POWER POINT PRESENTATION

ON

HVDC Transmission and FACTS devices

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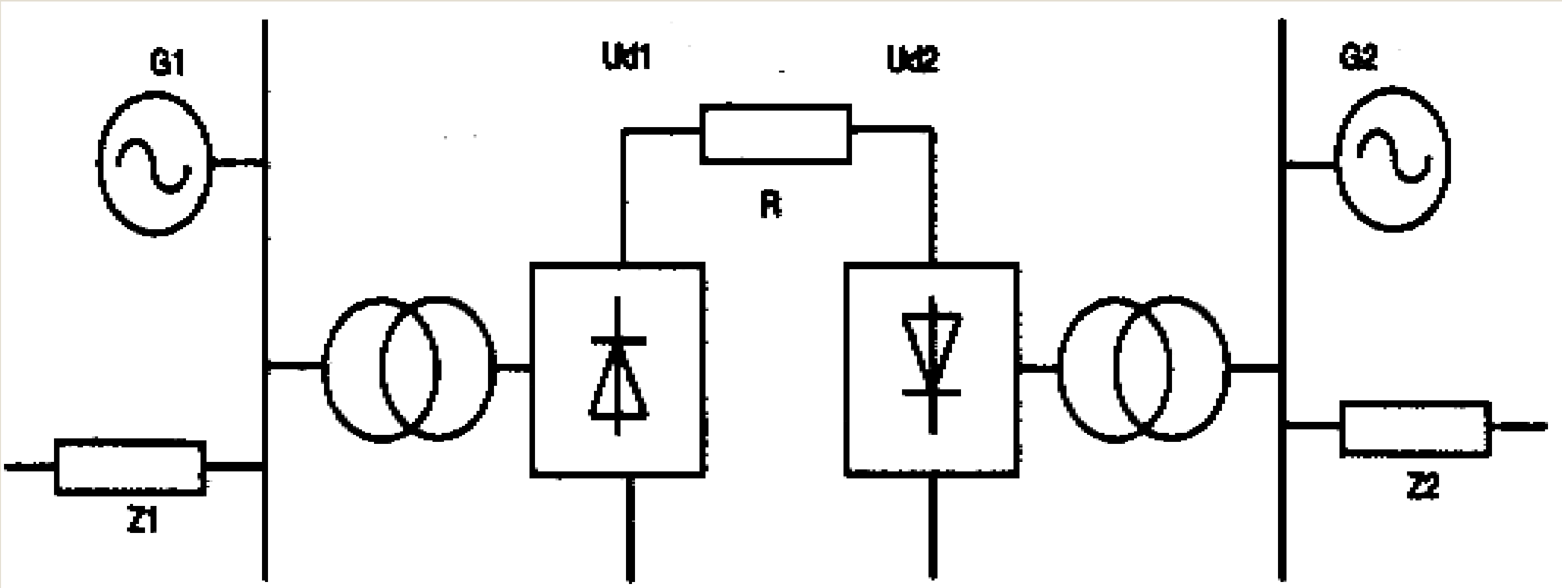
UNIT –I

INTRODUCTION TO HVDC TRANSMISSION SYSTEM

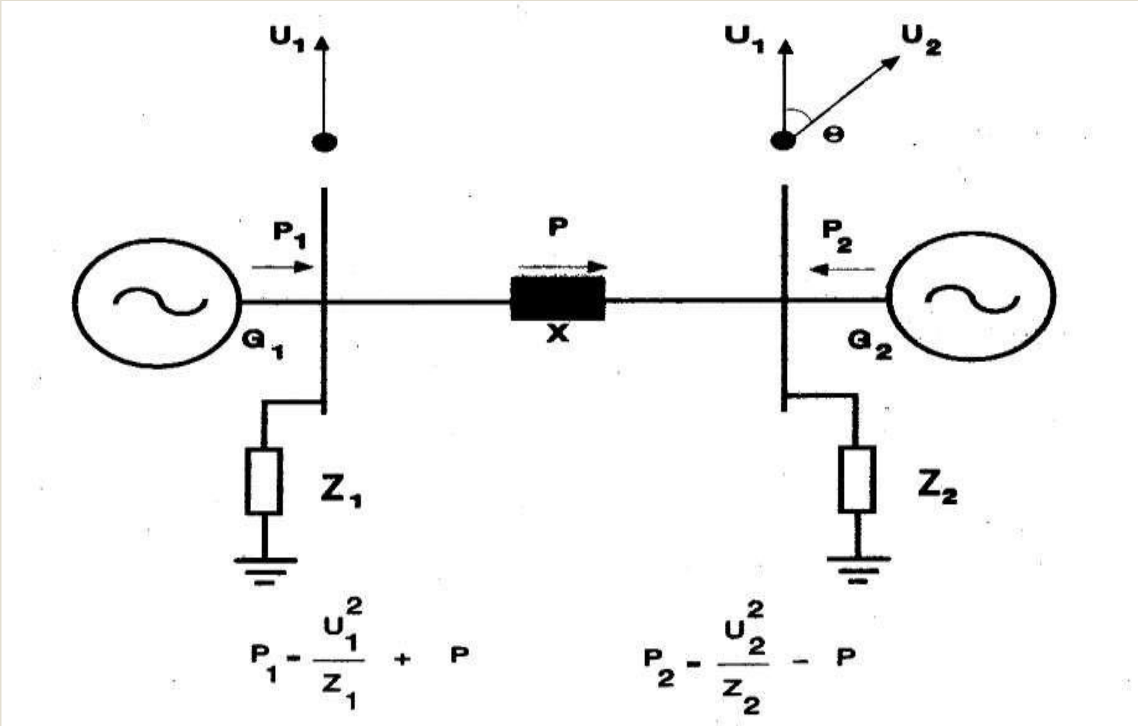
HVDC INTRODUCTION

HVDC technology is used to transmit electricity over long distances by overhead transmission lines or submarine cables.



HVDC Principle

PRINCIPLE OF AC TRANSMISSION



$$P = \frac{U_1 U_2}{X} \sin\theta$$

Schematic of AC system

REASONS FOR AC GENERATION AND TRANSMISSION

- Due to ease of transformation of voltage levels (simple transformer action)
- Alternating Current is universally utilized.—Both for GENERATION and LOADS and hence for Transmission.
- Generators are at remote places, away from the populated areas i.e. the load Centers.
- Turbines drive synchronous generators giving an output at 15-25 kV.
- Voltage is boosted up to 220 or 400 KV by step-up transformers for transmission to LOADS.
- To reach the loads at homes/industry at required safe levels, transformers step down voltage

COMPARISION OF HVAC & HVDC SYSTEMS

- HVAC transmission is having several limitations like line length , uncontrolled power flow, over/low voltages during lightly / over loaded conditions, stability problems, fault isolation etc

- The advantage of HVDC is the ability to transmit large amounts of power over long distances with lower capital costs and with lower losses than AC.

- HVDC transmission allows efficient use of energy sources remote from load centers. Depending on voltage level and construction details, losses are quoted as about 3% per 1,000 km.

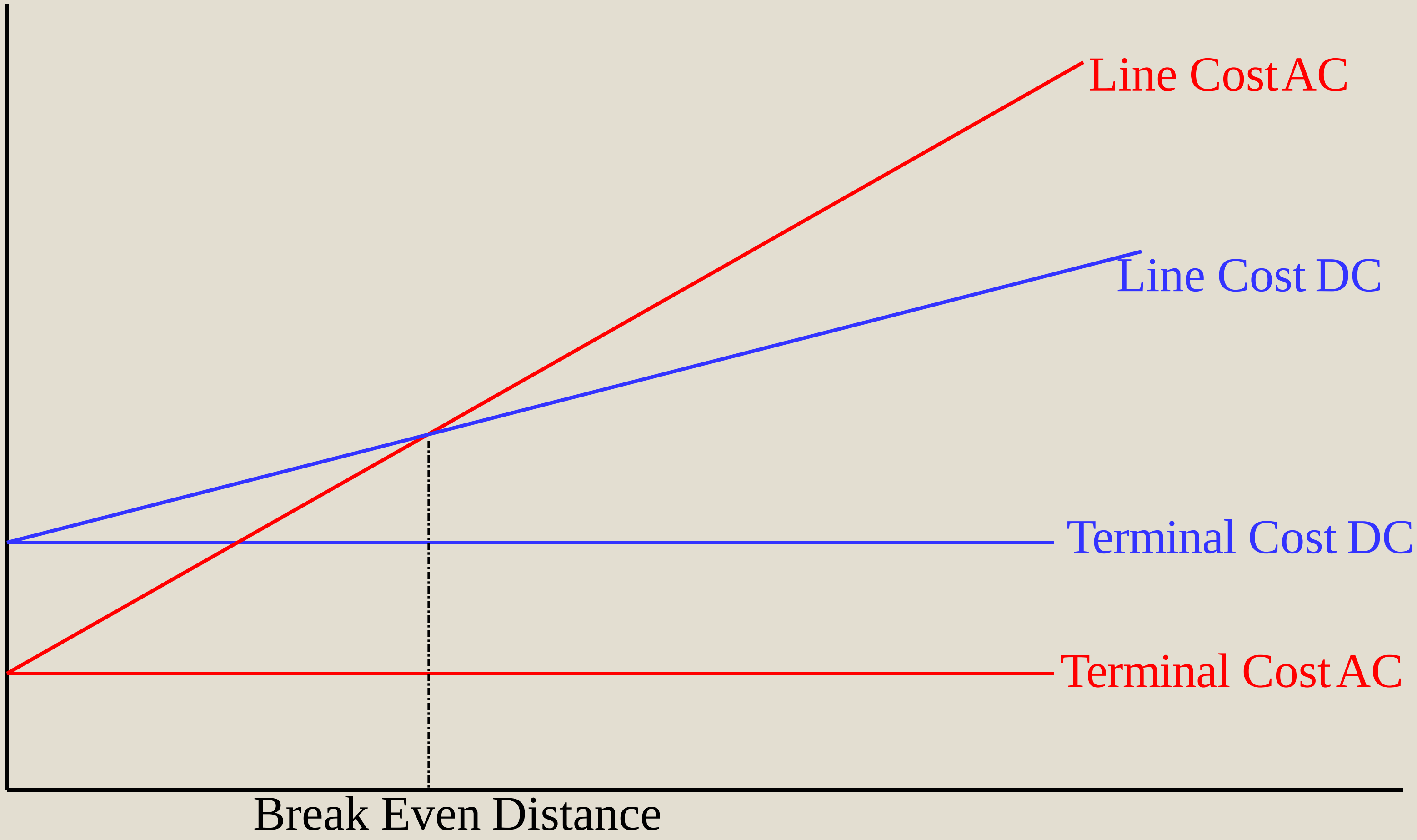
- In a number of applications HVDC is more effective than AC transmission. Examples include:
    - Undersea cables, where high capacitance causes additional AC losses. (e.g. 250 km Baltic Cable between Sweden and Germany) .
    - 600 km NorNed cable between Norway and the Netherlands

COMPARISION OF HVAC & HVDC SYSTEMS

- In HVDC Long power transmission without intermediate taps, for example, in remote areas .
- Increasing the capacity of an existing power grid in situations where additional wires are difficult or expensive to install
- Power transmission and stabilization between unsynchronized AC distribution systems
- Connecting a remote generating plant to the distribution grid
- Asynchronous operation possible between regions having different electrical parameters .
- Facilitate power transmission between different countries that use AC at differing voltages and/or frequencies
- Reducing line cost:
  - fewer conductors
  - thinner conductors since HVDC does not suffer from the skin effect

COMPARISION OF HVAC & HVDC SYSTEMS

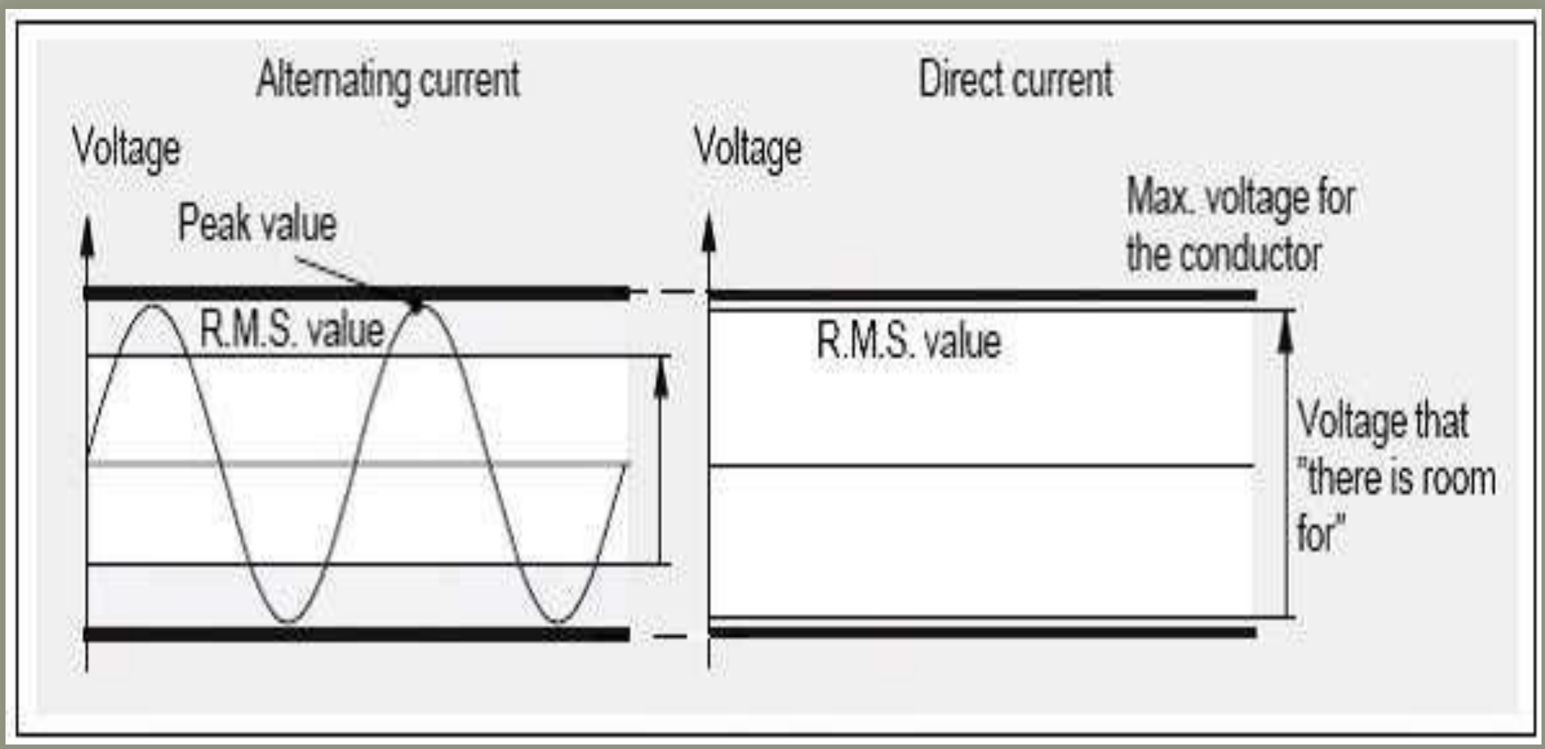
- HVDC Cheaper than HVAC for long distance.



COST: HVAC vs. HVDC Transmission

COMPARISION OF HVAC & HVDC SYSTEMS

- No restriction on line length as no reactance in dc lines
- HVDC can carry more power per conductor because, for a given power rating, the constant voltage in a DC line is lower than the peak voltage in an AC line.



COMPARISION OF HVAC & HVDC SYSTEMS

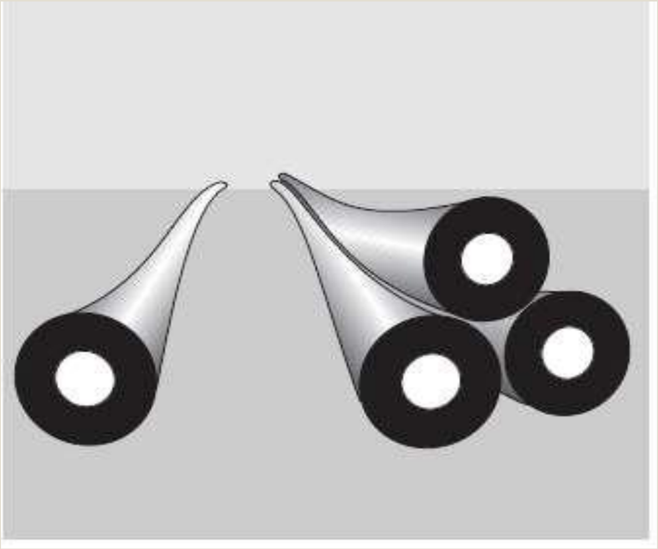
- HVDC uses less current i.e. low losses.

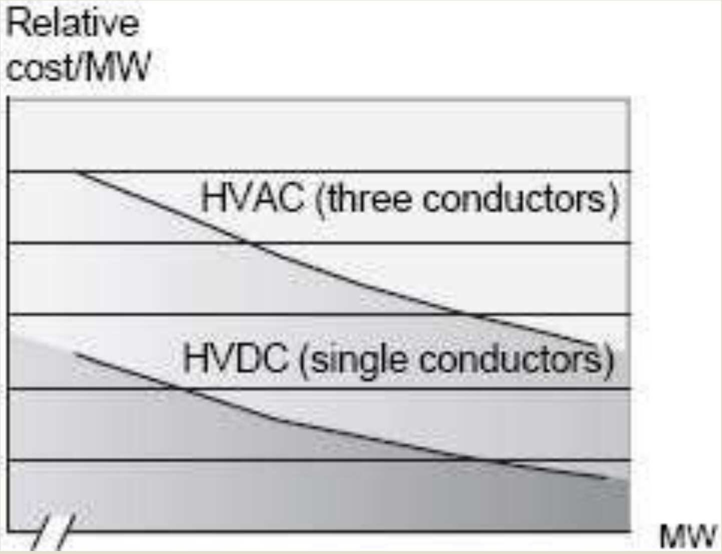
- AC current will struggle against inertia in the line (100times/sec)-electrical resistance –inductance- reactive power

- Direct current : Roll along the line ; opposing force friction (electrical resistance)

COMPARISION OF HVAC & HVDC SYSTEMS

- Distance as well as amount of POWER determine the choice of DC over AC

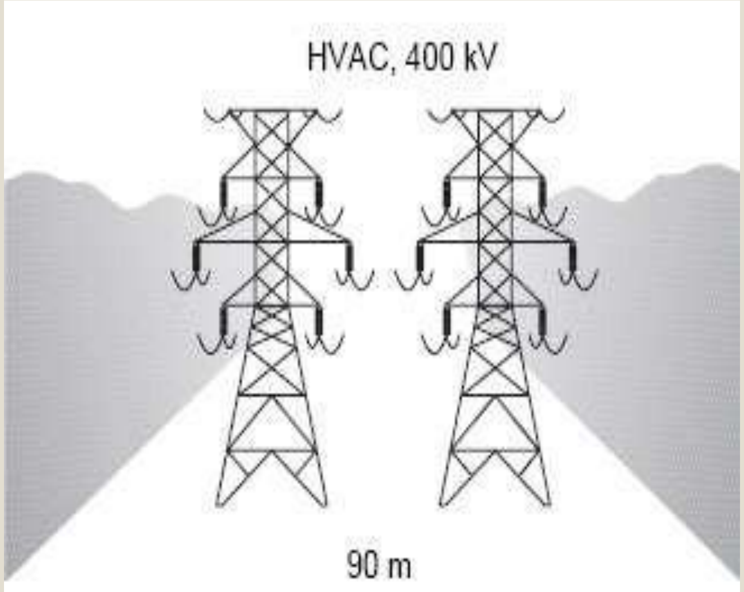




COMPARISION OF HVAC & HVDC SYSTEMS

- Direct current conserves forest and saves land

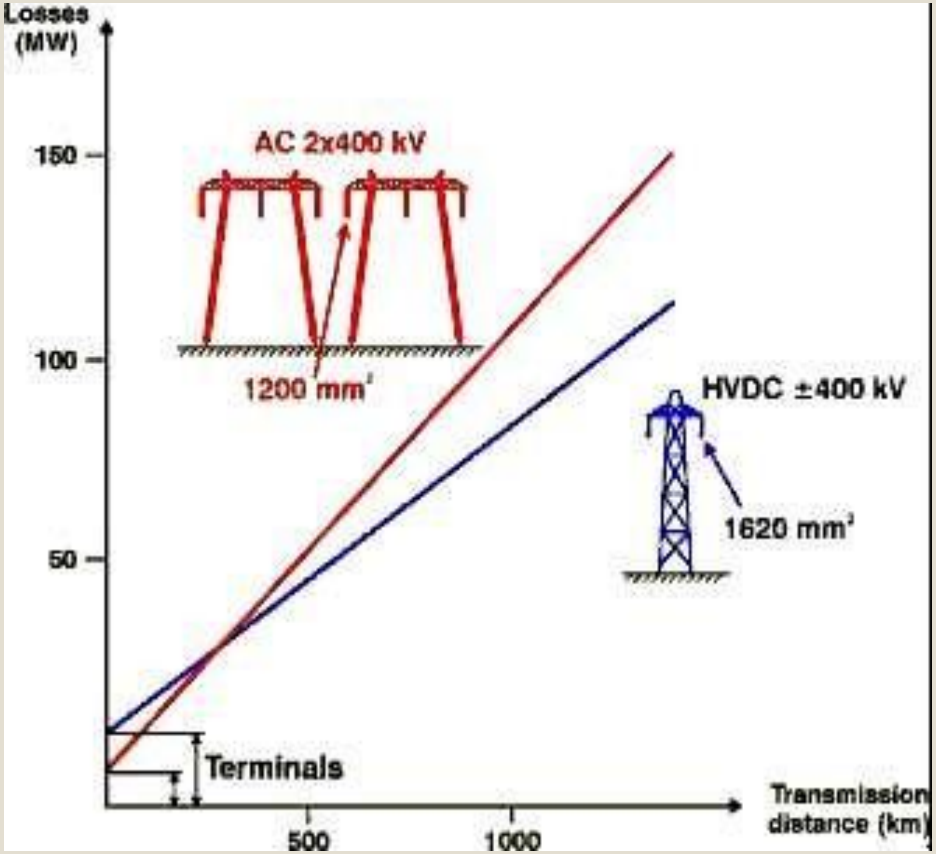
- The towers of the dc lines are narrower, simpler and cheaper compared to the towers of the ac lines.



COMPARISION OF HVAC & HVDC SYSTEMS

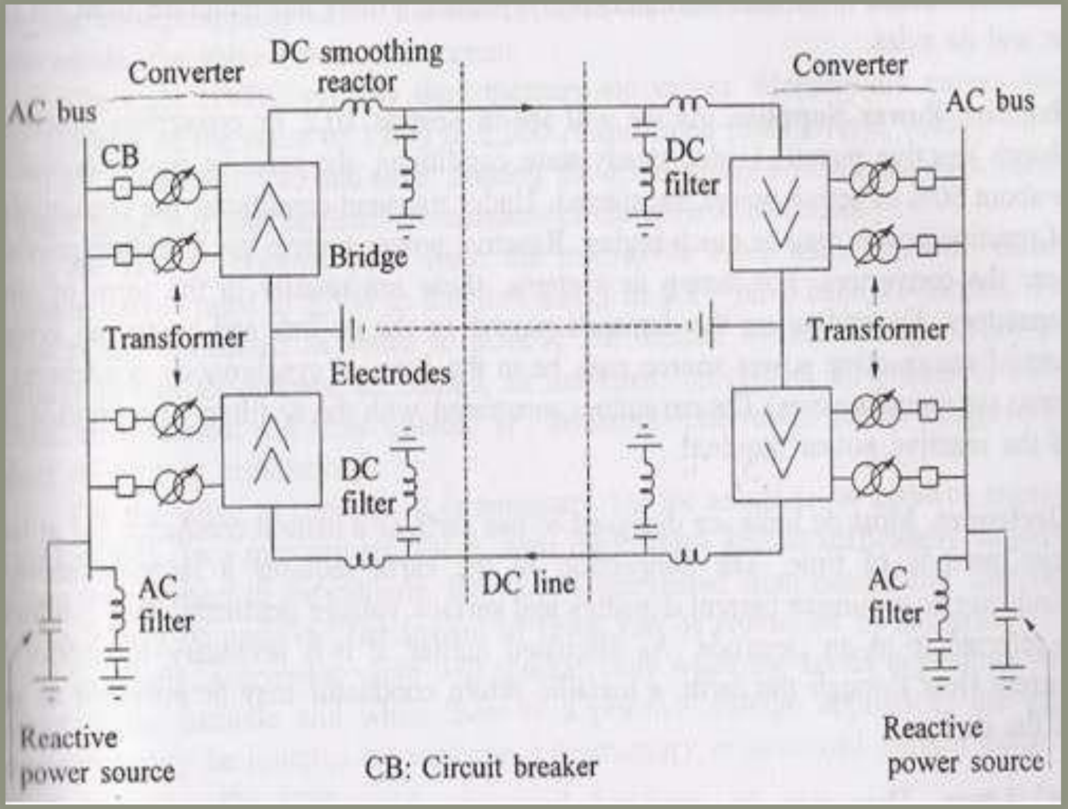
- Lesser Corona Loss than HVAC at same voltage and conductor diameter and less Radio interference.
- Direction of power flow can be changed very quickly
- HVDC has greater reliability. i.e. bipolar dc is more reliable than 3 phase HVAC.
- DC requires less insulation.
- An optimized DC link has smaller towers than an optimized AC link of equal capacity.
- DC line in Parallel with AC link.

Corona → (f+25)



Components of HVDC Transmission Systems

1. Converters
2. Smoothing reactors
3. Harmonic filters
4. Reactive power supplies
5. Electrodes
6. DC lines
7. AC circuit breakers

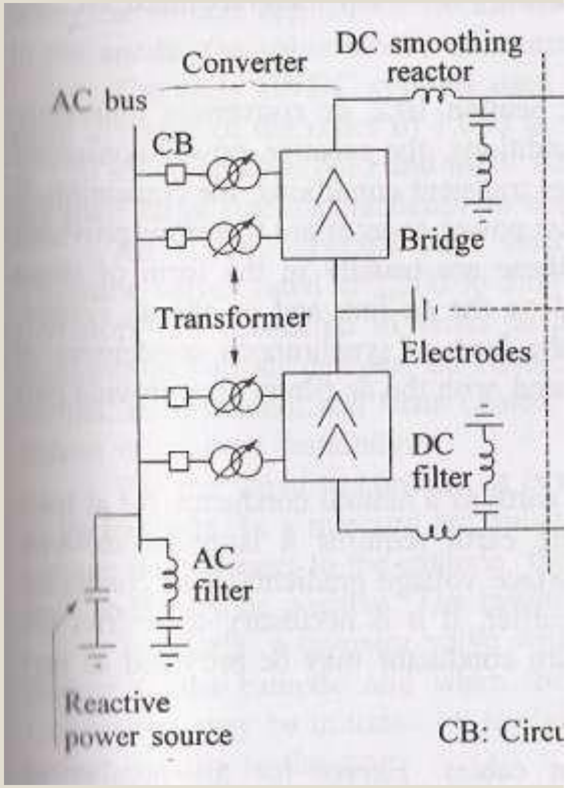


Components of HVDC

Components of HVDC Transmission Systems….

Converters

- They perform AC/DC and DC/AC conversion
- They consist of valve bridges and transformers
- Valve bridge consists of high voltage valves connected in a 6-pulse or 12-pulse arrangement
- The transformers are ungrounded such that the DC system will be able to establish its own reference to ground



Smoothing reactors

- They are high reactors with inductance as high as 1 H in series with each pole They serve the following:
  - They decrease harmonics in voltages and currents in DC lines
  - They prevent commutation failures in inverters
  - Prevent current from being discontinuous for light loads

Harmonic filters

- Converters generate harmonics in voltages and currents. These harmonics may cause overheating of capacitors and nearby generators and interference with telecommunication systems
- Harmonic filters are used to mitigate these harmonics

Components of HVDC Transmission Systems….

Reactive power supplies

- Under steady state condition, the reactive power consumed by the converter is about 50% of the active power transferred
- Under transient conditions it could be much higher

  Reactive power is, therefore, provided near the converters
- For a strong AC power system, this reactive power is provided by a shunt capacitor

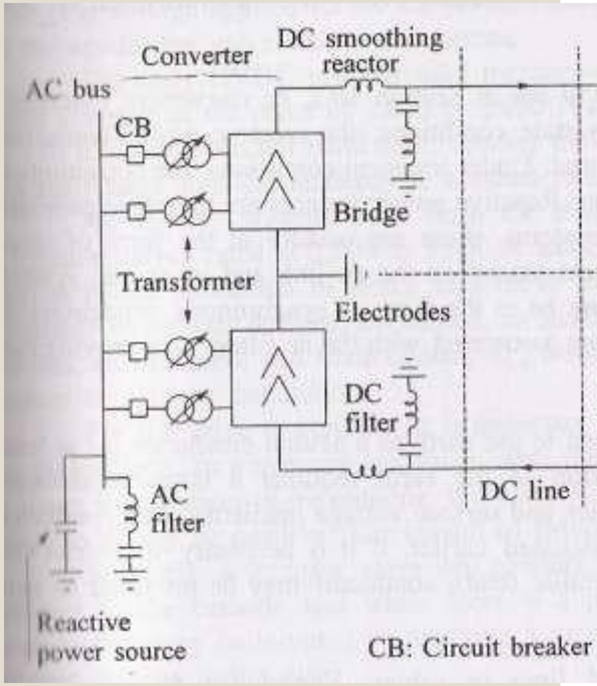
Electrodes

- Electrodes are conductors that provide connection to the earth for neutral. They have large surface to minimize current densities and surface voltage gradients

DC lines

- They may be overhead lines or cables DC lines are

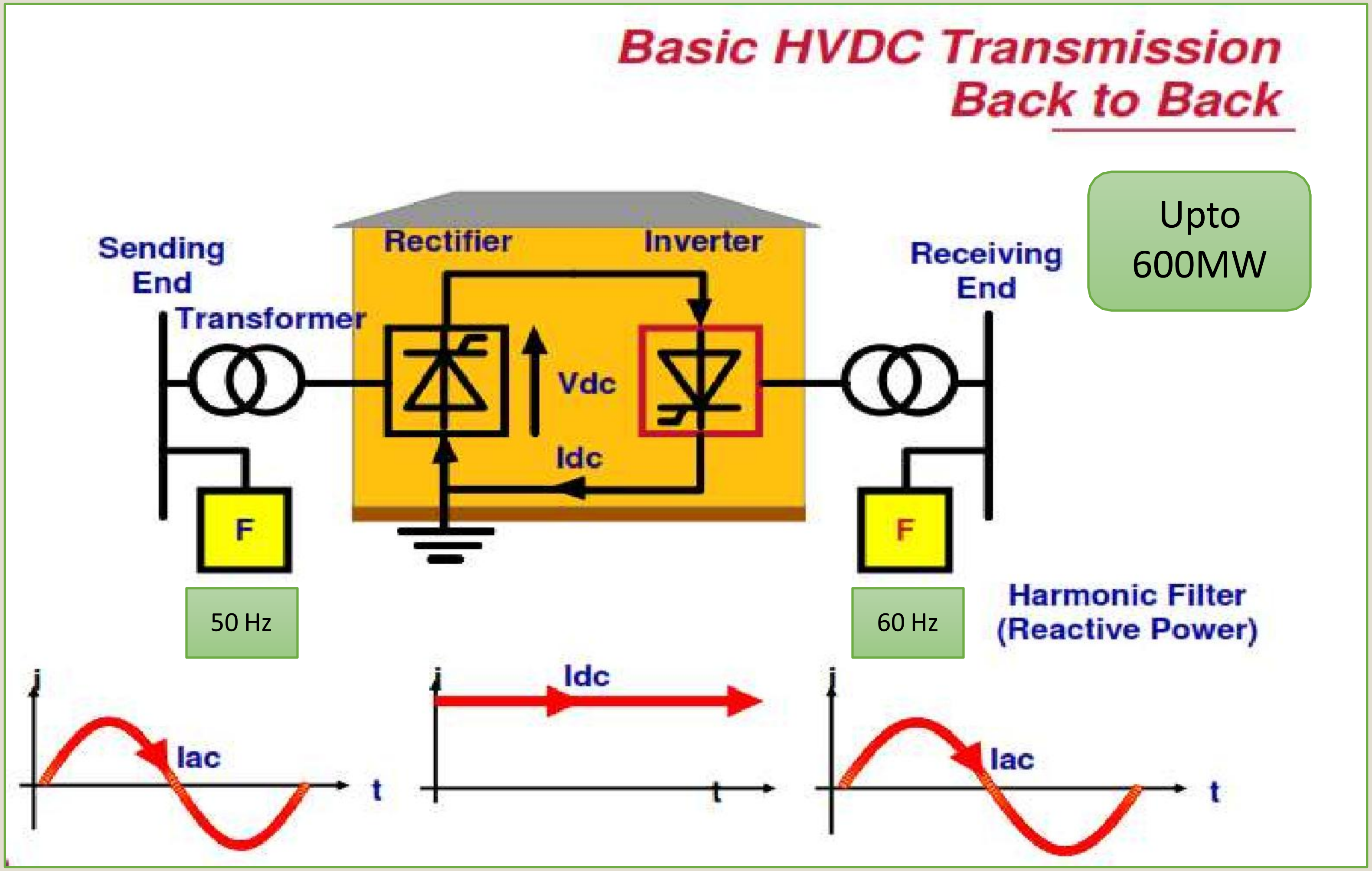
  very similar to AC lines



AC circuit breakers

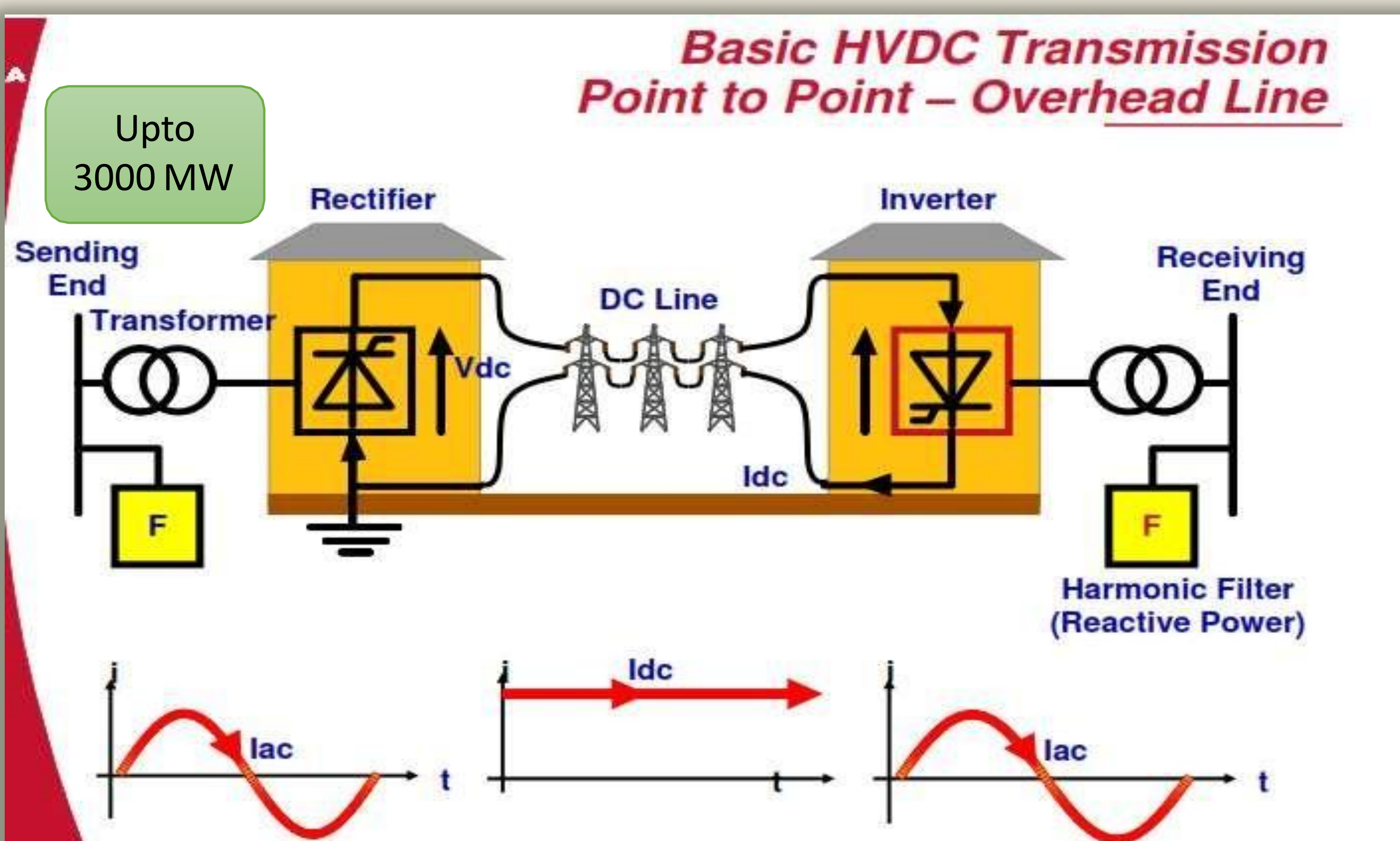
- They used to clear faults in the transformer and for taking the DC link out of service
- They are not used for clearing DC faults
- DC faults are cleared by converter control more rapidly

Application based HVDC Transmission Types



HVDC is the unique solution to interconnect Asynchronous systems or grids with different frequencies.

Application based HVDC Transmission Types



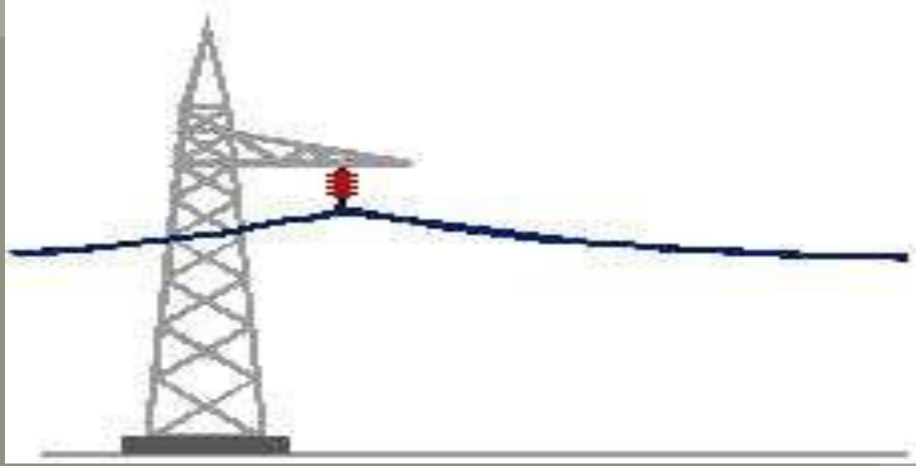
HVDC represents the most economical solution to transmit electrical energy over distances greater than approx. 600 km

HVDC System Configurations

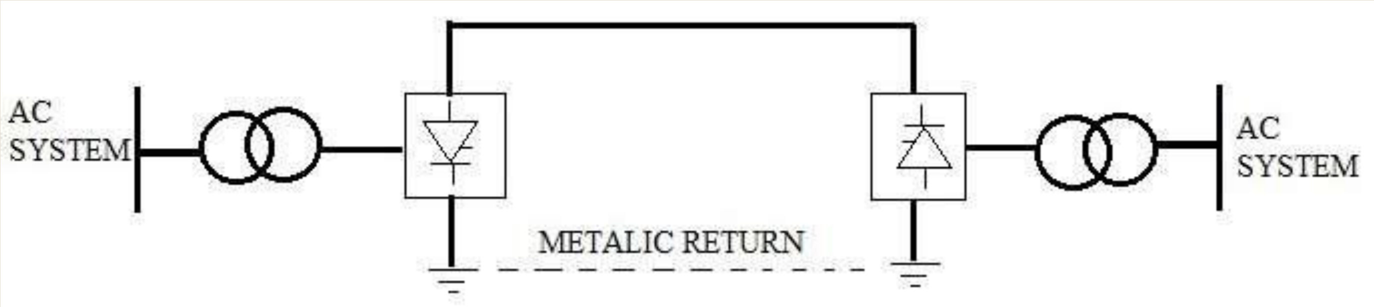
HVDC links can be broadly classified into:

- Monopolar links
- Bipolar links
- Homopolar links
- Multiterminal links

Monopolar Links

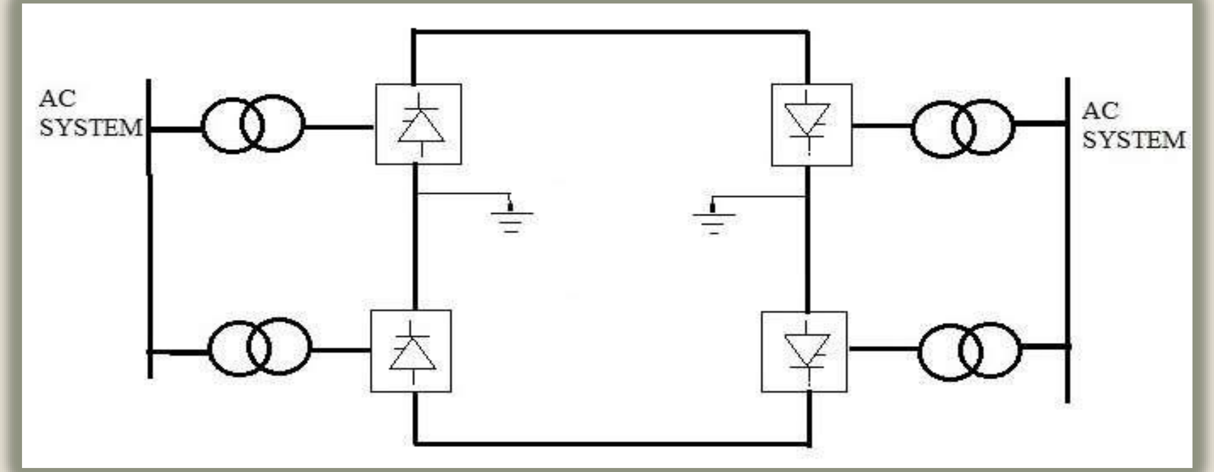


- It uses one conductor .
- The return path is provided by ground or water.
- Use of this system is mainly due to cost considerations.
- A metallic return may be used where earth resistivity is too high.
- This configuration type is the first step towards a bipolar link.

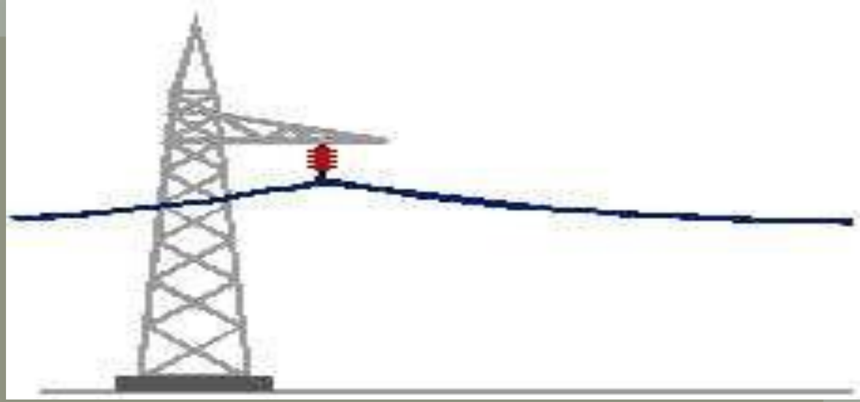


Bipolar Links

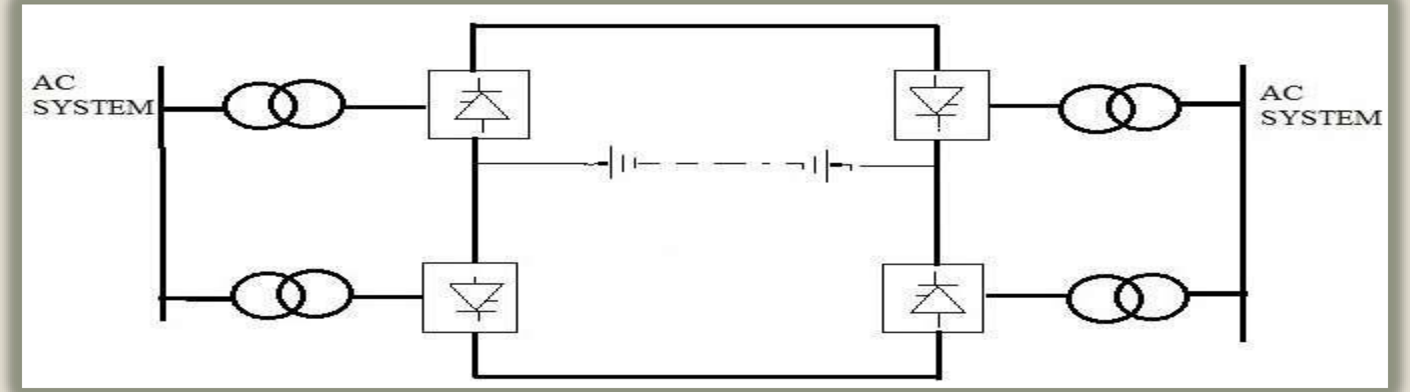
- Each terminal has two converters of equal rated voltage, connected in series on the DC side.
- The junctions between the converters is grounded.
- If one pole is isolated due to fault, the other pole can operate with ground and carry half the rated load (or more using overload capabilities of its converter line).



Homopolar Links



- It has two or more conductors all having the same polarity, usually negative.
- Since the corona effect in DC transmission lines is less for negative polarity, homopolar link is usually operated with negative polarity.
- The return path for such a system is through ground.



Dc as a Means of Transmission

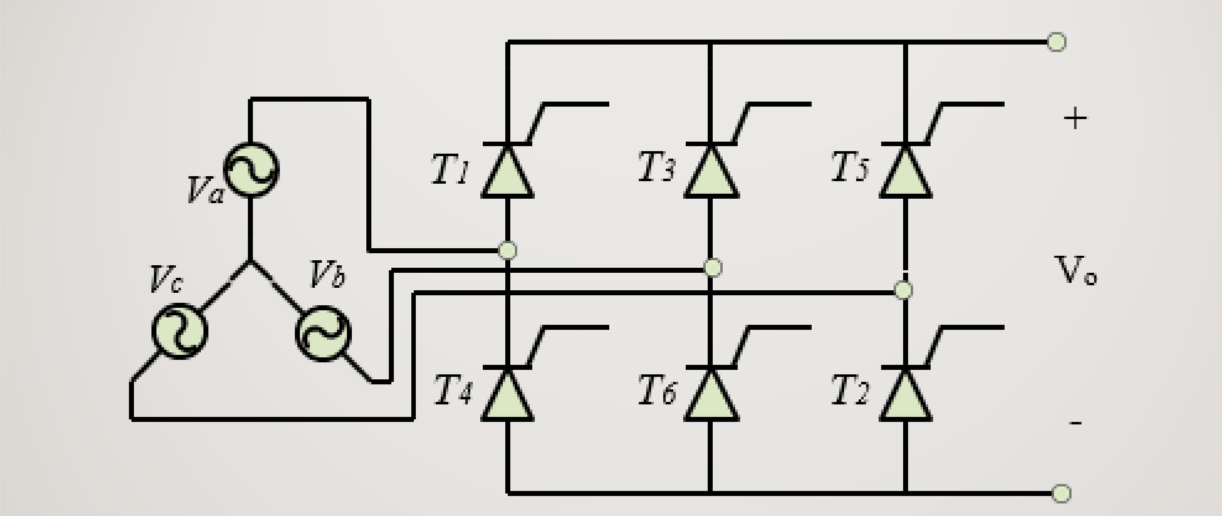
DC Transmission has been possible with beginning of

- High power/ high current capability thyristor.
- Fast acting computerized controls

Since our primary source of power is A.C, The three basic steps are

- Convert AC into DC (**rectifier)**
- Transmit DC
- Convert DC into AC (**inverter**)

Six Pulse Rectifier



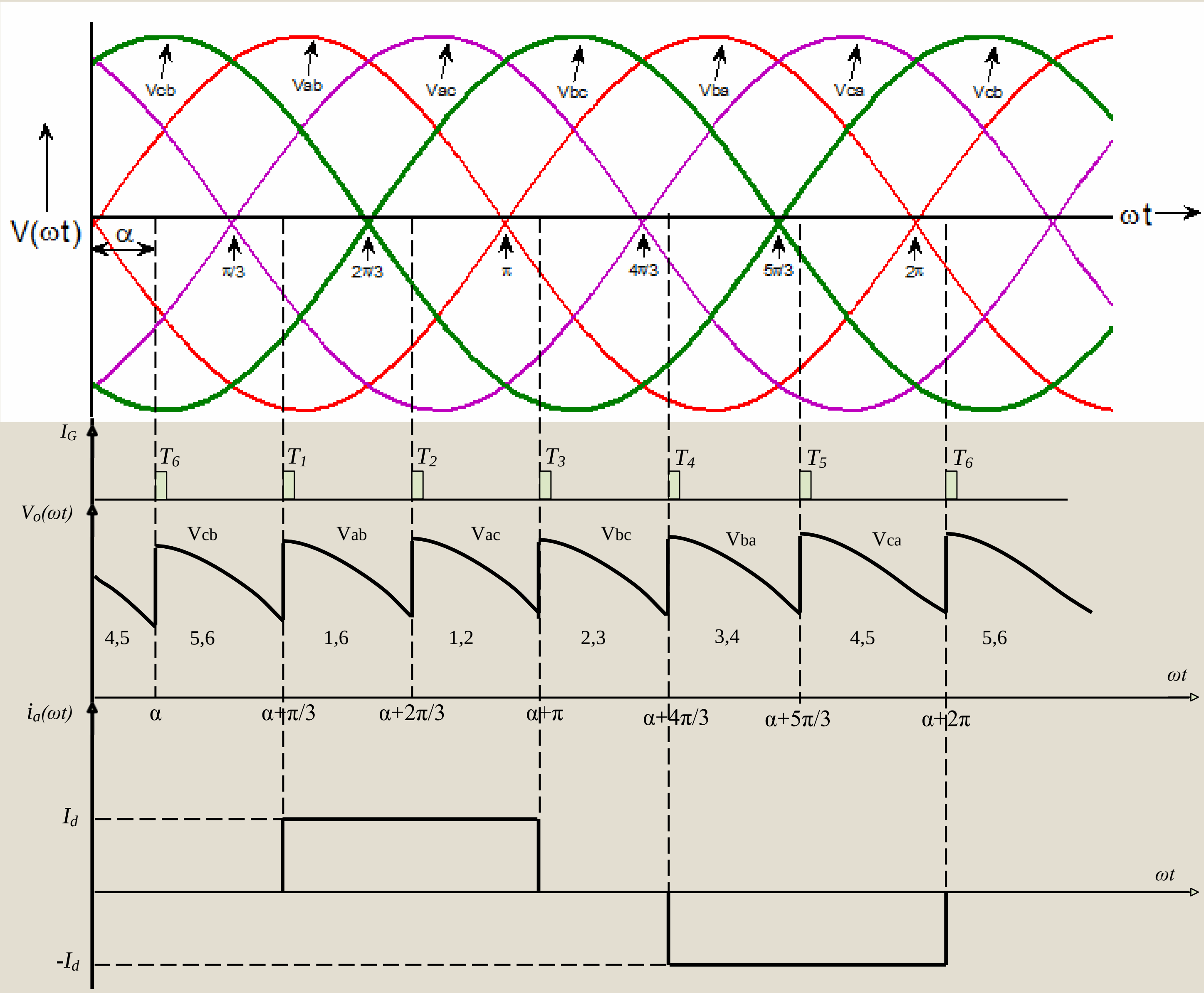
- The operating principle of the circuit is that, the pair of SCR connected between the lines having highest amount of line-to-line voltage will conduct provided that the gate signal is applied to SCRs at that instant.

Between $0 \leq \omega t \leq \pi/3$ the highest line-to-line voltage is V_{cb}, with T_4 & T_5 intially conducting. By firing T_6 at delay angle of α, results V_{cb} at load

- The converters are called Line Commutated converters or current source converter.

- Every 60º one Thyristor from +ve limb and one Thyristor from –ve limb is triggered

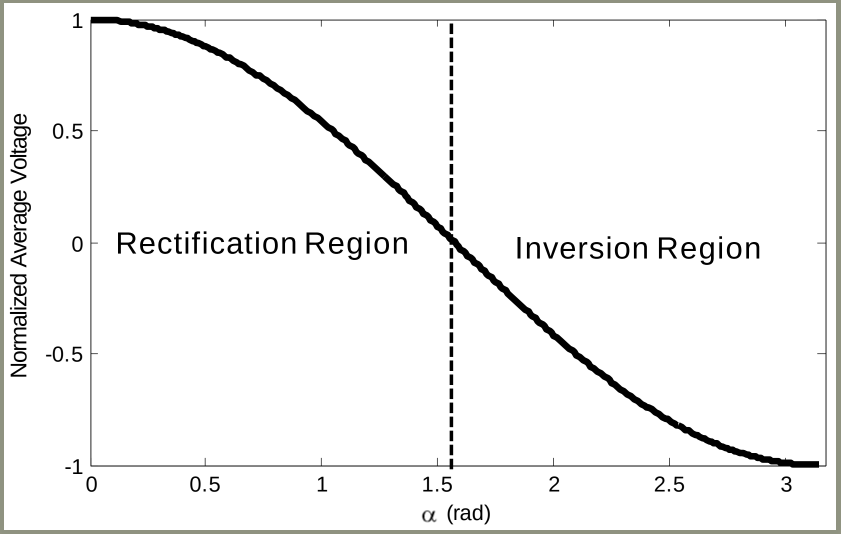
Six Pulse Rectifier Waveforms



Operation of Six Pulse Rectifier

It can be seen from Fig that for $\alpha = \pi/3$ the rectified output voltage reaches zero crossing. If α is increased beyond $\pi/3$ i.e. $\alpha > \pi/3$, the load voltage becomses discontinous for resistive load where as for inductive load the negative voltage appears across load.

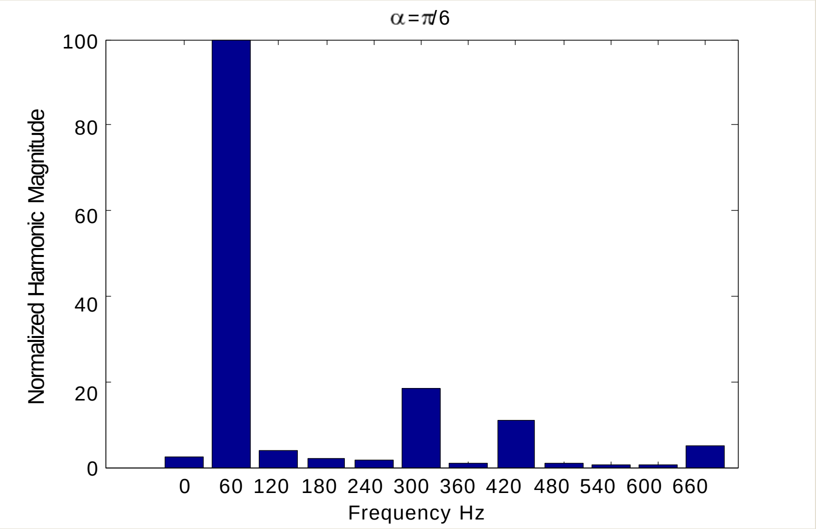
$$V_n = \frac{V_{dc}}{V_{dm}} \cos(\alpha)$$



Normalized Average (DC) Voltage as function of α

Fig shows that by varying α between $0 \; to \; \pi/2$ output varies between 1 & 0 i.e. rectification region and by varying α between $\pi/2 \; to \; \pi$ output varies between $0 \;\&\; -1$ i.e. inversion region. Rectification region is represented by 1st Quardant and inversion region by 4th Quardant resulting in 2 Quardant operation.

$$P.F = 0.9 \; \cos(\alpha)$$



Specturm at alpha=pi/6

Disadvantages of HVDC Transmission

- The disadvantages of HVDC are in conversion, switching and control.
- Expensive inverters with limited overload capacity.
- Higher losses in static inverters at smaller transmission distances.
- The cost of the inverters may not be offset by reductions in line construction cost and lower line loss.
- High voltage DC circuit breakers are difficult to build because some mechanism must be included in the circuit breaker to force current to zero, otherwise arcing and contact wear would be too great to allow reliable switching.
- HVDC is less reliable and has lower availability than AC systems, mainly due to the extra conversion equipment.

UNIT-II

CONVERTER AND HVDC CONTROL SYSTEM

Control of HVDC Systems

Objectives of Control	• Efficient and stable operation. • Maximum flexibility of power control without compromising the safety of equipment.
Content	• Principle of operation of various control systems. • Implementation and their performance during normal and abnormal system conditions.

Basic principles of control

- Direct current from the rectifier to the inverter

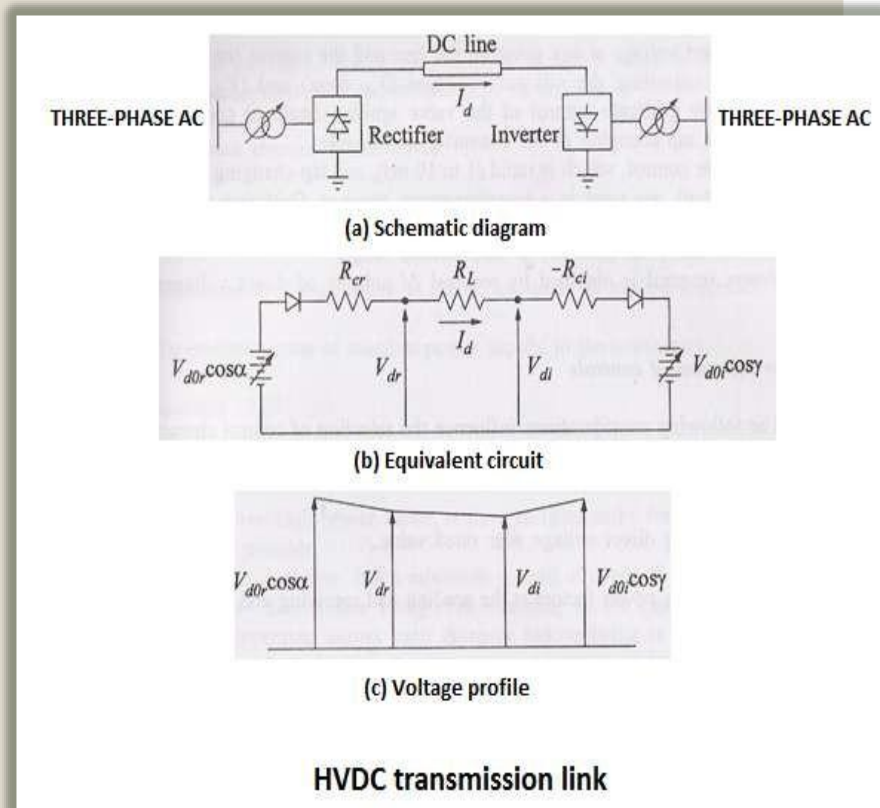
$$I_d = \frac{V_{dor}\cos\alpha - V_{doi}\cos\beta}{R_{cr} + R_l - R_{ci}}$$

- Power at the rectifier terminal

$$P_{dr} = V_{dr} I_d$$

- Power at the inverter terminal

$$P_{di} = V_{di} I_d = P_{dr} - R_L I_d^2$$



Schematic diagram of control

Basic Means of control

- Internal voltages $V_{dor} \cos\alpha$ and $V_{doi} \cos\beta$ can used be controlled to
    - control the voltages at any point on the line and the current flow (power).
    - This can be accomplished by:
        - Controlling firing angles of the rectifier and inverter (for fast action).
        - Changing taps on the transformers on the AC side (slow response).
    - Power reversal is obtained by reversal of polarity of direct voltages
    - at both ends.

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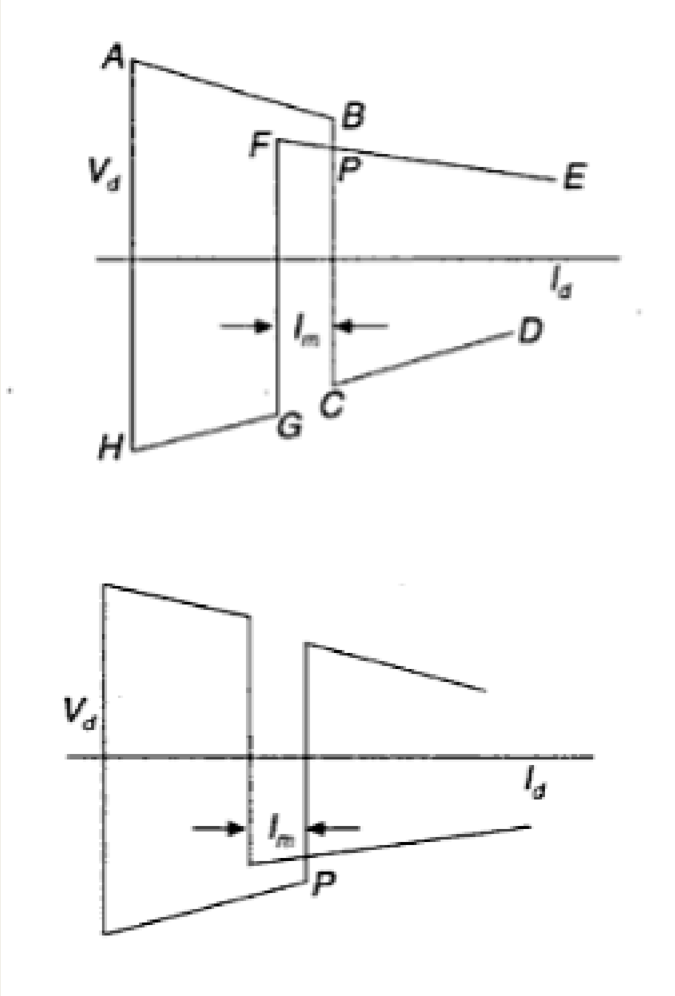
CONTROL CHARACTERISTICS

- The intersection of the two characteristics (point A) determines the mode of operation Station I operating as rectifier with constant current control and station II operating at constant (minimum) extinction angle.



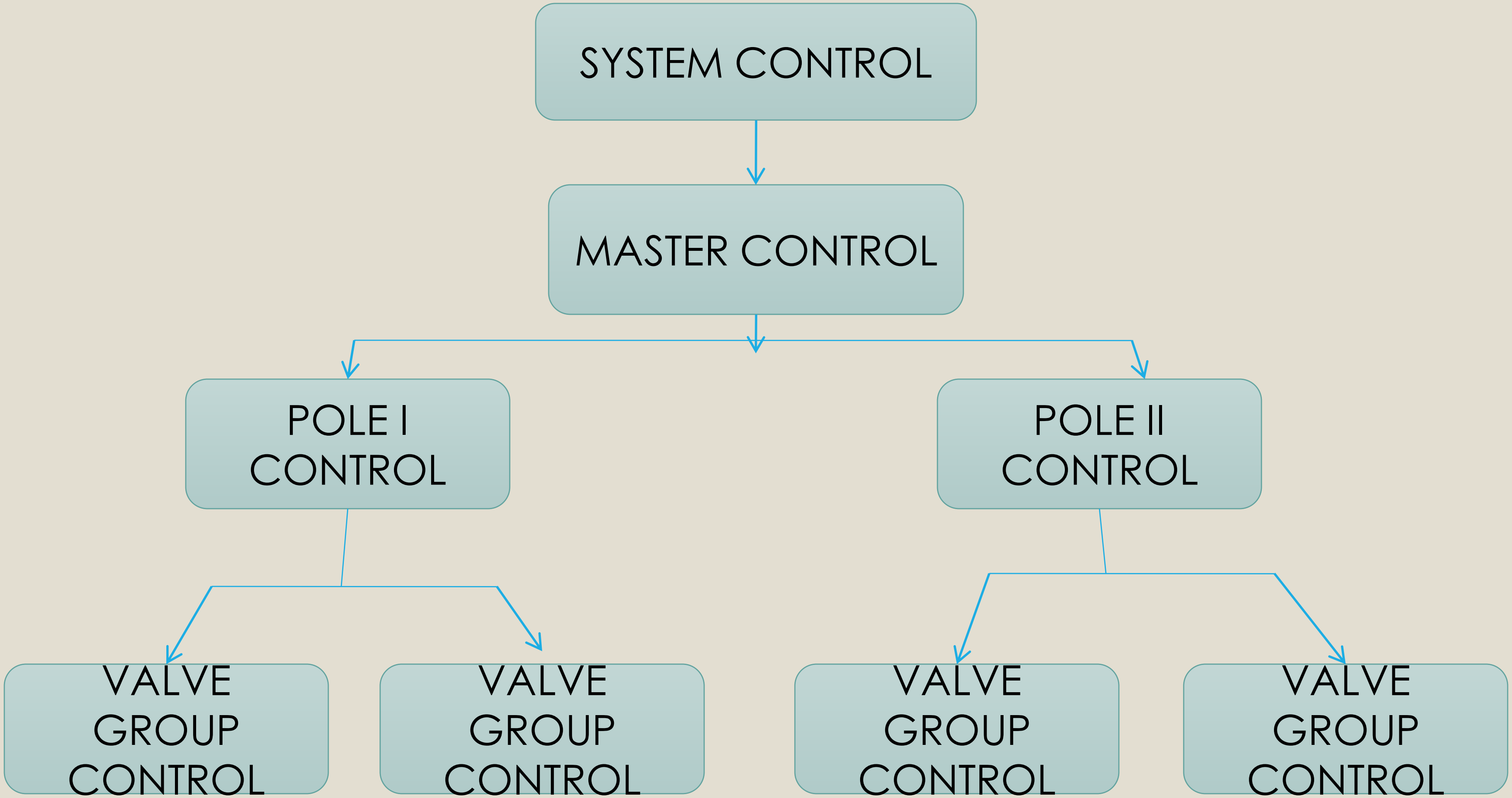
CONTROL CHARACTERISTICS

- There can be three modes of operation of the link (for the same direction of power flow) depending on the ceiling voltage of the rectifier which determines the point of intersection of the two characteristics which are defined below:
  1. CC at rectifier and CEA at inverter (operating point A) which is the normal mode of operation.
  2. With slight dip in the AC voltage, the point of intersection drifts to C which implies minimum α at rectifier and minimum γ at the inverter.
  3. With lower AC voltage at the rectifier, the mode of operation shifts to point B which implies CC at the inverter with minimum α at the rectifier.

Introduction to facts

- Flexible alternating current transmission system.
- Facts as they are generally known, are new devices that improve transmission systems.
- Facts is a static equipment used for the ac transmission of electrical energy.
- It is generally a power electronics based device.
- Meant to enhance controllability and increase power transfer capability.

SYSTEM CONTROL HIERARCHY



SYSTEM CONTROL HIERARCHY

- The master controller for a bipole is located at one of the terminals and is provided with the power order (Pref) from the system controller (from energy control centre). It also has other information such as AC voltage at the converter bus, DC voltage etc. The master controller transmits the current order (Iref) to the pole control units which in turn provide a firing angle order to the individual valve groups (converters). The valve group or converter control also oversees valve monitoring and firing logic through the optical interface. It also includes bypass pair selection logic, commutation failure protection, tap changer control, converter start/stop sequences, margin switching and valve protection circuits. The pole control incorporated pole protection, DC line protection and optional converter paralleling and deparalleling sequences. The master controller which oversees the complete bi-pole includes the functions of frequency control, power modulation, AC voltage and reactive power control and torsional frequency damping control.

FIRING ANGLE CONTROL

- The operation of CC and CEA controllers is closely linked with the method of generation of gate pulses for the valves in a converter. The requirements for the firing pulse generation of HVDC valves are
  - The firing instant for all the valves are determined at ground potential and the firing signals sent to individual thyristors by light signals through fibre-optic cables. The required gate power is made available at the potential of individual thyristor.
  - While a single pulse is adequate to turn-on a thyristor, the gate pulse generated must send a pulse whenever required, if the particular valve is to be kept in a conducting state.
- The two basic firing schemes are
  - Individual Phase Control (IPC)
  - Equidistant Pulse Control (EPC)

INDIVIDUAL PHASE CONTROL

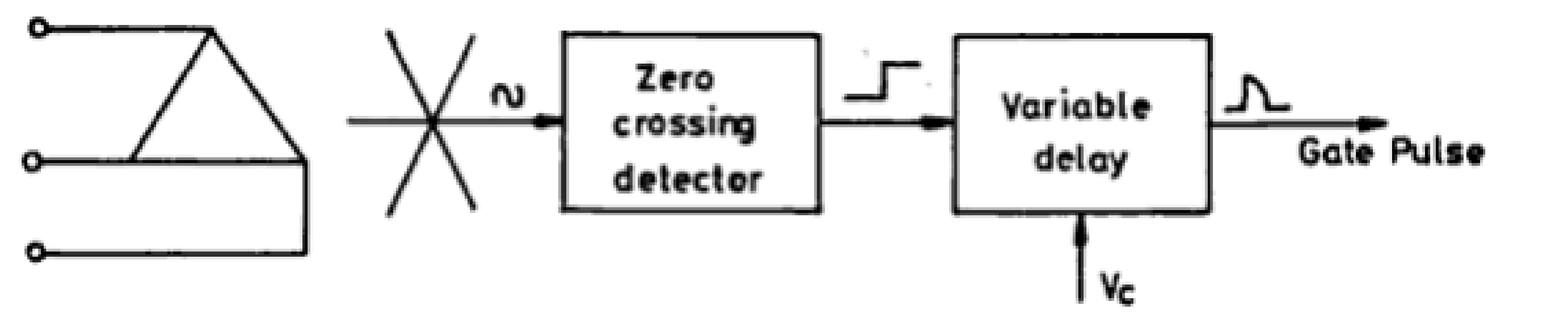
This was used in the early HVDC projects. The main feature of this scheme is that the firing pulse generation for each phase (or valve) is independent of each other and the firing pulses are rigidly synchronized with commutation voltages.

- There are two ways in which this can be achieved
  - Constant α Control
  - Inverse Cosine Control

INDIVIDUAL PHASE CONTROL

Constant α Control:

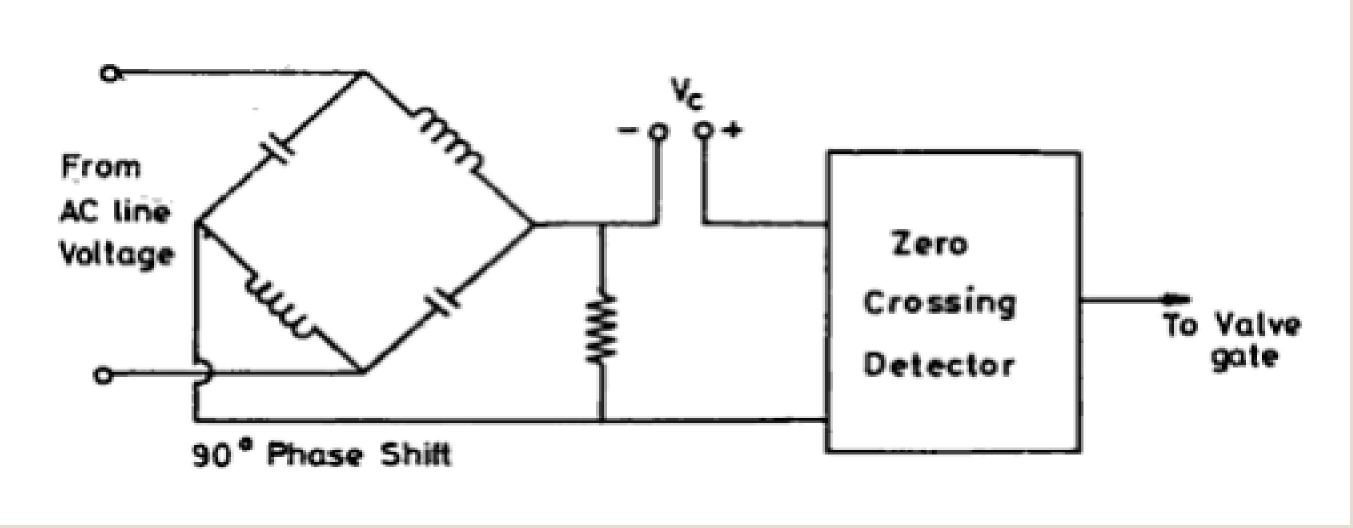
- Six timing (commutation) voltages are derived from the converter AC bus via voltage transformers and the six gate pulses are generated at nominally identical delay times subsequent to the respective voltage zero crossings. The instant of zero crossing of a particular commutation voltage corresponds to α = 0o for that valve.



INDIVIDUAL PHASE CONTROL

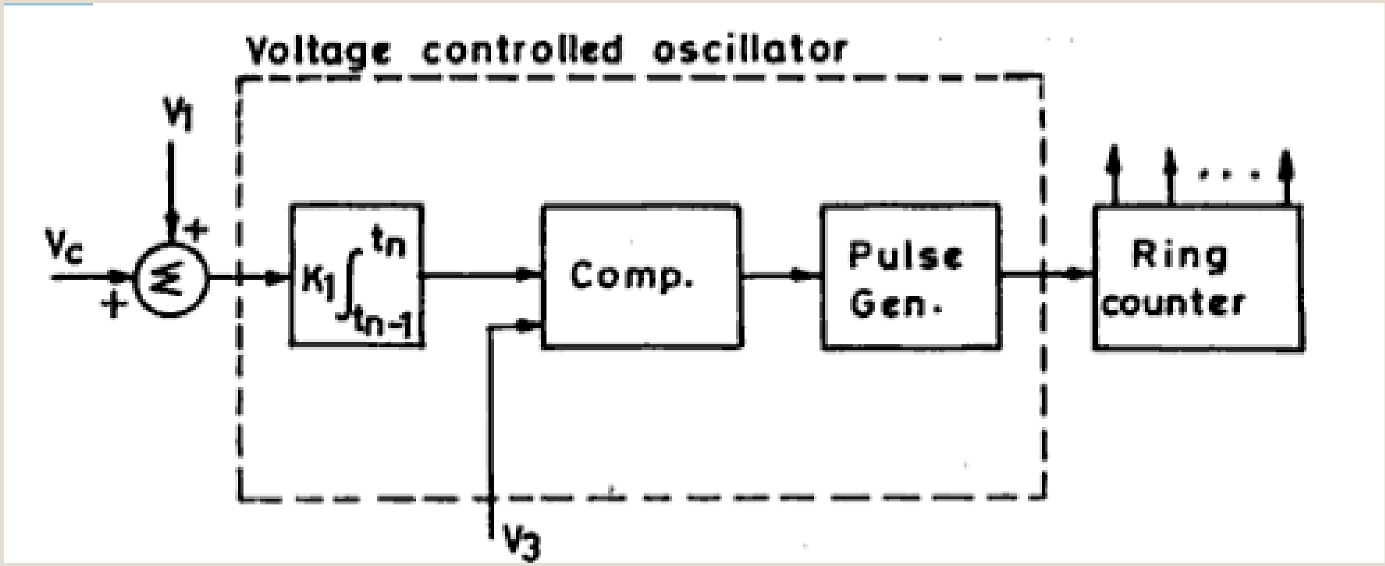
INVERSE COSINE CONTROL:

- The six timing voltages (obtained as in constant a control) are each phase shifted by 90o and added separately to a common control voltage V. The zero crossing of the sum of the two voltages initiates the firing pulse for the particular valve is considered. The delay angle a is nominally proportional to the inverse cosine of the control voltage. It also depends on the AC system voltage amplitude and shape.



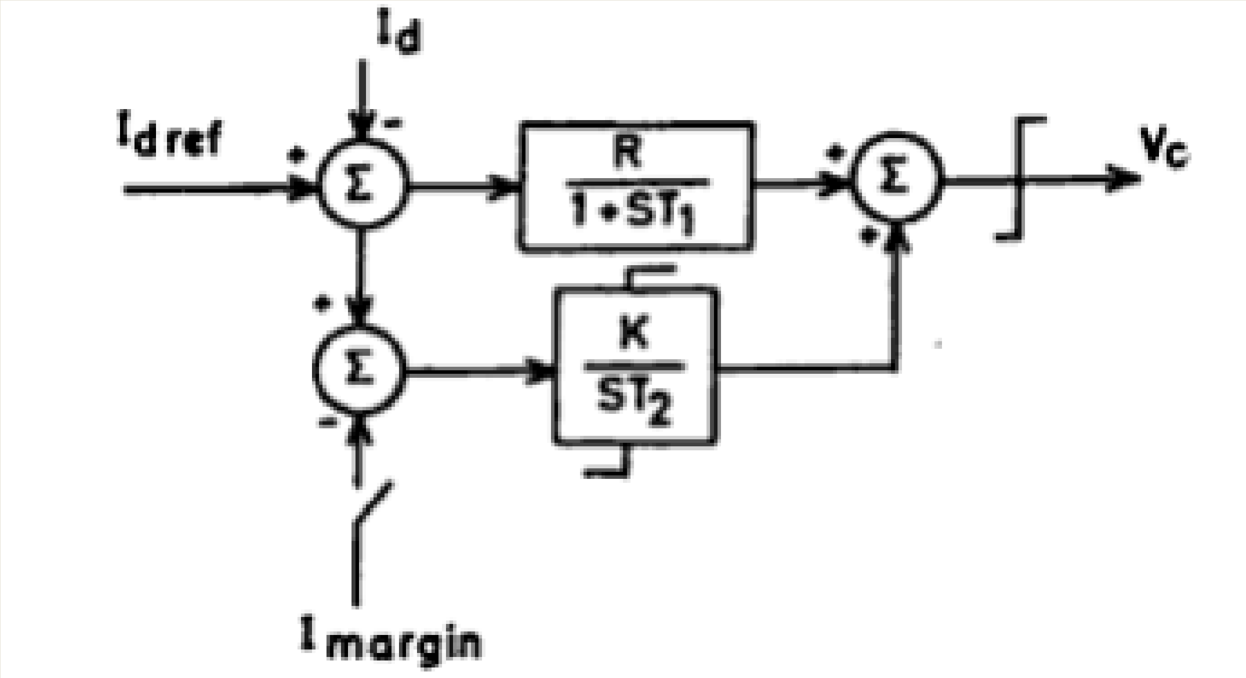
PULSE FREQUENCY CONTROL

- A Voltage Controlled Oscillator (VCO) is used, the frequency of which is determined by the control voltage Vc which is related to the error in the quantity (current, extinction angle or DC voltage) being regulated. The frequency in steady-state operation is equal to pfo where fo is the nominal frequency of the AC system. PFC system has an integral characteristic and has to be used along with a feedback control system for stabilization. The Voltage Controlled Oscillator (VCO) consists of an integrator, comparator and a pulse generator.



CURRENT AND EXTINTION ANGLE CONTROL

- The current controller is invariably of feedback type which is of PI type. The extinction angle controller can be of predictive type or feedback type with IPC control. The predictive controller is considered to be less prone to commutation failure and was used in early schemes. The feedback control with PFC type of Equidistant Pulse Control overcomes the problems associated with IPC.



STARTING AND STOPPING OF DC LINK

- **Energization and Deenergization of a Bridge:** Consider N series connected bridges at a converter station. If one of the bridges is to be taken out of service, there is need to not only block, but bypass the bridge. This is because of the fact that just blocking the pulses does not extinguish the current in the pair of valves that are left conducting at the time of blocking. The continued conduction of this pair injects AC voltage into the link which can give rise to current and voltage oscillations due to lightly damped oscillatory circuit in the link formed by smoothing reactor and the line capacitance. The transformer feeding the bridge is also subjected to DC magnetization when DC current continues to flow through the secondary windings. The bypassing of the bridge can be done with the help of a separate bypass valve or by activating a bypass pair in the bridge (two valves in the same arm of the bridge). The bypass valve was used with mercury arc valves where the possibility of arc backs makes it impractical to use bypass pairs. With thyristor valves, the use of bypass pair is the practice as it saves the cost of an extra valve.

STARTUP OF DC LINK

◦ **Start-up with long pulse firing:**

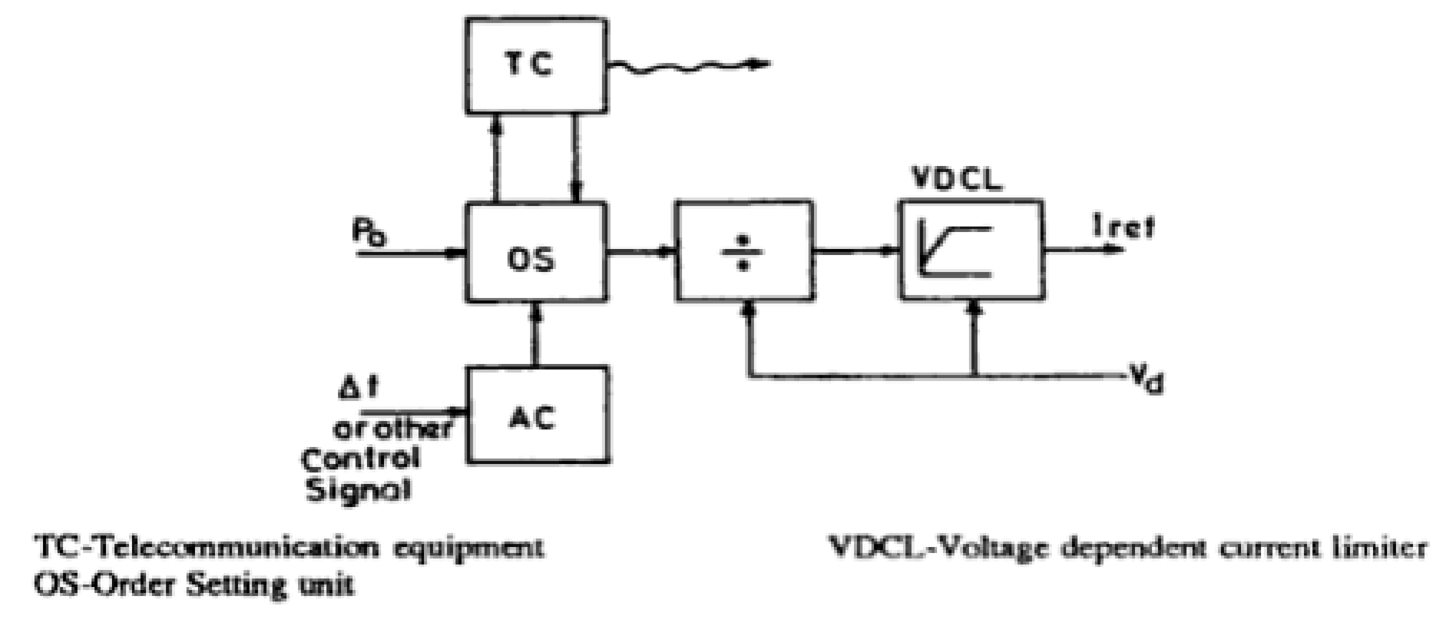
1. De block inverter at about γ = 900
2. De block rectifier at α = 850 to establish low direct current
3. Ramp up voltage by inverter control and the current by rectifier control.

◦ **Start-up with short pulse firing:**

1. Open bypass switch at one terminal
2. Deblock that terminal and load to minimum current in the rectifier mode
3. Open bypass switch at the second terminal and commutate current to the bypass pair
4. Start the second terminal also in the rectifier mode
5. The inverter terminal is put into the inversion mode
6. Ramp up voltage and current.

POWER CONTROL

- The current order is obtained as the quantity derived from the power order by dividing it by the direct voltage. The limits on the current order are modified by the voltage dependent current order limiter (VDCOL). The objective of VDCOL is to prevent individual thyristors from carrying full current for long periods during commutation failures. By providing both converter stations with dividing circuits and transmitting the power order from the leading station in which the power order is set to the trailing station, the fastest response to the DC line voltage changes is obtained without undue communication requirement.



UNIT III

FILTERS AND POWER FLOW ANALYSIS

INTRODUCTION TO HARMONICS

- 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.
   1. Heating of the equipments connected.
   2. Instability of converter control.
   3. Generates telephone and radio interference in adjacent communication lines, thereby inducing harmonic noise.
   4. Harmonics can lead to generation of over voltages due to resonance when filter circuits are employed.

Design of AC filters

Harmonic distortion:

- Harmonic Distortion is given by,

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

- **Telephone influence factor:**

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, Fn = 5 n f1 pn

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

Design of AC filters

Total harmonic form factor (THFF):

- It is similar to TIF and is given by,

$$F_n = (n\,f1 / 800)\, W_n$$

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

IT product:

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

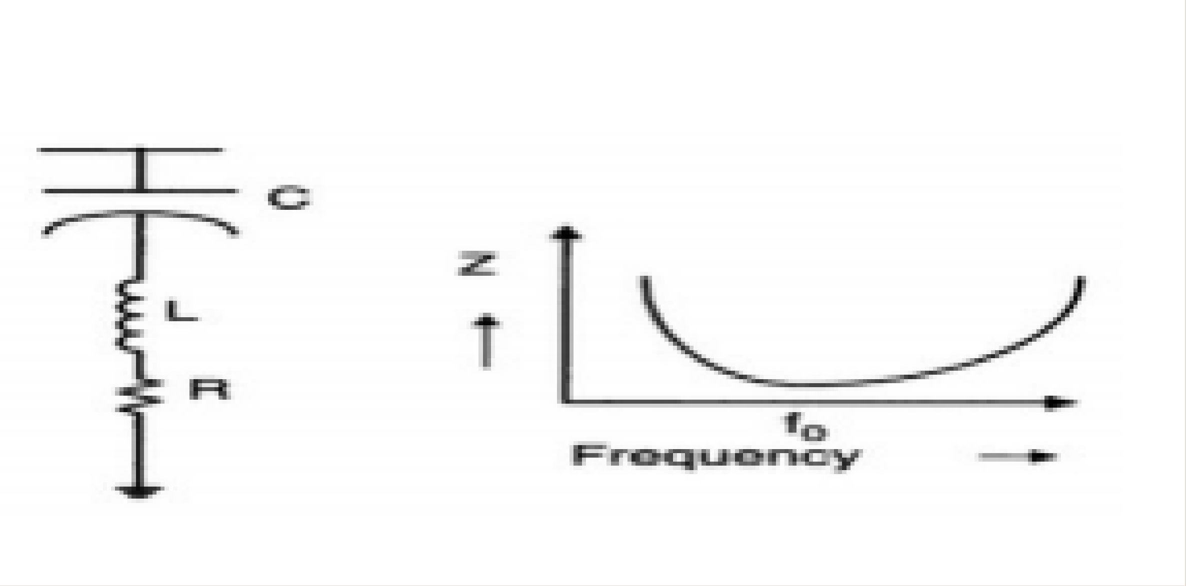
$$IT = \left[\sum_{n=2}^{m} (I_n F_n)^2 \right]^{1/2}$$

Types of AC filters:

- The various types of filters that are used are
  - Single Tuned Filter
  - Double Tuned Filter
  - High Pass Filter
    1. Second Order Filter
    2. C Type Filter

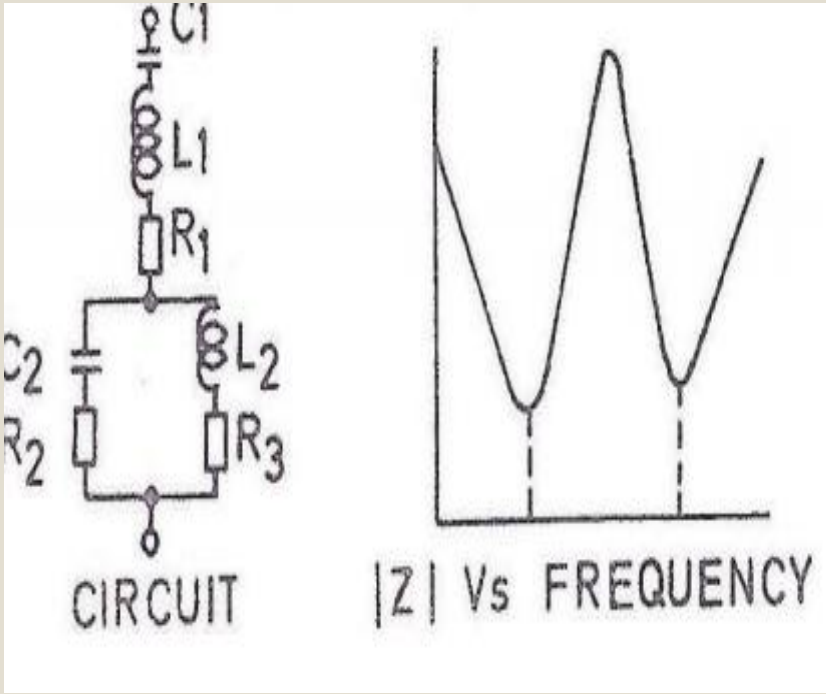
Single tuned filter:

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



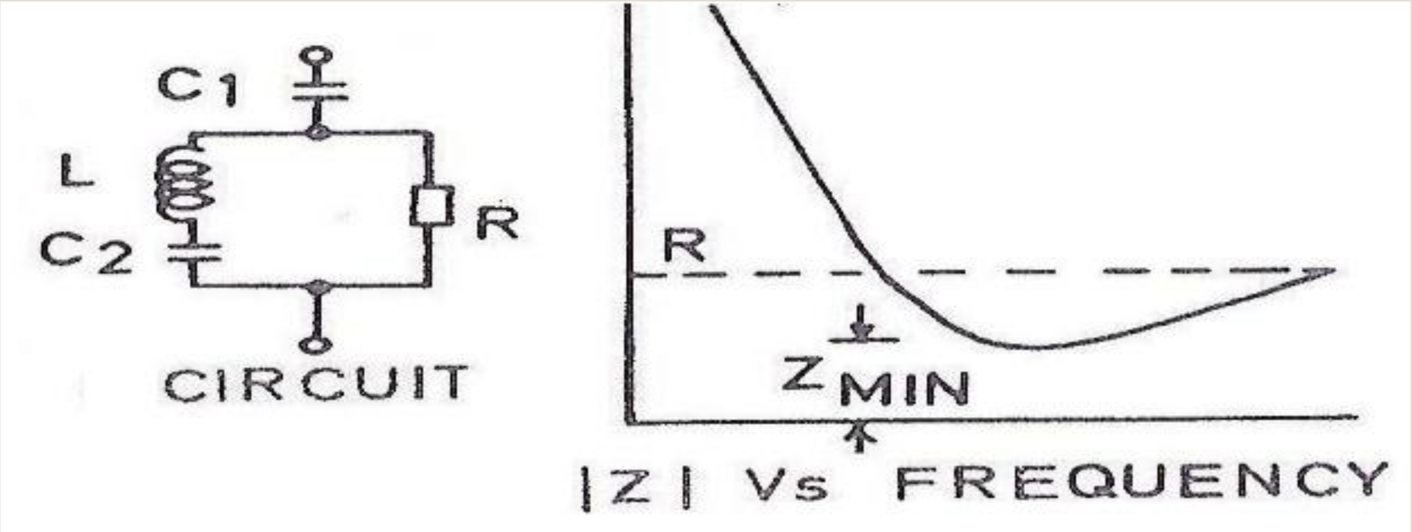
Double tuned filter

- The Double Tuned Filters are used to filter out two discrete frequencies, instead of using two Single Tuned Filters. Their main disadvantages are
  - only one inductor is subject to full line impulse voltage.
  - power loss at the fundamental frequency is considerably reduced.



High pass C type filter

- The losses at the fundamental frequency can be reduced by using a C Type Filter where capacitor C2 is in series with inductor L, which provides a low impedance path to the fundamental component of current. A converter system with 12 pulse converters has Double Tuned (or two Single Tuned) Filter banks to filter out 11th and 13th 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 3rd order particularly with weak AC systems where some voltage unbalance is expected. All filter branches appear capacitive at fundamental frequency and supply reactive power



Requirment of ratings:

Steady state calculation:

- The voltage and current stresses of AC filters consist of the fundamental frequency and harmonic components. Their magnitudes depend on the AC system voltage, harmonic currents, operating conditions and AC system impedances. The rating calculations are carried out in the whole range of operation to determine the highest steady-state current and voltage stresses for each individual filter component.

Transient Calculation:

- The objective of the transient rating calculation is to determine the highest transient stresses for each component of the designed filter arrangement. The results of the transient calculation should contain the voltage and current stresses for each component, energy duty for filter resistors and arresters, and the insulation levels for each filter component.

Requirement of ratings:

To calculate the highest stresses of both lightning and switching surge type, different circuit configurations and fault cases should be studied.

Single-Phase GroundFault

- The fault is applied on the converter AC bus next to the AC filter. It is assumed that the filter capacitor is charged to a voltage level corresponding to the switching impulse protective level of the AC busarrester.

Switching Surge

- For the calculation of switching surge stresses, a standard wave of 250/2500 with a crest value equal to the switching impulse protective level of the AC bus arrester is applied at the AC converterbus.

Dc filter circuits:

- Harmonic voltages which occur on the DC side of a converter station cause AC currents which are superimposed on the direct current in the transmission line. These alternating currents of higher frequencies can create interference in neighboring telephone systems despite limitation by smoothing reactors. DC filter circuits, which are connected in parallel to the station poles, are an effective tool for combating these problems. The configuration of the DC filters very strongly resembles the filters on the AC side of the HVDC station. There are several types of filter design. Single and multiple-tuned filters with or without the high-pass feature are common. One or several types of DC filter can be utilized in a converter station.

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 over currents 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.

UNIT IV

INTRODUCTION TO FACTS

FLEXIBLE AC TRANSMISSION SYSTEM

- FACTS

  AC transmission systems incorporating the power electronic-based to enhance controllability and increase power transfer capability.

- FACTS Controllers

  A power electronic based system & other static equipment that provide control of one or more AC transmission parameters.

BENEFITS OF USING FACTS

- Better utilization of existing transmission system assets
- Increased transmission system reliability and availability (lower vulnerability to load changes, line faults)
- Increased dynamic and transient grid
- Stability and reduction of loop flows
- Increased quality of supply for sensitive industries (through mitigation of flicker, frequency variations)
- Environmental benefits

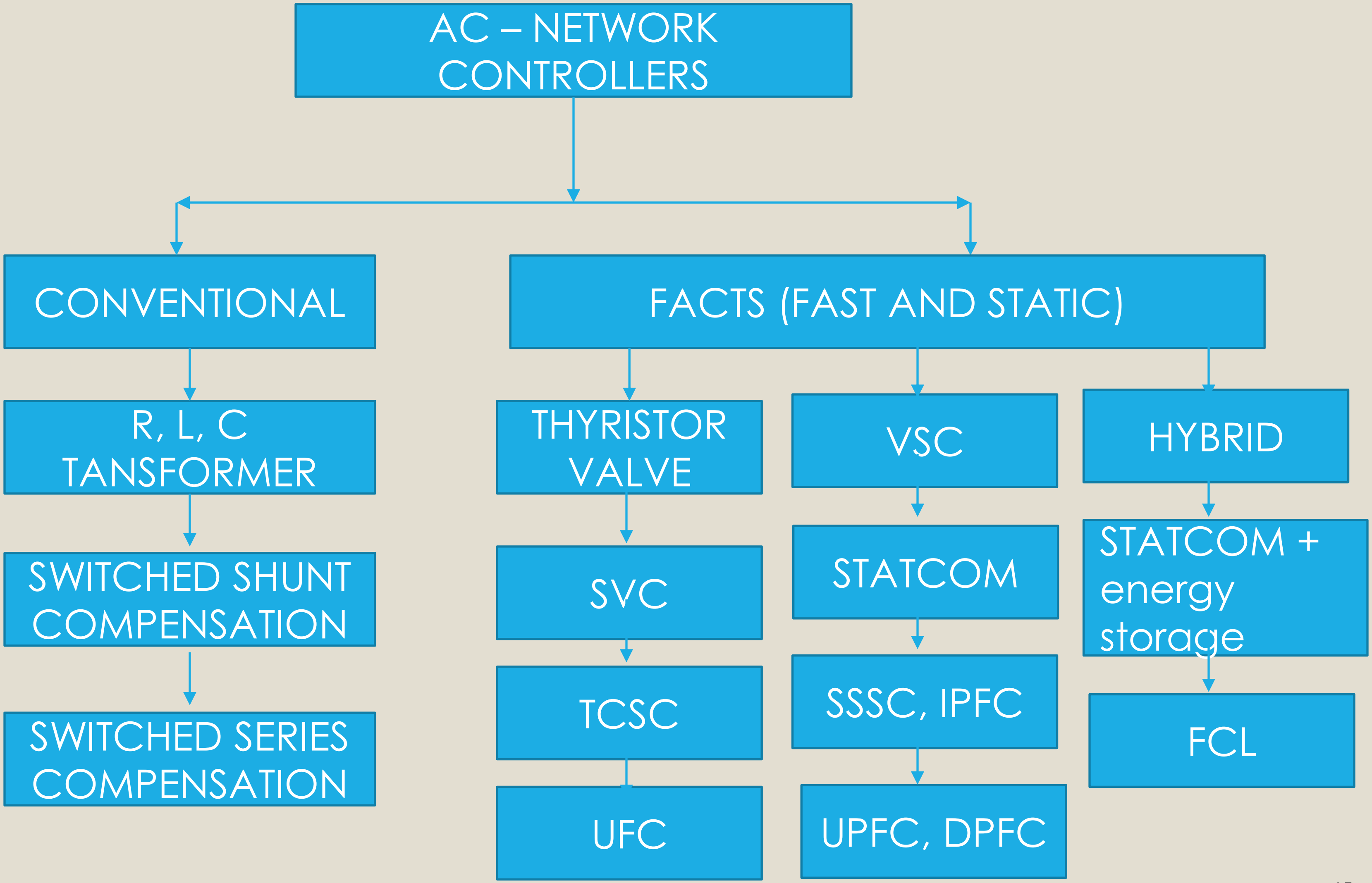
Power factor correction:

- The amount of Power Capacitor KVAR required to correct A system to a desired Power Factor level is the difference between the amount of KVAR in the uncorrected system and the amount of desired KVAR in the corrected system. The most efficient location for power factor capacitors is at the load. Capacitors work from the point of installation back to the generating source. Individual motor correction is not always practical, sometimes it is more practical to connect larger capacitors on the distribution bus or install an automatic system at the incoming service along with fixed capacitors at the load.

Power factor correction techniques:

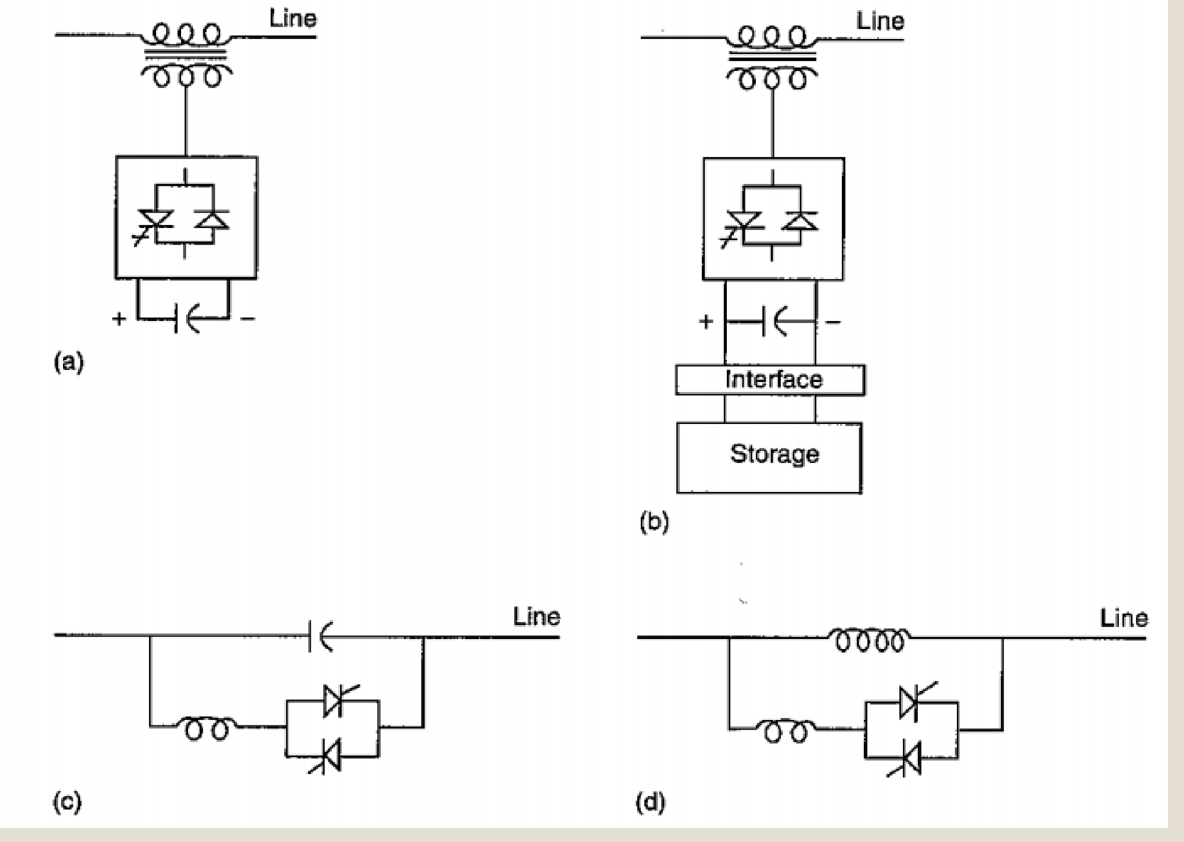
- Static VAR Compensator(SVC) •
  - Fixed Capcitors
  - Switch Capacitors
  - Synchronous Condensors
- Static Synchronous Compensator(STATCOM)
- Modulated power filter capacitor compensator

Overview of FACTS



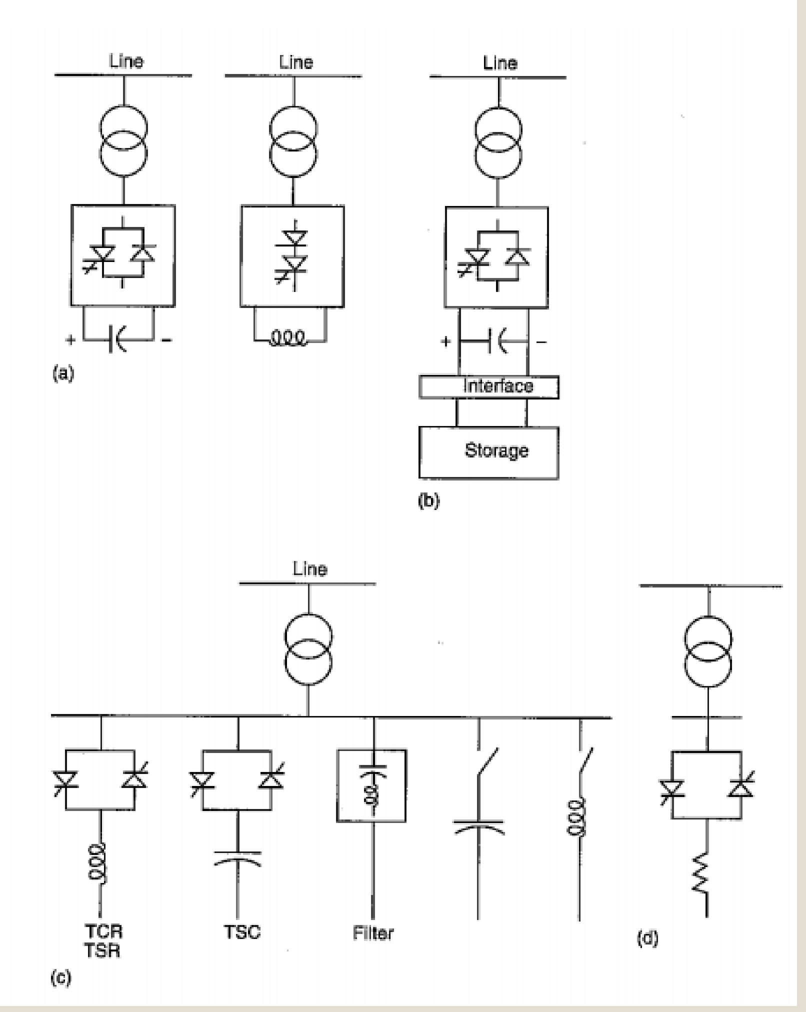
Basic FACTS controllers:

- **Series Controllers :** The series controller could be a variable impedance or a variable source both are power electronics based. In principle, all series controllers inject voltage in series with the line.



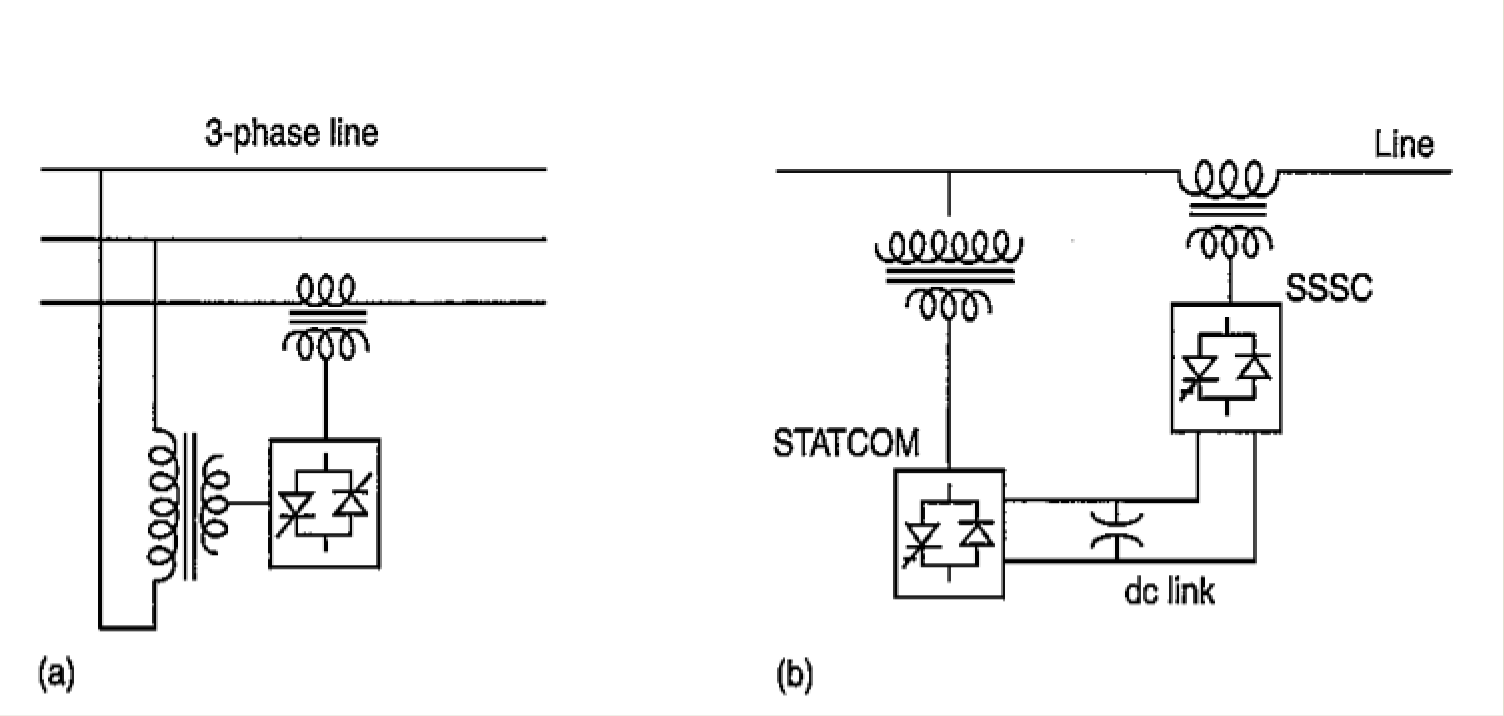
Basic FACTS controllers:

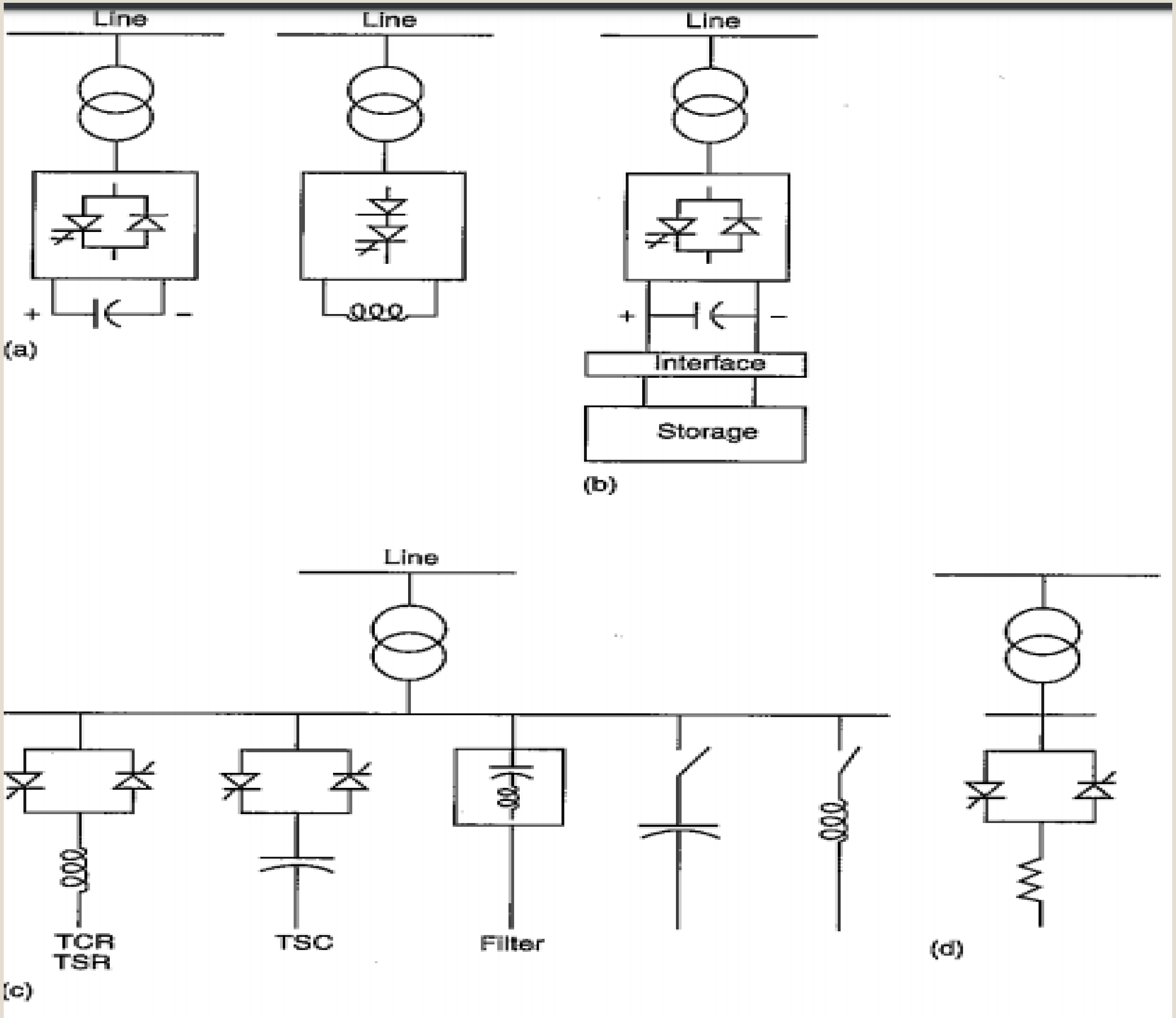
- **Shunt Controllers:** The shunt controllers may be variable impedance connected to the line voltage causes a variable current flow hence represents injection of current into the line.



Basic FACTS controllers:

- **Combined Series-series Controllers :**The combination could be separate series controllers or unified series-series controller-Interline Power Flow Controller.
- **Combined Series-shunt Controllers :** The combination could be separated series and shunt controllers or a unified power flow controller





Line
Line
Line
+
−
(a)
+
−
Interface
Storage
(b)
Line
TCR
TSR
TSC
Filter
(c)
(d)

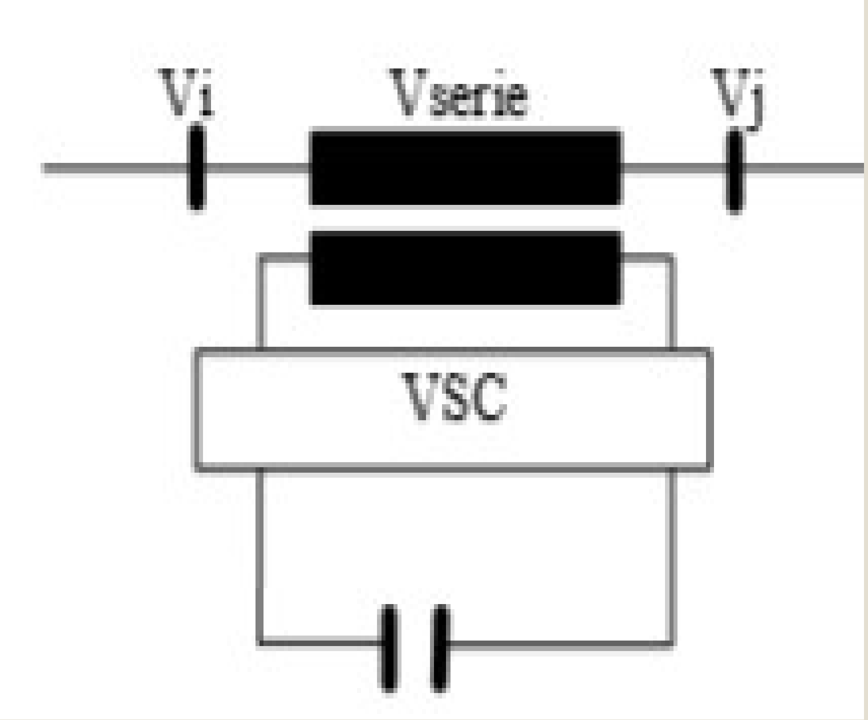
CLASSIFICATION OF FACTS

The FACTS device can be classified in TWO ways.

- Depending on the type of connection to the network
  - Serial controller
  - Derivation controller
  - Serial to serial controller
  - Serial derivation controllers
- Depending on technological features the FACTS devices can be divided into two generations:
  - First generation - uses thyristors with ignition controlled by door (SCR).
  - Second generation - semiconductors with ignition and extinction controlled by door (GTO, IGBT, etc.).

SERIAL CONTROLLER

- Consist of a variable impedance as a condenser, coil.
- Inject a serial tension(variable impedance multiplied by the current) to the line.
- Tension is in quadrature with the line current.
- Consumes reactive power.
- Ex: Serial Synchronous Static Compensator (**SSSC**).



CONTROLLERS IN DERIVATION

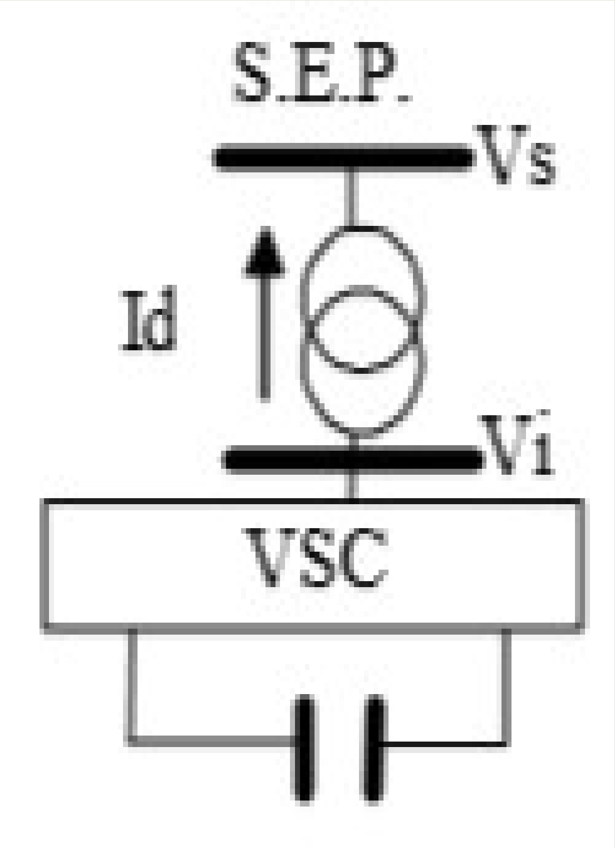
- Consist of a variable impedance, variable source or a combination of both.

- Inject current to the system in the point of connection. (variable impedance
  - connected to line tension causes variable current flow, thus injecting current to the line).

- While the injected current is in quadrature with the line tension.

- Consumes reactive power.

- Ex: Synchronous Static Compensator (**STATCOM**).



SERIAL – SERIAL CONTROLLERS

- Combination of coordinated serial controllers in a multiline transmission system or can also be an unified controller.
- The serial controllers provide serial reactive compensation for each line also transferring active power between lines through the link of power.
- The term “unified” means that the DC terminals of the converters of all the controllers are connected to achieve a transfer of active power between each other.
- Ex: Interline Power Flow Compensator (**IPFC**).

SERIAL DERIVATION CONTROLLERS

- Combination of serial and derivations controllers separated, co-ordinately controlled.
- Inject current to the system through the component in derivation of the controller, and serial tension with the line utilizing the serial component.
- When the serial and derivation controllers are unified, they can have an exchange of active power between them through their link.
- Ex: Unified Power Flow Controller (**UPFC**)

FIRST GENERATION OF FACTS :

- Static Compensator of VAR's (SVC, TCR)
- Tyristor Controlled Series Compensation (TCSC, TCSR)
- Tyristor Controlled phase shifting Transformer (TCPST)
- Tyristor Controlled voltage regulator (TCVR)

SECOND GENERATION OF FACTS :

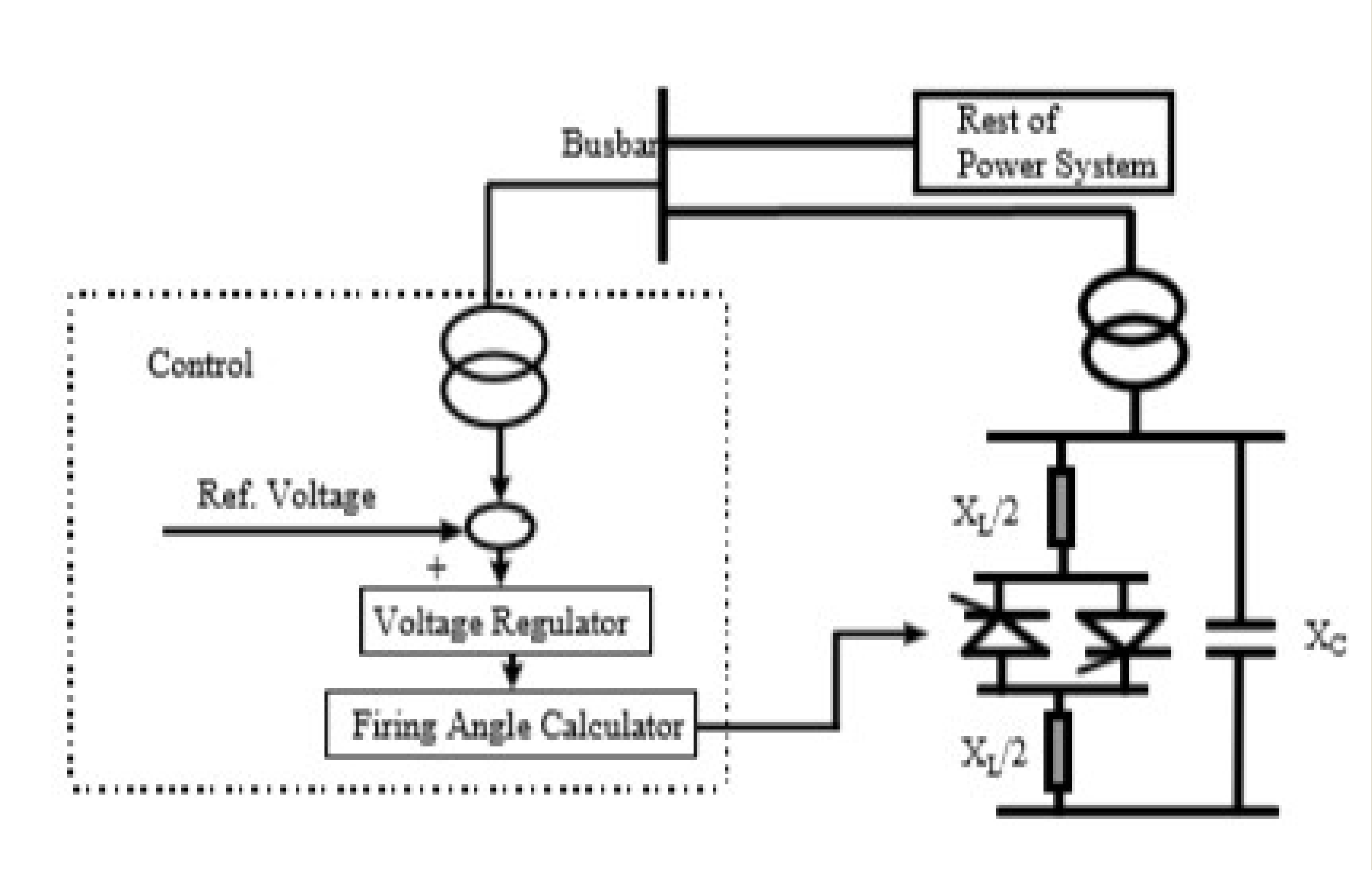
- Synchronous Static Compensator (STATCOM with and without storage)
- Static Synchronous Series Compensator (SSSC with and without storage)
- Unified Power flow Controller (UPFC)

  Interline Power Flow Controller (IPFC)

STATIC VAR COMPENSATOR

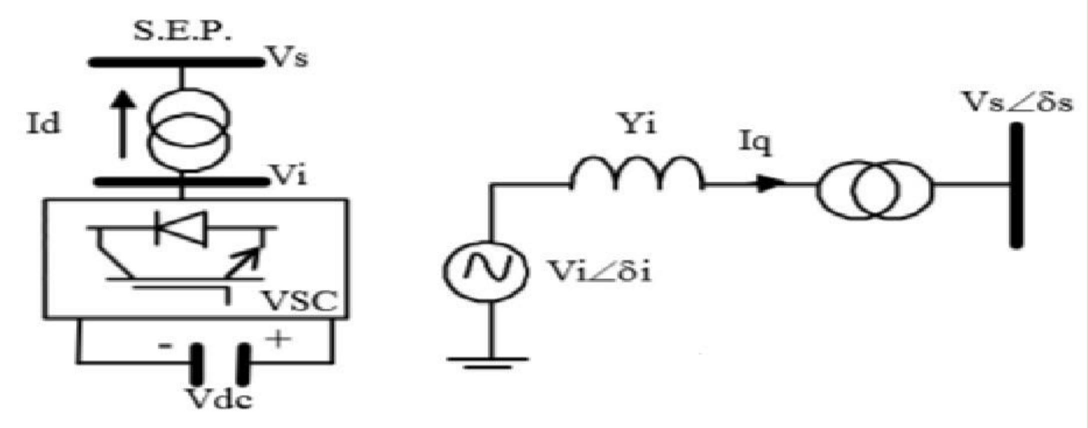
- Regulate voltage and stabilise(dynamic) the system.
- SVC is an automated impedance matching device, designed to bring the system closer to unity power factor.
- If load is capacitive (leading), the SVC will use reactors (in form of CR)
- Under inductive (lagging) ,the capacitor banks are automatically switched in.
- SVR may be placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage.

STATIC VAR COMPENSATOR

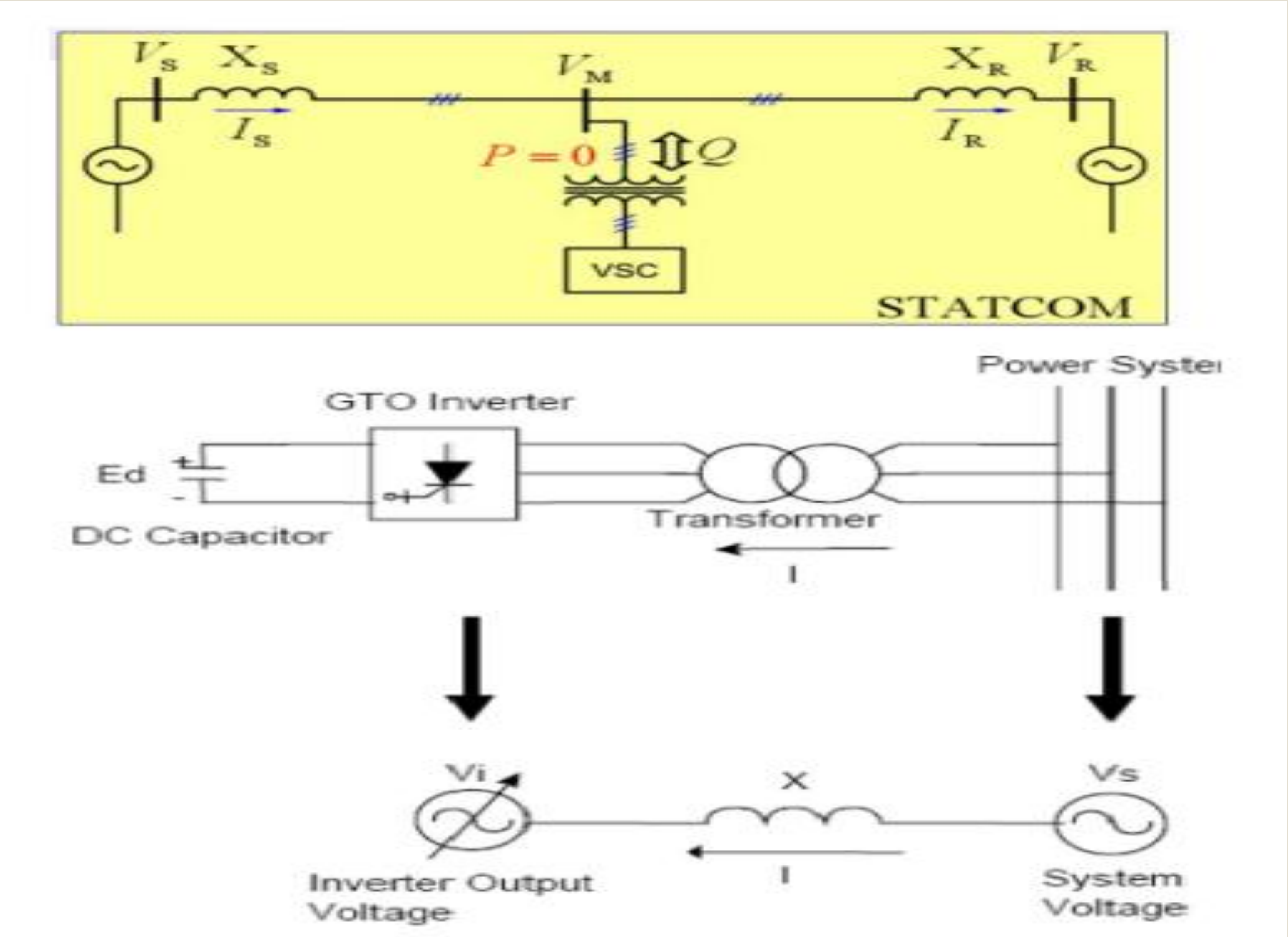


STATIC SYNCHRONOUS COMPENSATOR

- STATCOM is a regulating(poor power factor and poor voltage) device.
- Based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power.
- If connected to a source of power it can also provide active AC power.
- STATCOM provides better damping characteristics than the SVC as it is able to transiently exchange active power with the system.



Equivalent model of STATCOM



UNIT V

COMPENSATORS

SERIES COMPENSATION:

- The main purpose of series compensation in power systems is to decrease the reactive impedance of the transmission line to reduce voltage drop over long distances and to reduce the Ferranti effect. By adding series capacitors to the line, engineers can compensate for the physical inductance inherent in the transmission line. The voltage drop across the line is reduced with more compensation, allowing more power to be received by the load for any given sending power. Two main types of series compensation are fixed series compensation, and thyristor controlled series compensation, each with their own advantages.

FIXED SERIES COMPENSATION:

- Fixed series compensation (FSC) of a line is desirable for power transmission due to the effects of line reactance modification. By adding series capacitance, the reactive impedance of the line decreases, thus lowering the voltage drop across the transmission line. This effect can be seen through the simplified power flow equation (see the post about Power Transfer) obtained by neglecting line resistance and line charging capacitance.
- Line reactance is counteracted by a series capacitance, resulting in overall lower line impedance and a lower voltage drop across the line.
- By adding the series capacitance, it can be seen that the receiving line end voltage will be closer to the sending line end voltage. This decrease in voltage drop across the line allows more power to be transferred over the line for any given sending line end voltage.

METHODS OF CONTROLLABLE VAR GENERATION

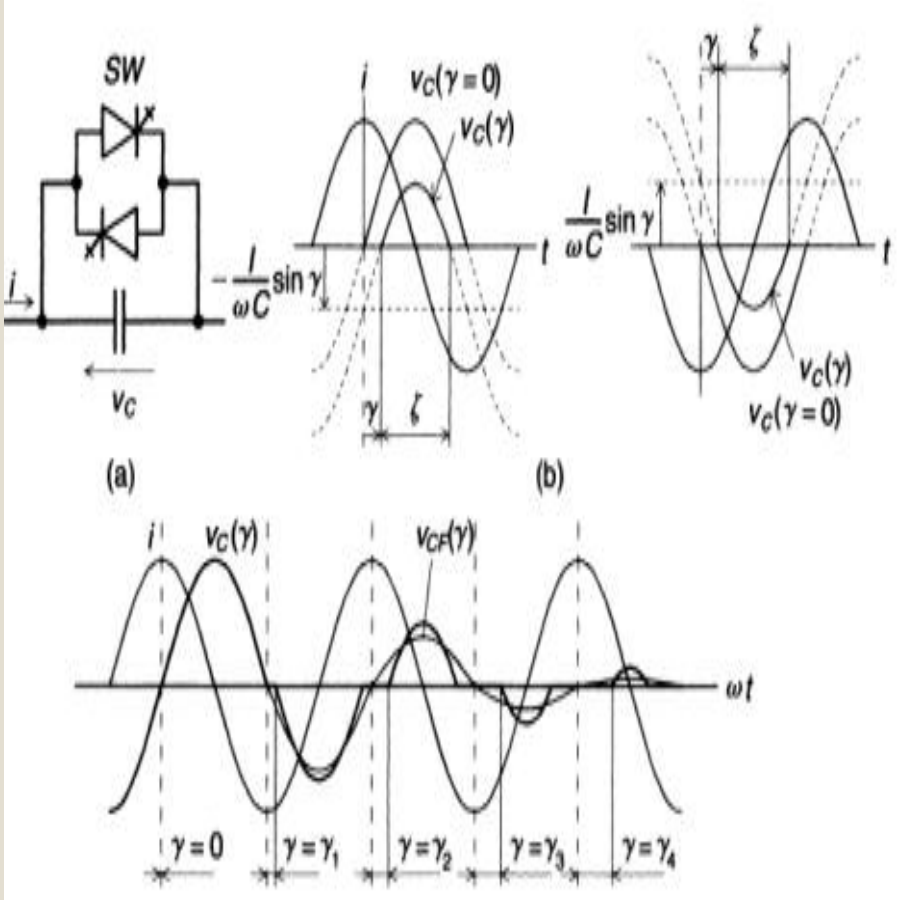
- VARIABLE IMPEDANCE TYPE STATIC VAR GENERATORS:
  - GTO THYRISTOR-CONTROLLED SERIES CAPACITOR (GCSC)
  - THYRISTOR-CONTROLLED SERIES CAPACITOR (TCSC)
  - THYRISTOR-SWITCHED SERIES CAPACITOR (TSSC)
- SWITCHING CONVERTER TYPE VAR GENERATORS
- STATIC SYNCHRONOUS SERIES COMPENSATOR (SSSC)

Basic operation of GSSC, TCSC, TSSC

- Structurally the internal controls for the three variable impedance type compensators (GCSC, TCSC, TSSC) could be similar. Succinctly, their function is simply to define the conduction and/or the blocking intervals of the valve in relation to the fundamental (power frequency) component of the line current. This requires the execution of three basic functions:
  - synchronization to the line current,
  - turn-on or turn-off delay angle computation, and
  - gate (firing) signal generation.
- These functions obviously can be implemented by different circuit approaches, with differing advantages and disadvantages. In the following, three possible internal control schemes are functionally discussed: one for the GCSC, and the other two for the TCSC power circuit arrangements. Either of the TCSC schemes could be adapted for the TSSC if sub synchronous resonance would be an application concern.

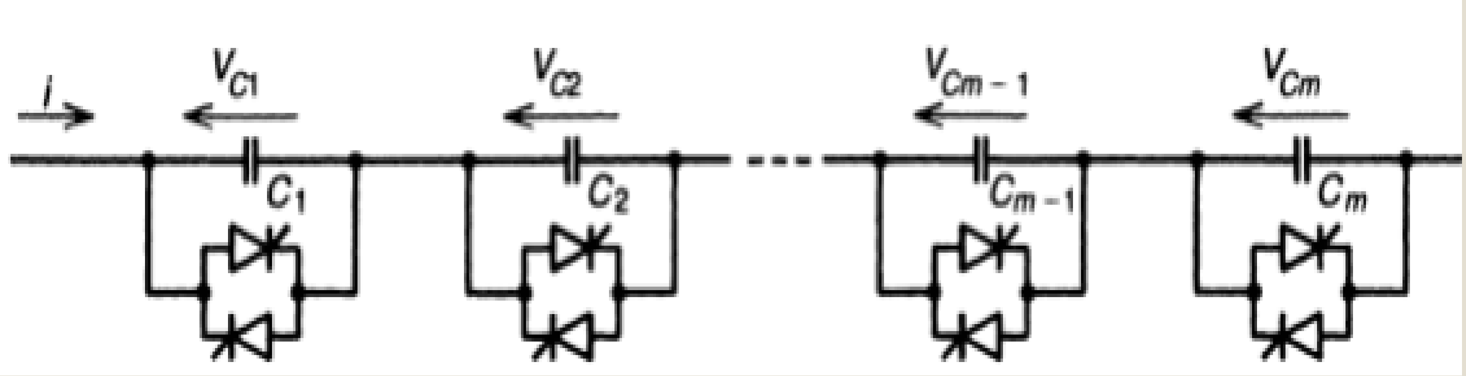
GTO THYRISTOR-CONTROLLED SERIES CAPACITOR (GCSC)

- The objective of the GCSC scheme shown is to control the ac voltage Vc across the capacitor at a given line current ic. Evidently, when the GTO valve, SW, is closed, the voltage across the capacitor .is zero, and when the valve is open, it is maximum. For controlling the capacitor voltage, the closing and opening of the valve is carried out in each half-cycle in synchronism with the ac system frequency.



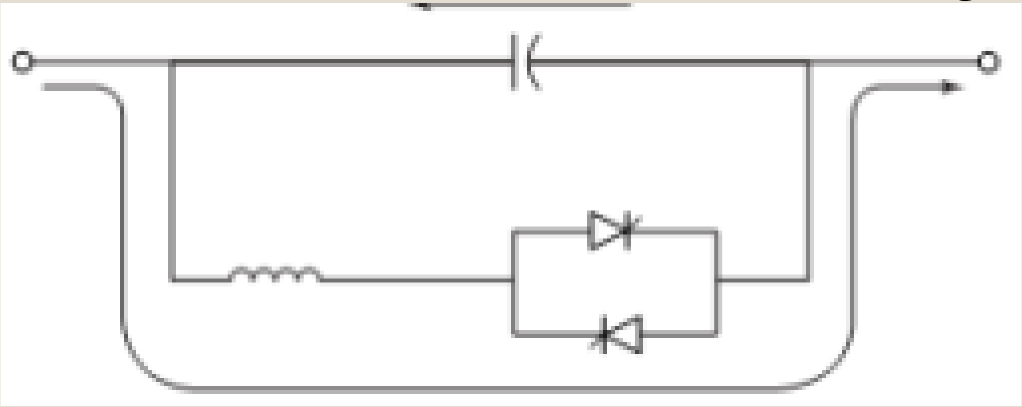
THYRISTOR-CONTROLLED SERIES CAPACITOR (TCSC)

- Its operation is different due to the imposed switching restrictions of the conventional thyristor valve. The operating principle of the TSSC is straightforward: the degree of series compensation is controlled in a step-like manner by increasing or decreasing the number of series capacitors inserted. A capacitor is inserted by turning off, and it is bypassed by turning on the corresponding thyristor valve. A thyristor valve commutates "naturally," that is, it turns off when the current crosses zero. Thus a capacitor can be inserted into the line by the thyristor valve only at the zero crossings of the line current. Since the insertion takes place at line current zero,



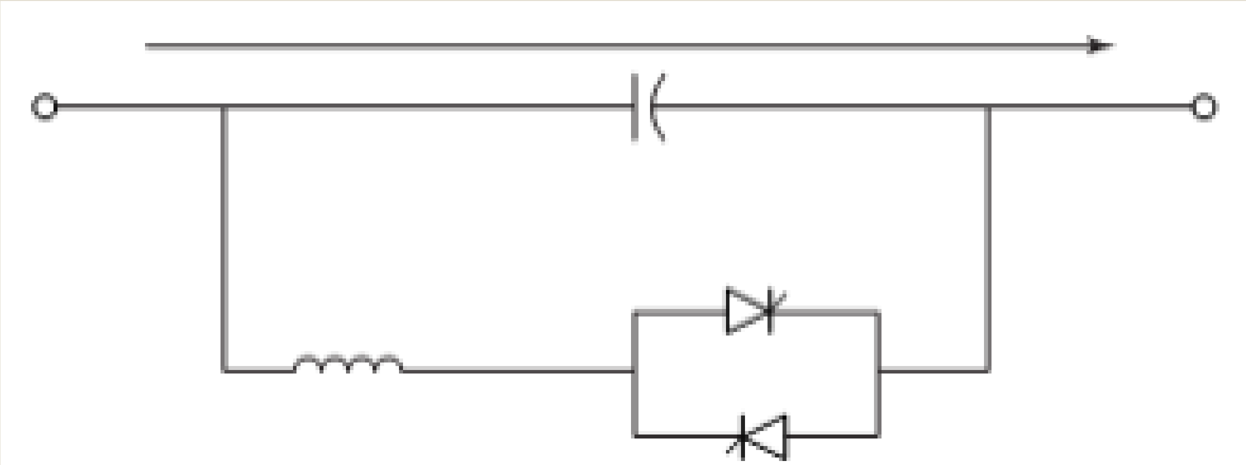
Modes of TCSC operation:

- **BYPASSED-THYRISTOR MODE:** In this bypassed mode, the thyristors are made to fully conduct with a conduction angle of 1800. Gate pulses are applied as soon as the voltage across the thyristors reaches zero and becomes positive, resulting in a continuous sinusoidal of flow current through the thyristor valves. The TCSC module behaves like a parallel capacitor–inductor combination. However, the net current through the module is inductive, for the susceptance of the reactor is chosen to be greater than that of the capacitor. Also known as the thyristor-switchedreactor (TSR) mode, the bypassed thyristor mode is distinct from the bypassed-breaker mode, in which the circuit breaker provided across the series capacitor is closed to remove the capacitor or the TCSC module in the event of TCSC faults or transient over voltages across the TCSC.



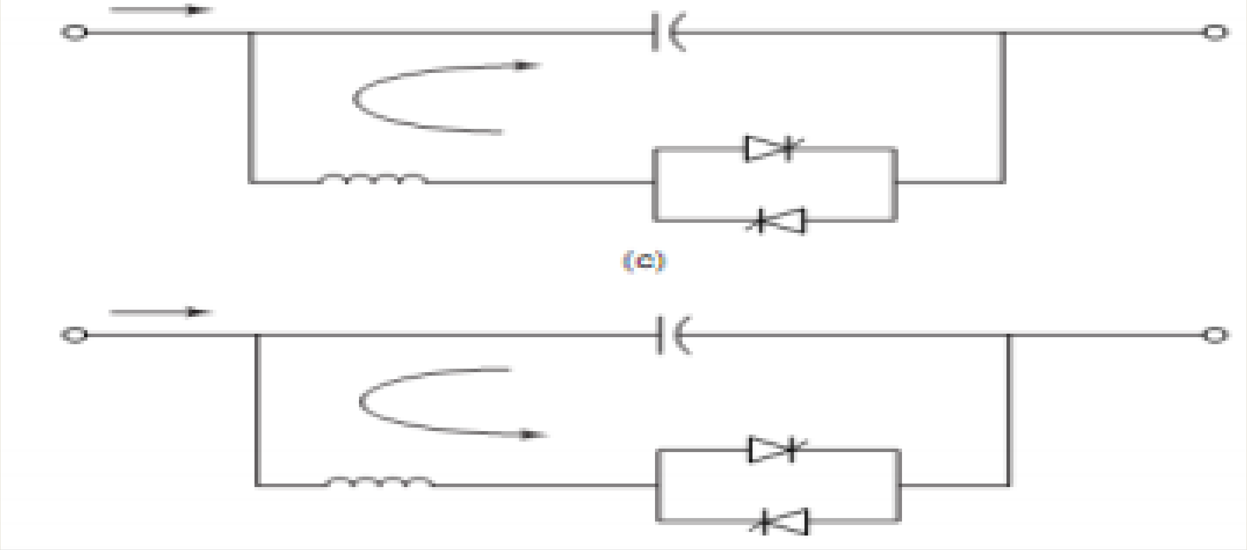
Modes of TCSC operation:

- **BLOCKED-THYRISTOR MODE:** In this mode, also known as the waiting mode, the firing pulses to the thyristor valves are blocked. If the thyristors are conducting and a blocking command is given, the thyristors turn off as soon as the current through them reaches a zero crossing. The TCSC module is thus reduced to a fixed-series capacitor, and the net TCSC reactance is capacitive. In this mode, the dc-offset voltages of the capacitors are monitored and quickly discharged using a dc-offset control without causing any harm to the transmission-system transformers.



Modes of TCSC operation:

- **Partial conduction:** This mode allows the TCSC to behave either as a continuously controllable capacitive reactance or as a continuously controllable inductive reactance. It is achieved by varying the thyristor-pair firing angle in an appropriate range. However, a smooth transition from the capacitive to inductive mode is not permitted because of the resonant region between the two modes. A variant of this mode is the capacitive-vernier-control mode, in which the thyristors are fired when the capacitor voltage and capacitor current have opposite polarity



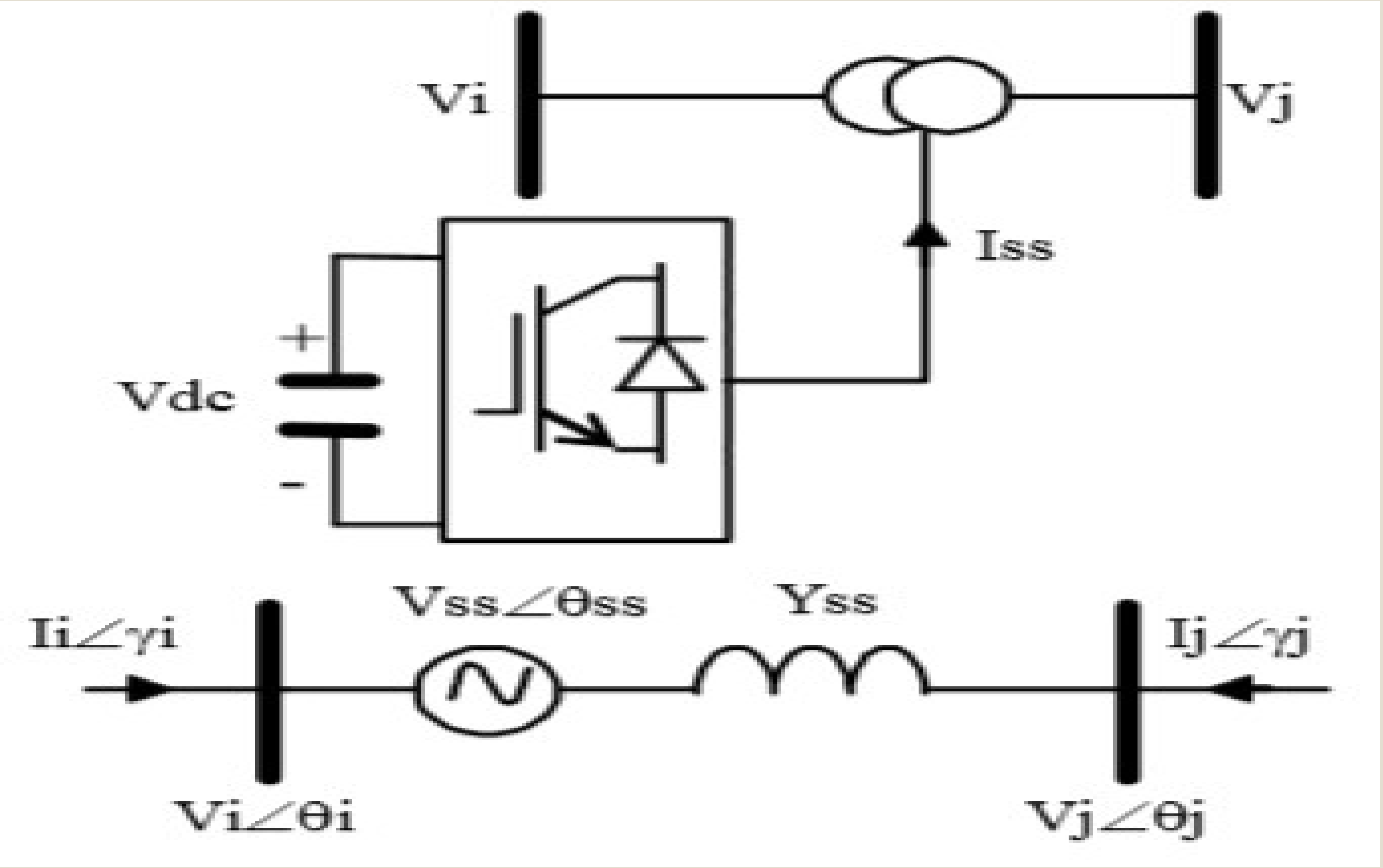
Advantages of TCSC

- Use of thyristor control in series capacitors potentially offers the following little-mentioned advantages:
- Rapid, continuous control of the transmission-line series-compensation level.
- Dynamic control of power flow in selected transmission lines within the network to enable optimal power-flow conditions and prevent the loop flow of power.
- Damping of the power swings from local and inter-area oscillations.
- Suppression of subsynchronous oscillations. At subsynchronous frequencies, the TCSC presents an inherently resistive–inductive reactance. The subsynchronous oscillations cannot be sustained in this situation and consequently get damped.
- Decreasing dc-offset voltages. The dc-offset voltages, invariably resulting from the insertion of series capacitors, can be made to decay very quickly (within a few cycles) from the firing control of the TCSC thyristors.
- Enhanced level of protection for series capacitors. A fast bypass of the series capacitors can be achieved through thyristor control when large over voltages develop across capacitors following faults. Likewise, the capacitors can be quickly reinserted by thyristor action after fault clearing to aid in system stabilization

STATIC SYNCHRONOUS SERIES COMPENSATOR

- Works the same way as the STATCOM.
- It has a VSC serially connected to a transmission line through a transformer.
- A SSSC is able to exchange active and reactive power with the transmission system.
- Thus SSSC can work like a controllable serial condenser and serial reactor.
- The voltage injected through a SSSC is not related to the line intensity and can be controlled independently.
- As a result SSSC can give good results with low loads as well as high loads.

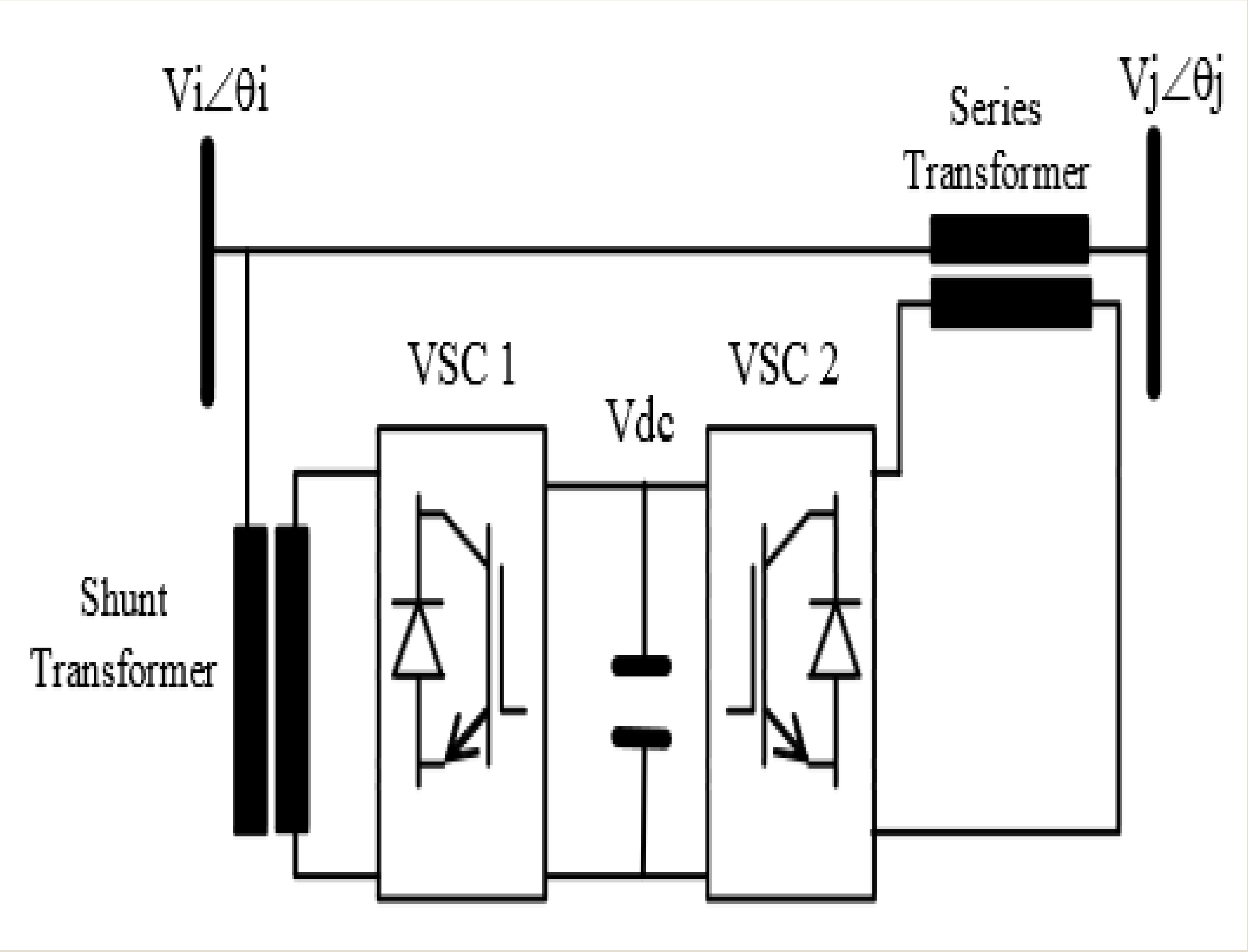
STATIC SYNCHRONOUS SERIES COMPENSATOR



UNIFIED POWE FLOW CONTROL

- A UPFC system can regulate the active and reactive power at same time.
- It has the ability to adjust the three control parameters(bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently).
- The converter 2 has the main function of the UPFC; it injects an AC voltage to the line, where magnitude and phase angle are controllable through a serial transformer.
- Converter 1 give or absorb the real power that the converter 2 demands.

UNIFIED POWE FLOW CONTROL



Reactive power control:

- In high voltage direct current (HVDC) converters, the stations are line commutated. This implies that the initial current of the valve can only be delayed in reference a zero value of the converter bus voltage in AC form. Consequently, for better control of voltage, the converter bus is connected to a reactive power source.
- Reactive power sources are used to vary capacitors in static systems. The response of the reactive power system is dictated by voltage control in dynamic conditions.
- When operating unstable AC systems, problems tend to arise because of unstable voltage and overvoltage surges. A better coordination of reactive power sources is required to simplify the control of the firing angles. As a result, this feature of the reactive power converter is increasingly being applied in modern converters using HVDC.

Reactive power control in steady state:

- The equations expressing reactive power as a function of active power are given in terms of unit quantities.

Base converter voltage is given by −

$$V_{db} = 3\sqrt{\frac{2}{\pi}} \times V_L$$

Where $\mathbf{V_L}$ = Line to line voltage (on winding side)

Base DC Current (I_{db}) = Rated DC Current **(I_{dr})**

Base DC Power (P_{dc}) = $n_b \times V_{db} \times I_{db}$, where $\mathbf{n_b}$ = number of bridges in series

BaseBase AC voltage (V_b) = **(V_a)**

-

TECHNICAL BENIFITS

	Load Flow Control	Voltage Control	Transient stability	Dynamic Stability
SVC	LESS	HIGH	LOW	MEDIUM
STATCOM	LESS	HIGH	MEDIUM	MEDIUM
TCSC	MEDIUM	LESS	HIGH	MEDIUM
UPFC	HIGH	HIGH	MEDIUM	MEDIUM

MAINTANANCE OF FACTS

- Is minimal and similar to that required for shunt capacitors, reactors and transformers

- The amount of maintenance ranges from 150 to 250 man-hours per year

Operation of FACTS devices

  - operated automatically

  - can be done locally and remotely

APPLICATION OF FACTS

- Steady state voltage stability
- Power flow control
- Damping of power system oscillations
- Reducing generation costs
- HVDC link application
- Deregulated power systems
- Flicker mitigation
- Interconnection of renewable, distributed generation and storages.

FUTURE ENHANCMENTS OF FACTS

- Several FACTS devices have been introduced for various application world-wide.

- A number of new types of devices are in the stage of being introduced in practice.

- Many new devices are under research process, such as HFC (Hybrid Flow Controller)
  - RHFC (Rotary Hybrid Flow Controller) DPFC (distributed power flow controller)
  - C-UPFC (center node) and many more…….

Thank you….