bus voltage. This decline eventually leads to a progressive yet rapid decline of voltage at that location, which may have a cascading effect on neighboring regions that causes a system voltage collapse.

Principle of SVC Control

The voltage at a load bus supplied by a transmission line is dependent on the magnitude of the load, the load-power factor, and the impedance of the transmission line. Consider an SVC connected to a load bus, as shown in Fig. The load has a varying power factor and is fed by a lossless radial transmission line. The voltage profile at the load bus, which is situated at the receiver end of the transmission line, is depicted in Fig. For a given load-power factor, as the transmitted power is gradually increased, a maximum power limit is reached beyond which the voltage collapse takes place.

V-I Characteristics of SVC

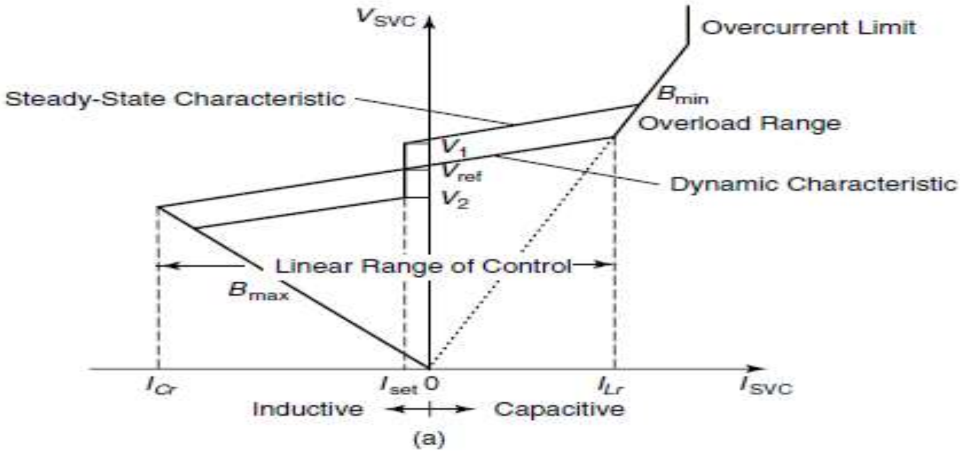


Figure 4.2.2 Control characteristics of SVC

[Source: "HVDC Power Transmission Systems" by K.P.Padiyar, page167]

The steady-state and dynamic characteristics of SVCs describe the variation of SVC bus voltage with SVC current or reactive power. V_{ref} : This is the voltage at the terminals of the SVC during the floating condition, that is, when the SVC is neither absorbing nor generating any reactive power. The reference voltage can be varied between the maximum and minimum limits—V_{ref} max and V_{ref} min—either by the SVC control system, in case of thyristor-controlled