20EE603

Hall Ticket Number:

III/IV B.Tech (Regular) DEGREE EXAMINATION

July/August,2023 **Electrical & Electronics Engineering**

Sixth Semester **HVDC & FACTS**

Time: Three Hours **Maximum:** 70 Marks

Answer question 1 compulsory. **(14X1 = 14Marks)**

Answer one question from each unit. **(4X14=56 Marks)**

			CO	BL	M
1	a)	List the factors to be considered for planning HVDC transmission systems.	CO1	L1	1M
	b)	Explain in two lines about choice of voltage level in DC transmission.	CO1	L1	1M
	c)	How will overcome the disadvantages in DC transmission?	CO1	L1	1M
	d)	Define harmonic.	CO2	L1	1M
	e)	Define DC filter.	CO2	L1	1M
	f)	Define AC filter.	CO2	L1	1M
	g)	What is the flexibility of electric power transmission?	CO3	L1	1M
	h)	What are the objectives of FACTs controllers?	CO3	L1	1M
	i)	What are the various categories of FACTs controllers?	CO3	L1	1M
	j)	What is IPFC?	CO4	L1	1M
	k)	List the different power electronic devices used in FACTs controllers.	CO4	L1	1M
	l)	What is reactive power compensation in transmission system?	CO4	L1	1M
	m)	What is VSC based HVDC systems?	CO1	L1	1M
	n)	What is ignition angle control in converter operation?	CO2	L1	1M
		Unit-I			
2	a)	List and explain the advantages of using DC transmission over AC transmission.	CO1	L2	7M
	b)	Draw the layout of HVDC transmission substation and explain its operation.	CO1	L2	7M
		(OR)			
3	a)	Differentiate bipolar and homopolar DC links in transmission system.	CO1	L2	7M
	b)	Explain the operation of voltage source converter-based systems.	CO1	L2	7M
		Unit-II			
4	a)	List and explain the features of controlling converter performance.	CO2	L2	7M
	b)	Explain the operation of multi terminal DC systems with their applications.	CO2	L2	7M
		(OR)			
5	a)	Explain the operation of current and extinction angle control in converters with necessary illustrations	CO2	L2	7M
	b)	Differentiate series and parallel MTDC systems with necessary diagrams.	CO2	L2	7M
		Unit-III			
6	a)	Explain the operation of reactive power compensators in used in FACTs controllers.	CO3	L2	7M
	b)	Explain the necessity of FACTS controllers.	CO3	L2	7M
		(OR)			
7	a)	Explain the procedure along with necessary connection diagrams to improve voltage profile using FACTs controllers using mid-point compensation.	CO3	L2	7M
	b)	Explain how the FACTs controllers can control the stability of transmission systems.	CO3	L2	7M
		Unit-IV			
8	a)	Explain the objectives and operation of shunt compensation in transmission systems.	CO4	L2	7M
	b)	Explain the operation of UPFC with necessary diagrams and mathematical expressions.	CO4	L2	7M
		(OR)			
9	a)	Explain the operation of SVC with necessary diagrams and mathematical expressions.	CO4	L2	7M
	b)	Explain the operating principle to control the active and reactive power flow using controllers.	CO4	L2	7M

Scheme of Evaluation

1.

a) List the factors to be considered for planning HVDC transmission systems.

Ans: The factors to be considered are (i) cost (ii)technical performance, and (iii) reliability.

b) Explain in two lines about choice of voltage level in DC transmission.

Ans: The DC voltage in the intermediate circuit can be selected freely at HVDC back-to-back stations because of the short conductor length. The DC voltage is usually selected to be as low as possible, in order to build a small valve hall and to reduce the number of thyristors connected in series in each valve.

c) How will overcome the disadvantages in DC transmission?

Ans: By Placing Flexible AC Transmission Systems.

d) Define harmonic.

Ans: A harmonic is a wave or signal whose frequency is an integral (whole number) multiple of the frequency of the same reference signal or wave.

e) Define DC filter.

Ans: This DC to DC Filter is a purpose built product to provide a stable voltage platform where house battery voltage fluctuates due to solar input and load variances and also filters out any "electronic noise" present in the vehicle's electrical system providing a smooth constant DC output.

f) Define AC filter.

Ans: A filter is an AC circuit that separates some frequencies from others within mixed-frequency signals.

g) What is the flexibility of electric power transmission?

Ans: Power system flexibility is the ability to adapt to dynamic and changing conditions, for example, balancing supply and demand by the hour or minute, or deploying new generation and transmission resources over a period of years.

h) What are the objectives of FACTs controllers?

Ans: The main objective of flexible AC transmission systems (FACTS) controllers is to improve system stability: transient, voltage, and small-signal, such that the AC transmission system becomes more reliable or additional power flow can be transferred on critical paths.

i) What are the various categories of FACTs controllers?

Ans: a) Shunt Type b) Series Type c) Combined series-series d) combined series - shunt

j) What is IPFC?

Ans: The Interline Power Flow Controller (IPFC) is a voltage-source-converter (VSC)-based flexible ac transmission system (FACTS) controller for series compensation in a multiline transmission system of a substation.

k) List the different power electronic devices used in FACTs controllers.

Ans: Thyristor valve, capacitor, inductor The other devices of FACTS controller family are static compensator (STATCOM), static synchronous series compensator (SSSC), generalized unified power flow controller (GUPFC) and interline power flow controller (IPFC) etc.

l) What is reactive power compensation in transmission system?

Ans: The reactive power compensation corresponds to the controlling of reactive power to increase the performance characteristics of the AC system. There are some methods by which the power factor of the system can be improved and hence these are regarded as methods of reactive power compensation.

m) What is VSC based HVDC systems?

Ans: VSC-based HVDC systems offer a faster active power flow control with respect to the more mature CSC-HVDC, while also ensuring flexible and extended reactive power controllability at the two converter terminals.

n) What is ignition angle control in converter operation?

Ans: To control the firing angle of a converter, it is necessary to synchronize the firing pulses emanating from the ring counter to the AC commutation voltage that has a frequency in steady state.

2 a) List and explain the advantages of using DC transmission over AC transmission.

Ans:

A DC transmission line has better voltage regulation than an AC transmission line. For the same voltage, A DC transmission system requires less insulation material because the potential stress on the insulation is less in case of DC transmission system than that in AC transmission system. The DC transmission is the transmission of electric power when the direct current system is employed for the power transmission.

Advantages of DC Transmission

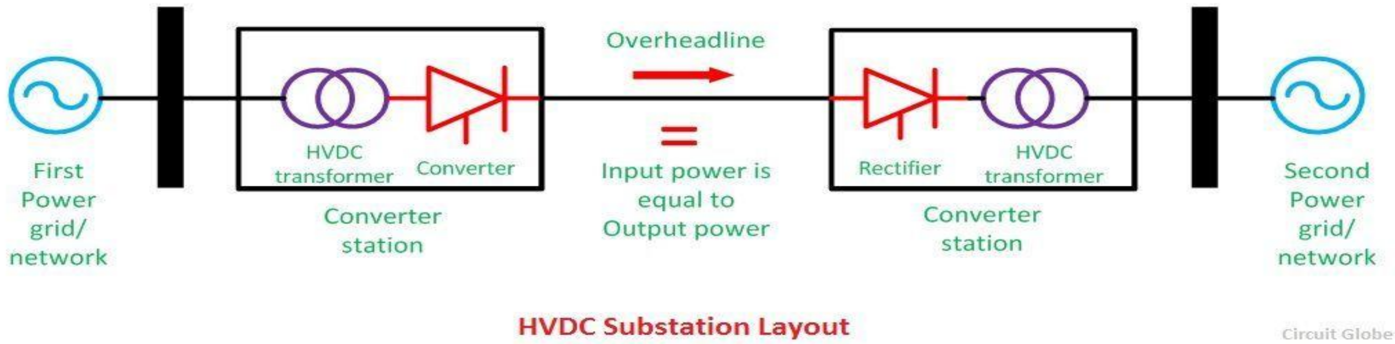
1. The high voltage DC transmission system has the following advantages −

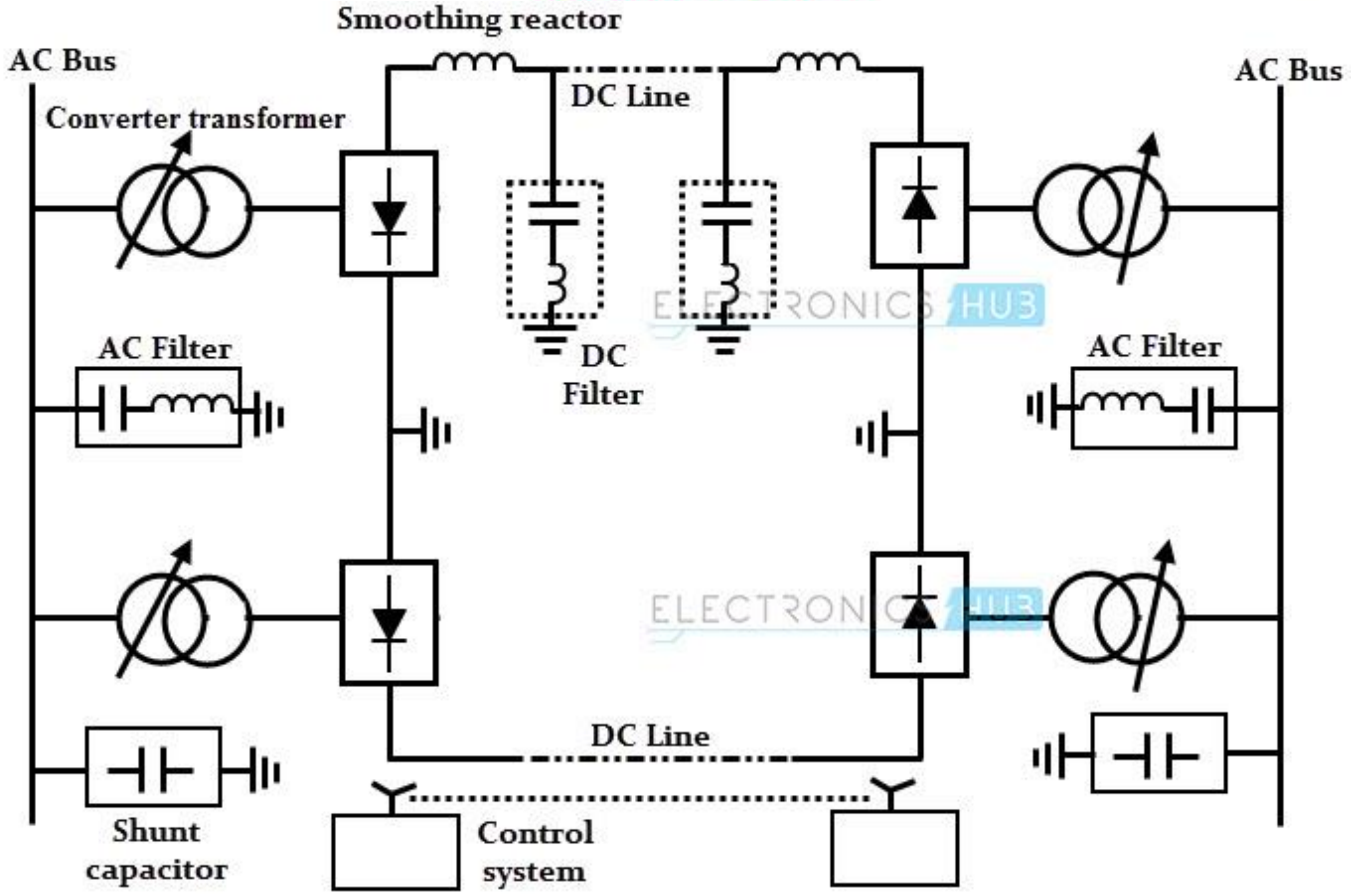
2. DC transmission requires less conductor material than AC transmission as only two wire are required for the power transmission through DC system.

3. DC transmission lines are free from the skin effect. Therefore, the entire cross-section of the line conductor is utilised, hence the effect resistance of the line is small.
4. There is no capacitance in the DC transmission. Therefore, there is no power loss due to the charging current.
5. There is no inductance, phase displacement, and surge problems in the DC transmission.
6. For the same sending end voltage and load conditions, the voltage drop in the DC transmission line is less than the AC transmission line. It is because of the absence of inductance in DC transmission line.
7. A DC transmission line has better voltage regulation than an AC transmission line.
8. For the same voltage, A DC transmission system requires less insulation material because the potential stress on the insulation is less in case of DC transmission system than that in AC transmission system.
9. DC transmission does not suffer from stability and synchronizing problems.
10. In high-voltage DC transmission, there is no dielectric losses.

11. A DC transmission line has less corona loss and reduced interference with the communication circuits.

2 b) Draw the layout of HVDC transmission substation and explain its operation.
Ans:





The system which uses the direct current for the transmission of the power such type of system is called HVDC (High Voltage Direct Current) system. The HVDC system is less expensive and has minimum losses. It transmits the power between the unsynchronized AC system.

Component of an HVDC Transmission System
The HVDC system has the following main components.

- Converter Station
- Converter Unit
- Converter Valves
- Converter Transformers
- Filters
- AC filter
- DC filter
- High-frequency filter
- Reactive Power Source
- Smoothing Reactor
- HVDC System Pole

Converter Station
The terminal substations which convert an AC to DC are called rectifier terminal while the terminal substations which convert DC to AC are called inverter terminal. Every terminal is designed to work in both the rectifier and inverter mode. Therefore, each terminal is called converter terminal, or rectifier terminal. A two-terminal HVDC system has only two terminals and one HVDC line.

hvdc-converter-station

Converter Unit
The conversion from AC to DC and vice versa is done in HVDC converter stations by using three-phase bridge converters. This bridge circuit is also called Graetz circuit. In HVDC transmission a 12-pulse bridge converter is used. The converter obtains by connecting two or 6-pulse bridge in series.

Converter Valves
The modern HVDC converters use 12-pulse converter units. The total number of a valve in each unit is 12. The valve is made up of series connected thyristor modules.The number of thyristor valve depends on the required voltage across the valve. The valves are installed in valve halls, and they are cooled by air, oil, water or freon.12-pulse-converter-unit

Converter Transformer
The converter transformer converts the AC networks to DC networks or vice versa. They have two sets of three phase windings. The AC side winding is connected to the AC bus bar, and the valve side winding is connected to valve bridge.These windings are connected in star for one transformer and delta to another.

The AC side windings of the two, three phase transformer are connected in stars with their neutrals grounded. The valve side transformer winding is designed to withstand alternating voltage stress and direct voltage stress from valve bridge. There are increases in eddy current losses due to the harmonics current. The magnetisation in the core of the converter transformer is because of the following reasons.

The alternating voltage from AC network containing fundamentals and several harmonics.
The direct voltage from valve side terminal also has some harmonics.
Filters
The AC and DC harmonics are generated in HVDC converters. The AC harmonics are injected into the AC system, and the DC harmonics are injected into DC lines. The harmonics have the following advantages.

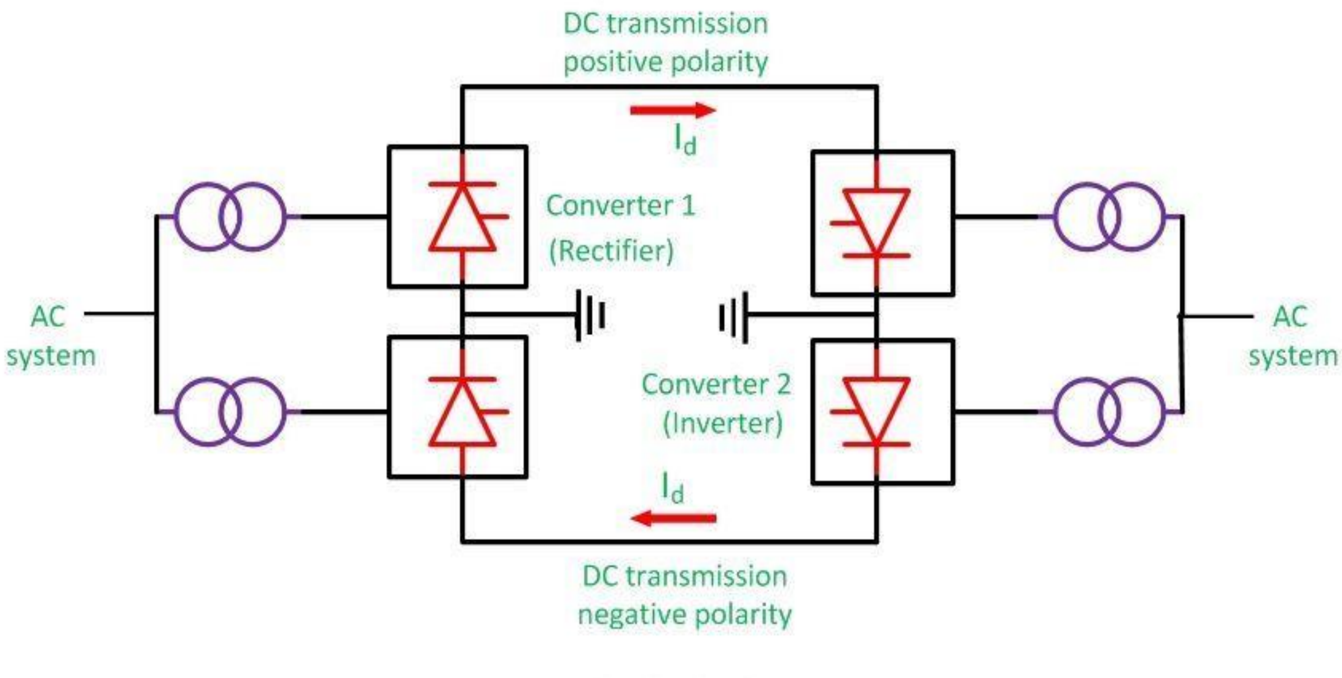
It causes the interference in telephone lines.
Due to the harmonics, the power losses in machines and capacitors are connected in the system.
The harmonics produced resonance in an AC circuit resulting in over voltages.
Instability of converter controls.
The harmonics are minimised by using the AC, DC and high-frequency filters. The types of filter are explained below in details.

AC Filters – The AC filters are RLC circuit connected between phase and earth. They offered low impedances to the harmonic frequencies. Thus, the AC harmonic currents are passed to earth. Both tuned and damped filters are used. The AC harmonic filter also provided a reactive power required for satisfactory operation of converters.
DC Filters – The DC filter is connected between the pole bus and neutral bus. It diverts the DC harmonics to earth and prevents them from entering DC lines. Such a filter does not require reactive power as DC line does not require DC power.
High-Frequency Filters – The HVDC converter may produce electrical noise in the carrier frequency band from 20 kHz to 490 kHz. They also generate radio interference noise in the megahertz range frequencies. High-frequency filters are used to minimise noise and interference with power line carrier communication. Such filters are placed between the converter transformer and the station AC bus.
Reactive Power Source
Reactive power is required for the operations of the converters. The AC harmonic filters provide reactive power partly. The additional supply may also be obtained from shunt capacitors synchronous phase modifiers and static var systems. The choice depends on the speed of control desired.

Smoothing Reactor
Smoothing reactor is an oil filled oil cooled reactor having a large inductance. It is connected in series with the converter before the DC filter. It can be located either on the line side or on the neutral side. Smoothing reactors serve the following purposes.

They smooth the ripples in the direct current.
They decrease the harmonic voltage and current in the DC lines.
They limit the fault current in the DC line.
Consequent commutation failures in inverters are prevented by smoothing reactors by reducing the rate of rising of the DC line in the bridge when the direct voltage of another series connected voltage collapses.
Smoothing reactors reduce the steepness of voltage and current surges from the DC line. Thus, the stresses on the converter valves and valve surge diverters are reduced.
HVDC System Pole
The HVDC system pole is the part of an HVDC system consisting of all the equipment in the HVDC substation. It also interconnects the transmission lines which during normal operating condition exhibit a common direct polarity with respect to earth. Thus the word pole refers to the path of DC which has the same polarity with respect to earth. The total pole includes substation pole and transmission line pole.

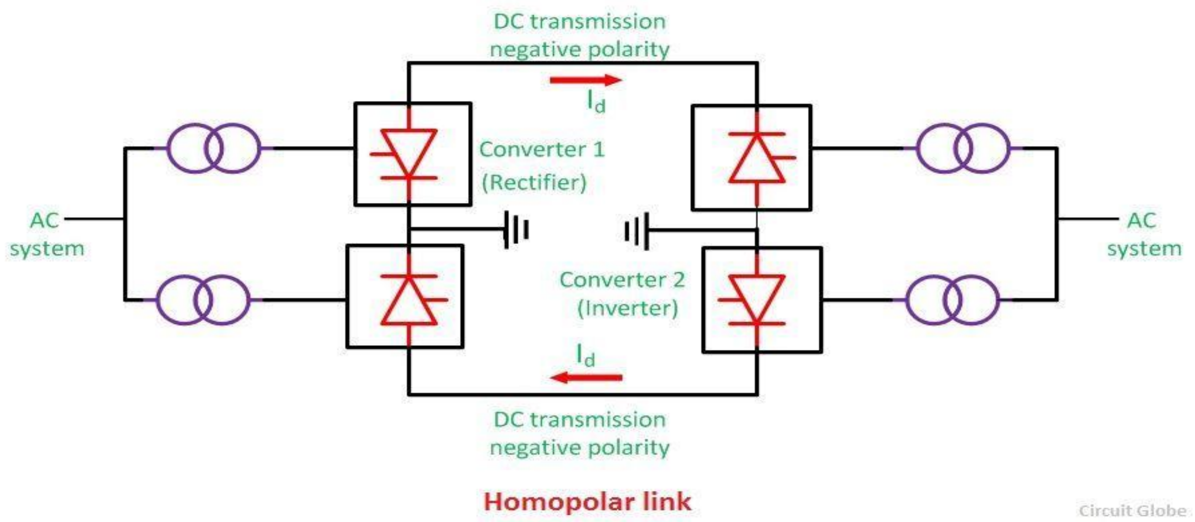
3 a) Differentiate bipolar and homopolar DC links in transmission system.
Ans:
Bipolar link – The Bipolar link has two conductors one is positive, and the other one is negative to the earth. The link has converter station at each end. The midpoints of the converter stations are earthed through electrodes. The voltage of the earthed electrodes is just half the voltage of the conductor used for transmission the HVDC.



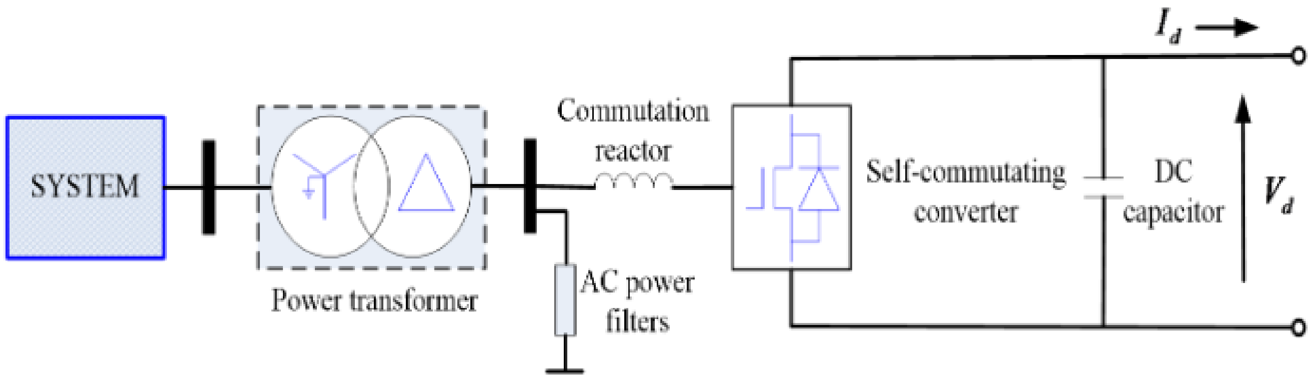
Bipolar link

The most significant advantage of the bipolar link is that if any of their links stop operating, the link is converted into Monopolar mode because of the ground return system. The half of the system continues supplies the power. Such types of links are commonly used in the HVDC systems.

Homopolar link– It has two conductors of the same polarity usually negative polarity, and always operates with earth or metallic return. In the homopolar link, poles are operated in parallel, which reduces the insulation cost.



3 b) Explain the operation of voltage source converter-based systems.
Ans:
Voltage Source Converters (VSC) are self-commutated converters to connect HVAC and HVDC systems using devices suitable for high power electronic applications, such as IGBTs. VSCs are capable of self-commutation, being able to generate AC voltages without the need to rely on an AC system. This allows for independent rapid control of both active and reactive power and black start capability. VSCs maintain a constant polarity of the DC voltage for their building blocks, such as the 2-level or 3-level converter as well as the so-called ‘modules’ in an MMC. The change of power flow direction is achieved by reversing the direction of the current. Thereby, VSCs are more easily integrated in multi-terminal DC systems. VSC-based HVDC systems offer a faster active power flow control with respect to the more mature CSC-HVDC, while also ensuring flexible and extended reactive power controllability at the two converter terminals.



Technology Types
VSC can be classified with respect to the converter technology types used, which have evolved over time:

Two-Level VSC – earliest technology used
Three Level Diode Neutral Point Clamped (NPC) or Three Level Active NPC
Two Level with Optimum Pulse-Width Modulation (OPWM)
Cascaded-two Level Converter (CTL)
Modular Multi-Level Converter (MMC), which is the latest and most advanced technology used for HVDC transmission. MMC differentiates further into the so-called Half Bridge type and Full Bridge type MMC.

In offshore HVDC grids, MMC is becoming the preferred power electronic converter for converting between AC and DC as it presents several benefits: (i) the ability to reverse the power flow without reversing the polarity of the DC voltages by DC current reversal; (ii) modularity and scalability features, making it advantageous compared to other VSC topologies; (iii) its inherent capability of storing energy internally in the converter. This can benefit the system in which it is connected and enables the drastic reduction of operating losses of the converter stations by avoiding the need for high frequency switching of the semi-conductor devices.

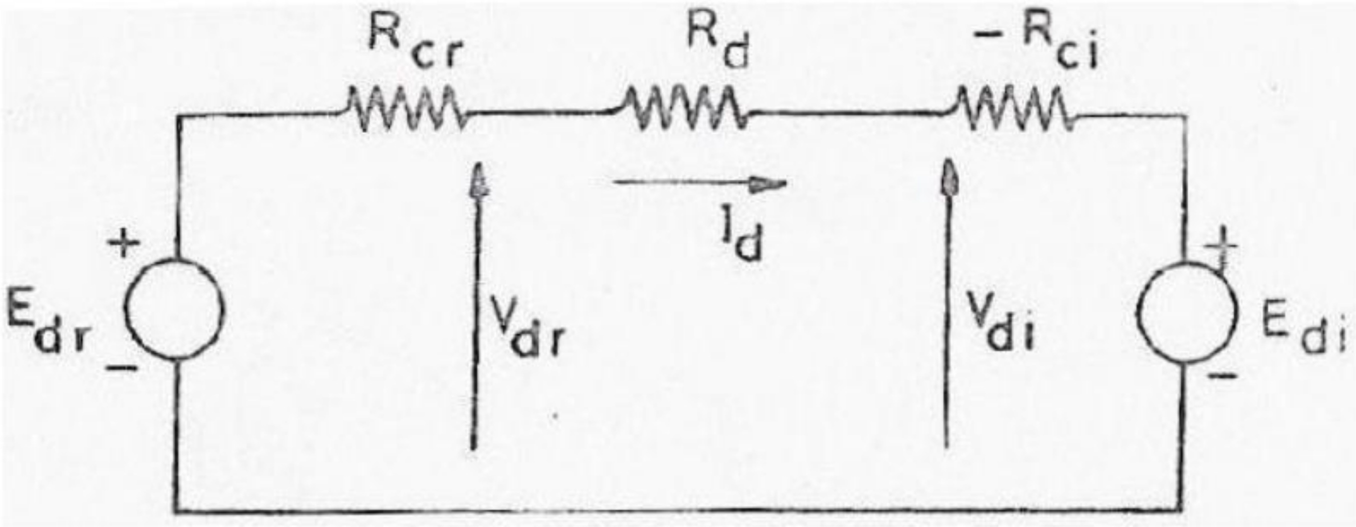
Components & enablers
DC/DC converter

Transformer (Optional Tapping in series/parallel)
DC-link capacitors
Passive high-pass filters
Phase reactors
DC cables
DC breaker (Optional)

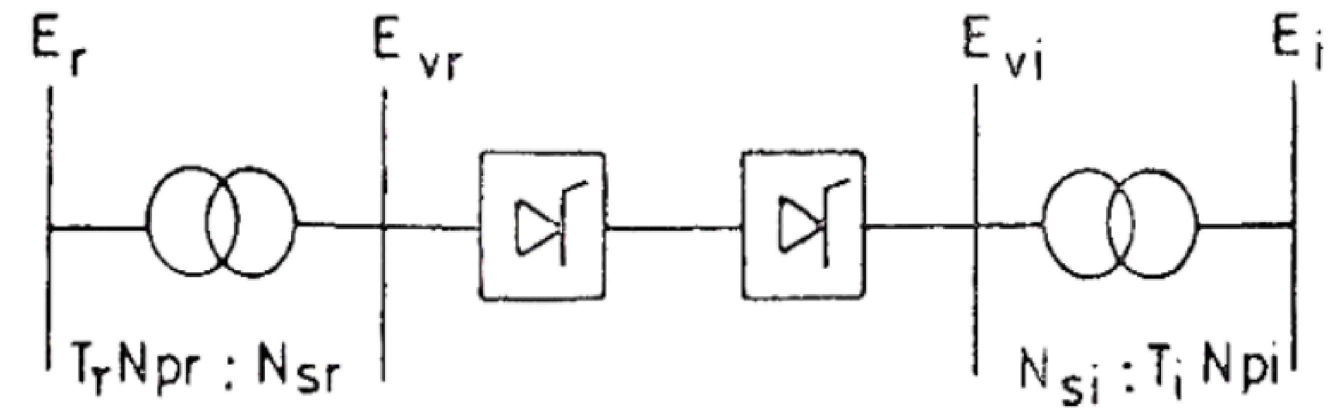
4 a) List and explain the features of controlling converter performance.
Ans:

Principles 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.



Consider the steady state equivalent circuit of a two terminal DC link. This is based on the assumption that all the series connected bridges in both poles of a converter station are identical and have the same delay angles. Also the number of series connected bridges (n_b) in both stations (rectifier and inverter) are the same.



The voltage sources E_{dr} and E_{di} are defined by

$$E_{dr} = (3\sqrt{2}/\pi)\ n_b\ E_{vr}\ \cos\alpha_r \quad \text{---- (1)}$$

$$E_{di} = (3\sqrt{2}/\pi)\ n_b\ E_{vi}\ \cos\gamma_i \quad \text{---- (2)}$$

where E_{vr} and E_{vi} are the line to line voltages in the valve side windings of the rectifier and inverter transformer respectively. From the above figure these voltages can be obtained by

$$E_{vr} = \frac{N_{sr}E_r}{N_{pr}T_r} \quad , \qquad E_{vi} = \frac{N_{si}E_i}{N_{pi}T_i} \quad \text{---- (3)}$$

where E_r and E_i are the AC (line to line) voltages of the converter buses on the rectifier and inverter side. T_r and T_i are the OFF-nominal tap ratios on the rectifier and inverter side.

Combining equations (1), (2) and (3),

$$E_{dr} = (A_r\, E_r\, /T_r) \cos\alpha_r \quad \text{---- (4)}$$

$$E_{di} = (A_i\, E_i\, /T_i) \cos\gamma_i \quad \text{---- (5)}$$

where A_r and A_i are constants.

The steady-state current I_d in the DC link is obtained as

$$I_d = \frac{(E_{dr} - E_{di})}{R_{cr} + R_d - R_{ci}}$$

Substituting equations (4) and (5) in the above equation, we get

$$I_d = \frac{(A_r E_r / T_r)\cos\alpha_r - (A_i E_i / T_i)\cos\gamma_i}{R_{cr} + R_d - R_{ci}}$$

The control variables in the above equation are T_r , T_i and α_r , β_i . However, for maintaining safe commutation margin, it is convenient to consider γ_i as control variable instead of β_i .

As the denominator in the final equation is small, even small changes in the voltage magnitude E_r or E_i can result in large changes in the DC current, the control variables are held constant. As the voltage changes can be sudden, it is obvious that manual control of converter angles is not feasible. Hence, direct and fast control of current by varying α_r or γ_r in response to a feedback signal is essential.

While there is a need to maintain a minimum extinction angle of the inverter to avoid commutation failure, it is economical to operate the inverter at Constant Extinction Angle (CEA) which is slightly above the absolute minimum required for the commutation margin. This results in reduced costs of the inverter stations, reduced converter losses and reactive power consumption. However, the main drawback of CEA control is the negative resistance characteristics of the converter which makes it difficult to operate stably when the AC system is weak (low short-circuit ratios). Constant DC Voltage (CDCV) control or Constant AC Voltage (CACV) control are the alternatives that could be used at the inverter.

Under normal conditions, the rectifier operates at Constant Current (CC) control and the inverter at the CEA control.

The power reversal in the link can take place by the reversal of the DC voltage. This is done by increasing the delay angle at the station initially operating as a rectifier, while reducing the delay angle at the station initially operating as the inverter. Thus, it is necessary to provide both CEA and CC controllers at both terminals.

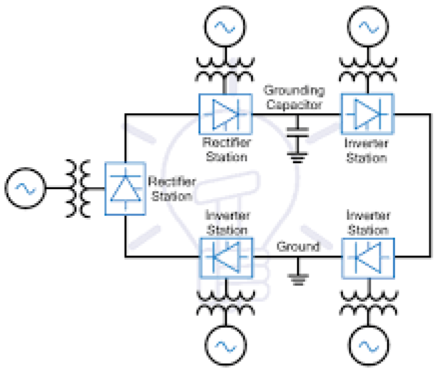
The feedback control of power in a DC link is not desirable because

1) At low DC voltages, the current required is excessive to maintain the required level of power. This can be counterproductive because of the excessive requirements of the reactive power, which depresses voltage further.
2) The constant power characteristic contributes to negative damping and degrades dynamic stability.

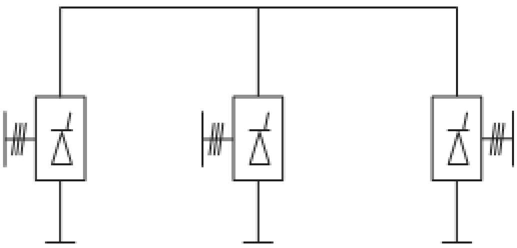
4 b) Explain the operation of multi terminal DC systems with their applications.
Ans:

A multiterminal DC (MTDC) system has more than two converter stations, some of them operating as rectifiers and others as inverters. The simplest way of building a MTDC system from an existing two terminal system is to introduce tappings.

Types of MTDC Systesm
(i) Series
(ii) Parallel
The parallel MTDC systems can be further subdivided into the following categories:
(a) Radial
(b) Mesh



Series Multi-Terminal DC (MTDC) System


Parallel MTDC Systems

Applications of MTDC Systems,

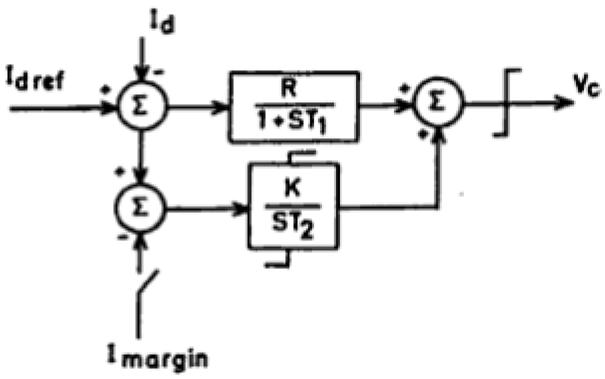
- Connects multiple DC renewable energy farms to multiple power grids.
- Connecting multiple offshore wind farms to the power grid.
- Transfer of bulk power from multiple remote AC generating stations to multiple load centers.

- Allow interconnection between two asynchronous AC power systems.

5 a) Explain the operation of current and extinction angle control in converters with necessary illustrations
Ans:
The current or extinction angle controller generates a control signal Vc which is related to the firing angle required. The firing angle controller generates gate pulses in response to the control signal Vc . The selector picks the smaller of the α determined by the current and CEA controllers.

Current and Extinction 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.

The extinction angle, as opposed to current, is a discrete variable and it was felt the feedback control of gamma is slower than the predictive type. The firing pulse generation is based on the following equation

$$0 = \int_{-\pi+\delta_{n-1}}^{\omega t_n} e_{cj}\, d(\omega t) + 2X_c I_d$$

where e_{cj} is the commutation voltage across valve j and t_n is the instant of its firing.

In general, the prediction of firing angle is based on the equation

$$B_j = \gamma_{ref} + \mu_j$$

where μ_j is the overlap angle of valve j, which is to be predicted based on the current knowledge of the commutation voltage and DC current.

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

5 b) Differentiate series and parallel MTDC systems with necessary diagrams.
Ans:
i) Series
(ii) Parallel
The parallel MTDC systems can be further subdivided into the following categories:
(a) Radial
(b) Mesh
Series MTDC System
This is a natural extension of the two terminal system which is a series connected system. A three-terminal MTDC system is shown in Fig. 9.4. This shows a monopolar arrangement; however, a homopolar arrangement with two

conductors is also possible. The system is grounded at only one point which may be conveniently chosen. If the line insulation is adequate, the grounding point can be shifted, based on changes in the operating conditions. Grounding capacitors may also be used to improve insulation coordination and system performance during transients.

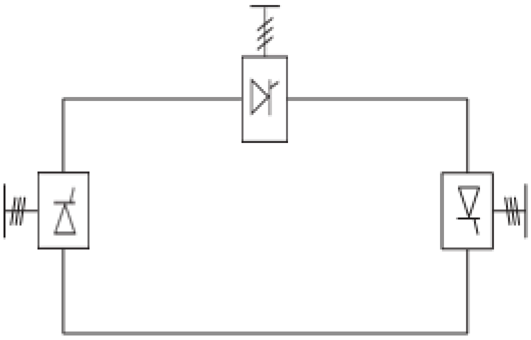


Figure 1.7.1 A series connected MTDC system

In a series connected system, the current is set by one converter station and is common for all the stations. The remaining stations operate at constant angle (extinction or delay) or voltage control. In order to minimize the reactive power requirements and the losses in valve damper circuits, the normal operating values of firing angles may be adjusted using tap changer control. At all times, the sum of the

The switching in or out of a bridge is accomplished by deblocking/block and bypass in a manner similar to that in a two terminal system. The clearing of a fault in the DC line is also similar. The power reversal at a station is also done as in a two terminal system, by reversing the DC voltage by converter control.
The power control in a two terminal system is accomplished by adjusting the current while trying to maintain a constant voltage in the system. This is done to minimize the losses. However, in a MTDC series system, central control would be required to adjust the current in response to changing loading conditions. The local control of power would imply adjusting voltage at the converter station using angle and tap controls. Using only one bridge or a 12 pulse unit for the voltage control and operating the remaining bridges at minimum (or maximum) delay angle can reduce the reactive power requirements.
Parallel MTDC System
Here, the operating philosophy of constant voltage AC systems is extended to DC systems. The currents in all the converter stations except one are adjusted according to the power requirement. One of the terminals operates as a voltage setting terminal at constant angle or voltage. An example of 3 terminal radial system is shown below. This shows a monopolar system but bipolar arrangement would be normally used.

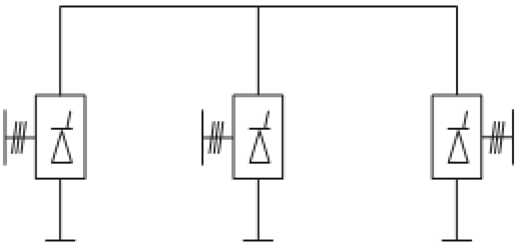


Figure 1.7.2 A parallel connected radial MTDC system

A radial system is one in which the disconnection of one segment of transmission would result in interruption of power from one or more converter stations. In a mesh system, the removal of one link would not result in a disruption, provided the remaining
links are capable of carrying the required power (with increased losses). Evidently, a
mesh system can be more reliable than a radial system. An example of a 4 terminal mesh system is shown in Figure 1.7.3

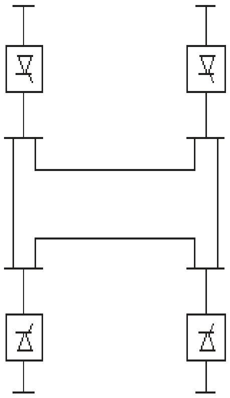


Figure 1.7.3 A parallel connected mesh type MTDC system

The power reversal in a parallel MTDC system would involve mechanical switching as the voltage cannot be reversed. Also, loss of a bridge in one converter station would require either the disconnection of a bridge in all the stations or disconnection of the affected station.

6 a) Explain the operation of reactive power compensators in used in FACTs controllers.
Ans:
Reactive power compensation has been very vital factor in designing and operation of transmission and distribution system. The modern power system becomes very complex. In the system, there are many static and dynamic devices are included. So, that automatic reactive power compensation is necessary. Apart from that a transmission line always produces VARs in proportion to the square of the voltage applied. At the same time, it also consumes VARs in proportion to the square of the current carried by it. That means consumption of VARs increases if load increases & decreases if load decreases.
For better performance of the power system capacities by introducing compensation devices like Flexible AC Transmission system [FACTS] device becomes very important. With the introduction of FACTS device, we can do real time control of the reactive power. By using FACTS device with controller, we can deal with variable reactive power demands. Device like Fixed Capacitor Thyristor Controlled Reactor (FC-TCR) can control variable reactive power with the use of controller. The controlling of reactive power depends on the rating of the Capacitor, rating of Reactor and rating of the Switches. By controlling firing angle and pulse width of the gate pulses we can control the reactive power.
Need of reactive power compensation
To enable the voltage and to provide active power (watt) along transmission line reactive power is mandatory. As in the system major loads are passive loads. This passive device stores reactive power produce by the ac source in the positive quarter of cycle and it sent back to the ac power source during the next quarter of cycle. And same for the negative cycle. During this operation frequency of reactive power motion is two times the rated value. So, to avoid the circulation between the passive loads and AC power source reactive power needs to compensate. And to maintain the power factor near to unity of the system and maintain the voltage stability reactive power should compensate.
FACTS Device
Now for the transmission planner most important aspect is that FACTS technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new upgraded lines . The likelihood that current through a line can be controlled at a practicable cost enables a large potential of increasing the capacity of existing line with huge conductors, and use of FACTS devices to make it possible.
Note: Give marks if they explain any one type reactive power compensators.
6 b) Explain the necessity of FACTS controllers.
Ans:

We need these interconnections because, apart from delivery, the purpose of the transmission network is to pool power plants and load centers in order to minimize the total power generation capacity and fuel cost. Transmission interconnections enable taking advantage of diversity of loads, availability of sources, and fuel price in order to supply electricity to the loads at minimum cost with a required reliability. In general, if a power delivery system was made up of radial lines from individual local generators without being part of a grid system, many more generation resources would be needed to serve the load with the same reliability, and the cost of electricity would be much higher. With that perspective, transmission is often an alternative to a new generation resource. Less transmission capability means that more generation resources would be required regardless of whether the system is made up of large or small power plants. In fact small distributed generation becomes more economically viable if there is a backbone of a transmission grid. One cannot be really sure about what the optimum balance is between generation and transmission unless the system planners use advanced methods of analysis which integrate transmission planning into an integrated value-based transmission/generation planning scenario. The cost of transmission lines and losses, as well as difficulties encountered in building new transmission lines, would often limit the available transmission capacity. It seems that there are many cases where economic energy or reserve sharing is constrained by transmission capacity, and the situation is not getting any better. In a deregulated electric service environment, an effective electric grid is vital to the competitive environment of reliable electric service.

On the other hand, as power transfers grow, the power system becomes increasingly more complex to operate and the system can become less secure for riding through the major outages. It may lead to large power flows with inadequate control, excessive reactive power in various parts of the system, large dynamic swings between different parts of the system and bottlenecks, and thus the full potential of transmission interconnections cannot be utilized. The power systems of today, by and large, are mechanically controlled. There is a widespread use of microelectronics, computers and high-speed communications for control and protection of present transmission systems; however, when operating signals are sent to the power circuits, where the final power control action is taken, the switching devices are mechanical and there is little high-speed control. Another problem with mechanical devices is that control cannot be initiated frequently, because these mechanical devices tend to wear out very quickly compared to static devices.

In effect, from the point of view of both dynamic and steady-state operation, the system is really uncontrolled. Power system planners, operators, and engineers have learned to live with this limitation by using a variety of ingenious techniques to make the system work effectively, but at a price of providing greater operating margins and redundancies. These represent an asset that can be effectively utilized with prudent use of FACTS technology on a selective, as needed basis. In recent years, greater demands have been placed on the transmission network, andthese demandswill continue to increasebecause of the increasingnumberof nonutility generators and heightened competition among utilities themselves. Added to this is the problem that it is very difficult to acquire new rights of way. Increased demands on transmission, absence of long-term planning, and the need to provide open access to generating companies and customers, all together have created tendencies toward less security and reduced quality of supply. The FACTS technology is essential to alleviate some but not all of these difficulties by enabling utilities to get the most service from their transmission facilities and enhance grid reliability. It must be stressed, however, that formany of the capacity expansion needs, building of newlines or upgradingcurrent and voltage capability of existing lines and corridors will be necessary.

7 a) Explain the procedure along with necessary connection diagrams to improve voltage profile using FACTs controllers using mid-point compensation.

Ans:

Consider the simple two-machine (two-bus) transmission model in which an ideal var compensator is shunt connected at the midpoint of the transmission line, as shown in Figure 5.1(a). For simplicity, the line is represented by the series line inductance. The compensator is represented by a sinusoidal ac voltage source (of the fundamental frequency), in-phase with the midpoint voltage, V_m, and with an amplitude identical to that of the sending- and receiving-end voltages ($V_m = V_s = V_r = V$) The midpoint compensator in effect segments the transmission line into two independent parts: the

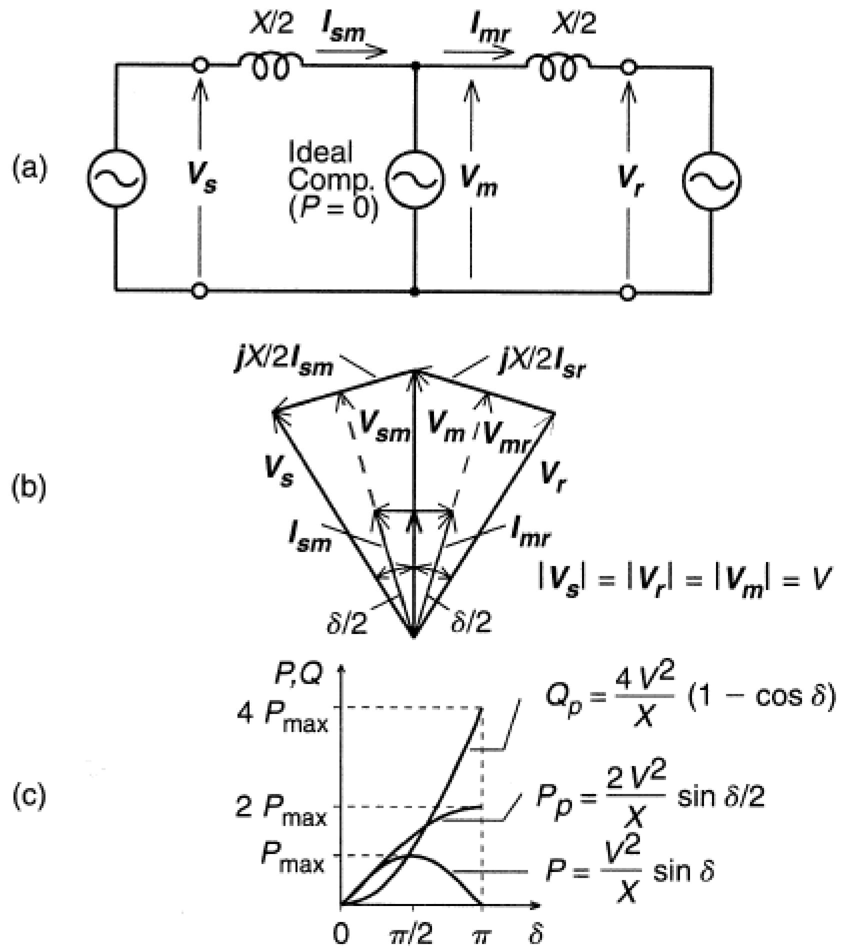


Figure 5.1 Two-machine power system with an ideal midpoint reactive compensator (a), corresponding phasor diagram (b), and power transmission vs. angle characteristic showing the variation of real power P_p and the reactive

first segment, with an impedance of $X/2$, carries power from the sending end to the midpoint, and the second segment, also with an impedance of $X/2$, carries power from the midpoint to the receiving end. The relationship between voltages, $\boldsymbol{V}_s$, $\boldsymbol{V}_r$, $\boldsymbol{V}_m$, (together with $\boldsymbol{V}_{sm}$, $\boldsymbol{V}_{rm}$,), and line segment currents $\boldsymbol{I}_{sm}$ and $\boldsymbol{I}_{mr}$ is shown by the phasor diagram in Figure 5.1(b). Note that the midpoint var compensator exchanges only reactive power with the transmission line in this process.

For the lossless system assumed, the real power is the same at each terminal (sending end, midpoint, and receiving end) of the line, and it can be derived readily from the phasor diagram of Fig. 5.1(b). With

$$V_{sm} = V_{mr} = V\cos\frac{\delta}{4}; \qquad I_{sm} = I_{mr} = I = \frac{4V}{X}\sin\frac{\delta}{4} \tag{5.1}$$

the transmitted power is

$$P = V_{sm}I_{sm} = V_{mr}I_{mr} = V_m I_{sm}\cos\frac{\delta}{4} = VI\cos\frac{\delta}{4} \tag{5.2a}$$

$$Q = VI\sin\frac{\delta}{4} = \frac{4V^2}{X}\left(1 - \cos\frac{\delta}{2}\right) \tag{5.3}$$

The relationship between real power P, reactive power Q, and angle δ for the case of ideal shunt compensation is shown plotted in Figure 5.1(c). It can be observed that the midpoint shunt compensation can significantly increase the transmittable power (doubling its maximum value) at the expense of a rapidly increasing reactive power demand on the midpoint compensator (and also on the end-generators).

It is also evident that for the single-line system of Figure 5.1 the midpoint of the transmission line is the best location for the compensator. This is because the voltage sag along the uncompensated transmission line is the largest at the midpoint. Also, the compensation at the midpoint breaks the transmission line into two equal segments for each of which the maximum transmittable power is the same. For unequal segments, the transmittable power of the longer segment would clearly determine the overall transmission limit.

The concept of transmission line segmentation can be expanded to the use of multiple compensators, located at equal segments of the transmission line, as illustrated for four line segments in Figure 5.2. Theoretically, the transmittable power would double with each doubling of the segments for the same overall line length. Furthermore, with the increase of the number of segments, the voltage variation along the line would rapidly decrease, approaching the ideal case of constant voltage profile.

It is to be appreciated that such a distributed compensation hinges on the instantaneous response and unlimited var generation and absorption capability of the shunt compensators employed, which would have to stay in synchronism with the prevailing phase of the segment voltages and maintain the predefined amplitude of the transmis-

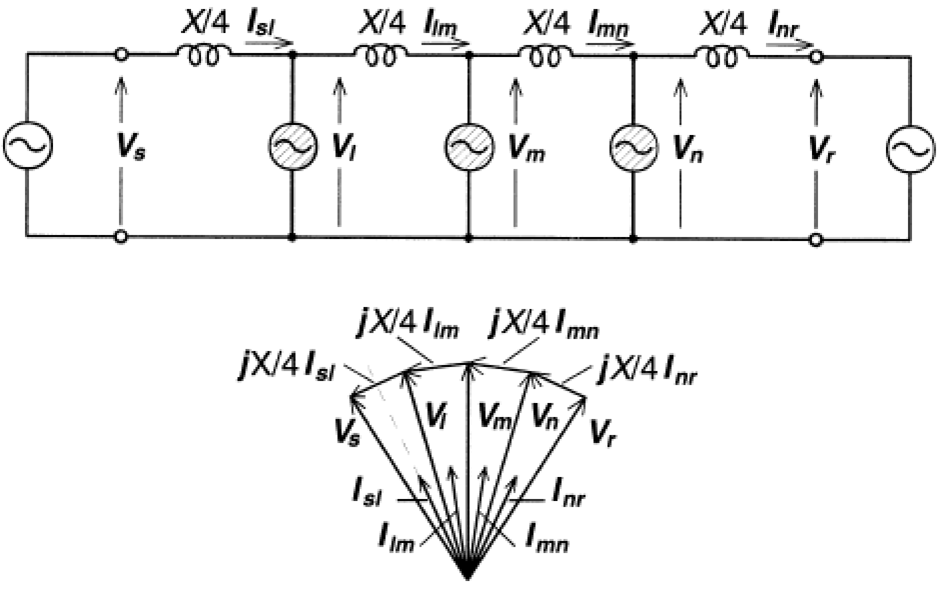


Figure 5.2 Two-machine system with ideal reactive compensators maintaining constant transmission voltage profile by line segmentation, and associated phasor diagram.

sion voltage, independently of load variation. Such a system, however, would tend to be too complex and probably too expensive, to be practical, particularly if stability and reliability requirements under appropriate contingency conditions are also considered. However, the practicability of limited line segmentation, using thyristor-controlled static var compensators, has been demonstrated by the major, 600 mile long, 735 kV transmission line of the Hydro-Quebec power system built to transmit up to 12000 MW power from the James Bay hydro-complex to the City of Montreal and to neighboring U.S. utilities. More importantly, the transmission benefits of voltage support by controlled shunt compensation at strategic locations of the transmission system have been demonstrated by numerous installations in the world.

7 b) Explain how the FACTs controllers can control the stability of transmission systems.

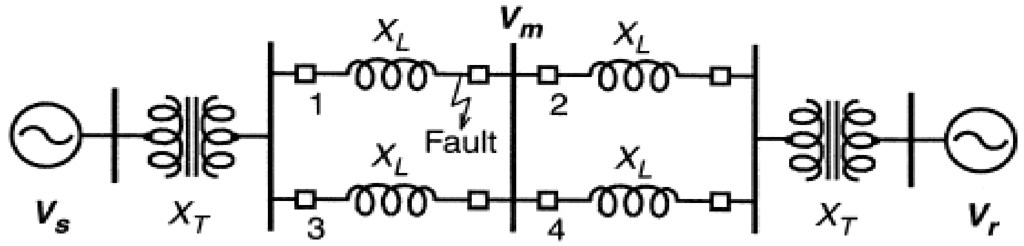
Ans:

As seen in the previous sections, reactive shunt compensation can significantly increase the maximum transmittable power. Thus, it is reasonable to expect that, with suitable and fast controls, shunt compensation will be able to change the power flow

in the system during and following dynamic disturbances so as to increase the transient stability limit and provide effective power oscillation damping.

The potential effectiveness of shunt (as well as other compensation and flow control techniques) on transient stability improvement can be conveniently evaluated by the *equal area criterion.* The meaning of the equal area criterion is explained with the aid of the simple two machine (the receiving end is an infinite bus), two line system shown in Figure 5.4(a) and the corresponding P versus δ curves shown in Figure 5.4(b). Assume that the complete system is characterized by the P versus δ curve "a" and is operating at angle δ_1 to transmit power P_1 when a fault occurs at line segment "1." During the fault the system is characterized by the P versus δ curve "b" and thus, over this period, the transmitted electric power decreases significantly while mechanical input power to the sending-end generator remains substantially constant corresponding to P_1. As a result, the generator accelerates and the transmission angle increases from δ_1 to δ_2 at which the protective breakers disconnect the faulted line segment "1" and the sending-end generator absorbs *accelerating* energy, represented by area "$A1$." After fault clearing, without line segment "1" the degraded system is characterized

(a)



(b)

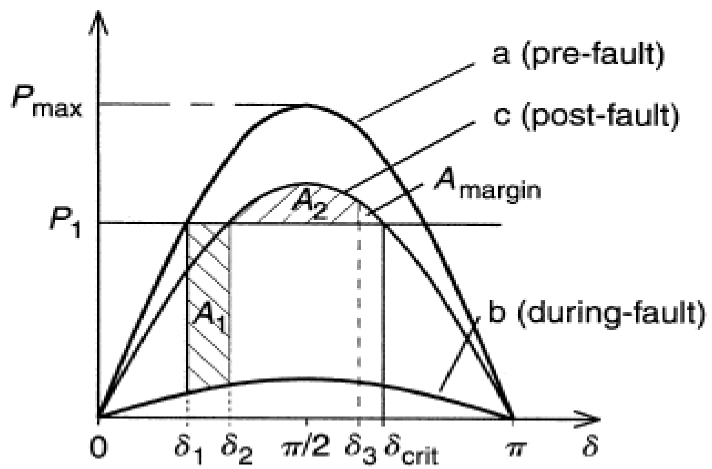


Figure 5.4 Illustration of the equal area criterion for transient stability of a two-machine, two-line power system.

by the P versus δ curve "c." At angle δ_2 on curve "c" the transmitted power exceeds the mechanical input power P_1 and the sending end generator starts to decelerate: however, angle δ further increases due to the kinetic energy stored in the machine. The maximum angle reached at δ_3, where the decelerating energy, represented by area "A_2," becomes equal to the accelerating energy represented by area "A_1". The limit of transient stability is reached at $\delta_3 = \delta_{crit}$, beyond which the decelerating energy would not balance the accelerating energy and synchronism between the sending end and receiving end could not be restored. The area "A_{margin}," between δ_3 and δ_{crit}, represent the transient stability margin of the system.

From the above general discussion it is evident that the transient stability, at a given power transmission level and fault clearing time, is determined by the P versus δ characteristic of the post-fault system. Since appropriately controlled shunt compensation can provide effective voltage support, it can increase the transmission capability of the post-fault system and thereby enhance transient stability.

For comparison, the above introduced equal-area criterion is applied here (and in subsequent chapters) in a greatly simplified manner, with the assumption that the original single line system shown in Figure 5.1(a) represents both the pre-fault and post-fault systems. (The impracticality of the single line system and the questionable validity of this assumption has no effect on this qualitative comparison, but improves the visual clarity considerably.) Suppose that this system of Figure 5.1(a), with and without the midpoint shunt compensator, transmits the same steady-state power. Assume that both the uncompensated and the compensated systems are subjected to the same fault for the same period of time. The dynamic behavior of these systems is illustrated in Figures 5.5(a) and (b). Prior to the fault both of them transmit power P_m (subscript m stands for "mechanical") at angles δ_1 and δ_{p1}, respectively. During the fault, the transmitted electric power (of the single line system considered) becomes zero while the mechanical input power to the generators remains constant (P_m). Therefore, the sending-end generator accelerates from the steady-state angles δ_1 and δ_{p1} to angles δ_2 and δ_{p2}, respectively, when the fault clears. The accelerating energies are represented by areas A_1 and A_{p1}. After fault clearing, the transmitted electric power exceeds the mechanical input power and the sending-end machine decelerates, but the accumulated kinetic energy further increases until a balance between the accelerating and decelerating energies, corresponding to areas A_1, A_{p1} and A_2, A_{p2}, respectively, is reached at δ_3 and δ_{p3}, representing the maximum angular swings for the two cases. The areas between the P versus δ curve and the constant P_m line over the intervals defined by angles δ_3 and δ_{crit}, and δ_{p3} and δ_{pcrit}, respectively, determine the margin of transient stability, that is, the "unused" and still available decelerating energy, represented by areas A_{margin} and $A_{pmargin}$.

Comparison of Figures 5.5(a) and (b) clearly shows a substantial increase in the transient stability margin the ideal midpoint compensation with unconstrained var output can provide by the effective segmentation of the transmission line. Alternatively, if the uncompensated system has a sufficient transient stability margin, shunt compensation can considerably increase the transmittable power without decreasing this margin.

In the preceding discussion, the shunt compensator is assumed to be *ideal.* The adjective "ideal" here means that the amplitude of the midpoint voltage remains constant all the time, except possibly during faults, and its phase angle follows the generator angle swings so that the compensator would not be involved in real power exchange, but it would continuously provide the necessary reactive power. As Figure 5.1(c) shows, the reactive power demand on the midpoint compensator increases rapidly with increasing power transmission, reaching a maximum value equal to four per unit at the maximum steady-state real power transmission limit of two per unit. For

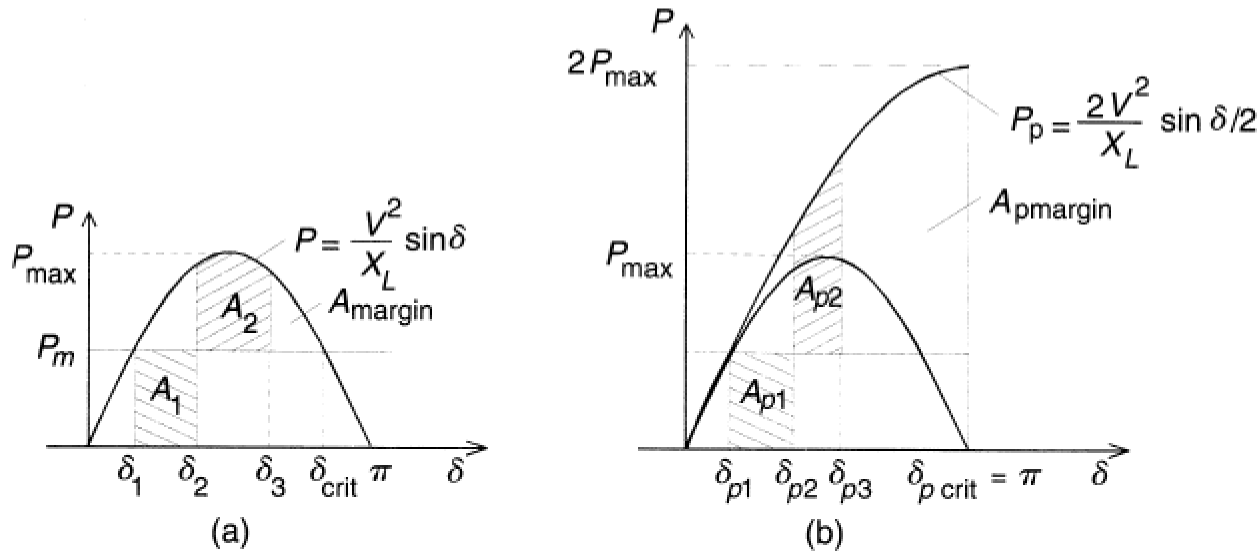


Figure 5.5 Equal area criterion to illustrate the transient stability margin for a simple two machine system without compensation (a), and with an ideal midpoint compensator (b).

obvious economic reasons, the maximum var output of a practical shunt compensator is normally considerably less than that required for full compensation. Thus, a practical compensator can perform as an ideal one only as long as the compensation var demand does not exceed its rating. Above its maximum rating the compensator either becomes a constant reactive impedance or a constant reactive current source, depending on the power circuit employed for reactive power generation. The necessary rating of the compensator is usually determined by planning studies to meet the desired power flow objectives with defined stability margins under specific system contingency conditions.

In the explanation of the equal area criterion at the beginning of this section, a clear distinction was made between the "pre-fault" and "post-fault" power system. It is important to note that from the standpoint of transient stability, and thus of overall system security, the post-fault system is the one that counts. That is, power systems are normally designed to be transiently stable, with defined pre-fault contingency scenarios and post-fault system degradation, when subjected to a major disturbance (fault). Because of this (sound) design philosophy, the actual capacity of transmission systems is considerably higher than that at which they are normally used. Thus, it may seem technically plausible (and economically savvy) to employ fast acting compensation techniques, instead of overall network compensation, specifically to handle dynamic events and increase the transmission capability of the degraded system under the contingencies encountered.

8 a) Explain the objectives and operation of shunt compensation in transmission systems.

Ans:

It has long been recognizedthat the steady-state transmittable power can be increased and the voltage profile along the line controlled by appropriate reactive shunt compensation. The purpose of, this reactive compensation is to chage the natural electrical characteristics of the transmission line to make it more compatible with the prevailing load demand. Thus, shunt connected, fixed or mechanically switched reactors are applied to minimize line overvoltage under light load conditions, and shunt connected, fixed or mechanically switched capacitors are applied to maintain voltage levels under heavy load conditions.

In this section, basic considerations to increase the transmittable power by ideal shunt-connected var compensation will be reviewed in order to provide a foundation for power electronics-based compensation and control techniques to meet specific compensation objectives. The ultimate objective of applying reactive shunt compensation in a transmission system is to increase the transmittable power. This may be required to improve the steady-state transmission characteristics as well as the stability of the system. Var compensation is thus used for voltage regulation at the midpoint (or some intermediate) to segment the transmission line and at the end of the (radial) line to prevent voltage instability, as well as for dynamic voltage control to increase transient stability and damp power oscillations.

5.2.1.1 The Thyristor-Controlled and Thyristor-Switched Reactor (TCR and TSR). An elementary single-phase thyristor-controlled reactor (TCR) is shown in Figure 5.7(a). It consists of a fixed (usually air-core) reactor of inductance L, and a bidirectional thyristor valve (or switch) *sw*. Currently available large thyristors can block voltage up to 4000 to 9000 volts and conduct current up to 3000 to 6000 amperes. Thus, in a practical valve many thyristors (typically 10 to 20) are connected in series to meet the required blocking voltage levels at a given power rating. A thyristor valve can be brought into conduction by simultaneous application of a gate pulse to all thyristors of the same polarity. The valve will automatically block immediately after the ac current crosses zero, unless the gate signal is reapplied.

The current in the reactor can be controlled from maximum (thyristor valve closed) to zero (thyristor valve open) by the method of firing delay angle control. That is, the closure of the thyristor valve is delayed with respect to the peak of the applied voltage in each half-cycle, and thus the duration of the current conduction intervals is controlled. This method of current control is illustrated separately for the positive and negative current half-cycles in Figure 5.7(b), where the applied voltage v and the reactor current $i_L(\alpha)$, at zero delay angle (switch fully closed) and at an arbitrary α delay angle, are shown. When $\alpha = 0$, the valve *sw* closes at the crest of the applied voltage and evidently the resulting current in the reactor will be the same as that obtained in steady state with a permanently closed switch. When the gating of the valve is delayed by an angle α $(0 \leq \alpha \leq \pi/2)$ with respect to the crest of the voltage, the current in the reactor can be expressed with $v(t) = V \cos \omega t$ as follows:

$$i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} v(t)\,dt = \frac{V}{\omega L}(\sin \omega t - \sin \alpha) \tag{5.4}$$

Since the thyristor valve, by definition, opens as the current reaches zero, (5.4) is valid for the interval $\alpha \leq \omega t \leq \pi - \alpha$. For subsequent positive half-cycle intervals the same expression obviously remains valid. For subsequent negative half-cycle intervals, the sign of the terms in (5.4) becomes opposite.

In (5.4) the term $(V/\omega L)\sin \alpha$ is simply an α dependent constant by which the sinusoidal current obtained at $\alpha = 0$ is offset, shifted down for positive, and up for negative current half-cycles, as illustrated in Figure 5.7(b). Since the valve automatically turns off at the instant of current zero crossing (which, for a lossless reactor, is symmetrical on the time axis to the instant of turn-on with respect to the peak of the current), this process actually controls the conduction interval (or angle) of the thyristor

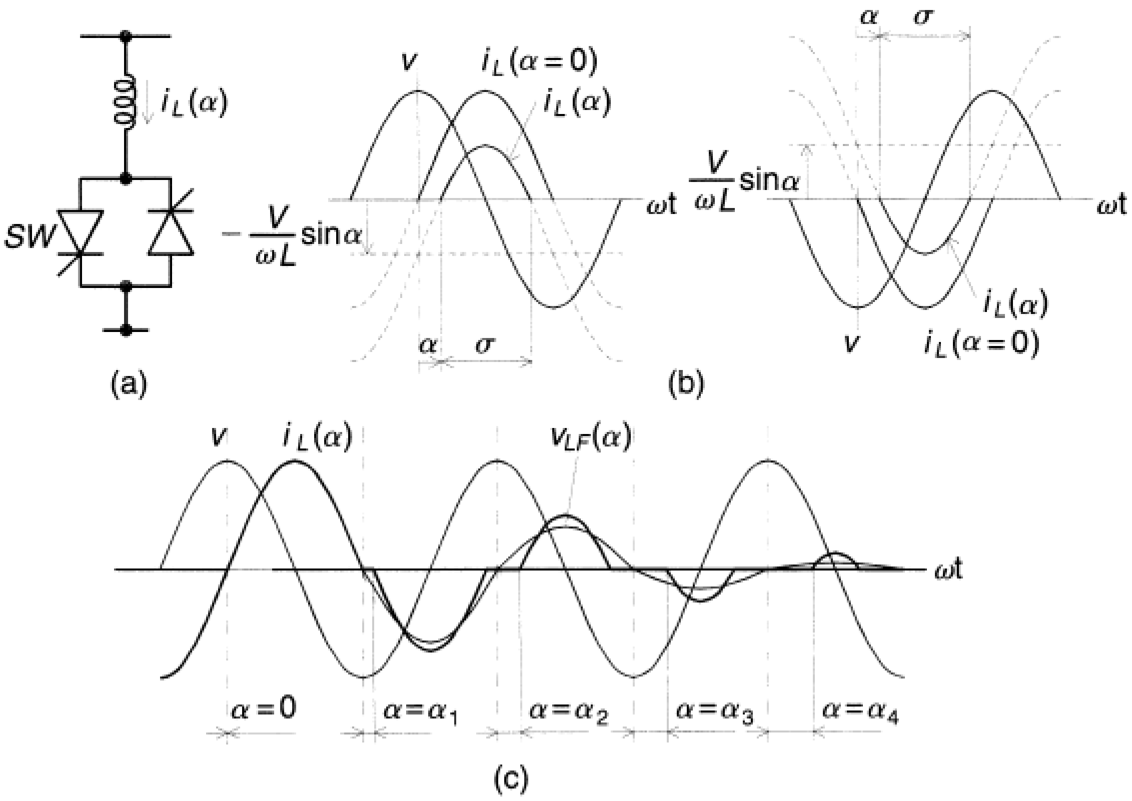


Figure 5.7 Basic thyristor-controlled reactor (a), firing delay angle control (b), and operating waveforms (c).

valve. That is, the delay angle α defines the prevailing conduction angle σ: $\sigma = \pi - 2\alpha$. Thus, as the delay angle α increases, the correspondingly increasing offset results in the reduction of the conduction angle σ of the valve, and the consequent reduction of the reactor current. At the maximum delay of $\alpha = \pi/2$, the offset also reaches its maximum of $V/\omega L$, at which both the conduction angle and the reactor current become zero. The reader should note that the two parameters, delay angle α and conduction angle σ, are equivalent and therefore TCR can be characterized by either of them; their use is simply a matter of preference. For this reason, expressions related to the TCR can be found in the literature both in terms of α and σ.

It is evident that the magnitude of the current in the reactor can be varied continuously by this method of delay angle control from maximum ($\alpha = 0$) to zero ($\alpha = \pi/2$), as illustrated in Figure 5.7(c), where the reactor current $i_L(\alpha)$, together with its fundamental component $i_{LF}(\alpha)$, are shown at various delay angles, α. Note, however, that the adjustment of current in the reactor can take place only once in each half-cycle, in the zero to $\pi/2$ interval ("gating" or "firing interval"). This restriction results in a delay of the attainable current control. The worst-case delay, when changing the current from maximum to zero (or vice versa), is a half-cycle of the applied ac voltage.

The amplitude I_{LF}(a) of the fundamental reactor current $i_{LF}(\alpha)$ can be expressed as a function of angle α:

$$I_{LF}(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right)$$

Note: Give marks if they explain any one type reactive power compensators.

8 b) Explain the operation of UPFC with necessary diagrams and mathematical expressions.

Ans:

UPFC consist of two back to back converters named VSC1 and VSC2, are operated from a DC link provided by a dc storage capacitor. These arrangements operate as an ideal ac to ac converter in which the real power can freely flow either in direction between the ac terminals of the two converts and each converter can independently generate or absorb reactive power as its own ac output terminal.

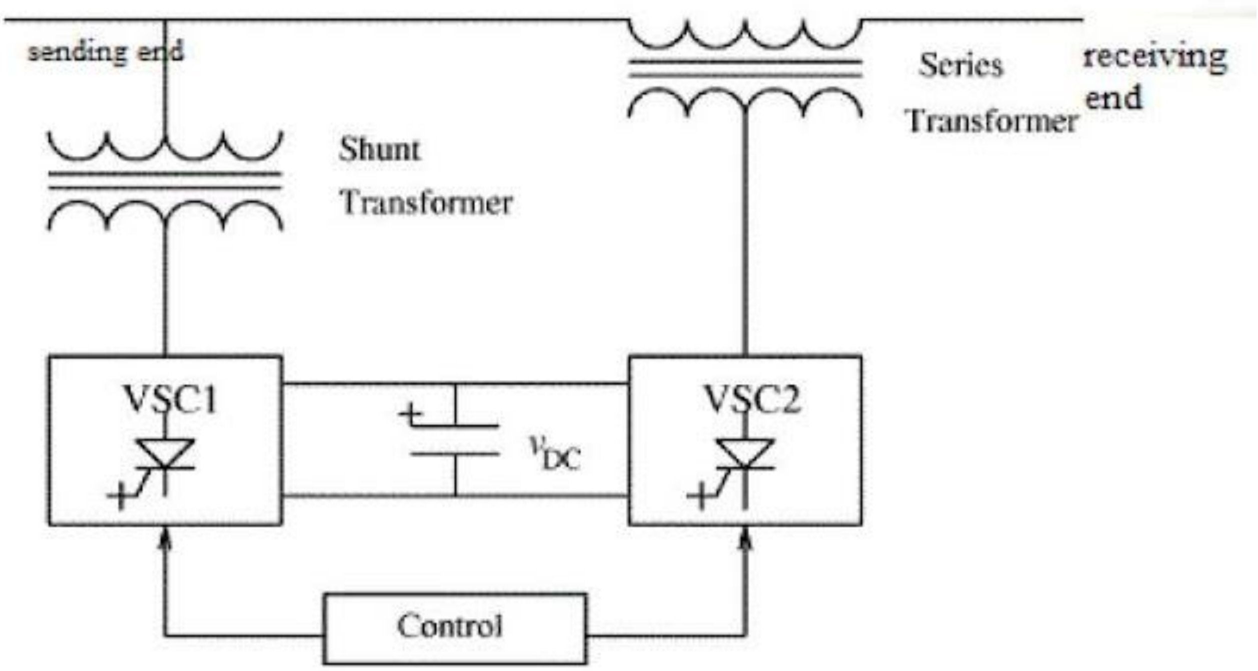


Figure: Basic UPFC scheme

One VSC is connected to in shunt to the transmission line via a shunt transformer and other one is connected in series through a series transformer. The DC terminal of two VSCs is coupled and this creates a path for active power exchange between the converters. VSC provide the main function of UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via an injection transformer. This injected voltage act as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in reactive and active power exchange between it and the ac system. The reactive power exchanged at the dc terminal is generated internally by the converter. The real power exchanged at the ac terminal is converted into dc power which appears at the dc link as a real power demand. And VSC1 is to supply or absorb the real power demanded by converter2 at the common dc link to support real power exchange resulting from the series voltage injection. This dc link power demand of VSC2 is converted back to ac by VSC1 and coupled to the transmission line bus via shunt connected transformer. In addition, VSC1 can also generate or absorb controllable reactive power if it is required and thereby provide independent shunt reactive compensation for the line. Thus VSC1 can be operated at a unity power factor or to be controlled to have a reactive power exchange with the line independent of the reactive power exchanged by VSC1. Obviously, there can be no reactive power flow through the UPFC dc link.

9 a) Explain the operation of SVC with necessary diagrams and mathematical expressions.
Ans:

A basic var generator arrangement using a fixed (permanently connected) capacitor with a thyristor-controlled reactor (FC-TCR) is shown functionally in Figure 5.18(a). The current in the reactor is varied by the previously discussed method of firing delay angle control. The fixed capacitor in practice is usually substituted, fully or partially, by a filter network that has the necessary capacitive impedance at the fundamental frequency to generate the reactive power required, but it provides a low impedance at selected frequencies to shunt the dominant harmonics produced by the TCR.

The fixed capacitor, thyristor-controlled reactor type var generator may be considered essentially to consist of a variable reactor (controlled by delay angle α) and a fixed capacitor, with an overall var demand versus var output characteristic as shown in Figure 5.18(b). As seen , the constant capacitive var generation (Q_C) of the fixed capacitor is opposed by the variable var absorption (Q_L) of the thyristor-controlled reactor, to yield the total var output (Q) required. At the maximum capacitive var output, the thyristor-controlled reactor is off ($\alpha = 90°$). To decrease the capacitive output, the current in the reactor is increased by decreasing delay angle α. At zero var output, the capacitive and inductive currents become equal and thus the capacitive and inductive vars cancel out. With a further decrease of angle α (assuming that the rating of the reactor is greater than that of the capacitor), the inductive current becomes larger than the capacitive current, resulting in a net inductive var output. At zero delay angle, the thyristor-controlled reactor conducts current over the full 180 degree

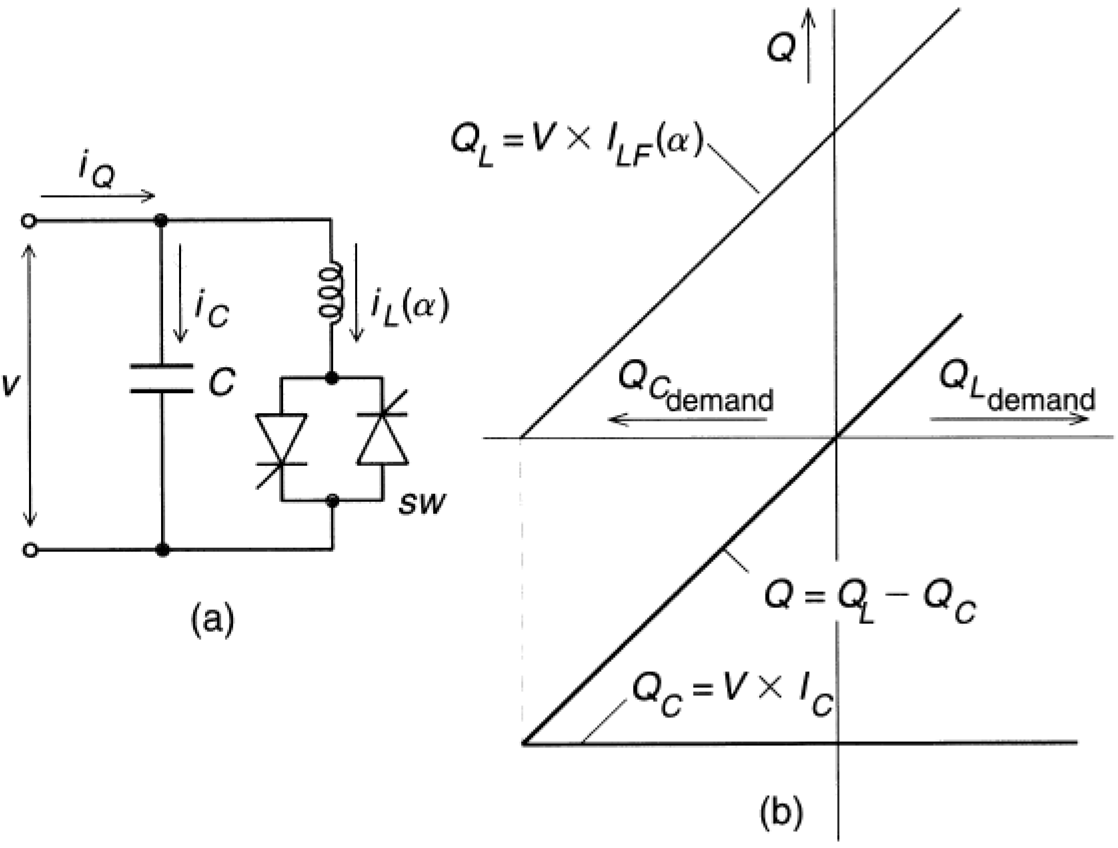


Figure 5.18 Basic FC-TCR type static var generator and its var demand versus var output characteristic.

interval, resulting in maximum inductive var output that is equal to the difference between the vars generated by the capacitor and those absorbed by the fullv conducting reactor.

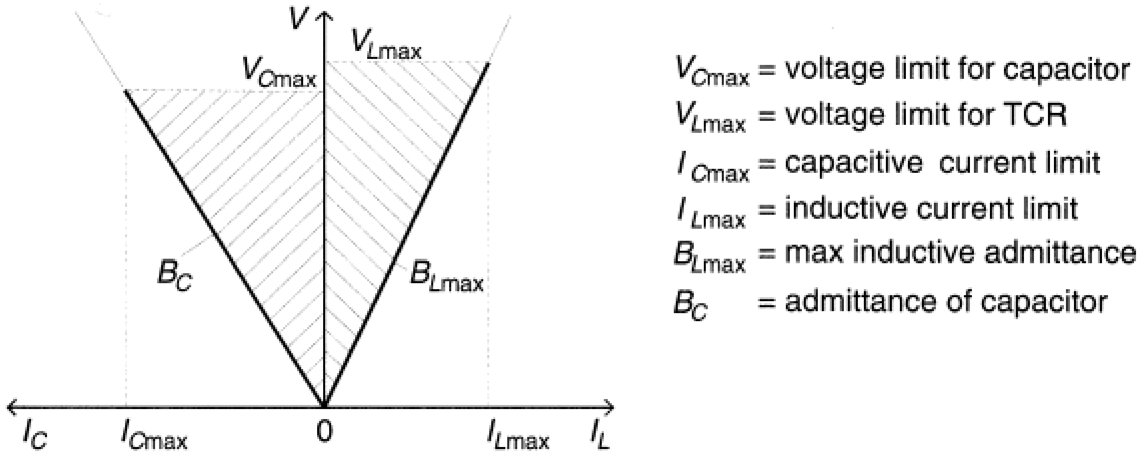


Figure 5.20 Operating *V-I* area of the FC-TCR type var generator.

Note: Give marks if they explain any one type static reactive power compensators.

9 b) Explain the operating principle to control the active and reactive power flow using controllers.
Ans:

Note: In IPFC Both active and reactive power control can be done hence award marks for either basic analysis of active and reactive power control or the operation of IPFC.

Active component of the current flow at E_1 is:

$$I_{p1} = (E_2 \sin \delta)/X$$

Reactive component of the current flow at E_1 is:

$$I_{q1} = (E_1 - E_2 \cos \delta)/X$$

Thus, active power at the E_1 end:

$$P_1 = E_1 (E_2 \sin \delta)/X$$

Reactive power at the E_1 end:

$$Q_1 = E_1 (E_1 - E_2 \cos \delta)/X$$

Similarly, active component of the current flow at E_2 is:

$$I_{p2} = (E_1 \sin \delta)/X$$

Reactive component of the current flow at E_2 is:

$$I_{q2} = (E_2 - E_1 \cos \delta)/X$$

Thus, active power at the E_2 end:

$$P_2 = E_2 (E_1 \sin \delta)/X$$

Reactive power at the E_2 end:

$$Q_2 = E_2 (E_2 - E_1 \cos \delta)/X$$

Naturally P_1 and P_2 are the same:

$$P = E_1 (E_2 \sin \delta)/X$$

Recent developments of FACTS research have led to a new device: the Interline Power Flow Controller (IPFC). This element consists of two (or more) series voltage source converter-based devices (SSSCs) installed in two (or more) lines and connected at their DC terminals. Thus, in addition to serially compensate the reactive power, each SSSC can provide real power to the common DC link from its own line. The IPFC gives them the possibility to solve the problem of controlling different transmission lines at a determined substation. In fact, the under-utilized lines make available a surplus power which can be used by other lines for real power control. This capability makes it possible to equalize both real and reactive power flow between the lines, to transfer power demand from overloaded to underloaded lines, to compensate against resistive line voltage drops and the corresponding reactive line power, and to increase the effectiveness of a compensating system for dynamic disturbances (transient stability and power oscillation damping). Therefore, the IPFC provides a highly effective scheme for power transmission at a multi-line substation. The IPFC is a multi-line FACTS device.

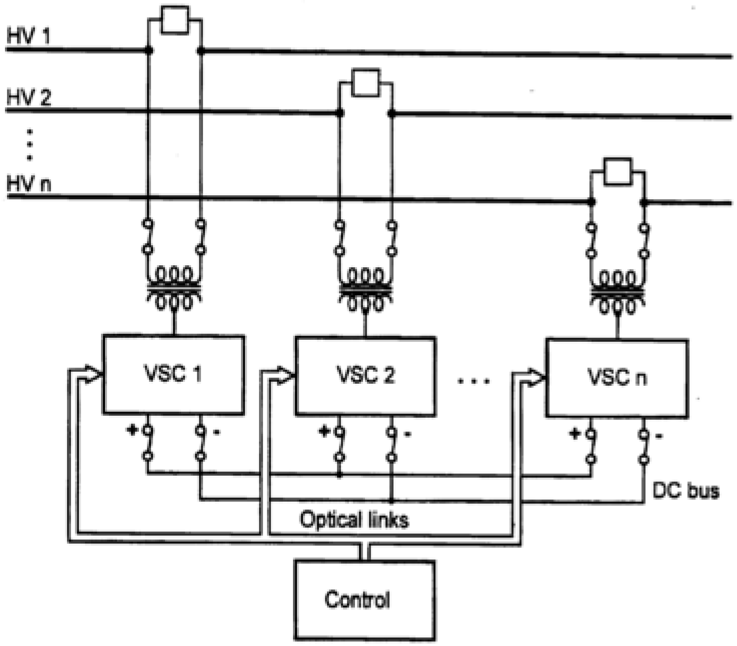


Figure 1: Schematic diagram of IPFC

An Interline Power Flow Controller (IPFC) consists of a set of converters that are connected in series with different transmission lines. The schematic diagram of IPFC is illustrated in Figure.1. In addition to these series converters, it may also include a shunt converter which is connected between a transmission line and the ground. The converters are connected through a common DC link to exchange active power. Each series converter can provide independent reactive compensation of own transmission line. If a shunt converter is involved in the system, the series converters can also provide independent active compensation; otherwise not all the series converters can provide independent active compensation for their own line. Compared to the Unified Power Flow Controller (UPFC), the IPFC provides a relatively economical solution for multiple transmission line power flow control, since only one shunt converter is involved. The IPFC also gains more control capability than the Static Synchronous Series Compensator (SSSC), which is like the IPFC but without a common DC link, because of the active compensation. From probabilistic point of view, the performance of the IPFC will be better when more series converter involves in to the IPFC system. However, because the converters are connected through the common DC link, the converters should be physically close to each other. The common DC link will become a location constrain for the IPFC and limits its commercial application in the future network. Therefore, a method which can eradicate the IPFC common DC link and provide the active power exchange between converters will be interesting.