Thyristor Valve

Defination of a Thyristore :→

→ A Thyristore is a solid state and four layered semiconductor used in electronic devices and equipment to control electrical power or current o/p through a phase angle control technique.

→ A thyristor is also known as a semiconductor-controlled or silicon controlled rectifier (SCR).

→ Thyristores are primarily designed to amplify and rectify the electrical currents that flow in high powered electronic devices.

→ A thyristore is basically an on-off switch to control the o/p power of an electrical ckt by switching on or off the load ckt in intervals of time.

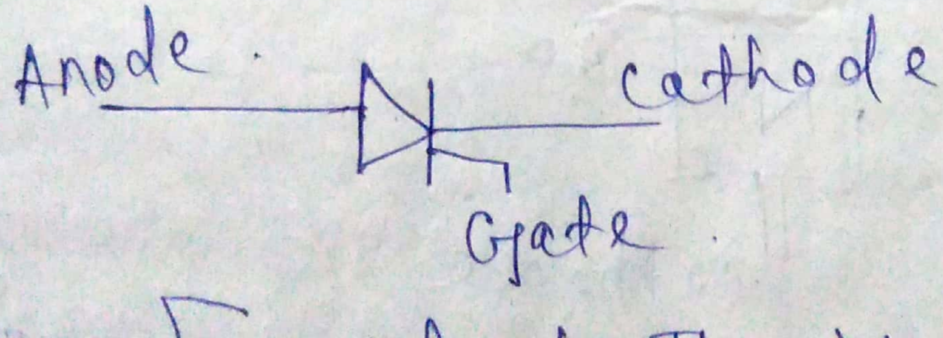
→ A thyristore is a unidirectional semiconductor solid state device with 4 layers of alternating p-type & N-type material.

It consists of 3 electrodes i.e. Anode, cathode and a gate terminal.

→ Anode is the (+)ve terminal, and cathode is the (−)ve terminal.

→ The gate controls the flow of current betn the anode and the cathode. It is used in the electronic devices and equipment to control the electric power or current. It acts as a rectifier and can onely transmits current in one direction.

→ The first thyristor was produced in the year 1956. The most common type of thyristor is Silicon controlled Rectifier (SCR).

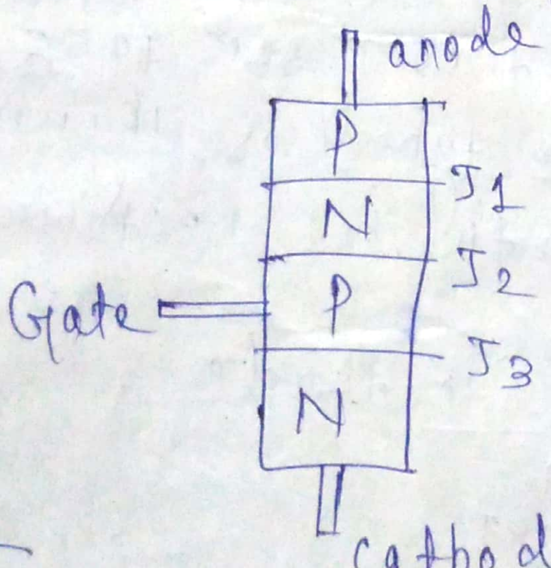


[symbol of Thyristor]

principle of operation of Thyristors

→ A thyristor acts like a diode. It has two layers of semiconductors namely p-type & n-type connected together to form a junction.

→ The anode is connected to the outer p-layer, cathode to the outer n-layer and gate to the internal p-layer. It has 3 junctions namely J_1, J_2 and J_3.



[Layer diagram of Thyristor]

→ Now when the (+)ve potential is increased beyond the (→ [illegible]) breakdown voltage, breakdown of junction J_2 takes place and it starts conducting.

→ Once the breakdown has occurred, it continues to conduct irrespective of the gate voltage until the potential at the anode is removed or current through the device is made less than the holding current.

→ Now, when a (+)ve potential is applied at the gate terminal with respect to cathode, the breakdown of junction J_2 takes place. To switch ON the thyristor quickly, an appropriate potential value has to be selected.

→ The gate acts as a controlling electrode. When a small voltage known as gate pulse is applied to its gate, the device is triggered in to conduction state. This continues until the voltage across the device is reversed or removed.

<u>breakdown voltage</u> :→ The voltage at which an insulator ruptures or at which ionization & conduction takes place in a gas or vapour.

Trigger:→ The signal used to initiate a sweep on an oscilloscope and determine the beginning point of the trace.

Voltage Ampere (VI) characteristic of Thyristor:→

→ Thyristors can either be forward biased or reverse biased.

① Thyristor in Forward Biased State:

→ When anode is made (+)ve, the PN junctions at the ends are forward biased and center junction becomes reverse biased. It will stay in blocked (OFF) mode (also known as forward Blocking stage) till the time it is triggered by Gate current pulse or the applied voltage reaches the forward breakover voltage.

Triggering by Gate current pulse:→

→ When it is triggered by the gate current pulse, it starts conducting and will act as a close switch.

The thyristors remains in the ON-state, i.e. it remains in the latched state. Here the gate losses its control to turn off the device.

Triggering by Forward Breakover voltage :→

→ When a forward voltage is applied, a leakage current starts to flow through the blocking (J_2) in the middle junction of Thyristors. When voltage exceeds the forward breakover voltage or critical limit, then J_2 breaks down and it reaches to the ON state.

→ When the gate current (I_g) is increased, it reduces the blocking area and so the forward breakover voltage is reduced. It will turn 'ON' when a minimum current called latching current is maintained.

→ When the gate current, $I_g = 0$ and anode current falls below a certain value called holding current during the ON state, it again reaches to its forward blocking state.

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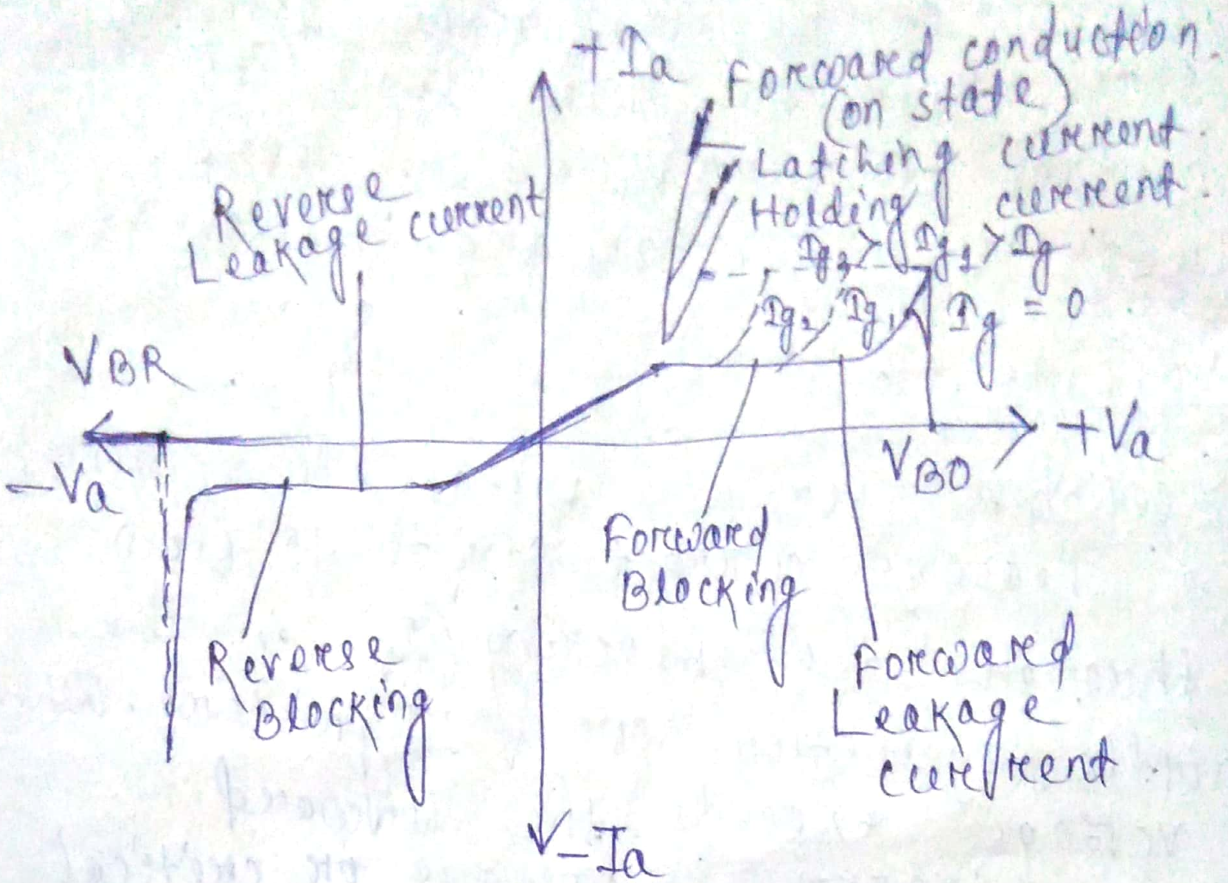


V_{BO} = Forward Breakover voltage
V_{BR} = Reverse Breakover voltage

Thyristor in Reverse Biased state :→

→ If the anode is (−)ve with respect to cathode i.e with the application of reverse voltage, both PN junctions at the end i.e. J_1 and J_3 become reverse biased and the centre junction J_2 becomes forward biased. Only a small leakage current flows through it. This is the reverse voltage Blocking mode or off state of Thyristor.

→ When the reverse voltage is increased further, then at a certain voltage avalanche breakdown of J_1 & J_2 occurs and it starts conducting in the reverse direcⁿ. The maxᵐ reverse voltage at which a thyristor starts conducting is known as Reverse Breakdown voltage.

Summary :→

→ Thyristor blocks the voltage in both forward and reverse direction and thus a symmetric blocking is formed.

→ A thyristor turns ON by the application of (+)ve gate current and turns OFF when the anode voltage drops to zero.

Modes of operation of Thyristor :→

→ A thyristor has 3 operating modes. They are :→

(1) Forward Blocking.
(2) Reverse Blocking
(3) Forward conducting.

(1) Forward Blocking :- In this state or mode, the forward current conduction is blocked. The upper diode and lower diode are forward biased and the junction in the centre is reverse biased. Thus, the thyristor does not turn on as the gate is not fired and no current flows through it.

(2) Reverse Blocking :- In this mode, the connection of anode & cathode is reversed and still no current flows through it.

→ Thyristors can conduct current only in one direction and it blocks in the reverse direction and so the flow of current is blocked.

(3) Forward conducting :- When the current is applied to the gate, the Thyristor is triggered and it will start conducting. This stays on until the forward current drops below the threshold value and that can be achieved by switching off the ckt.

Thyristor valve :-

Introduction :-

→ HVDC converters are an assembly of valves which have the property of conducting in the forward direction and blocking in the reverse directions.

→ The term "valve" carried over from the mercury is applied even now for thyristor valves which are made up of series and parallel connection of many thyristor cells or devices.

Valve firing :-

→ The basic valve firing scheme the valve control generates the firing signals. Each thyristor level receives the signal directly from a separate fibre-optic cable. Thus each thyristor level is independent and sharing only a duplicated light source at the group potential.

→ The valve control unit also includes many monitoring and protective functions. The return pulse system coupled with short pulse firing scheme is used in present day valve control units.

<u>Valve protection</u> :→ It defines the tests for checking the mechanical strength and physical properties of the valve protection cap or valve guard. This international standard applies to valve protection devices to be fitted to gas cylinders intended for liquified, dissolved or compressed gasses.

<u>Valve Tests</u> :→ Valve "type testing" is a new protocol where valves are tested at the operating pressure and temperature ranges specified by the manufacturer.

→ This requires that some valves are tested at temperatures down to the range or over 1000 degrees Farenhite

→ In addition to the temperature and pressure testing extremes, the valves are also often required to be tested emissions leakage during the test program. United valve can perform type testing on valves of all sizes, materials and types.

Recent trends of HVDC valves :→

The worldwide trend in the evolution of high voltage thyristor valves is reviewed, using HVDC applications as an example.

→ The key technologies involved are identified. It is shown that the move towards direct light triggered thyristors (LTT) is but the most recent step in a continuous effort to simplify high voltage thyristor valve technology and make it more reliable.

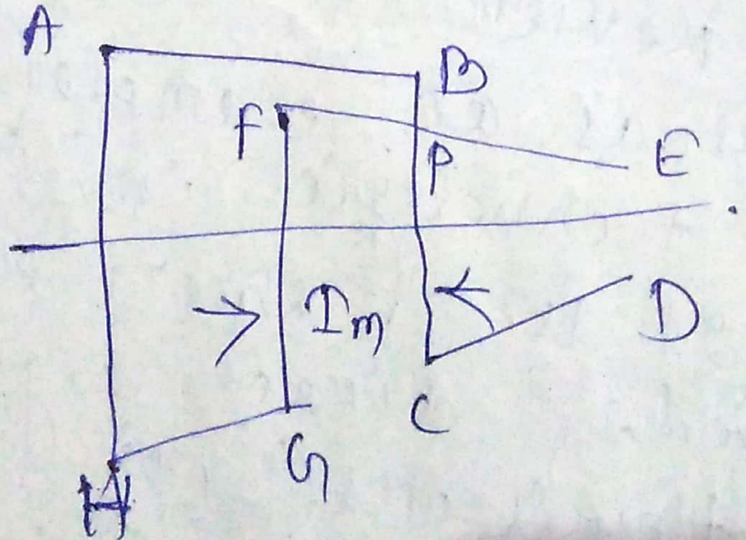
Converter And HVDC system control

principle of DC link control :→

→ The control of power in a DC link can be achieved through the control of current or voltage. From minimization of loss considerations, we need to maintain constant voltage in the link and adjust the current to meet the required power.

Converter control characteristics

Basic characteristics :→



[Controller characteristics]

→ The intersection of the two characteristics (point A) determines the mode of operation station-1 operating as rectifier with constant current control and station-2 operating at constant (minimum) extinction angle.

→ There can be 3 modes of operation of the link (for the same direction of power flow) depending on the voltage of the rectifier which determines the intersection of the 2 characteristics.

1. ~~with~~ one at rectifier and one 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 at the inverter with minimum 'α' at the rectifier.

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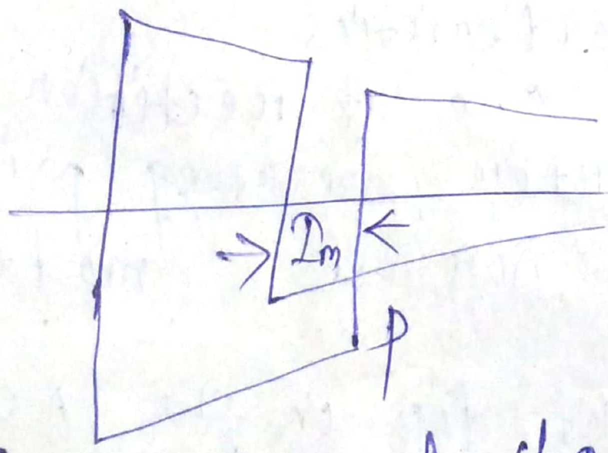
Types of station control characteristics :→

station-1	station-2	controller type
AB	HG	minimum α
BC	GF	constant current
CD	EF	minimum γ

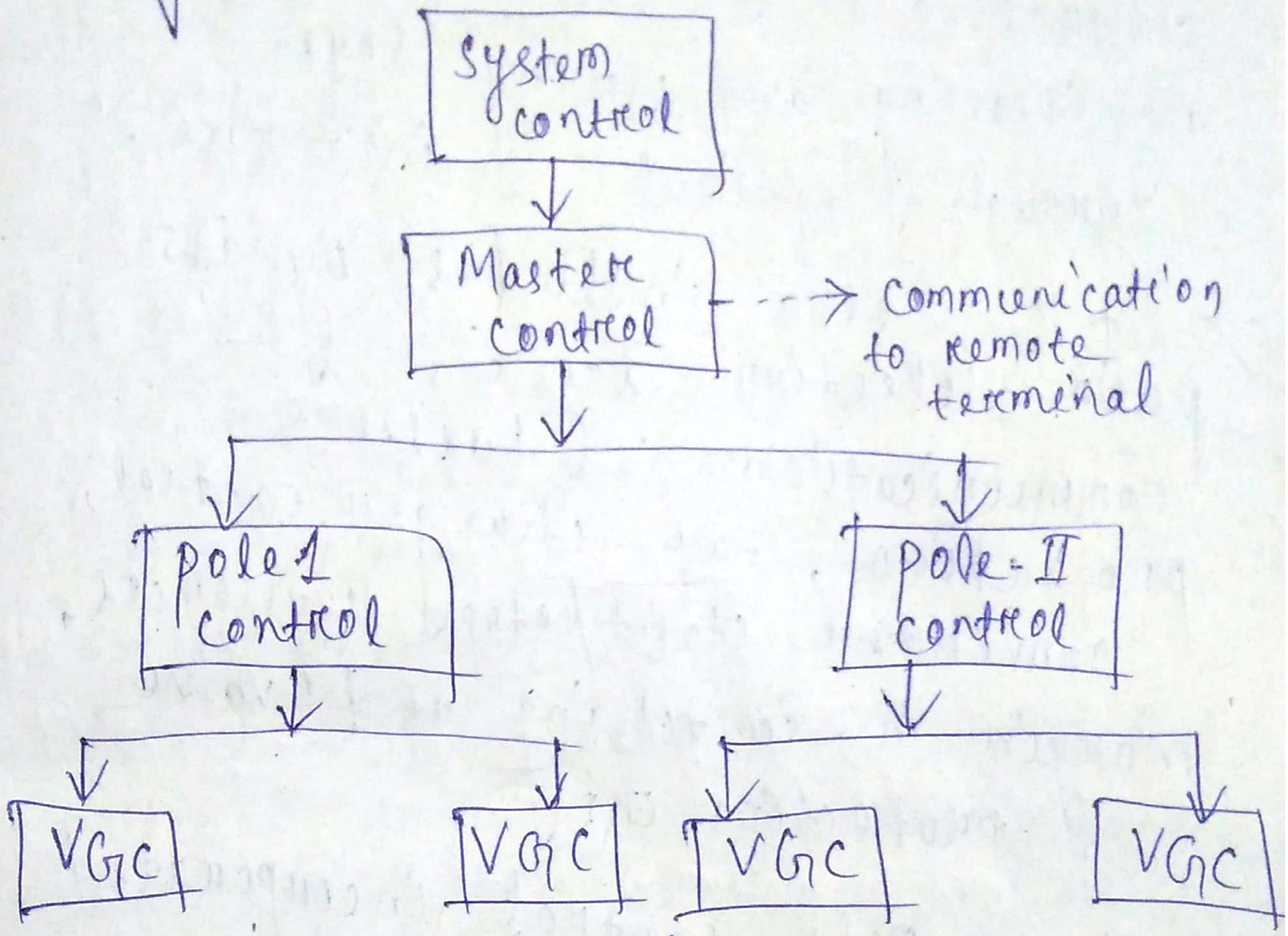


power reversal characteristics

→ This figure shows the control characteristics for negative current margin. When the current reference of station-II is larger than that of station-I.

System control Hierarchy :-

→ The control function required for the HVDC link is performed using the hierarchical control structure.



VGC → Valve Group control.

→ The master control for a bipole is located at one of the terminals and is provided with the power order from the system controller.

→ It also has other information such as AC voltage at the converter bus, DC voltage etc.

→ The valve group or converter control also oversees valve monitoring and firing logic through optical interface.

→ It also includes bypass pair selection logic, communication failure protection, tap changer control, converter start/stop sequences, margin in switching and valve protection ckt.

→ The pole control incorporated the pole protection, DC line protection and optional converter paralleling and deparalleling sequences.

→ The current or extinction angle controller generates a control signal which is related to the firing angle required.

The firing angle controller generates gate pulses in response to the control signal.

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 following are the 2 basic requirements for the firing pulse generation of HVDC valves.

(1) The firing instant for all the valves are determined at ground potential and the firing signals sent to individual thyristors by light signals for this electrically triggered thyristor (ETT) and light triggered thyristor (LTT) valves are used.

(2) The gate pulse generator must send a pulse whenever required.

→ In HVDC link, there are two basic firing schemes;

(1) Individual phase control (IPC)
(2) Equidistant pulse control (EPC)

(1) Individual phase control (IPC) :→

→ 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 communication voltages.

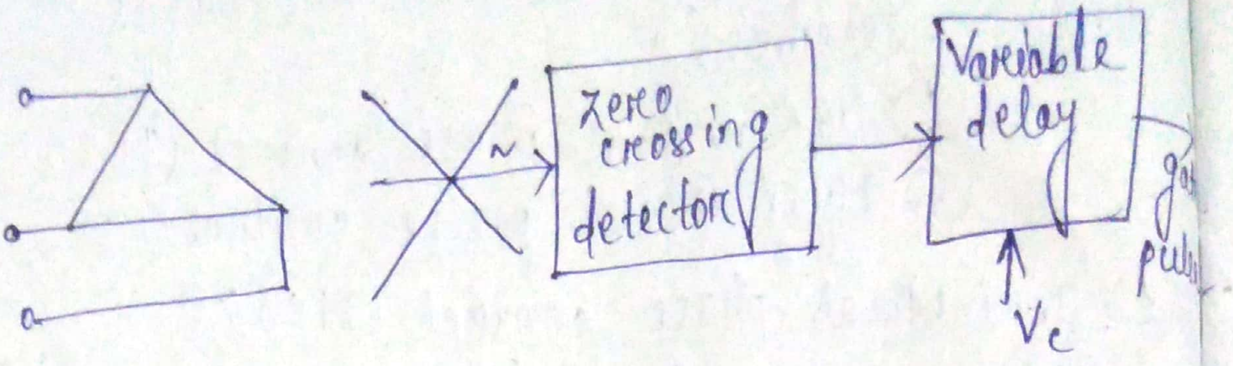
→ There are 2 ways in which this can be achieved. These are :→

(a) constant α control
(b) Inverse cosine control

(a) Constant α control :→

→ Communication voltages (six timing voltages) are derived from the converter AC bus via voltage transformers and the gate pulses are generated at nominally identical delay times subsequent to the respective voltage of zero crossings.

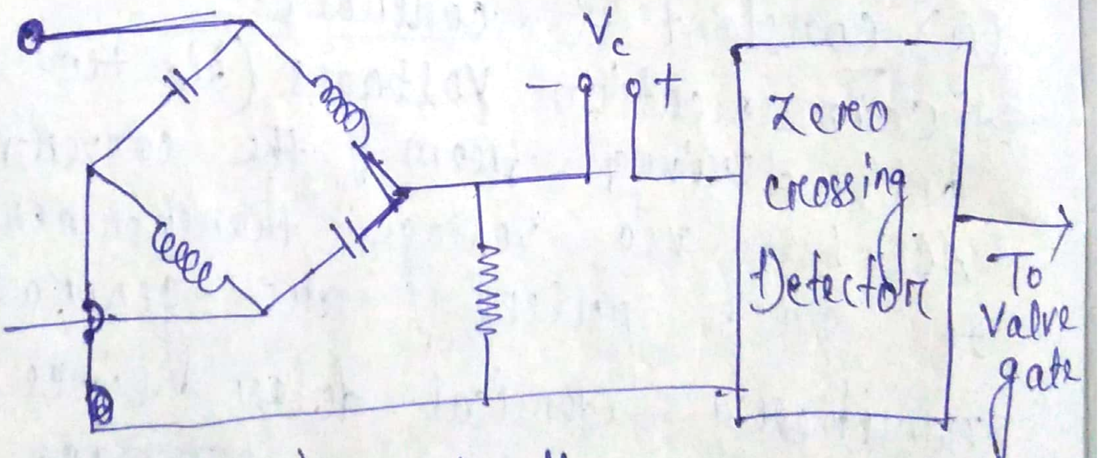
→ The instant of zero crossing of a particular communication voltage corresponds to α = 0° for that valve.



V_c = control voltage

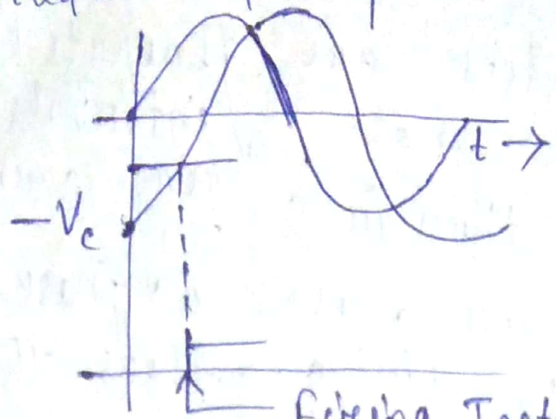
→ The delays are produced by independent delay ckts and controlled by a common control voltage 'V_c' derived from the current controllers.

(b) <u>Inverse cosine control</u>:→ The six timing voltages (obtained as in constant α control) are each phase shifted by 90° and added a separately to a common control voltage 'V_c'.



→ The zero crossing of the sum of the two voltages initiates the firing pulse for the particular valve is considered. The delay angle 'α' is nominally proportional to the inverse cosine of the control voltage.

→ It also depends on the AC system voltage amplitude and shape.



→ The main advantage of this scheme is that the average DC voltage across the bridge varies linearly with the control voltage V_c.

Drawbacks of IPC scheme :→

→ The major drawback of IPC scheme is of the harmonic stability problem. that was encountered particularly in systems with low short ckt ratios. The problem of harmonic instability can be overcome by the following measures:-

(i) Through the provision of synchronous condensers or additional filters for filtering out non-characteristic harmonics.

(ii) Use of filters in control ckt to filter out non-characteristic harmonics in the communication voltages.

(iii) The use of firing angle control is independent of the zero crossings of the AC voltages. This is the most attractive solution and leads to the pulse firing scheme.

HVDC

(2) Equidistant pulse control (EPC) :→

→ The firing pulses are generated in steady-state at equal intervals of 1/power factor, through a ring counter.

This control scheme uses a phase locked oscillator to the firing pulses. There are 3 variations of the EPC scheme:-

(a) Pulse frequency control (PFC)
(b) Pulse period control
(c) pulse phase control (PPC)

(a) pulse frequency control (PFC) :→

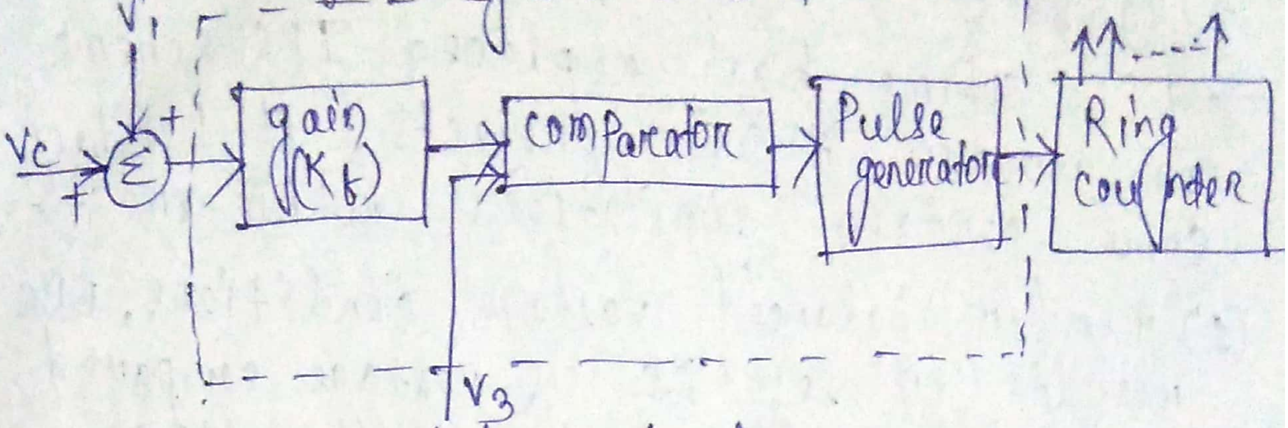
→ A voltage controlled oscillator (VCO) is used, the frequency of which is determined by the control voltage 'V_c' which is related to the error in the quantity (current, extinction angle or DC voltage) being regulated.

→ The frequency in steady-state operation is equal to 'pf_0' where, 'f_0' 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.

Voltage controlled oscillator



(b) Pulse period control :→

→ It is similar to PFC except for the way in which the control voltage 'V_c' is handled. The structure of the controller is same, however the 'V_c' is now summed with V_3 instead of V_1 according to PFC.

(c) Pulse phase control (PPC) :→

→ Here, the proportional current control, the steady state can be reached when the error of the control voltage 'V_c' is constant.

→ The major advantage claimed for PPC over PFC are :→

(i) easy inclusion of a limit by the limiting 'V_c'.

(ii) Linearization of control characteristic by including an inverse cosine function block after the current controller.

→ Limits can also be incorporated into PFC or the pulse period control system.

Drawbacks of EPC scheme :→

→ EPC scheme has replaced IPC scheme in modern HVDC projects; it has been some certain limitations which are :→

(1) Under balanced voltage conditions, EPC results in less DC voltage compared to IPC. Unbalance in the voltage results from single phase to ground fault in the AC system which may persists for over 10 cycles due to stuck breakers. Under such conditions, it is desirable to maximize DC power transfer in the link which calls for IPC.

(2) EPC scheme also results in higher negative damping contribution to oscillations when HVDC is the major transmission link from a thermal station.

Current and Extinction Angle control :→

→ This can be of predictive type or feedback type with IPC control. The predictive controller is considered to be less communication failure and was used in early schemes.

→ The feedback control with PFC type of EPC overcomes the problems associated with IPC.

→ The extinction angle, as opposed to current, is a discrete variable and it was felt the feedback control is slower than the predictive type.

→ Under large disturbances such as a sudden trip in the AC voltage, signals derived from the derivative of the voltage or DC current aid the advancing of the delay angle for fast recovery from the communication failures.

Starting and stopping of DC link :→

Energization and Deenergization of a Bridge :→

→ 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 ckt 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 the mercury arc valves where the possibility of arc backs makes it impractical to use bypass pairs. With thyristor valves,

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the use of bypass pair is the practice as it saves the cost of an extra valve.

→ The current from bypass pair is shunted to a mechanical switch. With the aid of the isolators, the bridge can be isolated. The isolator pairs are interlocked such that one or both are always closed.

→ The energisation of a blocked bridge is done in 2 stages. The current is first diverted from the switch to the bypass pair.

→ For this to happen the switch must generate the required arc voltage and to minimize this voltage, the ckt inductance must be small. Incase the bypass pair fails to take over the current, the switch must close automatically if the current in that does not become zero after a predetermined time interval.

→ AC breakers with sufficient arc voltage, but with reduced breaking capacity are used as the switch.

→ In the second stage of energization, the current is diverted from the bypass pair. For the rectifier, this can take place instantaneously neglecting overlap.

Start-up of DC link :→

→ There are two different start-up procedures depending upon whether the converter firing controller provides a short gate pulse or long gate pulse. The long gate pulse lasts nearly 120°, the average conduction period of a valve.

→ The voltage is raised before raising the current. This permits the insulation of the line to be checked before raising the power. The ramping of power avoids stresses on the generator shaft. The switching surges in the line are also reduced.

→ The required power ramping rate depends on the strength of the AC system. Weaker systems require fast restoration of DC power for maintaining the transient stability.

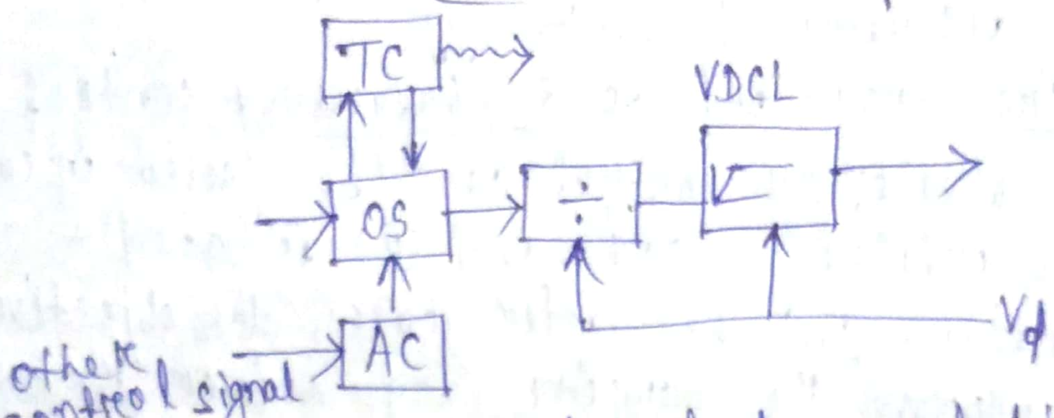
Power control :→ The current order is obtained as the quantity derived from the power order by dividing it by the direct voltage.

→ The limits on the current order are modified by the "voltage dependent current order limiter" (VDCOL). The objective of VDCOL is to prevent individuals thyristors from carrying full current for long periods during communication failures.

→ By providing both converter stations with dividing ckts 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.

→ The figure below shows the basic power controller used.

[Power and auxillary controller]



Where, VDCL → Voltage dependent current Limiter
TC → Tele communication equipment.
OS → Other setting unit.

→ When the DC line resistance is large and varies considerably e.g, when the overhead line is very long and exposed to large temperature variations, the DC line voltage drop cannot be compensated individually in the two stations. This problem can be solved by using a current order calculated in one substation only and transmitting its output to the other substation.

Higher level controllers:→ The power in a DC link can also be controlled in response to the quantities derived from the AC system (such as frequency) in order to improve the security of the over-all power system. This is achieved by an additional power (or current) order derived from an emergency power controller or auxillary controller. The functions of such higher level controllers are discussed below:-

(1) Frequency and power/frequency control:→

→ The frequency control can be used in case of (i) isolated load and (ii) isolated generation. In the latter case, the objective is to improve the damping and reduce the wear of the generator and governor system.

→ The neuclear power stations are very sensitive to output power and frequency fluctuations. By proper control of the power carried on the DC link in a hybrid transmission system consisting of both HVDC and UHV (ultra High voltage) lines, the frequency variations both during steady-state and transient conditions can be minimized. The prospects of a coordinated control between nuclear station and HVDC system has been investigated in Japan.

→ When the DC link is used as a tie between two power systems, the frequency bias can be used to adjust the power flow over the tie to assist the system in difficulty. It is to be noted that an HVDC link has to inherent sensitivity to system frequency unless it is deliberately in the control system.

→ Without it, a constant power flow can overspeed a receiving system which has become separated from part or all of its load, even if governors cut-off all primary energy inflow to local generation. Similarly, a sending system can be brought eventually to a halt, if more power is required from it than the connected generation can produce.

→ Thus, although it would first appear that there is little benefit in the frequency control for a DC link between two systems so large that the link cannot be expected to influence the frequency of either, it is prudent to incorporate an element of the frequency control which in the event of a partial break-up of a system, will prevent overspeed or underspeed.

② <u>Stabilization of AC Ties</u> :→ When a DC tie is connected to a system with weak AC ties to neighbouring systems, DC link power can be varied quickly and automatically to balance the load flows and maintain stability if one of the AC tie trips.

→ A DC tie used in parallel with an AC tie can be employed to damp the low frequency

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interarea oscillations in the AC tie. The control signal used can be the rate of change of AC tie line power (or current) or the phase angle difference across the AC tie. The DC tie can also provide frequency control for one end if the AC tie becomes disconnected and can thus permit resynchronization of the AC tie.

(3) **Reactive power control** :→ The reactive power control is important, particularly in weak AC systems in reducing the dynamic over voltages. Also in inverters, the fast reactive power control can help in allowing the injection of increased power at times of need to improve the stability of the receiving end AC system.

(4) **Subsynchronous Damping Control** :→ A radial HVDC link connected to a thermal generating station can contribute to the negative damping of the torsional oscillations at sub-synchronous frequency due to the interactions with the current controller. This problem usually surfaces when there are no parallel AC links. The power modulation controller mentioned earlier which is designed to damp low frequency rotor oscillations can aggravate the problem. However, a suitably designed subsynchronous damping controller (SSDC) with control signal derived from the rotor velocity can help to damp torsional frequency oscillations.

(5) Emergency control :→

→ In an AC tie line, the power flow is determined by conditions in the systems which it interconnects. If one of the systems suffers a disturbance there are only two options; to allow the disturbance to affect the other system also, possibly resulting in a catastrophe for both or to trip the tie in which case the system in difficulty may lose one of the main infeeds on which it is dependent even before the disturbance.

→ A HVDC link on the other hand, even with simplest controls, buffers one system from disturbances on the other, power flow can continue at worst unchanged but the option is available to vary power flow to assist the system in trouble to the extent to which the healthy system can allow without putting itself in difficulty, subject only to the rating of the link. In general, with the suitable control, a disturbance originating in either system can be shared in a predetermined manner and the oscillations occurring in the two systems can be damped simultaneously. Substantial damping can be achieved with a very small amount of DC power modulation. However, if a large degree of modulation is required with the DC line already operating close to its full capacity, it is found that significant results can be achieved simply by the reduction of DC power at the appropriate instants.

Telecommunication Requirements :→

→ Although manual power order setting with voice communication is possible, the utilization of inherent speed of response of the DC link requires communication channel of appropriate capacity.

→ For the use of stabilization control, a 1200 baud channel is required for the power flow control. This gives a sampling interval of 20 m.sec. with a resolution of 0.05 percent of the maximum current order, which should be adequate for the most cases.

→ The maintenance of proper current margin is essential and is the primary objective of the telecommunication channel, provided. Certain precautions can help in overcoming the problems arising from the failure of communication. In raising the current order, it is preferable to carry it out first at the rectifier and then at the inverter. In reducing the current order, the inverter current reference is reduced before that at the rectifier.

Smoothing Reactor :→ Smoothing Reactors are serially connected reactors inserted in DC systems to reduce harmonic currents and the transient over currents and/or current ripples in DC systems. They are necessary in order to smooth the direct current wave shape to reduce losses and improve system performance.

→ A smoothing reactor is connected in series with the DC high voltage line as either part of the converter station or back-to-back interconnection between different transmission networks. It reduces the harmonic current (ripple), limits the inrush current during fault conditions, limits the DC phase current rate of rise and improves the dynamic stability of the power system.

Functions of smoothing Reactors :→

→ Smoothing Reactors are used in HVDC links and the industrial applications including traction systems, variable speed drives, UPS systems, etc.

→ Smoothing Reactors reduce the occurance of alternation failure in inverters caused by the dips in AC voltage at the converter bus.

HVDC

Corona effect in DC line :→

→ The phenomenon of ionisation of surrounding air around the conductor due to which luminous glow with hissing noise is rise are known as the corona effect. Air acts as a dielectric medium between the transmission lines. In other words, it is an insulator between the current carrying conductors.

→ If the voltage induces between the conductor is of alternating nature then the charging current flows between the conductors and this charging conductor increases the voltage of the transmission line. The electric field intensity also increases because of the charging current.

→ If the intensity of the electric field is less than 30 KV, the current induces between the conductor is neglected. But if the voltage rise beyond the 30 KV then the air between the conductors becomes charge and they start conducting. The sparking occurs between the conductors till the complete breakdown of the insulation properties of conductors takes place.

Corona Formation :→ Air is not a perfect insulator, and even under normal conditions, the air contains many free electrons and ions. When an electric field intensity establishes between the conductors, these ions and free electrons experience forced upon them. Due to this effect, the ions and free electrons get accelerated and moved in the opposite direction.

→ The charged particles during their motion collide with one another and also with the very slow moving uncharged molecules. Thus, the no. of charged particles goes on increasing rapidly. This increase the conduction of air between the conductors and a break-down occurs. Thus, the arc establishes between the conductors.

Factors affecting the corona effect :→

(1) Effect of supply voltage :→ If the supply voltage is high then the corona loss is higher in the lines. In low voltage transmission lines, the corona is negligible, due to the insufficient electric field to maintain ionization.

(2) The condition of conductor surface :→ If the conductor is smooth, the electric field will be more uniform as compared to the rough surface. The roughness of the conductor is caused by the deposition of dirt, dust and by scratching etc. Thus, rough line decreases the corona loss in the transmission lines.

(3) Air Density Factor :→ The corona loss is inversely proportional to air density factor i.e. corona loss, increase with decrease in density of air. Transmission lines passing through a hilly area may have higher corona loss than that of similar transmission lines in the plains because in a hilly area

the density of air is low.

(4) **Effect of system voltage** :→ Electric field intensity in the space around the conductors depends on the potential difference between the conductors. If the potential difference is high, electric field intensity is also very high, and hence corona is also high. Corona loss increase with the increase in the voltage.

(5) **The spacing between conductors** :→ If the distance between two conductors is much more as compared to the diameter of the conductor than the corona loss occurs in the conductor. If the distance between them is extended beyond certain limits, the dielectric medium between them get decreases and hence the corona loss also reduces.

Minimizing corona effect :→ Corona decreases the efficiency of transmission lines. Therefore it is necessary to minimize corona. The following factors may be considered to control the corona effect :-

(1) Conductor diameter (2) The voltage of the line (3) spacing between conductors.

Disadvantages of Corona discharge :→ The undesirable effects of the corona effect are :→

(1) The glow appear across the conductor which shows the power loss occur on it.

(2) The audio noise occurs because of the corona effect which causes the power loss on the conductor.

(3) The vibration of conductor occurs because of corona effect.

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(4) The corona effect generates the ozone because of which the conductor becomes corrosive.

(5) The corona effect produces the non-sinusoidal signal thus the non-sinusoidal voltage drops occur in the line.

(6) The corona power loss reduces the efficiency of the line.

(7) The radio and TV interference occurs on the line because of corona effect.

Some important points about corona effect :→

→ Disruptive voltage is the minimum voltage at which the breakdown of air occurs and corona effect starts.

→ Visual critical voltage is the minimum voltage at which visible corona effect begins.

Proximity effect :→ When the conductors carry the high alternating voltage then the currents are non-uniformly distributed on the cross-section area of the conductor. This effect is called proximity effect.

Skin effect :→ The non-uniform distribution of electric current over the surface or skin of the conductor carrying AC is called the skin effect.

Ferranti effect :→ The effect in which the voltage at the receiving end of the transmission line is more than the sending voltage is known as the Ferranti effect. Such type of effect mainly occurs because of light load or open ckt at the receiving end.

HVDC

Protection of DC line :→ DC transmission line protection is an important protection and the most basic protection in DC transmission systems. It maintains the normal operation of DC transmission lines. The direct current transmission is often used for long-distance transmission.

DC line travelling wave protection :→

→ Travelling wave protection is the primary protection for the DC line faults, its purpose is to detect ground faults on DC lines. The basic principle of travelling wave protection is, when a DC line has a ground fault, a travelling wave appears when the DC voltage drops, the DC current on the rectifier side is overshooted by the current controller, and the DC current on the inverter side is also reduced until it stabilizes to a stable value.

Differential undervoltage protection :→

→ Differential undervoltage protection is a backup protection for travelling wave protection and protection is only effective at the rectifier station. It detects DC voltage and DC, and has two different protection action conditions, differential and undervoltage.

→ The combination of each other can improve the correctness of the protection action.

The differential part has a differential ckt.

→ When the DC line has a ground fault, the DC voltage is reduced to a lower value at a higher rate and the differential detection part is fast. To make the differential detection more perfect, and to detect the DC under-voltage, higher differential settings and lower under voltage levels, combined with appropriate delays, prevent protection from the false transients, To distinguish between faults in the rectifier station and DC line faults.

DC line differential protection :→ The purpose of the differential protection is to detect the high-impedance ground fault that cannot be detected by the travelling wave on the DC line and the differential under voltage protection. The working principle measuring and comparing the polar currents of the two stations and delaying the time difference that the measured current may occur.

→ The action criterion for the differential protection of the DC line is, when the absolute value of the absolute difference between the two stations is greater than the fixed value under normal communication conditions, the protection is activated and the protection delay is 500Ms.

DC Breakers :→ The design and operation of the DC system is different from AC ckt. The breaker which is used for the interruption of the high voltage direct current is known as the HVDC ckt Breaker. The voltage breaking capacity of the HVDC ckt breaker is nearly 33 kV. and for the current it is 2KA.

HVDC ckt Breaker :- → The HVDC ckt breaker is a switching device that interrupts the flow of abnormal DC in the ckt. When the fault occurs in the system, the mechanical contacts of the ckt breaker are pulled apart and thus their ckt is open. In HVDC ckt breaker, ckt breaking is difficult because the current flow through it is unidirectional and there is no zero current.

→ The main application of the HVDC ckt breaker is to interrupt the high voltage (HV) DC flows in the network. AC ckt breaker easily interrupts the arc at natural current zero of the AC wave. At zero current, the energy to be interrupted is also zero. The contact gap has to recover the dielectric strength to withstand the natural transient recovery voltage.

→ With DC ckt breakers, the problem is more complex as the DC wave form does not have natural current zeros. In designing of HVDC ckt breakers, there are three main problems to be overcome. These problems are:-

(1) Creation of artificial current zero.

(2) Prevention of restrikes arc.

(3) Dissipation of stored energy.

→ The artificial current zero principles are used in the HVDC ckt breakers for arc extinction.

HVDC

Reactive power control:→

Introduction:→ Reactive power is required to maintain the voltage to deliver active power (watts) through transmission lines. Motor loads and other loads require reactive power to convert the flow of electrons in to useful work.

→ We always in practice to reduce reactive power to improve system efficiency. These are acceptable at some level. If the system is purely resistively or capacitance it make cause some problem in electrical system. Alternating systems supply or consume two kind of power i.e. real power and reactive power.

→ Real power accomplishes useful work while reactive power supports the voltage that must be controlled for system reliability. Reactive power has a profound effect on the security of power systems because it affects voltages throughout the system.

Importance of Reactive power:→

→ Voltage control in an electrical power system is important for proper operation for electrical power equipment to prevent damage such as over-heating of generators and motors, to reduce the transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse.

→ Decreasing reactive power causing voltage to fall while increasing it causing voltage to rise. A voltage collapse may be occurs when the system try to serve much more load than the voltage can support. When reactive power supply lower voltage, as voltage drops current must increase to maintain power supplied, causing system to consume more reactive power and the voltage drops further. If the current increase too much, transmission lines go off line, overloading other lines and potentially causing cascading failures.

→ If the voltage drops too low, some generators will disconnect automatically to protect themselves. Voltage collaps occurs when an increase in load or less generation or transmission facilities causes dropping voltage, which causes a further reduction in reactive power from capacitor and line charging, and still there further voltage reductions. If voltage reduction continues, these will cause the additional elements to trip, leading further reduction in voltage and loss of the load. The result in these entire progressive and uncontrollable declines required supplying the reactive power demands.

<u>Necessary to control of voltage and Reactive power</u> :-

→ Voltage control and reactive power management are two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission networks.

→ On an AC power system, voltage is controlled by managing production and absorption of reactive power. There are 3 reasons why it is necessary to manage reactive power and control voltage.

→ First, both customer and power system equipment are designed to operate within a range of voltages, usually within ±5% of the nominal voltage. At low voltages, many types of equipment perform poorly, light bulbs provide less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at high voltages can damage equipment and shorten their lifetimes.

→ Second, reactive power consumes transmission and generation resources. To maximize the amount of real power that can be transferred across a congested transmission interface, reactive power flows must be minimized. Similarly, reactive power production can limit a generator's real power capability.

→ Third, moving reactive power on the transmission system incurs real power losses. Both capacity and energy must be supplied to replace these losses.

→ Voltage control is complicated by two additional factors. First, the transmission system itself is a nonlinear consumer of reactive power, depending on system loading. At very light loading the system generates reactive power that must be absorbed, while at heavy loading the system consumes a large amount of reactive power that must be replaced. The system's reactive power requirements also depend on the generation and transmission configuration.

→ Consequently, system reactive requirements vary in time as load levels and load and the generation patterns change. The bulk power system is composed of many pieces of equipment, any one of which can fail at any time. Therefore, the system is designed to withstand the loss of any single piece of equipment and to continue operating without impacting any customers. That is, the system is designed to withstand a single contingency. The loss of a generator or a major transmission line can have the compounding effect of reducing the reactive supply and, at the same time, reconfiguring flows such that the system is consuming additional reactive power.

→ At least a portion of the reactive supply must be capable of responding quickly to changing reactive power demands and to maintain acceptable voltages throughout the system. Thus, just as an electrical system requires real power reserves to respond to contingencies, so too it must maintain reactive-power reserves.

→ Loads can also be both real and reactive. The reactive portion of the load could be served from the transmission system. Reactive loads incur more voltage drop and reactive losses in the transmission system than do similar size (MVA) real loads.

Q:→ How voltages controlled by Reactive power :→

Ans:→ Voltages are controlled by providing sufficient reactive power control margin to supply needs through :-

(i) shunt capacitor & reactor compensations.

(ii) Dynamic compensation.

(iii) Proper voltage schedule of generation.

→ Voltages are controlled by predicting and correcting reactive power demand from loads.

HVDC

Basic concept of Reactive power:→

Why we need Reactive power:→ Active power is the energy supplied to run a motor, heat a home, or illuminate an electrical light bulb. Reactive power provides the important function of the regulating voltage. If voltage on the system is not high enough, active power cannot be supplied.

→ Reactive power is used to provide the voltage levels necessary for active power to do useful work.

→ Reactive power is essential to move active power through the transmission and distribution system to the customer. Reactive power is required to maintain the voltage to deliver active power (watts) through transmission lines.

→ Motor loads and other loads require reactive power to convert the flow of electrons into useful work. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines."

Reactive power is a Byproduct of AC systems:→

→ Transformers, Transmission lines, and motors require reactive power. Electric motors need reactive power to produce magnetic fields for their operation.

→ Transformers and transmission lines introduce inductance as well as resistance:-

(i) Both oppose the flow of current.

(ii) Must raise the voltage higher to push the power through the inductance of the lines.

(iii) Unless capacitance is introduced to offset the inductance.

Reactive power and power Factor :→ Reactive power is present when the voltage and current are not in phase.

(1) One waveform leads the other.
(2) phase angle not equal to 0°.
(3) Power factor less than unity.

→ Measured in volt-ampere reactive (VAR).
→ Produced when the current wave form leads voltage waveform (Leading power factor).
→ Vice versa, consumed when the current waveform lags voltage (lagging power factor).

Reactive power limitations :→
→ Reactive power does not travel very far.
→ usually necessary to produce it close to the location where it is needed.
→ A supplier/source close to the location of the need is in a much better position to provide reactive power versus one that is located far from the location of the need.
→ Reactive power supplies are closely tied to the ability to deliver real or active power.

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.
These sources are :→

(1) 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.

(2) Synchronous Compensators :→ Certain smaller generators, once run up to speed and synchronised to the system, can be declutched from their turbine and provide reactive power without producing real power. This mode of operation is called synchronous compensation.

(3) Capacitive and Inductive 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.

(4) Overhead lines and underground cables :→ Overhead lines and underground cables, when operating at the normal system voltage, both produce strong electric fields and so generate reactive power. When current flows through a line or cable it produces a magnetic field which absorbs the reactive power. A lightly loaded overhead line is a net generator of reactive power whilst a heavily loaded line is a net absorber of reactive power. In the case of cables designed for use

at 275 or 400KV the reactive power generated by the electric field is always greater than the reactive power absorbed by the magnetic field and so cables are always net generators of reactive power.

(5) Transformers :→ Transformers produce magnetic fields and therefore absorb reactive power. The heavier the current loading the higher the absorption.

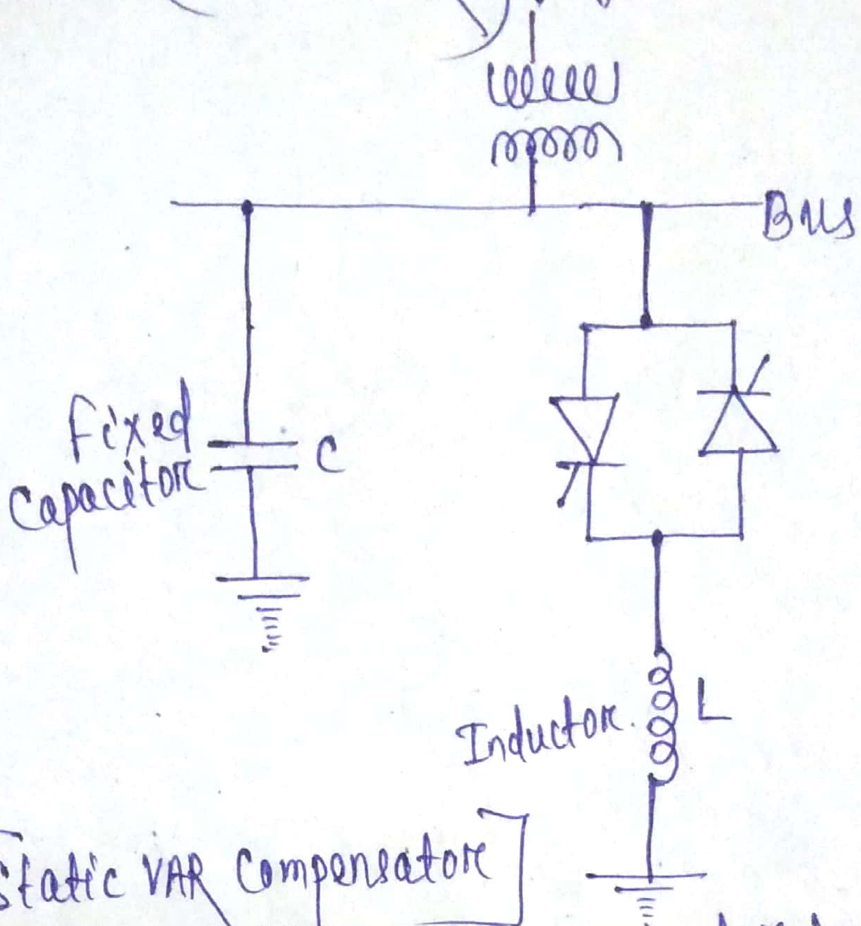
(6) Consumer loads :→ Some loads such as motors produce a magnetic field and therefore absorb reactive power but other customer loads, such as fluorescent lighting, generate reactive power. In addition reactive power may be generated or absorbed by the lines and cables of distribution systems.

Static VAR compensator :→ A static VAR compensator is a parallel combination of controlled reactor and fixed shunt capacitor shown in the figure below. The thyristor switch assembly in the SVC controls the reactor. The firing angle of the thyristor controls the voltage across the inductor and thus the current flowing through the inductor. In this way, the reactive power draw by the inductor can be controlled.

→ The SVC is capable of step less adjustment of reactive power over an unlimited range without any time delay. It improves the system stability and system power factor. Most commonly used SVC shemes are as follows :→

(1) Thyristor controlled reactor (TCR).
(2) Thyristor-switched capacitor (TSC).

(3) self Reactor(SR)
(4) Thyristor controlled reactor - Fixed capacitor(TCR-FC)
(5) Thyristor-switched capacitor - Thyristor controlled reactor (TSC - TCR)



Static VAR Compensator

Advantages of static VAR compensator :→

→ It increased the power transmission capability of the transmission lines.

→ It improved the transient stability of the system.

→ It controlled the steady state and temporary over voltages.

→ It improved the load power factor, and therefore, reduced line losses and improved system capability.

* static VAR compensator has no rotating parts and is employed for surge impedance compensation and compensation by sectionalizing a long transmission line.

DC power transmission technology

Introduction :-

→ Electric power transmission was originally developed with direct current. The availability of transformers and the development and improvement of induction motors at the beginning of the 20th century, led to the use of AC transmission.

→ Due to its fast controllability, a DC transmission has full control over transmitted power, an ability to enhance transient and dynamic stability in associated AC networks and can limit fault currents in the DC lines.

→ Furthermore, DC transmission overcomes some of the following problems associated with AC transmission.

→ With reduced size, cost and improved reliability of power electronic converters, has made HVDC transmission more wide-spread.

→ With the fast development of converters (rectifiers and inverters) at higher voltages and larger currents, DC transmission has become a major factor in the planning of the power transmission.

→ In the beginning, all HVDC schemes used mercury arc valves, invariably single phase in construction, in contrast to the low voltage polyphase units used for industrial application.

Comparison of AC and DC Transmission :→

→ The merits of two modes of transmission (AC and DC) should be compared based on the following factors.

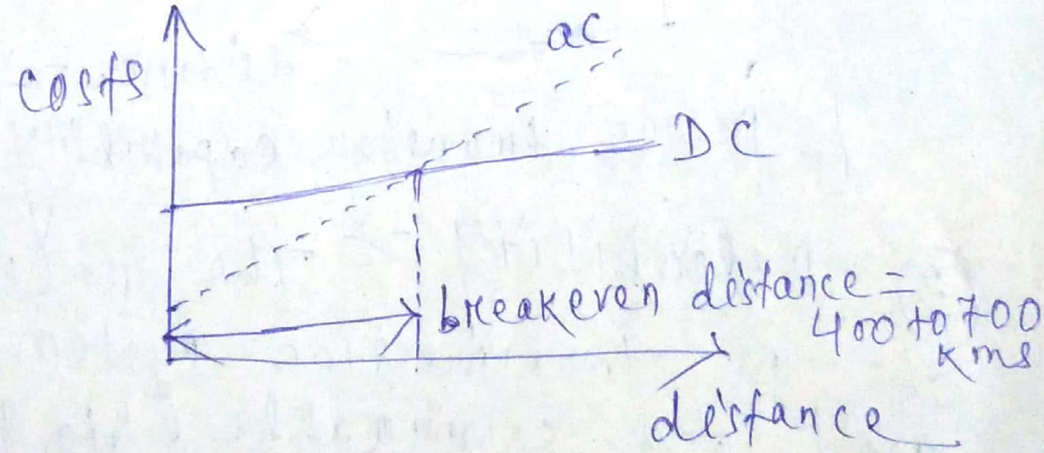
(1) Economics of transmission.
(2) Technical performance
(3) Reliability.

(1) Economics of Transmission :→

→ In DC transmission, inductance & capacitance of the line has no effect on the power transfer capability of the line drop. Also there is no leakage or charging current of the line under steady conditions.

→ A DC line requires only 2 conductors where as AC line requires 3 conductors in 3-ϕ AC systems. The cost of the terminal equipment is more in DC lines than in AC line.

→ Break-even distance is one at which the cost of the two systems is same.



(Relative costs of AC & DC transmission lines v_s distance)

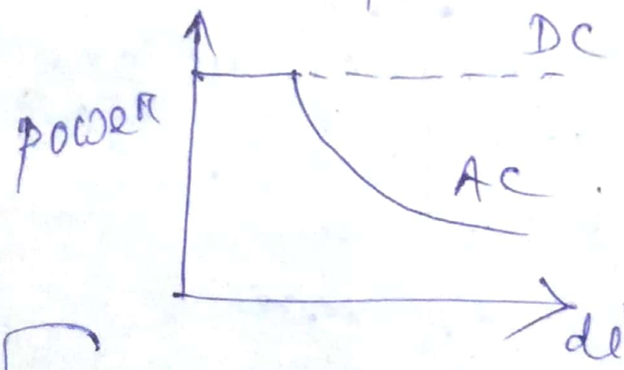
→ It is understood from the figure that a DC line is economical for long distances which are greater than the break-even distance.

② Technical performance :→

→ Due to its fast controllability, a DC transmission has full control over transmitted power, an ability to enhance transient & dynamic stability in associated AC networks & can limit fault in the DC lines.

→ The problems are :→

(i) stability limits :→
(ii) voltage control.
(iii) Line compensation.



power transfer capability v/s distance

③ Reliability :→ The reliability of DC transmission system is good and comparable to that of AC systems.

→ There are 2 majors of overall system reliability.

(1) Energy availability :→

Energy availability $= 100\left(1 - \text{equivalent outage time}\right)\%$

where equivalent outage time is the product of the actual outage time and the fraction of the system capacity lost due to outage.

(2) Transient Reliability :→

→ This is a factor specifying the performance of HVDC systems during recordable faults on the associated AC systems.

$$\text{Transient reliability} = \frac{100 \times \text{no. of time HVDC systems performed as designed}}{\text{No. of recordable AC faults.}}$$

→ Recordable AC system faults are those faults which cause one or more AC bus phase voltages to drop below 90% of the voltage prior to the fault.

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→ Both energy availability and transient reliability of existing DC systems with thyristor valves is 95% or more.

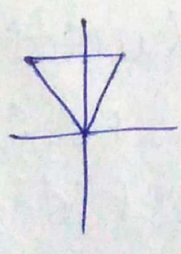
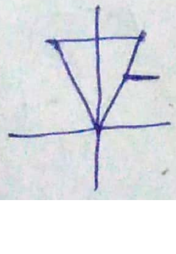
Applications of DC Transmission :→

→ Due to their costs and special nature most applications of DC transmission generally fall into one of the following 3 categories.

1. underground or underwater cables.
2. Long distance bulk power transmission. → [illegible] / High / Huge amount
3. stabilization of power flows in integrated power system.

Types of valves :→

→ Based on the controllability and configuration, valves are classified into 4 types as under.

1.  Non-controllable valve or arm
2.  controllable valve or arm.

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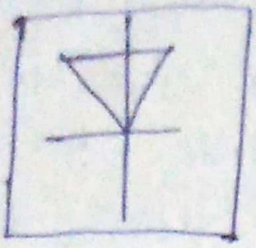
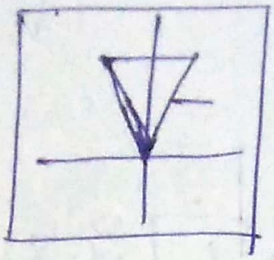
(3)  Non-controllable bridge or valve group.

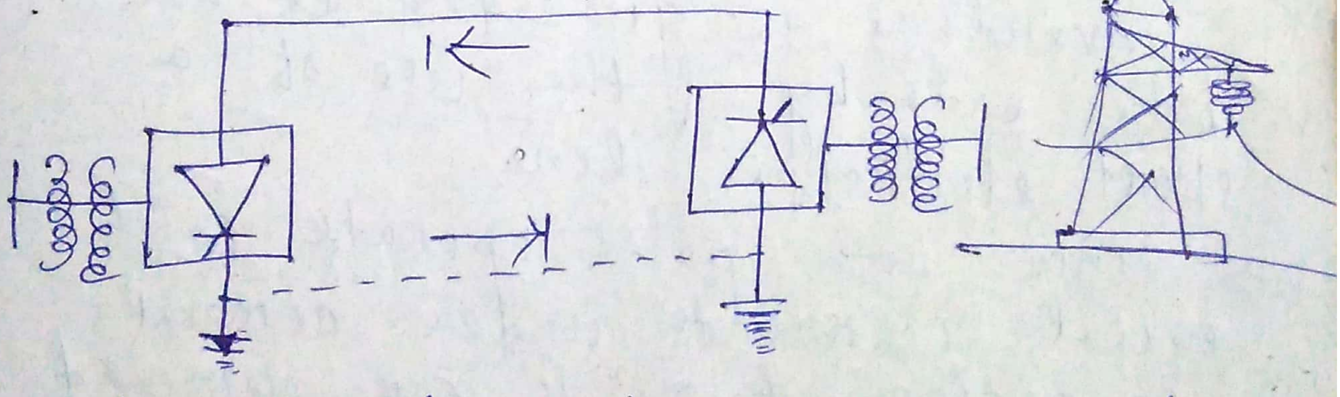
(4)  controllable bridge or valve group.

Types of HVDC links :→

→ The types of HVDC links are considered in HVDC applications which are :→

(1) Monopolar link
(2) Bipolar link
(3) Homopolar link

(1) Monopolar link :→

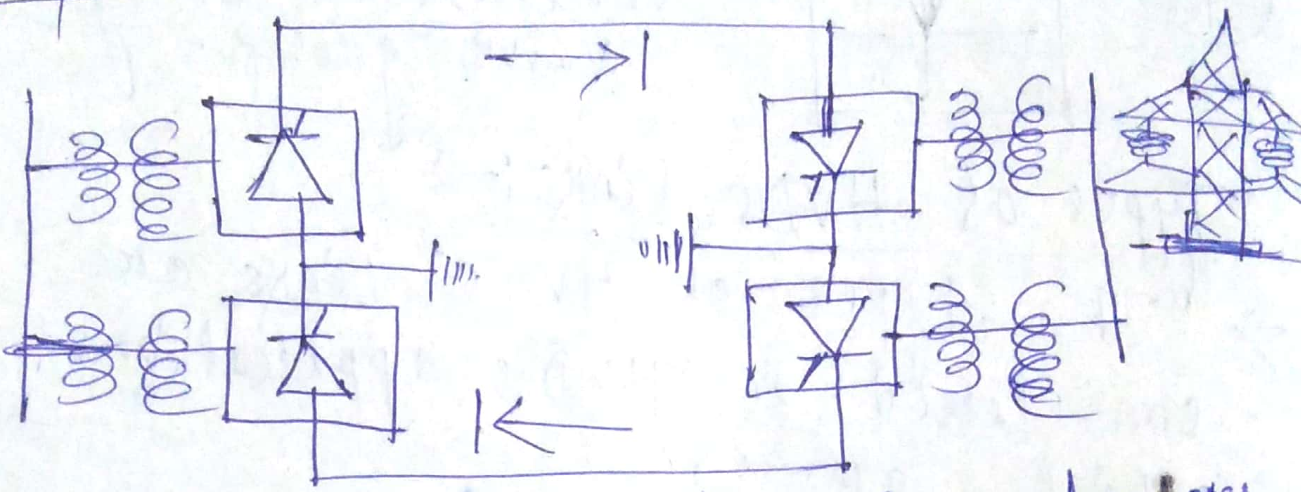


→ A monopolar link has one conductor and uses either ground or sea return.

→ A metallic return can also be used where concerns for harmonic interference or corrosion exists.

→ A monopolar link is normally operated with (−)ve polarity.

Bipolar link :→



→ A bipolar link has 2 conductors, one (+)ve and the other (−)ve.

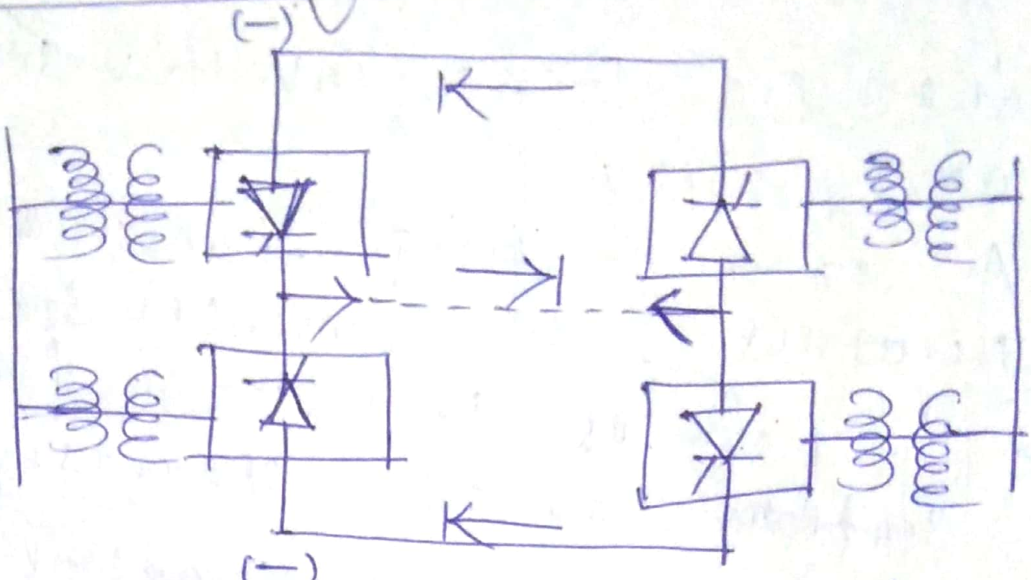
→ Each terminal has 2 sets of converters of equal rating in series on the DC side.

→ The junction bet the two sets of converters is grounded at one or both ends by the use of a short electrode line.

→ Since both poles operate with equal currents under normal operation, there is zero ground current flowing under these conditions.

→ Monopolar operation can also be used in the 1st stages of the development of a bipolar link.

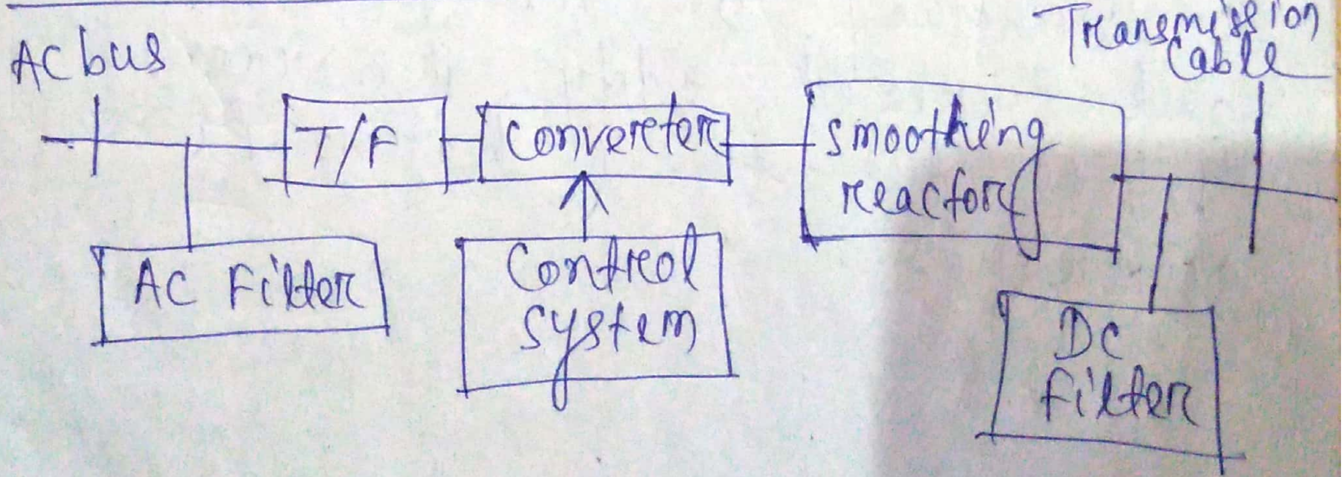
Homopolar link :→



→ In this type of link two conductors having the same polarity (usually (−ve)) can be operated with ground.

→ A homopolar link has the advantages of reduced insulation costs, but the disadvantages of earth return outweigh the advantages.

HVDC converter station :→



→ The major components of a HVDC transmission system are converter stations where conversions from AC to DC (Rectifier station) and from DC to AC (inverter station) are performed.

→ A point to point transmission requires two converter stations.

→ The role of rectifier and inverter stations can be reversed by suitable converter control.

Converter T/F ⇒

→ It has 3 different configurations.

1. Three phase two winding.
2. 1-ϕ, 3 winding and
3. 1-ϕ, 2 winding.

→ The converter T/Fs are designed to withstand DC voltage stresses and increased eddy current losses due to harmonic currents.

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Filters :→ There are 3 types of filters used which are :→

① AC Filters :→ These are passive ckts used to how impedance, shunt paths for AC harmonic currents, both tuned and damped filters arrangements are used.

② DC filters :→ These are similar to AC filters and are used for the filtering of DC harmonics.

③ High frequency Filters :→

→ These are connected between the converter T/F and the station AC bus to suppress any high frequency currents.

→ These filters are provided DC bus connected betn the DC filter and DC line and also on the neutral side.

Reactive power source :→

Converter stations require reactive power supply that is dependent on the active power loading. But part of the reactive power requirement is provided by AC filteres.

Smothing Reactore :→ A sufficiently large series reactore is used on DC side to smooth DC current and also fore portection.

→ The reactore is designed as a linear reactore and is connected on the line side, neutral side ore at intermediate location.

DC Switchgeare :→ It is a modified AC equipment used to interrupt small DC currents.

→ In addition to the DC switchgeare, AC switchgeare and associated equipment fore protection and measurement are also part of the converterstation.

Modern Trends in DC Transmission :→

→ To overcome the losses and faults in AC transmission, HVDC transmission is preferred.

→ The trends which are being introduced are fore the effective development to reduce the cost of the converteres and to improve the performance of the transmission system.

power semiconductors and valves :→

→ The power rating of thyristors is also increased by better cooling methods.

Converter control :→ The development of micro-computer based converter control equipment has made possible to design systems with completely the converter control with automatic transfer betn systems in the case of a problem.

→ The micro-computer based control also has the flexibility to implement adaptive control algorithms or even the use of expert systems for fault diagnosis and protection.