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Work Book Solution

for

Power System



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PART - A

2 Marks Questions

1.
Sol.

The per unit impedance is same on the both side of Transformer. By taking the quantities in per unit calculations are simplified. It avoid the discontinuity problem due to the presence of Transformer in power system.

2.
Sol.

$$\cos \theta = \frac{\text{Active power}}{\text{Apparent power}}$$

$$\cos \theta = \frac{R}{Z}$$

Cosine of angle between voltage and current is known as power factor. Most of the load are inductive in nature, mostly power factor is lagging.

In inductive circuit current lag the voltage and in capacitive circuit current lead the voltage.

3.
Sol.

1. Current increases:- $\uparrow I \propto \frac{1}{\cos \theta \downarrow}$
2. Greater conductor size is required.
3. Large copper losses
4. Poor voltage regulation .
5. Large KVA rating of equipment is required.
6. Efficiency decreases

4.
Sol.

An over excited synchronous motor running on no load work as synchronous condenser.

5.
Sol.

Boiler field pump is having the highest pressure generating pump in the thermal plant. It consume about 4 MW of electrical power and can generate pressure up to 165 kg/cm²

6.
Sol.

It is used to absorb the remaining heat from flue gasses to heat feed water to the boiler. So that thermal efficiency increases.

7.
Sol.

The area corresponding to the rainfall of water collected for storing of water in the reservoir is called catchment area. It is measure in km sq.

8.
Sol.

It is enlarge body of water at the intake to store water temporarily to meet the hourly load fluctuation it may be the enlarge section of the canal or a pond.

9.

Sol.

It is used in medium and high head plant. In case of sudden load thrown off water hammering effect occur inside the penstock due to sudden closing of control valve. This may damage the penstock, to protect the penstock from water hammering surge tank is used. In case of sudden load demand addition water in the surge tank is used to meet the load demand.

10.

Sol.

Every dam is provided with an arrangement of discharge excess water during flood. This arrangement is known as spill way.

11.

Sol.

Fissile :- The material which are under go nuclear fission reaction is known as fissile.

Ex :- U_{92}^{233} , U_{92}^{235} , PU_{94}^{239}

Fertile :- These material are not fissionable but converted into fissile.

Ex. U^{238} , Th^{232}

12.

Sol.

It is used to reduce the speed of neutron inside the nuclear reactor.

Ex. Graphite, heavy water, beryllium

13.

Sol.

It is used to absorb the excess neutron from the nuclear reactor.

Ex. Boron, Cadmium, Hafnium.

14.

Sol.

It is used for absorbing heat produce by the nuclear chain reaction and transfer to water.

Ex. Heavy water, CO_2 , liquid metal (sodium and potassium).

15.

Sol.

The fuel element in a nuclear reactor is canned so the fuel does not contaminant the coolant.

Ex. Aluminium, Magnesium, Beryllium

16.

Sol.

A fast breeder reactor is different from the thermal reactor. A thermal reactor uses fissile nuclear fuel and produces heat. A fast breeder reactor produces heat and at the same time convert fertile material into fissile material no moderator is needed in this reactor.

17.

Sol.

Peak Load Power Plant

1. Pump storage
2. Diesel



Base Load Power Plant

1. Nuclear power plant
2. Thermal power plant
3. Hydro power plant

18.

Sol.

In pump storage plant machine work as a synchronous generator in case of peak load. Otherwise it work as a synchronous motor.

19.

Sol.

It is the ratio of average load to the maximum demand

$$L.f. = \frac{P_{avg}}{P_{max}} = \frac{A}{M}$$

Practical value of load factor is less than 1. If maximum demand is low, then load factor increases. Due to P_{max} is low initial investment on the electrical equipment is low. So that cost per unit is minimum.

20.

Sol.

It is the ratio of maximum demand on the power station to its connected load.

$$D.f = \frac{P_{max}}{\text{connected load}} = \frac{M}{C}$$

It is usually less than 1.

21.

Sol.

It is the ratio of sum of individual maximum demand to the maximum demand of group.

$$D_i, F = \frac{\text{Sum of Individual max. demand}}{\text{Max. demand of group}}$$

Its value is always greater than 1.

22.

Sol.

It is ratio of actual energy produced to the maximum possible energy that could have been produced during a given period.

$$P.C.f = \frac{P_{avg}}{P.C} \times \frac{T}{T}$$

23.

Sol.

It is ratio of kwh generated to the product of plant capacity and the no of hour for which the plant was in operation.

$$P.U.F = \frac{\text{Station o / p in kwh}}{\text{Plant capacity} \times \text{no of hour used}}$$

24.

Sol.

It is ratio of maximum demand to the plant capacity



$$U.f = \frac{P_{\max}}{P.C}$$

25.

Sol.

In case of 3 - ϕ power line the current flowing in the outside conductor produces maximum flux linkage in the middle conductor. So that, the current in the middle conductor decreases, due to increasing a reactance the unbalance of system, to reduce this effect the 3 - ϕ transmission line is to be transposed at regular interval of the distance.

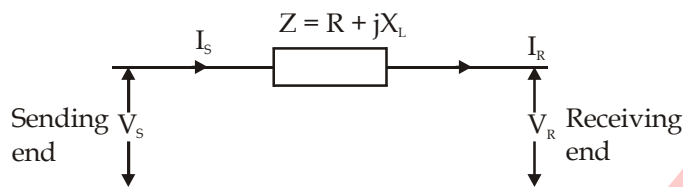
26.

Sol.

1. **Short Transmission line** :- $Fl < 4000$ Hz where F = Frequency $l < 80$ km
2. **Medium Transmission line** :- $4000 < fl < 10,000$ $80 \text{ km} < l < 200$ km
3. **Long Transmission** :- $fl > 10,000$ $l > 200$ km

27.

Sol.



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$$

$A=D \Rightarrow$ System symmetrical

$AD - BC = 1 \Rightarrow$ System reciprocal

28.

Sol.

In case of no load or low load condition, the sending end voltage is less than the receiving end voltage is known as Ferranti Effect. It is due to the transmission line capacitance.

To reduce this effect, shunt reactor is used.

29.

Sol.

The maximum active power transfer capability of transmission line at a given surge impedance (Z_s) is called surge impedance loading. It is measured in watt or kW.

$$V_s = V_R$$

$$X = Z_s$$

In that condition

$$SIL = \frac{V_s^2}{Z_s}$$

30.

Sol.

Electric power cannot be generated at high D.C voltage due to commutation problem.

DC voltage cannot be step up for transmission of power at high voltage easily.

31.

Sol.

Power can be generated at high voltage

Maintenance of AC sub station is easy and cheaper

AC voltage can be step up on step down by transformer this permit to transmit power at higher voltage.

32.

Sol.

AC line require more copper than a DC line

Due to skin effect and proximity effect effective resistance of line is increased.

AC line has capacitance therefore there is continuous loss of power due to charging current.

33.

Sol.

Reduces losses that is inversely proportional to voltage square. $P_L \propto \frac{1}{V^2}$

Volume of conductor require is decrease (volume) $V \propto \frac{1}{V^2}$

Increase transmission line efficiency

Improve voltage regulation

34.

Sol.

765kV, 440kV, 220kV, 132kV

35.

Sol.

The phenomenon of ionization of atmospheric air surrounding the power conductor. It is a self sustained electric discharge in which electric field is intensified to the ionization process start over a portion of distance surrounding the conductor. O_3 (ozone) gas is formed around the conductor.

36.

Sol.

The voltage at which corona is just initiated is called critical disruptive voltage. It is measured in rms. At this voltage a hissing noise can be heard

$$V_c = m g r \delta \ln \frac{d}{r}$$

m = surface factor $\rightarrow 1$ for hollow conductor $\rightarrow 0.72 \rightarrow$ for ACSR conductor.

r = radius of conductor (in cm)

d = distance between conductor (in cm)

$$\delta = \text{Air density factor} = \delta = \frac{3.92b}{273 + T}$$

b = barometric pressure of air in cm of (Hg)

T = temperature in degree 'C'

$$g = \text{Gradient or dielectric strength of air } (g_{rms} = 30 \text{ kV/cm}, g_{max} = \frac{30}{\sqrt{2}}) = 21.1 \text{ kV/cm}$$

37.

Sol.

The voltage at which corona is visible with violet glow is called critical visual voltage (V_v).



$$V_v = mgr\delta \left(1 + \frac{0.3}{\sqrt{r\delta}} \right) \ell \ln \frac{d}{r}$$

38.

Sol.

It is the ratio of puncture voltage to flash over voltage

$$\text{Safety factor} = \frac{\text{Puncture voltage}}{\text{Flash over voltage}}$$

Safety factor value is greater than 10

puncture voltage is always greater than flash over voltage.

39.

Sol.

It is used for line above 33 KV, Each insulator disc is design for 11 KV (phase voltage). The unit near to the conductor require more maintenance.

40.

Sol.

High mechanical strength, longer life, light in weight, low cost.

41.

Sol.

It is difference between lowest point and point of support

$$S = \frac{w\ell^2}{8T} \text{ meter}$$

where ℓ = span

w = weight per unit length

T = Tension

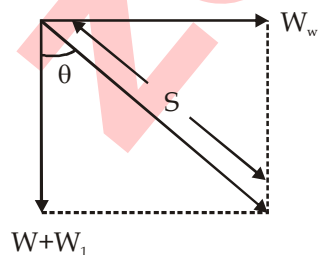
42.

Sol.

Due to the Ice coating on the transmission line weight per unit length increases and hence sag increases. ($W + W_1$)

43.

Sol.



Due to the wind the transmission line tilted at an angle of θ . Due to this effective sag increases.

44.

Sol.

A feeder is a conductor which connects the substation (Local substation) to the area where power is to be distributed. Generally no tapping are taken from the feeder so that current remain same so it is

designed according to current carrying capacity while voltage drop consideration is relatively unimportant.

45.

Sol.

A distributor is a conductor from which tapping are taken for supply to the consumer it is designed according to the voltage drop in it because distributor supply power to the consumer. The size and length of the distributor should be such that voltage at the consumer terminal is within the permissible limit ($\pm 6\%$ of rated value)

46.

Sol. A service main is a small cable which connect the distributor to the consumer terminal service main selected according to the load.

47.

Sol.

There are less voltage fluctuation at consumer terminal
System is reliable (continuity of supply)
more complex and costly.

48.

Sol.

When the feeder ring is energized by two or more than two substations.

1. It increases the system reliability.
2. There are less voltage fluctuation at consumer side.
3. This reduces the reserve power capacity & increases efficiency of the system.

49.

Sol.

1. Low melting point
2. High conductivity
3. Low cost
4. Free from deterioration due to oxidation
5. Fuse element material Lead (Pb), Tin (Sn), Copper (Cu), Zinc (Zn), Silver (Ag)

50.

Sol.

$I^2 \alpha d^3$ (current)² through the fuse element is proportional to d^3
 d = diameter of fuse element

51.

Sol.

Fuses are burned at the time of over current flows in the circuit but breakers are just open (not burn) at the time of over current flow. Fuses are used in only one time but breakers are used by multiple number of times.

52.

Sol.

It will operate only after C.B. Operation as manually so it can works only at no load condition.

53.

Sol.

The function of circuit breaker is to isolate the fault part of the power system in case of abnormal condition. When flow of current is interrupted then there is formation of arc between the contact.



54.

Sol.

The transient voltage which appear across the breaker contact at the instant as arc being extinguish is known as restriking voltage.

Restriking voltage $V_c = E_m(1 - \cos wt)$

Peak value of restriking voltage $V_c = 2E_m$

55.

Sol.

The RMS voltage which appear across the breaker contact when transient oscillation die out is known as recovery voltage obtain after final arc extinguish is known recovery voltage it is a equals to system voltage.

56.

Sol.

To reduce the restriking voltage and RRRV a resistance is connected across the contact of circuit breaker this is known as resistance switching.

If the value of resistance connected across the contact of the circuit breaker is less than or equal to

$R \leq \frac{1}{2} \sqrt{\frac{L}{C}}$ then there is no transient oscillation.

R = critical resistance

If $R > \frac{1}{2} \sqrt{\frac{L}{C}}$ there will be oscillation

Resistance switches is used in ABCB

57.

Sol.

SF₆ has good dielectric strength and excellent arc quenching property, it is electro negative gas. It is inert, non-toxic, non flammable and heavy gas.

58.

Sol.

It is the RMS value of the AC component of the fault current that the circuit breaker is capable of breaking under specified condition.

Symmetrical breaking capacity of C.B is generally expressed in MVA that is equal to

$\sqrt{3} \times \text{Rated voltage in KV} \times \text{Rated current in KA.}$

59.

Sol.

The rated making current is defined as the peak value of the current in the first cycle at which a C.B. can be closed due to short circuit

Making capacity = $2.55 \times$ symmetrical breaking capacity.

60.

Sol.

The Threshold value of the actuating quantity above which relay operate.

61.

Sol.

An instantaneous relay is an overcurrent relay which has no intentional time delay in its operation it is about 0.1 sec.



62.

Sol.

A relay in which operating time is inversely proportional to the magnitude of the operating current.

63.

Sol.

A relay which gives an inverse time characteristics at lower value as the operating current and definite time characteristic at higher value of the operating current

These relay are widely used for the protection of distribution line.

The characteristic achieved by using a core the electromagnet which gets saturated for current slightly greater than the pick up current.

64.

Sol.

Generalised equation of torque

$$\tau = K_1 I^2 + K_2 V^2 + K_3 VI \cos(\theta - \tau) + K_4$$

A relay which measure impedance or a component of impedance (reactance) at the relay location is known as distance relay. It is used for the protection of transmission line.

65.

Sol.

A backup relay operate after a slight delay. If the main relay fail to operate.

66.

Sol.

Back up protection is designed to clear the fault if the primary protection fail.

67.

Sol.

A relay which operate when the system voltage fall below a certain preset value.

68.

Sol.

The relay utilize the electro thermal effect of the actuating current for its operation

69.

Sol.

A relay is use for the protection of an element of an power system against earth fault.

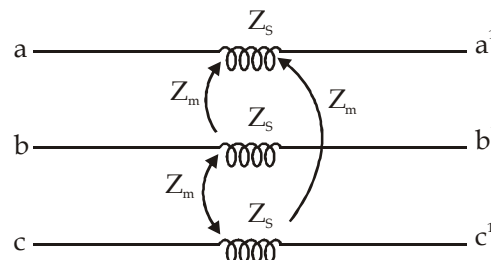
70.

Sol.

It refer to the differential protection of T/F or alternator against ground fault. It does not respond to fault beyond its zone of protection.

71.

Sol.



Positive sequence component

$$Z_1 = Z_s - Z_m$$

Negative sequence component

$$Z_2 = Z_s - Z_m$$

Zero sequence component

$$Z_0 = Z_s + 2Z_m + 3Z_n$$

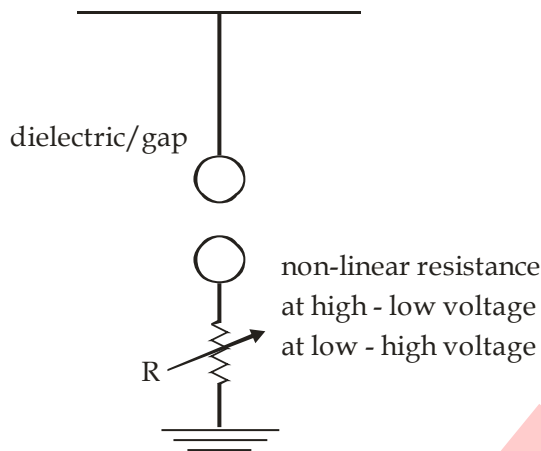
$$Z_0 > Z_1 = Z_2$$

Z_0 (2.5 to 3 times more than $Z_1 = Z_2$)

72.

Sol.

A lightning arrester is a protective device which conduct at the high voltage surges on the power system to the ground.



73.

Sol.

Stranding is done so that conductor may become flexible and carry more current.

74.

Sol.

Slow and gradual changes are applied to system and system attain its initial position then system is said to be steady state stable.

75.

Sol.

If sudden and fast changes are applied to an system and system attain its initial position then system is said to be transient state stability limit.

Steady state stability limit > Transient state stability limit.

76.

Sol.

$$\frac{Md^2\delta}{dt^2} = P_m - P_e$$

$$\frac{Md^2\delta}{dt^2} = P_a \rightarrow P \text{ accelerating Power}$$

77.

Sol.

1. To extend the existing system.
2. To design a new system
3. To find the solution for load flow equation.

78.

Sol.

Known Parameter	Unknown Parameter
1. Load bus:- (PQ bus)	P, Q V, δ
2. Generator bus:- (PV bus)	P, V Q, δ
3. Slack bus:- (V δ bus)	V, δ P, Q

79.

Sol.

Slack Bus is the responsible for the delivering losses in the power system. in this bus the magnitude of voltage and phase angle are specified. This bus is first to respond to a changing load condition.

80.

Sol.

Resistance grounding system means connecting the neutral point of the load to the ground to carry the residual current in case of unbalanced conditions through the neutral to the ground whereas resistance earthing system is done in an electric equipment in order to protect the equipment in occurrence of fault in the system.

PART - B

5 Marks Questions

81.

Sol. General Tariff Form: Quite a large number of tariffs have been proposed from time to time and are in use. They are all derived from the following equation:

$$A = cx + dy + f$$

A = Total amount of bill for a certain period

x = Max. demand during the period (kW or kVA)

y = Total energy consumed during the period (kWh)

c = Unit charge for maximum demand, Rs. per kW (or Rs. per kVA)

d = Unit cost of energy, as per kWh

f = Constant charge Rs.

Thus, the total bill consists of three parts, one depending on maximum power demand, the second depending on total energy consumed and third being a constant figure.

Objective of Tariffs: Electric utilities derive their income from customers through electricity bills. Different methods of charging customers are known as tariffs. A tariff should fulfil the following objectives:

1. Cost of capital investment in generation, transmission and distribution equipment must be recovered.
2. Cost of operation, supplies maintenance and losses must be recovered.
3. Cost of metering, billing, collection and miscellaneous services must be recovered.
4. A satisfactory net return on the capital investment must be ensured.



82.

Sol.

Accumulation of current on the surface of conductor is called skin effect. If an A.C current passes through the conductor the flux linkage of inner layer of conductor is more compare to outer layer. So that inductance is more at centre of conductor which cause reduction in current in the centre conductor and more current is passing on the surface of the conductor. Due to this effective area of current flowing path reduces, which increases the resistance.

Skin effect depends upon

1. Frequency
2. Relative permeability of conductor.
3. Resistivity of conductor.
4. Size of conductor.

Skin effect is more in case of communication line, where the frequency is in Mega Hz. Compare to the power line where frequency is 50Hz.

83.

Sol.

The current flowing in the adjacent conductor produces unequal flux linkage within a conductor, so the current is disturbed and effective area decreases.

Proximity effect depend on

1. Frequency
2. Relative permeability of conductor.
3. Resistivity of conductor.
4. Size of conductor.
5. Distance between the conductor.

Proximity effect is more in case of underground cable where distance between the conductor is minimum compare to the over-head line.

84.

Sol.

$$C_{AB} = \frac{\pi \epsilon}{\ell n \frac{d}{r \sqrt{1 + \left(\frac{d}{2h}\right)^2}}}$$

Earth consisting of infinite no. of positive and negative charge carrier. These charge carrier interact with the charge of the transmission line conductor. Due to this effect the capacitance between conductor increases which causes increases in the charging current. Which produces more reactive power one these disturb the voltage profile of transmission line. To reduce this effect height of the tower is increased as the voltage level of transmission line is increased.

$$h \gg d \quad C_{AB} = \frac{\pi \epsilon}{\ell n(d/r)}$$

If height is increases, then effect of earth is neglected.

85.

Sol.

It is preferred to use more than one conductor per phase which is known as bundling of conductor. It has many advantages.

1. Reduce reactance (X_L)
2. Reduce voltage loss
3. Reduce corona loss



4. Reduce surge impedance $\left(Z_s = \sqrt{\frac{L}{C}} \right)$

5. Reduce radio interference.

(Self GMD = GMR)

By bundling the self GMD is increased, inductance is reduced and capacitance increases. Due to this maximum power that can be transmitted is increased.

Imp. To decrease the inductance per phase distance between the conductor is to be decreases but due to corona limitation, distance is limited.

If radius of conductor is increases than L decreases. If higher radius is use then weight of conductor increases and skin effect increases.

Hence bundle conductors are used.

86.

Sol.

Change in the terminal voltage when full load is removed divided by the full load voltage is known Voltage Regulation

$$V.R = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100$$

$$V.R = \frac{\left| \frac{V_s}{A} \right| - |V_R|}{|V_R|}$$

$$V.R = R_{P.U} \cos \theta \pm X_{p.u} \sin \theta$$

Condition for zero voltage regulation :- Zero voltage regulation is only possible in leading load

$$\tan \theta = \frac{R_{P.U}}{X_{P.U}}$$

Condition for maximum voltage regulation :- maximum voltage regulation is only possible in lagging load.

$$\tan \theta = \frac{X_{P.U}}{R_{P.U}}$$

87.

Sol.

It require only 2 conductor as compare to AC transmission

There is no inductance, capacitance and surge problem in system

Due to the absence of inductance, the voltage drop in a DC transmission line is less (V.R improve).

There is no skin effect in DC system.

There is no proximity effect and hence $R_{dc} < R_{AC}$

Less corona loss

High voltage D.C transmission is free from dielectric losses

In D.C transmission there are no stability problem and synchronizing difficulties.

88.

Sol.

Surface Factor :- Lower the value of 'm' lower will the value of V_c and hence corona is more frequent in ACSR conductor compare to hollow conductor.

Air Density Factor :- In case of hilly area barometric pressure is low, so that δ is low and hence V_c is low which causes corona more frequent in hilly area compare to plain area.

In case of rainy season, value of b reduce and corona is more visible.



Depending upon the operating voltage of line.

89.

Sol.

Depending upon the distance between the conductor. To keep V_c higher, we increase the distance between the conductor. Hence effect of corona is reduced.

By polishing, corona is reduced

Conductor should be smooth for less corona

Corona is improved by bundled conductor. In case of bundle conductor self GMD is higher due to this r is higher and hence V_c is higher.

Transposition of line reduces corona

Minimum clearance of conductor from ground is to be maintained.

90.

Sol.

It is preferred for rural area because it is simple and less costly

The end of the distributor nearest to the feeding point is heavily loaded

The consumer is dependent on a single feeder or a single distributor

The consumer at the distant end of the distributor would be subjected to serious voltage fluctuation when the load on the distributor changes.

91.

Sol.

1. Low Voltage Fuses

(a) **Kit Kat Type**:- It is a semi enclosed Rewirable type. Low value of fault current interrupted. Use for domestic and lighting load

(b) **HRC**:- In that type of fuse, fuse wire carries short circuit heavy current for a known time period. During this time if fault is removed then it does not blow off otherwise it blows off or melts. Filling powder acts as a quenching and cooling medium. HRC fuse is capable of clearing high as well as low fault current

2. High voltage Fuses

(a) **Cartridge type** :- use upto 33 KV

(b) **Liquid type** :- Filled with carbon tetrachloride used upto 132 KV

(c) **Metal Clad** :- Substitute for the oil circuit breaker used for high voltage circuit.

92.

Sol.

1. High Resistance Interruption

In this method of arc interruption resistance is increased by elongation (lengthening of arc) of arc, cooling and split the arc when current is interrupted energy associated with the magnetic field appears in the form of electrostatic energy. It is used for both AC and DC circuit breaker

2. Low Resistance Method (Current Zero Interruption)

It is applicable only in case of AC circuit breaker. When the current wave passes through a zero point at this instant current is interrupted this phenomenon known as current zero interruption. To extinguish the arc the rate of rise of dielectric strength should be greater than rate of rise of restriking voltage.

93.

Sol.

The current will be interrupted before its natural zero is known as current chopping in such a situation the energy stored in magnetic field will appear in form of electrostatic energy



$$\frac{1}{2}LI^2 = 1/2CV^2$$

$$v = i\sqrt{\frac{L}{C}}$$

Current chopping phenomena mainly occur in air blast circuit breaker (ABCB), vacuum circuit breaker (VCB)

94.

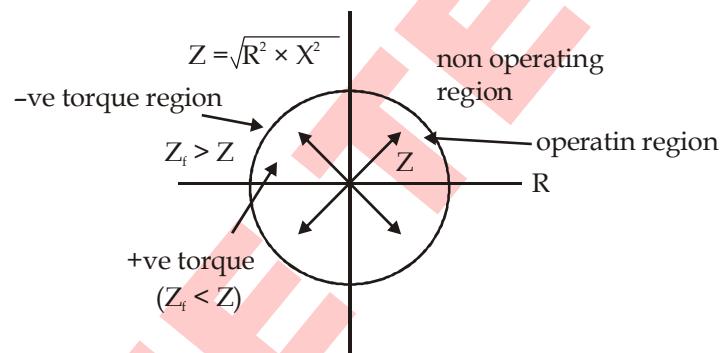
Sol.

A relay which measure impedance at the relay location is known as impedance relay.

Torque equation :- $K_1 I^2 - K_2 V^2 > 0$

$$\sqrt{\frac{K_1}{K_2}} > Z$$

The impedance relay will operate only if the impedance seen by the relay is less than a pre specified value. It is a voltage restraint overcurrent relay. It is used for the protection of medium transmission line.



95.

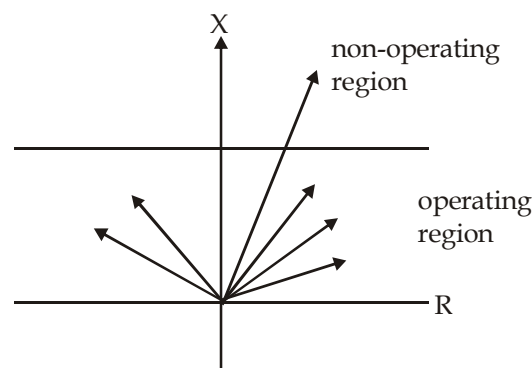
Sol.

A relay which measure reactance at the relay location is called reactance relay. In this relay's operation torque is obtained by current and restraining torque due to a current voltage directional unit. So it is a directional restraint overcurrent relay.

Operating torque

$$\tau_2 = K_1 I^2 - K_3 VI \sin\theta > 0$$

$$\frac{K_1}{K_3} > X$$



Resistance component of the impedance has no effect on the operation of the relay it is non directional relay. It is used for the protection of short transmission line.

96.

Sol.

It measure a particular component of impedance that is $\frac{Z}{\cos(\theta - \tau)}$ it's Characteristic on the RX diagram

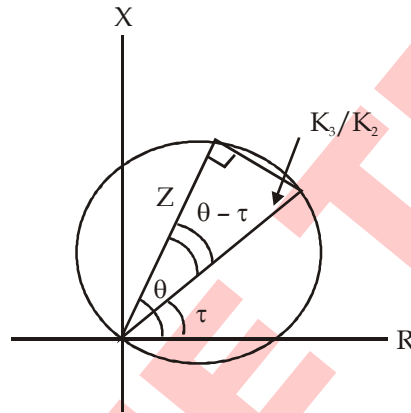
is a circle passing through the origin. It is use for long transmission line.

It is voltage restrain direction relay.

$$\tau = K_3 VI \cos(\theta - \tau) - K_2 V^2 > 0$$

$$\frac{K_3}{K_2} > \frac{Z}{\cos(\theta - \tau)}$$

$$\frac{K_3}{K_2} = \text{Diameter of circle}$$



The relay operate when the impedance seen by the relay falls within the circle.

97.

Sol.

Generally symmetrical fault is serious but in case of fault at generator side the L-G fault is more severe for generator

3 - ϕ fault current

$$I_{3\phi} = \frac{\varepsilon}{X_1}$$

1- ϕ fault current

$$I_{f1\phi} = \frac{3\varepsilon}{X_1 + X_2 + X_0}$$

Fault at generator terminal with generator neutral solidly grounded.

The current for a single line to ground (L - G) fault is more than the current for a 3 - ϕ fault

$I_{fLG} > I_{3-\phi}$ because $X_0 \ll X_1 = X_2$ (fault at generated terminal)

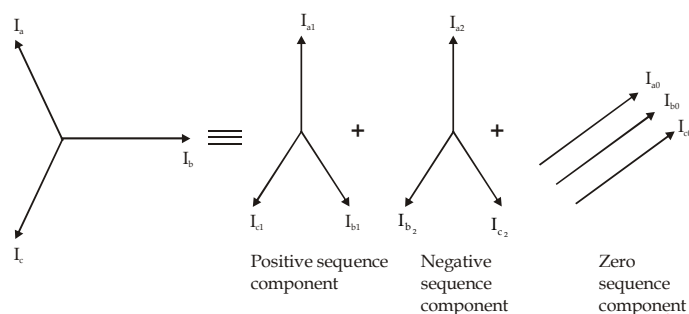
A L - G fault at the terminal of generator with solidly grounded neutral is more severe than a 3 - ϕ fault at the same location

because

$$I_{f1\phi} \uparrow = \frac{3\varepsilon}{X_1 + X_2 + X_0} \downarrow$$



98.
Sol.



Imp :-

In the delta connection zero sequence component of current can flow in the phase of delta but they are absent in the line of delta.

In star connection zero sequence current flow only if neutral is grounded

Zero sequence component of line voltage always absent in line voltage

99.
Sol.

1. **Earth Screen** :-The power station and substation have expensive equipment these station can be protected against direct lightning stroke by providing earthing screen it consist of a network of copper conductor mounted all the electrical equipment in the sub-station or power station. The screen is properly connected to earth.
2. **Over Head Ground Wire** :-The most effective method of providing protection to transmission line against direct lightning stroke by the use of over head ground wire.
3. **Lightning arrestor (LA)** :-Earthing screen and ground wire can protect the electrical system against direct lightning stroke but they fail to provide protection against travelling wave which may reach the terminal of the apparatus. The lightning arrestor provide protection against such surges.

100.
Sol.

High insulation resistance
High dielectric strength
Good mechanical property
Non hygroscopic
It should not effected by chemical reaction

Hygroscopic :- It means dielectric strength of any material reduces with moisture contents.

101.
Sol.

Advantages of GS

1. Less memory storage required
2. Less time is required for each iteration
3. Simple

Disadvantage of GR

1. Slow convergence
2. Solution depend on the choice of slack bus
3. It takes more time when no of buses increases

Advantages of NR

1. Fast convergence
2. Solution does not depend upon the choice of slack bus
3. It takes less time compare to GS when number of buses increases



Disadvantages of NR

1. More memory storage
2. More time is required for each iteration
3. Complex

102.

Sol.

$$\text{Diversity factor} = \frac{\text{Sum of individual max. demand}}{\text{Maximum demand on station}}$$

$$\text{Maximum demand on station} = \frac{\text{Sum of individual max. demand}}{\text{Diversity factor.}}$$

$$\therefore \text{Maximum demand on station} = \frac{100 + 125 + 50}{1.5} = 183.33 \text{ MW}$$

Also, Load factor

$$= \frac{\text{Average load}}{\text{Maximum demand}}$$

or, Average load

$$= 0.5 \times 183.33 = 91.66 \text{ MW}$$

103.

Sol :

1. Causes of Low Power Factor:

- Induction motor is the most commonly used A.C. motor. It is used for a variety of purposes. At full load a 3-phase induction motor operates at a power factor of around 0.8 lagging. The power factor of single phase induction motors is about 0.6 lagging.
- The transformer draw a magnetising current from the system. This current is at a power factor of zero lagging.
- Miscellaneous equipment like arc lamps, welding equipment etc. also contribute to low power factor in the system.

104.

Sol :

Effects of Low power Factor:

- To meet the load requirement at a low power factor the capacity of power plant, transmission and distribution equipment has to be more than that which would be necessary if the load were demanded at unity power factor.
- For the same active power operation of an existing power system at a low power factor means overloading the equipment .
- For the same active power, a low power factor means a greater current and hence higher energy losses.
- Low power factor causes the voltage regulation to be poor.

105.

Sol. The effects of corona are summarized as below.

- (i) A violet glow is observed around the conductor.
- (ii) It produces a hissing noise.
- (iii) It produces ozone which can be readily detected by its characteristic odour.
- (iv) The glow is maximum over rough and dirty surfaces of the conductor.
- (v) It is accompanied by a power loss the wattmeter connected in the electric circuit will show a

reading.

- (vi) The charging current under corona condition increases because the corona induces harmonic currents.

106.

Sol.

The pick up value of the relay is 5 Amps but since the relay setting is 50%, therefore, the operating current of the relay is,

$$5 \times \frac{50}{100} = 2.5 \text{ Amp.}$$

The plug setting multiplier of the relay is,

$$\begin{aligned} \text{PSM} &= \frac{\text{Secondary current}}{\text{Relay current setting}} = \frac{\text{Primary current (fault current)}}{\text{Relay current setting} \times \text{C.T. ratio}} \\ &= \frac{2000}{2.5 \times 80} = 10 \end{aligned}$$

107.

Sol.

Types of Transmission Lines.

- Short transmission line:** The length of transmission line is lesser than 80 km and operating voltage lower than 20 kV. And product of operating frequency and length of transmission line is less than 4000.
i.e. $l.f < 4000$ (for 50 Hz operation)
 - Medium transmission line:** The length of transmission line is between 80 km and 200 km and line voltage between 20 kV and 100 kV product operating frequency, and length of transmission line is
i.e. $4000 < l.f < 10000$ (for 50 Hz operation)
 - Long transmission line:** The length of transmission line above 200 km and line voltage above 100 kV. Product of operating frequency and length of frequency line is above 10000.
i.e. $l.f > 10000$ (for 50 Hz operation)
- In these lines impedance and admittance are to be considered uniformly distributed.

108.

Sol: **Merits of a Vacuum circuit breaker:**

- Because of the short gap and excellent recovery characteristics of vacuum breakers, they can be used where the switching frequency is high and required to be reliable.
- For low fault interrupting capacities the cost is low as compared to other interrupting devices.
- The vacuum switches can be used for capacitor switching which is a very difficult task using oil circuit breakers.
- They can be used along with static over current relays and gives an overall clearance time of less than 40 m-sec on phase-to-phase fault.
- They can interrupt any current (fault). The outstanding feature of a VCB is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.
- Less maintenance requirement.
- Better than air or oil C.B. when voltages are high and current to be interrupted is less.

Demerits:

Contacts get roughened after use and thus dielectric strength decreases.
Cost is higher than SF₆ circuit breakers.

109.

Sol. Advantages of interconnection of power stations:

- With interconnected power station, the peak load can be exchanged between the generating stations.

From the load curve if there is peak load demand which is more than rated capacity of the plant then the excess load can be shared by other interconnected stations.

2. With interconnected power station system, the economical operation of the plant is possible. The total load is arranged in such a way that more efficient plants can be used as base load stations which can work continuously throughout the year at high load factor and the less efficient plants can be made to operate as peak load plants. Also, larger generator unit can be employed to reduce capital cost per kW.
3. Various interconnected power stations, have their different load curves due to which maximum demand on the system is reduced as compared to sum of individual maximum demands on various stations. Thus the effective capacity of the system increased as there is improvement in diversity factor.
4. It can be seen that the load curves of the two different power stations are not identical. In worst condition the peak loads may occur at a time different by few minutes. Thus the maximum demands on individual power stations are not occurring simultaneously, it is possible to work with lesser installed capacity with interconnected power station system.
5. In abnormal conditions every power station should have reserve stand by unit to be put in operation with interconnected system the reserve capacity is reduced which increases efficiency of the system.
6. The reliability and continuity of the supply is improved with interconnected power station system. With fault condition occurring in any one station, the supply can be maintained with the help of other stations.

110.

Sol.

1. The large charging current on very high voltage cables limits the use of cable for long length transmission. Where a long distance transmission is required, overhead transmission lines are used.
2. The conductor in the overhead line is less expensive than the underground cable. The size of the conductor for the same power transmission is smaller in case of overhead lines than the cables because of the better heat dissipation in overhead lines.
3. The insulation cost is more in case of cables than the overhead lines. Overhead lines use bare conductors supported on steel towers insulated from the towers through the porcelain insulators. There is sufficient spacing between the conductor depending upon the operating voltage; the air between the conductors provides insulation. The insulation in underground cables is provided by various wrappings of fibrous grade paper tapes. A metal sheath is applied over the insulation to prevent moisture from entering. Oil or inert gas is introduced to fill the voids. Storage vessels containing a reservoir of the oil or gas are installed at intervals along the route of the cable to take up the expansion and contraction of the oil or gas in the cable. Thus for high voltage underground transmission, the insulation problem is quite complicated and expensive.
4. The erection cost of an overhead line is much less than the underground cable.

111.

Sol.

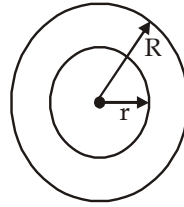
Maximum dielectric stress = $g_{\max}$

$$g_{\max} = \frac{V}{r \ln \frac{R}{r}}$$

Minimum dielectric stress = $g_{\min}$



$$g_{\min} = \frac{V}{R \ln \frac{R}{r}}$$



∴ The ratio of maximum to minimum dielectric

$$\text{stress} = \frac{g_{\max}}{g_{\min}}$$

$$\text{or } \frac{g_{\max}}{g_{\min}} = \frac{\frac{V}{r \ln \frac{R}{r}}}{\frac{V}{R \ln \frac{R}{r}}} = \frac{R}{r} = \frac{D}{d}$$

112.

Sol.

$$\begin{aligned} Z_{\text{pu(given)}} &= 0.9 \text{ p.u.} \\ \text{MVA}_{\text{b(given)}} &= 20 \text{ MVA} \\ \text{KV}_{\text{b(given)}} &= 33 \text{ KV} \\ \text{MVA}_{\text{b(new)}} &= 50 \text{ MVA} \\ \text{KV}_{\text{b(new)}} &= 11 \text{ KV} \end{aligned}$$

$$Z_{\text{pu(new)}} = Z_{\text{pu(given)}} \times \frac{\text{MVA}_{\text{b(new)}}}{\text{MVA}_{\text{b(given)}}} \times \frac{(\text{KV}_{\text{b(given)}})^2}{(\text{KV}_{\text{b(new)}})^2}$$

$$= 0.9 \times \frac{50}{20} \times \frac{(33)^2}{(11)^2}$$

$$Z_{\text{pu(new)}} = 20.25 \text{ pu}$$

113.

Sol. 1. The capital cost of a gas turbine plant is lower than that of a steam plant of the same size.

2. It has no standby losses.
3. It requires lesser area than a steam plant of the same capacity.
4. It has less water requirement as compared to a steam plant.
5. Its foundations and buildings are simple and cheap.
6. They can be started and put on load more quickly than steam plants.
7. A gas turbine plant can be located very near the load even in the cities and towns
8. The operating costs of a gas turbine plant are very high as compared to steam plants.
9. Gas turbine plants can be used only in small sizes about 50 MW or so.



114.

Sol. Advantages of Corona:

In the past, the corona was considered as something to be avoided because of the energy loss associated with it and the distortion of the waveform. But now the corona is considered beneficial because of the following advantages.

1. On the formation of corona the sheath of air surrounding the conductor becomes conductive and there is a virtual increase in conductor diameter and due to this virtual increase in conductor diameter the maximum potential gradient or maximum electrostatic stress is reduced. Thus probability of flash-over is reduced and system performance is improved.
2. Effects of transients produced by lightning and other causes are reduced, since charges induced on the line by lightning or other causes will be partially dissipated as a corona loss. In this way it acts as a safety valve and sometimes lines have been purposely designed to have an operating voltage near to the critical voltage in order to do away with the necessity for, and expense of lightning arrester gear. An objection to this scheme is that the critical voltage is not fixed for a given line, but may vary considerably with changes in the weather.

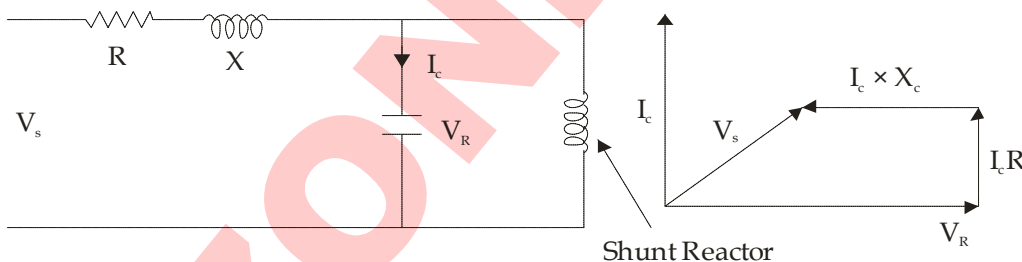
Disadvantages of corona are given below:

1. There is a definite loss of power, although this is not important except under abnormal weather conditions.
2. There is a non-sinusoidal voltage drop due to non-sinusoidal corona current and these may cause some interference with neighbouring communication circuits due to electromagnetic and electrostatic induction effects.
3. Owing to the formation of corona, ozone gas is produced which chemically reacts with the conductor and causes corrosion.

115.

Sol. Ferranti Effect :- In case of no load or low load condition, the sending end voltage is less than the receiving end voltage. Due to the transmission line capacitance. Which produces the charging current. Due to this the voltage drop across transmission line impedance is in phase opposition to the sending end voltage. this will occur in medium and long transmission line where the capacitance is considered.

$$V_s < V_R$$



$$V_s = V_R + I_c R + jI_c X_c$$

To reduce this effect, shunt reactor is used.

In EHV line

At no load or light loads $I_R \approx 0$

The percentage rise in voltage in a EHV line depends on the square of its length

So, for short transmission line no control is needed. For a medium length line shunt reactor compensation at the receiving end is sufficient.

But for long line compensation has to be provided in the middle of the line in addition to the receiving end.

116.

Sol. (i) Infinite line: When the line is terminated in its characteristic impedance i.e. $Z_1 = Z_c$, the reflected wave is zero then such a line is called infinite line and the incident wave can not distinguish between



a termination and the continuation of the line.

Infinite bus: Infinite bus concept is a simplifying assumption that is applied to buses or nodes with an infinite upstream fault capacity. The voltage at this bus or node is always constant and any downstream disturbances do not affect the voltage. In an infinite bus :

1. System frequency is constant, independent of power flow.
2. System voltage is constant, independent of reactive power consumed.

(ii) The characteristic impedance of a loss less line is known as surge impedance of the line. Characteristic impedance is given by,

$$Z_c = \sqrt{\frac{z}{y}} = \sqrt{\frac{r + j\omega L}{g + j\omega C}}$$

For a loss less line, $r = 0$

$$\therefore Z_c \text{ (surge impedance)} = \sqrt{\frac{L}{C}}$$

Surge impedance loading of a line is the power transmitted when the line is terminated through a resistance equal to surge impedance.

A line terminated in its characteristic impedance is called a flat line or an infinite line.

117.

Sol. Generally there are two types of buses in a power system.

(i) **PV bus or generator bus** - real power of generator & voltage specified.

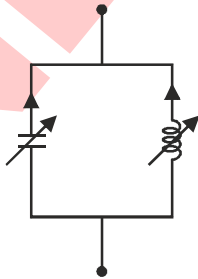
(ii) **PQ bus or load bus** - real & reactive power of load is specified.

Now until load flow is over, losses (both real & reactive) remain unknown. Hence one of generator buses is taken to be a 'slack or swing' bus. Here voltage & angle is specified whereas real & reactive are obtained through the load flow solution. This is the only bus where δ is known.

118.

A 3-phase static var compensator.

Sol. A three phase static VAR compensator is a thyristor controlled shunt reactor and shunt capacitor.



Thyristor varies firing angle its smoothly so as to achieve voltage control of substation buses. To inject reactive power during heavy loads, I_c is increased. To absorb reactive power during low loads, I_L is increased.

Various applications of VAR compensator are:

- (i) Voltage control of sub-station buses-as explained above.
- (ii) Dynamic compensation of fluctuating reactive power swings during disturbances - by faster firing angle control, control of thyristor.
- (iii) Control of over voltage during load rejection - same as low load condition.
- (iv) Improving voltage stability by rapid voltage control through thyristor.
- (v) Damping sub-synchronous resonance as LC combination acts as a filter too.



PART - C

20 Marks Questions

119.

Sol :

1. Advantages of Power Factor Improvement:

Installation of power factor improvement device, to raise the power factor, results in one or more of the following effects and advantage:

- Reduction in circuit current.
- Increase in voltage level at load.
- Reduction in copper losses in the system due to reduction in current.
- Reduction in investment in the system facilities per kW of the load supplied.
- Improvement in power factor of the generators.
- Reduction in kVA loading of the generation and circuits. This reduction in kVA loading may relieve an overloaded conditions or release capacity for additional growth of load.
- Reduction in kVA demand charges for large consumers.

2. Method to improve power factor :-

(1)**Static capacitor** :- The power factor can be improved by connecting capacitor in parallel with the equipment, operating at lagging power factor. The capacitor draws a leading current.

(2)**Synchronous condenser** :- An over excited synchronous motor running on no load is known as synchronous condenser.

When synchronous condenser is connected in parallel with the supply it takes a leading current and these improve the power factor.

Advantages :-

(i) By changing the field excitation. The magnitude of current drawn by the motor can be changed by any amount. This help in achieving step-less / smooth control of power factor.

Disadvantage :-

(i) Maintenance cost is high.

(ii) Produces noise

(iii) Synchronous motor is not self starting. Therefore a auxiliary equipment has to be provided.

(3)**Phase Advancer** :- They are used to improve the power factor of induction motor. The low P.F of induction motor is due to the fact that it's stator draw magnetizing current which lag behind the supply voltage by 90° .

If the phase advancer is mounted on the same shaft of the main motor and is connected in the rotor circuit of motor. It provide exciting ampere turn to the rotor circuit at slip frequency and hence improve the power factor.

120.

Sol. Given that:

Daily load of an industry 100 kW for 2 hour.

150 kW for 4 hour,

200 kW for 8 hour and

250 kW for remaining time.

Annual bill = $b \times \text{maximum demand in kW} + c \times \text{unit consumed in a year}$

Unit consumed for 1 day = $100 \times 2 + 150 \times 4 + 200 \times 8 + 250 \times 10$

= 4900 kWh

So, unit consumed in 365 days = $4900 \times 365 = 1788500 \text{ kWh}$

Annual bill = $1000 \times 250 + 2.25 \times 1788500$

= 250000 + 4024125



$$= \text{Rs. } 4274125$$

So the electricity expenditure for one year is Rs. 4274125.

121.

Sol. 1. Selectivity or discrimination:-

Selectivity, is the quality of protective relay by which it is able to discriminate between a fault in the protected section and the normal condition. Also, it should be able to distinguish whether a fault lies within its zone of protection or outside the zone. Sometimes, this quality of the relay is also called discrimination.

The relay should also be able to discriminate between a fault and transient conditions like power surges or inrush of a transformer's magnetising current. The magnetising current of a large transformer is comparable to a fault current, which may be 5 to 7 times the full load current.

2. Reliability:

A protective system must operate reliably when a fault occurs in its zone of protection. The failure of a protective system may be due to the failure of any one or more elements of the protective system. Its important elements are the protective relay, circuit breaker, VT, CT, wiring battery, etc. To achieve a high degree of reliability, greater attention should be given to the design, installation, maintenance and testing of the various elements of the protective system. Robustness and simplicity of the relaying equipment also contribute to reliability. The contact pressure, the contact material of the relay, and the prevention of contact contamination are also very important from the reliability point of view. A typical value of reliability of protective scheme is 95%.

3. Sensitivity:

A protective relay should operate when the magnitude of the current exceeds the preset value. This value is called the pick-up current. The relay should not operate when the current is below its pick-up value. A relay should be sufficiently sensitive to operate when the operating current just exceeds its pick-up value.

4. Stability:

A protective system should remain stable even when a large current is flowing through its protective zone due to an external fault, which does not lie in its zone. The concerned circuit breaker is supposed to clear the fault. But the protective system will not wait indefinitely if the protective scheme of the zone in which fault has occurred fails to operate. After a preset delay the relay will operate to trip the circuit breaker.

5. Fast Operation:

A protective system should be fast enough to isolate the faulty element of the system as quickly as possible to minimise damage to the equipment and to maintain the system stability. For a modern power system, the stability criterion is very important and hence, the operating time of the protective system should not exceed the critical clearing time to avoid the loss of synchronism. Other points under consideration for quick operation are protection of the equipment from burning due to heavy fault currents, interruption of supply to consumers and the fall in system voltage which may result in the loss of industrial loads. The operating time of a protective relay is usually one cycle. Half-cycle relays are also available. For distribution system the operating time may be more than one cycle.

122.

Sol. 1. General Tariff Form:

Quite a large number of tariff have been proposed from time to time and are in use. They are all derived from the following equation:

$$A = cx + dy + f \dots\dots 1$$

where

A = Total amount of bill for a certain period (Say one month)

x = Maximum demand during the period (kW or kVA)

y = Total energy consumed during the period (kWh)

- c = Unit charge for maximum demand, Rs per kW
 (or Rs. per kVA)
 d = Unit cost of energy, Rs, per kWh
 f = Constant charge, Rs.

Thus the total bill consists of three parts, one depending on maximum power demand, the second depending on total energy consumed and the third being a constant figure.

2. Flat Demand Rate:

The flat demand rate can be expressed in the form, $A = cx$ i.e. the bill depends only on the maximum demand irrespective of the amount of energy consumed.

This is the earliest form of tariff and the bill in those days was based on the total number of lamps installed in the premises. Now-a-days the use of this tariff is restricted to sign lighting signal system, street lighting etc. where the number of hours are fixed and energy consumption can be easily predicted. Its use is very common for supplied to irrigation tube wells since the number of hours for which the tube well feeders are switched on are fixed. The charge is made according to the horse power of the motor installed. The cost of metering equipment and meter reading is eliminated by the use of this form of tariff.

3. Straight Meter Rate:

This can be represented by the equation

$$A = dy$$

The charges depend on the energy used. This tariff is sometimes used for residential and commercial customers. It has the advantage of simplicity. However the main disadvantage of this tariff is that a customer who does not use energy has zero bill though he has caused the utility to incur a definite expenditure due to its readiness to serve him. Another disadvantage is that this method does not encourage the use of electricity.

4. Block Meter Rate:

To remove the inconsistency of straight meter rate, the block meter rate charges the customers on a sliding scale. A certain unit rate is for a certain block of energy and for each succeeding block of energy, the corresponding unit charge decreases.

$$A = d_1 y_1 + d_2 y_2 + \dots + d_n [y - (y_1 + y_2 + \dots + y_n + \dots + y_{n-1})]$$

...(iii)

where d_1, d_2, d_3 are unit charges for energy blocks of magnitude y_1, y_2, y_3 etc. Generally the charge and energy consumption are divided into three blocks, a high rate for the initial certain number of energy units, a lower rate for the next certain number of energy units and a still lower rate for the remaining energy units. This tariff is very commonly used for residential and commercial customers.

In many states in India, a reverse form of this tariff is being used to restrict the energy consumption. In this reverse form, the unit energy charges increase with increase in energy consumption.

5. Hopkinson Demand Rate:

This tariff, also known as two part tariff, can be expressed in the form

$$A = cx + dy$$

...(iv)

Thus the total bill includes a demand charge based on the maximum demand plus a charge based on energy consumed. The factors c and d may be constant or may vary as per sliding scale. This tariff is used for industrial customers. This tariff introduces the problem of measuring the maximum power demand of the customers. This maximum demand can either be taken as a certain fraction of the connected load or measured by a maximum demand meter. It is usual to specify a minimum demand that must be paid for. Sometimes, to discourage the customers from using low power factor devices, the demand charges are based on kVA of maximum demand.

6. Doherty Rate:

This rate, also known as three part tariff extends the two part tariff adding a constant term, the form being identical with equation (i). This tariff is suitable for and applied to industrial customers.

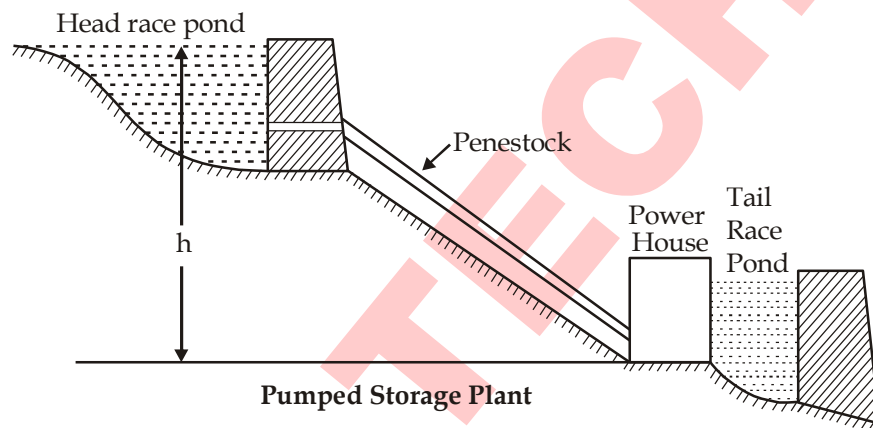
7. Wright Demand Rate:

Hopkinson demand rate offers an inducement to a customer to keep his maximum demand at a low value. Wright demand rate intensifies this inducement by lowering both the demand charge and energy charge for a reduction in maximum demand i.e. an improvement in load factor. This tariff is generally specified for those industrial customers who have a control over their maximum demands.

123.

Sol. Pumped storage Plant: Pumped storage plants are an special type of power plant which work as ordinary hydro power plants for part of the time and when such plants are not producing power, they can be used as pumping stations which pump water from tail race to the head race. During this time, these plants utilize power available from the grid to run the pumping set.

Thus, pumped storage plants can operate only if these plants are interconnected in a large grid.



Principle of Operation: The pumped storage plant consists of two ponds, one at high level and other at low level with power house near the low level pond. The two ponds are connected through a penstock.

It is an igneous way of conserving the limited water resources on the one hand and balancing the load on the distribution system, on the other hand. The plant operates as a source of electrical energy during system peak hours and as a sink during off-peak hours.

Role of the Plant in a Large Interconnected Power System:

(a) **Increased Reliability of Supply:** In the event of power failure at one station, the system can be fed from the other station. Generation in a hydrostation is greatly affected by river flow, storage available, floods and droughts. Forced outages at steam, station depends on efficient working of boilers, turbines and all the associated auxiliary plants. Forced outages as well as scheduled outages can be easily met in an interconnected system.

(b) **Reduction in Total Installed Capacity:** The amount of such reduction depends on the characteristics of the interconnected system and the desired degree of service reliability. In case of isolated operation of power stations, reserve would have to be maintained separately in each power station. Similarly spinning reserve required in a power system is reduced.

(c) **Economic Operations:** Various methods of loading the generator units in the most economical way with interconnection should be studied. Savings derived from reduction in spinning reserve and economic loading of the generator units can be calculated. This ultimately reduces the total capital and running costs to a minimum.



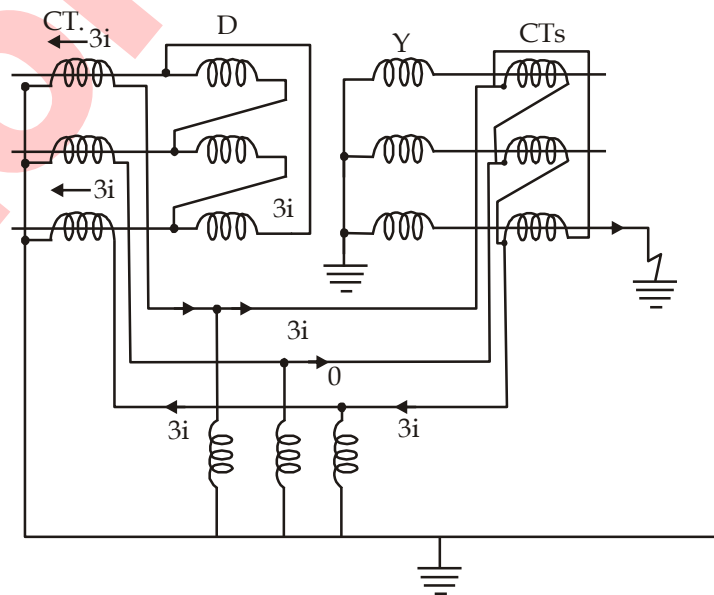
124.

Sol.	Average load	$= 100 \times 0.6 = 60 \text{ MW}$
	Energy generated	$= 60 \times 1000 \times 8760 = 5256 \times 10^5 \text{ kW-hr}$
	Total Investment	$= 120 \times 10^3 \times 40000 = \text{Rs. } 4800 \times 10^6$
	Interest and depreciation	$= \text{Rs. } 4800 \times 10^6 \times \frac{15}{100} = \text{Rs. } 720 \times 10^6 \text{ per year}$
	Fuel consumption	$= 0.64 \times 5256 \times 10^5 \text{ kg / year} = 3363.84 \times 10^5 \text{ kg per year}$
	Fuel cost	$= \text{Rs. } 3363.84 \times 10^5 \times \frac{1500}{1000} \text{ per year}$ $= \text{Rs. } 504.576 \times 10^6 \text{ per year}$
	Salaries, wages etc.	$= \text{Rs. } 50 \times 10^6 \text{ per year}$
	Annual plant cost	$= \text{Rs. } 1274.576 \times 10^6 \text{ per year}$
	Generation cost	$= \text{Rs. } \frac{1274.576 \times 10^6}{5256 \times 10^5} = \text{Rs. } 2.425 / \text{kWh}$

125.

Sol.

- Transformers need to be protected against short circuits and over heatings. For transformers having kVA ratings over current relays are used but for transformers with large MVA ratings differential protections are used.
- Primary and secondary windings of transformer differ from each other in number of turns. They are also phase displaced if transformer is star-delta connected. Requirement in differential is that relay don't operate under external fault condition, so adjustment need to be made for different turns ratio of primary and secondary and phase displacement due to star-delta connection., The CTs on star side are connected in delta and on delta side are connected in star.



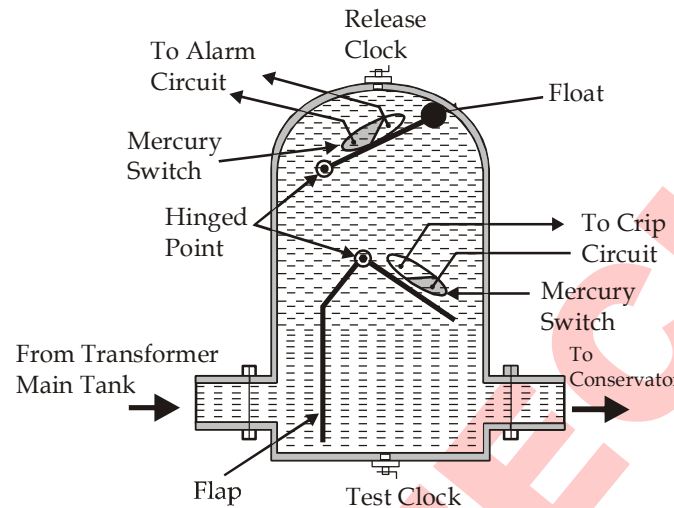
126.

Sol.

It is a gas actuated relay

It is usually installed in the pipe connected between conservator and the main T/F tank.

It is used for oil immersed T/F of rating more than 750 kVA



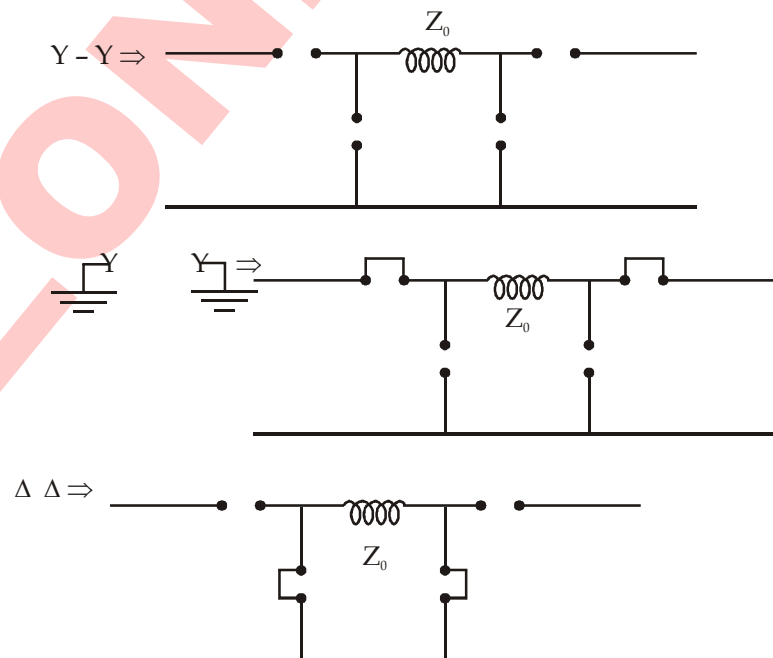
The upper element consist of a mercury type switch attach to a float

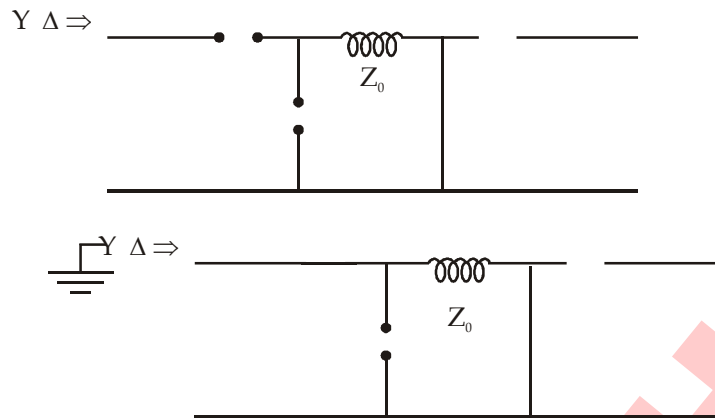
The lower element consist of a mercury switch mounted on a flap located in the direct path of the flow of oil is a serious fault occur in the transformer gas is generated.

When a fault take place in T/F. The oil as the tank get overheated ad gases are formed. The generation of gases is depending upon the fault is or the major (heavy short CKT)

127.

Sol.





In transformer positive sequence impedance is equal to the leakage impedance. The resistance of winding usually small as compared to leakage reactance.

Negative sequence impedance = Positive sequence impedance

zero sequence impedance of transformer is slightly different from positive sequence it's depend on winding connection.

The zero sequence current can flow through the winding connected in star only and the star point is grounded.

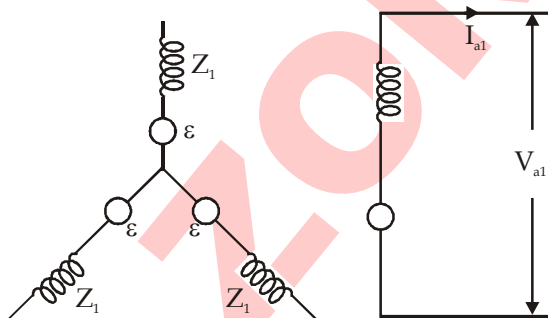
If the star point is isolated zero sequence current cannot flow in the winding. The zero sequence current cannot flow in the line connected in delta because no return path is available for zero sequence current.

128.

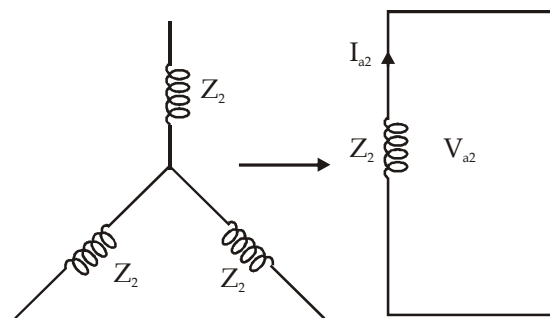
Sol.

Induced emf in the synchronous generator will always balanced as the no of turn are fixed in each phase winding are placed 120° in space. As direction of rotation of generator is kept fixed the phase sequence as induced emf remain fixed it is taken as positive sequence so the induced emf are always positive sequence, there is no negative for zero sequence induced emf. phase current and terminal voltage may be balanced or unbalanced

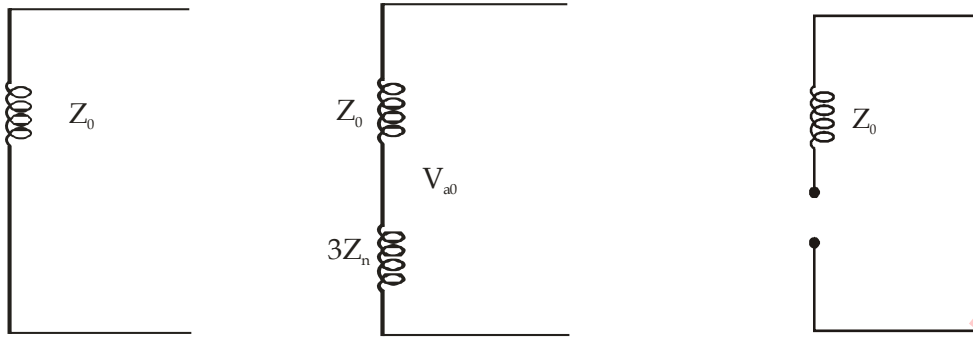
The generated voltage are of positive sequence only the positive sequence network consist as an emf in series with the positive sequence impedance of the machine.



Positive sequence for star connection



Negative Sequence for Star connection



Y star with grounded Star grounded with Z_n

Y star without grounded

Zero Sequence Connection

129.

Sol.

The hydro-power plants are well suited for both base load as well as peak load operational plants.

The hydro power plants should be employed for base load operations as far as possible

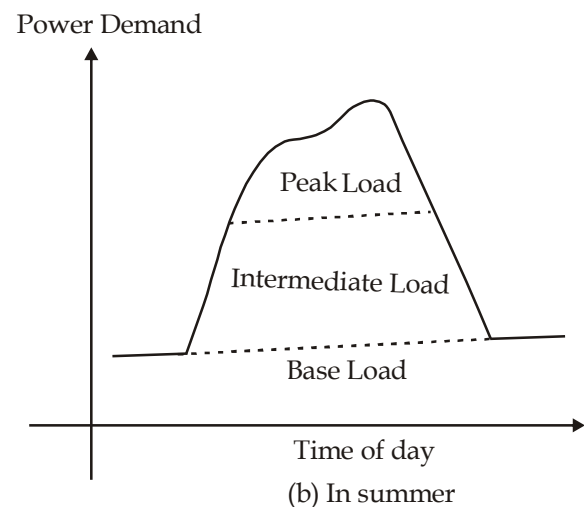
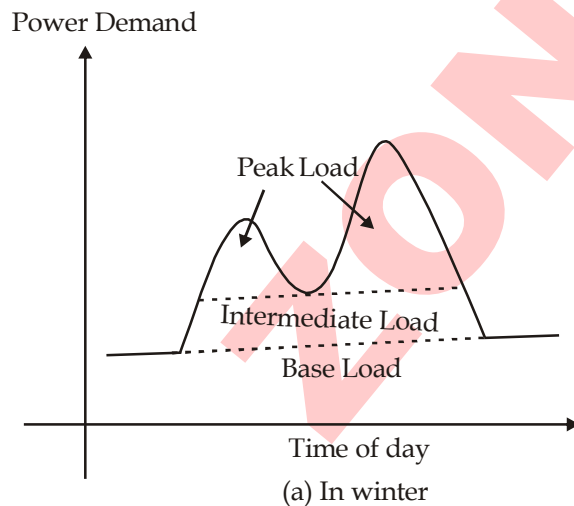
Pumped storage power plants may be used as a peak load power plants.

Steam power plants or thermal power plants gives minimum cost of generation per unit when employed as base load plant.

Nuclear power plants are suitable only for base load operation. Nuclear power plants have the highest load factor of over 0.8 to 0.9.

Gas turbine power plants are best suited for peak load power plant operations.

Diesel engine power plants are generally will have higher operational costs and is uneconomical to operate them continuously. Diesel plants are mostly operated as peak load



S. No.	Base load plants	Peak load plants
1.	These plants operate on the base portion of the load curve of the power system.	These plants supply power to the system corresponding to the load at the top portion of the load curve.
2.	Plants with large storage can best be used as base load plants especially in rainy seasons.	Run-off river plants with pondage can be used for such purposes.
3.	As these loads operate throughout the year at approximately full capacity the load factor of such plants is high.	The load factor of such plant is relatively low as they operate only for a short period of the total operating time.
4.	Base load plants have low operating cost.	Peak load plant have high operating cost.
5.	The starting process of these plants is slow.	The starting process of these plants is quick.
6.	Capability of operating for longer period	Capability of operating for short period
7.	Maintenance should be simpler and requires less time	Maintenance time is more.

130.

Sol. (i) Diversity Factor: Diversity factor is defined as the ratio of the sum of individual maximum demand to the simultaneous maximum demand of the whole group of consumers.

$$\text{Diversity Factor} = \frac{\text{Sum of individual maximum demands}}{\text{Simultaneous maximum demand of the consumers}}$$

(ii) Plant Capacity Factor: The plant capacity factor give an idea about the reserve capacity requirements of a power station. It is defined as

$$\text{Plant capacity factor} = \frac{\text{Actual energy generated}}{\text{Maximum energy that could have been generated during the period}}$$

(iii) Plant Use Factor : Another factor which affects the cost of energy is the plant use factor and is defined as

$$\text{Plant use factor} = \frac{\text{Annual energy generated}}{(\text{Capacity of plant}) \times (\text{No. of hours plant is actually in operation during the year})}$$

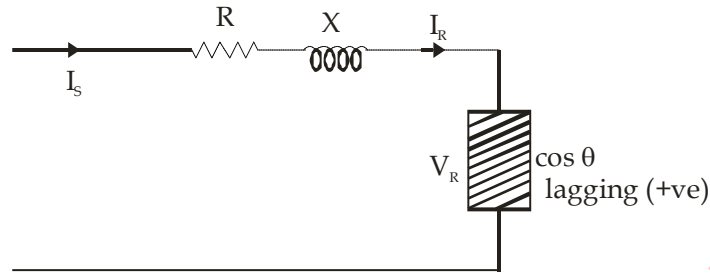
(iv) Loss load factor:- It is defined as the ratio of actual loss during period to the loss assuming maximum current to flow over the same period.

$$\text{Loss load factor (G)} = \frac{\text{Actual loss (kWh) during a period}}{\text{loss (KWh) assuming maximum current to flow over the same period}}$$



131.

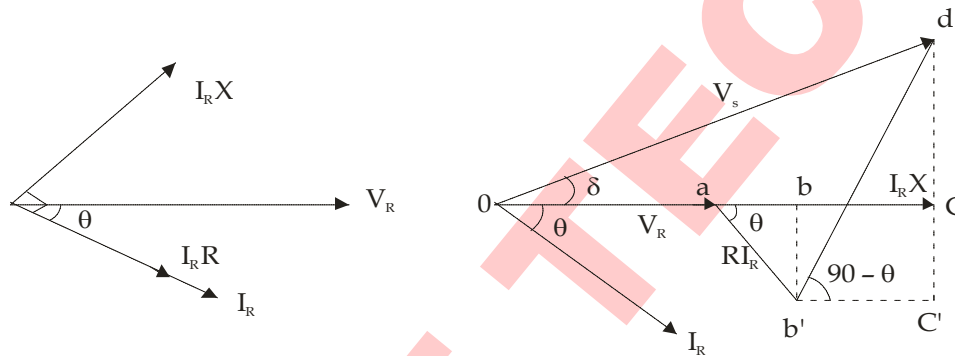
Sol. Phasor diagram :-



$$V_s = V_R + I_R (R + jX)$$

$$V_s = V_R + I_R R + I_R jX$$

$$V_s = V_R + I_R R + jI_R X$$



$$OC = oa + ab + bc$$

$$OC = oa + ab + b'c'$$

$$OC = V_s \cos \delta$$

$$oa = V_R$$

In $\Delta abb'$:-

$$ab = I_R R \cos \theta$$

In $\Delta b'c'd$:-

$$b'c' = I_R X \cos (90 - \theta)$$

$$b'c' = I_R X \sin \theta$$

$$OC = oa + ab + b'c'$$

$$V_s \cos \delta = V_R + I_R R \cos \theta + I_R X \sin \theta$$

$$\delta \approx 0$$

$$\cos \delta \approx 1$$

$$\frac{V_s - V_R}{V_R} = \frac{I_R R \cos \theta}{V_R} + \frac{I_R X \sin \theta}{V_R}$$

$$V \cdot R = R_{p,u} \cos \theta \pm X_{p,u} \sin \theta$$

132.

Sol: As compared to EHV AC, HVDC has following advantages and disadvantages.

Advantages:

1. HVDC systems are economical for long distance bulk power transmission by overhead lines (reduced tower costs).
2. There is greater power per conductor and simpler line construction.



3. Ground return is possible.
4. There is no charging current and skin effect.
5. The voltage regulation problem is much less serious for DC, since only the IR drop is involved ($IX = 0$). For the same reason steady stability is no longer a major problem.
6. There is easy reversibility and controllability of power flow through a DC link.
7. The DC line is an asynchronous link and it can interconnect two rigid systems operating at different frequencies.
8. Each conductor can be operated as an independent circuit.
9. Smaller amount of right of way and narrower tower are required.
10. AC line requires more insulation between the tower and conductors as well as greater clearance above the earth as compared to DC line.
11. Line losses are smaller.
12. No reactive compensation of DC line is required.
13. Corona loss, radio interference and audible emissions are less as compared to AC.

Disadvantages

1. The systems are costly since installation of complicated converters and DC switchgear is expensive.
2. Converters require considerable reactive power.
3. Harmonics are generated which require filters.
4. Lack of HVDC circuit breakers hampers network operation.
5. There is nothing like DC transformers which can change the voltage level. Voltage transformation has to be provided on the AC sides of the system.
6. Reactive power required by the load is to be supplied locally as no reactive power can be transmitted over a DC link.
7. Pollution affects DC more than AC. More frequency clearing of insulators is required.

Advantage of AC

1. Power can be generated at high voltage
2. Maintenance of AC sub station is easy and cheaper
3. AC voltage can be step up or step down by transformer this permit to transmit power at higher voltage.

Disadvantage of AC Transmission

1. AC line require more copper than a DC line
2. Due to skin effect and proximity effect effective resistance of line is increased.
3. AC line has capacitance therefore there is continuous loss of power due to charging current

133.

Sol. Distribution systems may be classified in various ways as followed:

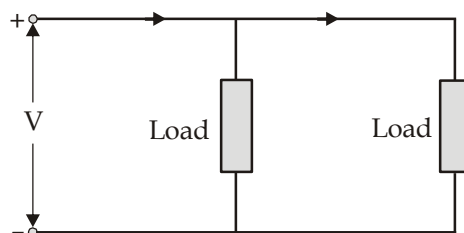
1. According to current, the distribution systems are two types:

(a) dc distribution system, (b) ac distribution system.

(a) **dc distribution system:**

(i) **2-wire dc distribution system:** This system of distribution consists of two wires, one is the positive and other is the negative wire.

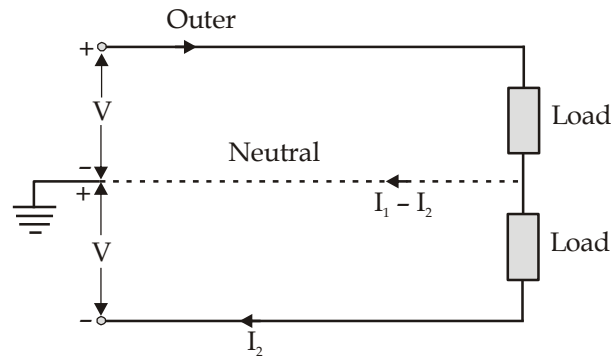
This system is never used for transmission purpose due to low efficiency but may be employed for distribution of dc power.



(ii) **3-wire dc distribution system:** This system consists of two outers and a middle or neutral wire which is earthed at the substation. The voltage between the outer is twice the voltage between either



outer and neutral wire



This system is used for transmission purpose.

2. According to types of construction of distribution systems:

(a) Overhead

(b) Underground

(a) The overhead system is generally employed for distribution as it is cheaper than underground system.

(b) The underground system is used at places where overhead construction is impracticable.

3. According to the scheme of connection of distribution system

(a) Radial system

(b) Parallel system

(c) Ring system

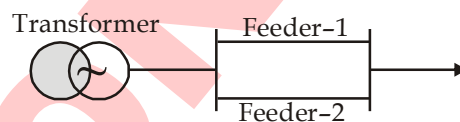
(d) Interconnected system

(a) **Radial system:** In this system, separate feeder radiates from a substation and feed the distribution at one end only.

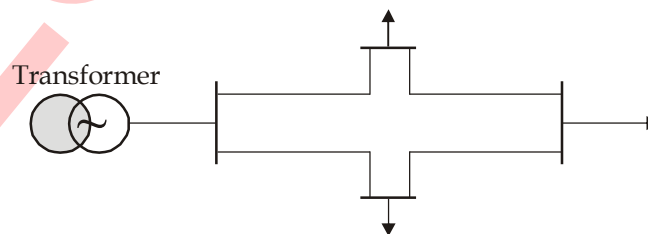


This system is simplest, most economical and most commonly used one.

(b) **Parallel system:** In this system, two radial feeders originated from the same or different substations are run in parallel. Each feeder, though cable of supplying the entire load, share the total load equally in normal conditions.



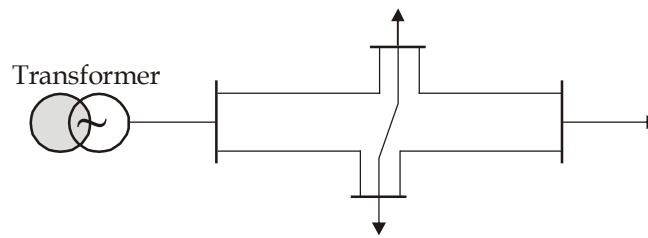
(c) **Ring system:** In this system, two or more radial feeders originating from the same or different substations are laid on different routes of load areas.



This system is most reliable for continuity of supply and gives better voltage regulation and less power losses.

(d) **Inter-connected system:** When the feeder of ring main is energised from two or more than two generating stations or substations it is called the inter-connected system.

This system provides better reliability and flexibility and is employed in large metropolitan cities where continuity of supply is the most important.



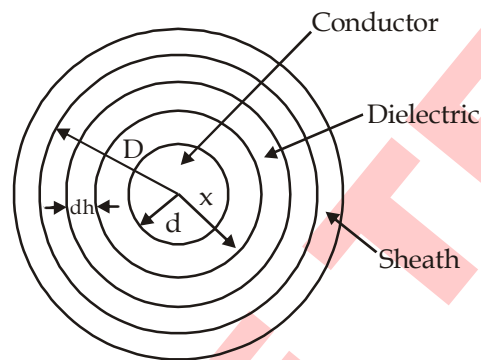
134.

Sol.

- Gradient at a distance x

$$g = \frac{q}{2\pi\epsilon x} = E$$

where E is the electric field intensity



Electric stress in a single core cable

- Potential of the conductor with respect to sheath.

$$V = -\int_D^d E dx = \int_d^D \frac{q}{2\pi\epsilon x} dx$$

$$V = \frac{q}{2\pi\epsilon} \ln\left(\frac{D}{d}\right)$$

- Gradient at distance x from centre

$$g = \frac{2V}{x \ln\left(\frac{D}{d}\right)}$$

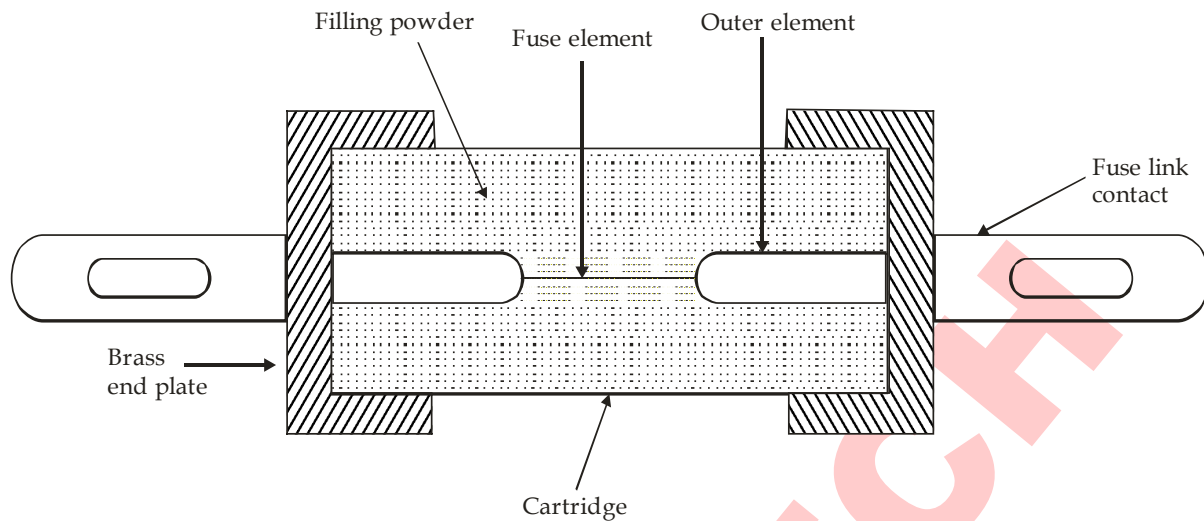
- The gradient is maximum at the surface of the conductor.

$$g_{\max} = \frac{2V}{d \ln\left(\frac{D}{d}\right)}$$

135.

Sol. (i) High-Rupturing capacity (H.R.C.) cartridge fuse. The primary objection of low and uncertain breaking capacity of semi-enclosed rewirable fuses is overcome in H.R.C. cartridge fuse. It consists of a heat resisting ceramic body having metal end-cups to which is welded silver current-carrying element. The space within the body surrounding the element is completely packed with a filling powder. The filling material may be chalk, plaster of paris, quartz or marble dust and acts as an arc quenching and

cooling medium.



Under normal load conditions, the fuse element is at a temperature below its melting point, so it carries the normal current without overheating. When a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak. The heat produced in the process vapourises the melted silver element. The chemical reaction between the silver vapour and the filling powder results in the formation of a high resistance substance which helps in quenching the arc.

Advantages

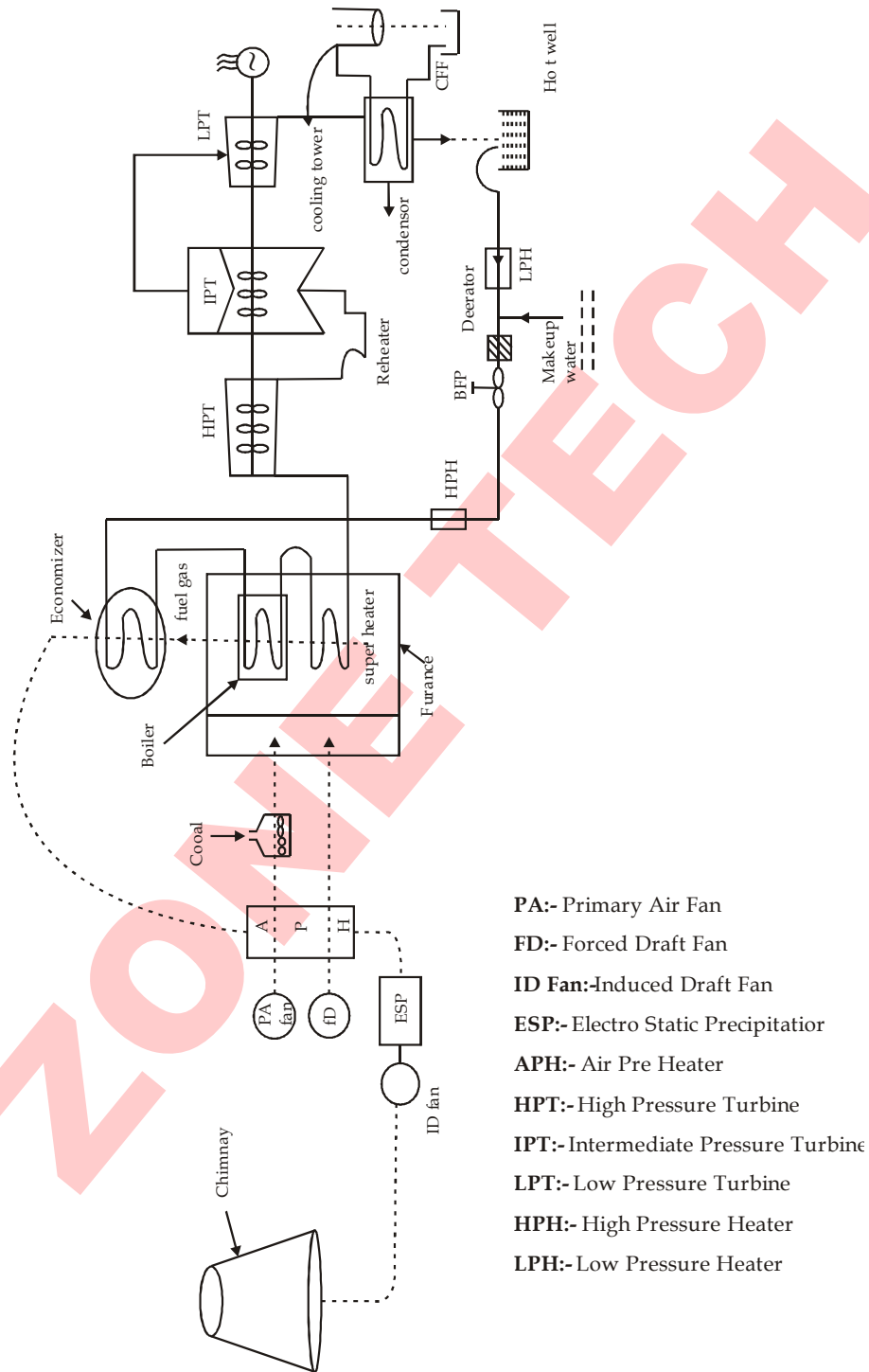
- (i) They are capable of clearing high as well as low fault currents.
- (ii) They do not deteriorate with age.
- (iii) They have high speed of operation.
- (iv) They provide reliable discrimination.
- (v) They require no maintenance.
- (vi) They are cheaper than other circuit interrupting devices of equal breaking capacity.
- (vii) They permit consistent performance.

Disadvantages

- (i) They have to be replaced after each operation.
- (ii) Heat produced by the arc may affect the associated switches.



136.

Sol: Schematic Diagram of a Typical Steam Power Station:

Comparison of steam power plant with hydroelectric power plant.

Item	Steam Power Plant	Hydroelectric Power Plant
1. Initial cost (approximate) per kW in rupees	Initial cost is lower than those of hydroelectric and nuclear power plant (1000 to 1500).	Initial cost is very high because of dam construction and excavation work (1500 to 4000).
2. Running cost	Higher than hydroelectric and nuclear plant because of the requirement of huge amount of coal.	Practically nil because no fuel is required.
3. Cost of fuel	Maximum because huge amount of coal is transported to the plant site.	Practically nil.
4. Maintenance cost	Quite high as skilled operating staff is required.	Quite low.
5. Transmission and distribution cost	Quite low as these are generally located near the load centres.	Quite high as these are located quite away from the load
6. Fixed cost per annum (interest) on capital	13%	10%

137.

Sol. (i) Demand factor

$$= \frac{\text{Maximum demand}}{\text{Connected load}}$$

$$= \frac{20 \text{ MW}}{23 \text{ MW}} = 0.869$$

Hence demand factor = 0.86

(ii) Average Demand

$$= \frac{\text{kWh generated / annum}}{\text{Hours in a year}}$$

$$= \frac{61.5 \times 10^6}{8760} \Rightarrow 7.0205 \times 10^3 \times 10^6$$

$$\Rightarrow 7.02 \times 10^3 \text{ kW}$$

(iii) Load factor

$$= \frac{\text{Average load}}{\text{Maximum demand}} = \frac{7020 \text{ kW}}{20 \text{ MW}}$$

$$= \frac{7020 \times 10^3}{20 \times 10^6} \text{ Watts} = 0.351 \approx 35.1\%$$

(iii) Plant capacity factor

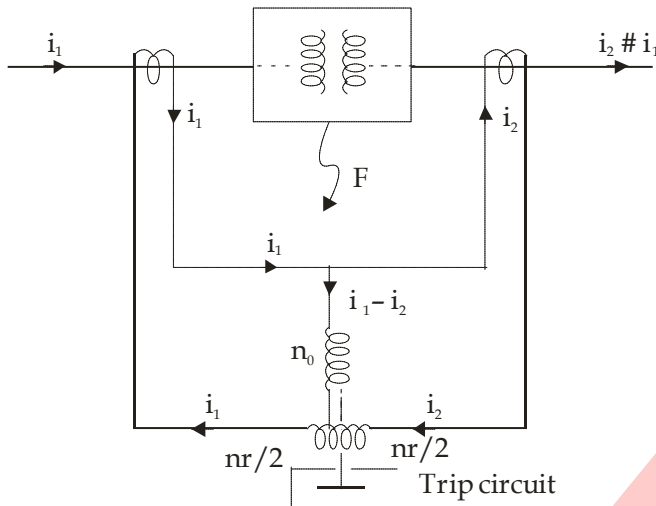
$$= \frac{\text{Average load}}{\text{plant capacity}} = \frac{7020 \text{ kW}}{25 \text{ MW}}$$



$$= \frac{7020 \times 10^3}{25 \times 10^6} \text{ Watts} = 0.281 \cong 28.1\%$$

138.

Sol.



N_0 = no of turn of operating coil

The relay consist of an operating coil and restraining coil. The operating coil is connected to the mid point of the restraining coil.

Torque due to the operating coil is proportional to

$$T_o \propto n_0 (i_1 - i_2)$$

Torque due to restraining coil

$$T_r \propto \frac{nr}{2} i_1 + \frac{nr}{2} i_2$$

Torque Balance equation

Torque due to the operating coil = Torque due to restraining coil

$$n_0 (i_1 - i_2) = \frac{nr}{2} i_1 + \frac{nr}{2} i_2$$

$$\frac{(i_1 - i_2)}{\left(\frac{i_1 + i_2}{2}\right)} = \frac{n_r}{n_0}$$

139.

Sol. Under fault conditions, a circuit breaker is required to perform the following three duties :

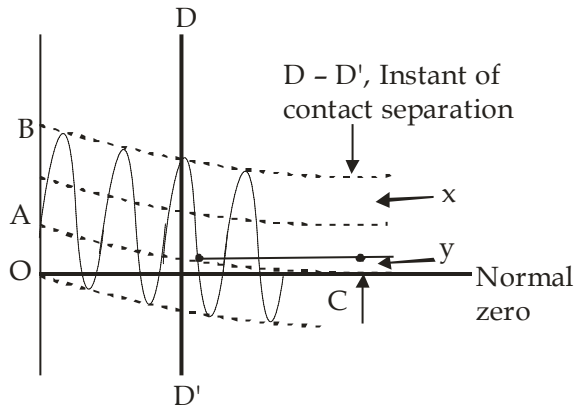
- (i) It must be capable of opening the faulty circuit and breaking the fault current.
- (ii) It must be capable of being closed on to a fault.
- (iii) It must be capable of carrying fault current for a short time while another circuit breaker (in series) is clearing the fault.

The circuit breakers have three ratings

- (i) breaking capacity

- (ii) making capacity and
- (iii) short-time capacity.

Breaking capacity. It's current (r.m.s.) that a circuit breaker is capable of breaking at given recovery voltage and under specified conditions (e.g. power factor, rate of rise of re-striking voltage).



The breaking capacity is always stated at the r.m.s. value of fault current at the instant of contact separation. When a fault occurs, there is considerable asymmetry in the fault current due to the presence of a d.c. component. At this instant, the fault current has

x = maximum value of a.c. component

y = d.c. component

Symmetrical breaking current = r.m.s. value of a.c. component

$$= \frac{x}{\sqrt{2}}$$

Asymmetrical breaking current = r.m.s. value of total current

$$= \sqrt{\left(\frac{x}{\sqrt{2}}\right)^2 + y^2}$$

breaking capacity expressed in MVA by taking into account the rated breaking current and rated service voltage. Thus, if I is the rated breaking current in amperes and V is the rated service line voltage in volts, then for a 3-phase circuit.

$$\text{Breaking capacity} = \sqrt{3} \times V \times I \times 10^{-6} \text{ MVA}$$

Making capacity. There is always a possibility of closing or making the circuit under short-circuit conditions. The capacity of a breaker to make current depends upon its ability to withstand and close successfully against the effects of electromagnetic forces. These forces are proportional to the square of maximum instantaneous current on closing. Therefore, making capacity is stated in terms of a peak value of current instead of r.m.s. value.

The peak value of current (including d.c. component) during the first cycle of current wave after the closure of circuit breaker is known as **making capacity**.

$$\text{Making capacity} = 2.55 \times \text{Symmetrical breaking capacity}$$

Short-time rating. It is the period for which the circuit breaker is able to carry fault current while remaining closed. Sometimes a fault on the system is of very temporary nature and persists for 1 or 2 seconds after which the fault is automatically cleared. In the interest of continuity of supply, the breaker



should not trip in such situations. This means that circuit breakers should be able to carry high current safely for some specified period while remaining closed *i.e.*, they should have proven short-time rating. The short-time rating of a circuit breaker depends upon its ability to withstand (a) the electro-magnetic force effects and (b) the temperature rise. The oil circuit breakers have a specified limit of 3 seconds when the ratio of symmetrical breaking current to the rated normal current does not exceed 40. However, if this ratio is more than 40, then the specified limit is 1 second.

Normal current rating. It is the r.m.s. value of current which the circuit breaker is capable of carrying continuously at its rated frequency under specified conditions. The only limitation in this case is the temperature rise of current-carrying parts.

140.

Sol. The power consumed by each load can be tabulated as given below:

Power consumed

Lighting	$500 \times 60 = 30,000 = 30 \text{ kW}$
Heating	$= 100 \text{ kW}$
Motors	$= 75/0.75 = 100 \text{ kW}$
Misc.	$= 200 \times 40/1000 = 8 \text{ kW}$

Similarly, the energy consumed/day can be tabulated as follows:

Energy consumed/day

Lighting	$= 30 \text{ kW} \times 8 \text{ hr} = 240 \text{ kWh}$
Heating	$= 100 \text{ kW} \times 10 \text{ hr} = 1,000 \text{ kWh}$
Motors	$= 100 \text{ kW} \times 2 \text{ hr} = 200 \text{ kWh}$
Misc.	$= 8 \text{ kW} \times 2 \text{ hr} = 16 \text{ kWh}$
Total daily consumption	$= 1456 \text{ kWh}$
Weekly consumption	$= 1456 \times 6 = 8736 \text{ kWh}$
Current taken by the lighting load alone	$= 30 \times 1000/200 = 150 \text{ A}$

141.

Sol. Advantages of a nuclear plant as compared to other conventional plants:

- (i) A nuclear power plant is totally free of air pollution. It is a more green technology compared thermal.
- (ii) it requires very little fuel in terms of volume & weight & thus poses no transportation problem & may be sited, independently of nuclear fuel supplies, close to load centres.
- (iii) It lasts longer-over 45 years as against 30 in case of coal & 15 in case of gas turbines.

Disadvantages :

- (i) Nuclear reactors produces radioactive fuel waste, the disposal of which poses serious environmental threats
- (ii) The rate of nuclear reaction can be lowered only by a small margin, so the load on a nuclear plant can only be permitted to be marginally reduced below its full load value. Hence nuclear power stations must be reliably connected to a power network, as tripping of the lines connecting ' , station can be quite serious & may require shutting down of the reactor with all its consequence
- (iii) The plant has a relatively high capital as against the running cost. The nuclear plant thus shou operate continuously as a base load station.
- (iv) There are risks in terms of fuel supplies and safety.
- (v) Requirement of large quantity of water.

142.

Sol. Loss load factor:- It is defined as the ratio of actual loss during period to the loss assuming maximum current to flow over the same period.

$$\text{Loss load factor (G)} = \frac{\text{Actual loss (kWh) during a period}}{\text{loss (KWh) assuming maximum current to flow over the same period}}$$

If the load factor of a plant is 100%, the copper loss will be at its full value throughout the period and it is easy to find the cost of losses. But in actual practice the load factor is normally less than 100% and let this be f .

Determination of losses

It is difficult to evaluate copper losses over the year as they vary as the square of current and hence approximately the square of load, which in turn keeps on varying throughout the period. Therefore, the annual copper losses only vary with the mean height of annual load curve (i.e. the load factor) but also depends on its shape.

- Therefore an empirical formula, for estimating losses, is evolved using load factor (F), say, the maximum current with the load factor F .
- The greatest possible loss would occur if maximum current flows for fraction f of the year and no current in the remaining part of the year. Under this condition,

$$\text{loss} \propto I^2 F^2$$

The least possible loss will occur, with the same load factor, if the mean current if flows continuously except when a peak current I is reached momentarily, when the copper could be considerably negligible. Under this condition.

$$\text{loss} \propto I^2 F^2 [\text{copper loss mean current}^2]$$

Now it is convenient to omit the factor F from both the case and express the losses as a fraction of those which would occur if the maximum current flows continuously.

- This factor which is actually load factor of losses, called as load factor by definition, would then be F in first case and F^2 in the second case.

In any given situations, the losses would be somewhere between these extreme situations and the most convenient to assume will be load factor of 50%. It gives a simple formula for the loss factor as

$$G = 0.5F + 0.5F^2$$

But generally, in practice, the peak load occurs for a relatively short time and the above formula seems to give a relatively high value of loss. A better approximation could be that, three tenths of the consumption takes place at maximum load and the remainder is the mean load. This gives the loss factor as

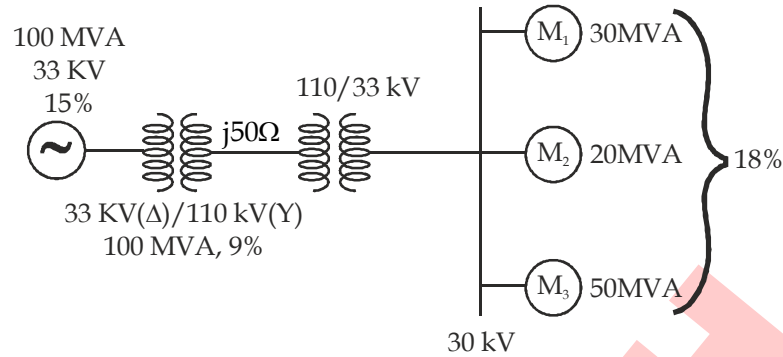
$$G = 0.3F + 0.7F^2$$

$$\begin{array}{ccc} \downarrow & & \downarrow \\ \left(\begin{array}{c} \text{factor at} \\ \text{maximum load} \end{array} \right) & & \left(\begin{array}{c} \text{Remainder at} \\ \text{mean load (1-0.3)} \end{array} \right) \end{array}$$

This is the process through which loss load factor can be determined. Note that it is an empirical formula.

143.

Sol.



Let

$$(\text{MVA})_{\text{Base}} = 100 \text{ MVA}$$

$$(\text{kV})_{\text{Base}} = 33 \text{ kV}$$

$$X_g = j0.15 \text{ (given)}$$

As transformers have also MVA and kV ratings same as base values

 $\therefore$ p.u. reactance of transformer (X_T) = $j0.09$ p.u.

for transmission line, $(\text{KV})_{\text{Base}} = 33 \times \frac{110}{33} = 110 \text{ kV}$

$$\therefore \text{Base impedance} = \frac{(110 \text{ kV})^2}{100 \text{ MVA}} = 121 \Omega$$

$$\therefore \text{p.u. reactance of line} = \frac{j50}{121}$$

$$(X_{TL}) = j0.413 \text{ p.u.}$$

for motor M_1 , p.u. reactance on new base value

$$X_{m1} = X_0 \left(\frac{\text{MVA}_n}{\text{MVA}_0} \right) \left(\frac{\text{kV}_0}{\text{kV}_n} \right)^2$$

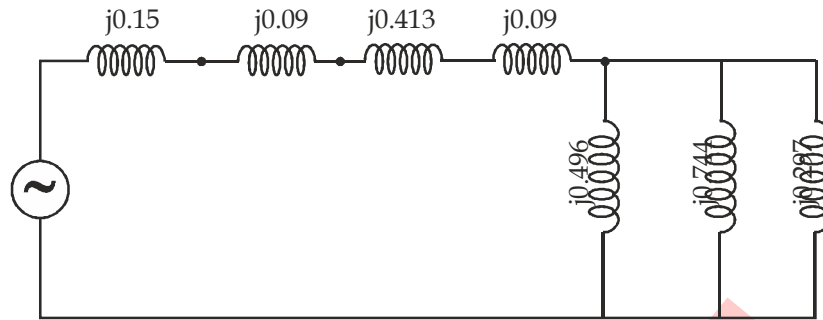
$$X_{m1} = j0.18 \times \left(\frac{100}{30} \right) \times \left(\frac{30}{33} \right)^2$$

$$X_{m1} = j0.4958 \text{ p.u.}$$

for motor M_2 , $X_{m2} = j0.18 \times \left[\frac{100}{20} \right] \times \left(\frac{30}{33} \right)^2 = j0.744 \text{ p.u.}$

for motor M_3 , $X_{m3} = j0.18 \times \left(\frac{100}{50} \right) \times \left(\frac{30}{33} \right)^2 = j0.2975 \text{ p.u.}$

p.u. reactance diagram:



144.

Sol. String efficiency: String efficiency can be defined as the ratio of voltage across the whole string to the product of number of disc and voltage across disc nearest to the conductor.

$$\eta = \frac{\text{Voltage across whole string}}{n \times \text{voltage of the disc nearest to conductor}}$$

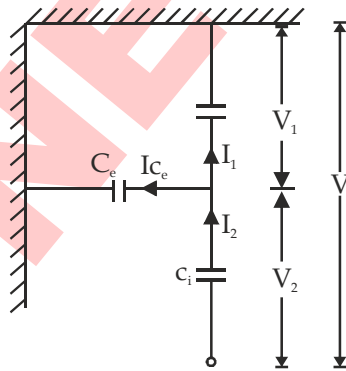
In ideal condition string efficiency is 100%. It indicates that all disc are sharing equal voltage. String efficiency can be raised by introduction of a combination of grading ring and arcing horns. A grading ring is basically a metal ring which is electrically connected to the conductor surrounding the bottom unit of the string insulator. The grading ring introduces a capacitance between metal link and the line conductor which tends to cancel out the shunt capacitances. As a result nearly same charging current flows through each disc and hence improves string efficiency.

According to question

Given,

$$V_1 = 0.4 \text{ V}$$

$$V_2 = 0.6 \text{ V}$$



From the diagram,

$$V = V_1 + V_2$$

$$I_1 = \omega C_1 V_1$$

$$I_{ce} = \omega C_e V_1$$

$$I_2 = I_1 + I_{ce} = \omega C_1 V_1 + \omega C_e V_1$$

Also

$$I_2 = \omega C_2 V_2$$

$\Rightarrow$

$$\omega C_2 V_2 = \omega C_1 V_1 + \omega C_e V_1$$

$$C_2 V_2 = C_1 V_1 + C_e V_1$$

$$C_2(0.6) = C_1(0.4) + C_e(0.4)$$

$$C_2(0.2) = C_e(0.4)$$



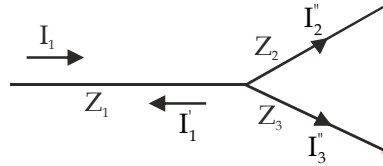
$$\frac{C_i}{C_e} = 2$$

Therefore the ratio of capacitance of insulator to the earth capacitance of earth is

$$\frac{C_i}{C_e} = 2$$

145.

Sol.



Let V_2, I_2 and V_3, I_3 be the voltages and currents in the lines with surge impedances Z_2 and Z_3 respectively.

$V_2 = V_3 = V''$ because Z_3 & Z_2 are in parallel.

$$I_1 = \frac{V}{Z_1}, I_1 = -\frac{V'}{Z_1}$$

$$I_2 = \frac{V''}{Z_2} \text{ and } I_3 = \frac{V''}{Z_3}$$

Therefore the following relations hold good.

$$V + V' = V'' \quad \dots(1)$$

$$I + I' = I_2 + I_3 \quad \dots(2)$$

or

$$\frac{V}{Z_1} - \frac{V'}{Z_1} = \frac{V''}{Z_2} + \frac{V''}{Z_3}$$

From equation (1) $V' = V'' - V$, Now equation (3) changes to

$$\frac{V}{Z_1} - \frac{V'' - V}{Z_1} = \frac{V''}{Z_2} + \frac{V''}{Z_3}$$

$$\frac{2V}{Z_1} = V'' \left(\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} \right)$$

or

$$V'' = \frac{2V / Z_1}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}}$$

$$\left. \begin{array}{l} Z_1 = 600\Omega \\ Z_2 = 800\Omega \\ Z_3 = 200\Omega \end{array} \right\} \text{(given in problem)}$$

$\Rightarrow$ Since Z_2 and Z_3 form a parallel path as for as the surge wave is concerned, $V_2 = V_3 = V''$.

$\therefore$

$$V'' = \frac{2V / Z_1}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}}$$

$$= \frac{2 \times 100}{\frac{1}{\frac{1}{600} + \frac{1}{800} + \frac{1}{200}}} = \frac{200}{1 + \frac{6}{8} + 3}$$

$$= \frac{200 \times 8}{8 + 6 + 24} = 42.10 \text{ kV}$$

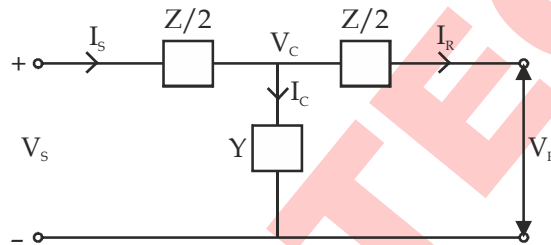
Value of current transmitted depends upon the impedance of the line,

$$\therefore I_2'' = \frac{V''}{800} = \frac{42.01 \text{ kV}}{800} = 52.63 \text{ A}$$

Similarly,
$$I_3'' = \frac{42.01 \times 10^3}{200} = 210.05 \text{ A}$$

146.

Sol. Nominal T-model of the line as shown in figure.



load current,

$$I_R = \frac{35 \times 10^6}{\sqrt{3} \times 132 \times 10^3 \times 0.8} = 191.356 \text{ A}$$

$$\therefore I_R = 191.35 \angle -\cos^{-1}(0.8) = 191.35 \angle -36.86^\circ$$

$$\therefore R = 10 \Omega$$

$$L = 0.1 \text{ H} \quad \therefore X_L = 2\pi f \times L = 2\pi \times 50 \times 0.1 = 31.41 \Omega$$

$$\therefore Z = R + jX = 10 + j31.41$$

$$\therefore \frac{Z}{2} = 5 + j15.70$$

$$\therefore \text{Capacitance} = 0.9 \times 10^{-6} \text{ F}$$

$$\therefore X_c = \frac{-j}{2\pi f \times 0.9 \times 10^{-6}}$$

$$\therefore Y = \frac{1}{X_c} = j2.827 \times 10^{-4} \Omega$$

$$\therefore V_s = AV_R + BI_R$$

$$A = 1 + \frac{1}{2}YZ = 1 + \frac{1}{2} \times (j2.827 \times 10^{-4}) \times (10 + j31.41)$$

$$A = 0.9955 \angle 0.0813^\circ$$

$$B = z \left(1 + \frac{1}{4}YZ \right) = 32.89 \angle 72.3806^\circ$$

$$\therefore V_s = AV_R + BI_R$$

$$V_s = (0.9955 \angle 0.0813)(76210.23) + 32.89(\angle 72.3806)(191.35 \angle -36.86) \\ = 81076.95 \angle 2.66^\circ$$

for no load voltage,

$$V_R' = \frac{|V_s|}{|A|} = 81443.4455 \text{ V}$$

$$\therefore V_R = \frac{132 \times 10^3}{\sqrt{3}} = 76210.23 \text{ V}$$

$$\therefore V_R = \frac{132 \times 10^3}{\sqrt{3}} = 76210.23 \text{ V}$$

$$\therefore \text{Voltage regulation} = \frac{V_R' - V_R}{V_R} \times 100 \\ = \frac{81440.87 - 76210.23}{76210.23} \times 100 = 6.86\%$$

$$\therefore V_C = V_R + I_R \times \frac{Z}{2} = \frac{132 \times 10^3}{\sqrt{3}} + 191.356 \angle -36.86 (5 + j15.70) \\ = 78797.31 \angle 1.33 = 78.8 \angle 1.33 \text{ kV}$$

$$\therefore I_C = Y \times V_C = j2.827 \times 10^{-4} \times 78796.31 \angle 1.33 \\ = 22.2765 \angle 91.33 \text{ A}$$

$$\therefore I_s = I_C + I_R = 178.4379 \angle -31.229$$

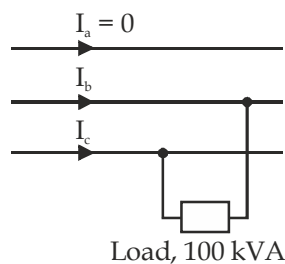
$$\therefore \text{Line Loss} = 3 \left(I_s^2 \frac{R}{2} + I_R^2 \frac{R}{2} \right) \\ = 3 \times \frac{R}{2} [I_s^2 + I_R^2] = 3 \times \frac{10}{2} [(178.44)^2 + (191.35)^2] \\ = 1.03 \text{ MW}$$

$$\therefore \text{efficiency} = \frac{\text{output power}}{\text{output power} + \text{losses}} \times 100 \\ = \frac{35 \times 10^6}{35 \times 10^6 + 1.03 \times 10^6} \times 100 = 97.150\%$$

$$\text{Line voltage of the system} = V_1 + V_2 + V_3 = 26 \text{ kV}$$

147.

Sol.



The line current $I_s = 0$

$$I_b = \frac{100 \times 10^3}{3.3 \times 10^3} = 30.3 \text{ A}$$

$$I_c = -I_b = -30.3 \text{ A}$$

In terms of symmetrical components,

$$\begin{bmatrix} I_{a_0} \\ I_{a_1} \\ I_{a_2} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Here

$$\alpha = 1 \angle 120^\circ$$

$$\alpha^2 = 1 \angle 240^\circ$$

∴ Zero sequence component, $I_{a_0} = \frac{1}{3} [I_a + I_b + I_c] = \frac{1}{3} [0 + I_b - I_b]$

⇒ Positive sequence component, $I_{a_1} = \frac{1}{3} [I_a + \alpha I_b + \alpha^2 I_c]$

$$= \frac{1}{3} [0 + \alpha I_b - \alpha^2 I_b] = \frac{1}{3} I_b (\alpha - \alpha^2)$$

$$= \frac{1}{3} \times 30.3 \times (\sqrt{3}) = 17.5 \text{ A}$$

∴ Negative sequence component, $I_{a_2} = \frac{1}{3} [I_a + \alpha^2 I_b + \alpha I_c] = \frac{1}{3} [0 + \alpha^2 I_b - \alpha I_b]$

$$= \frac{1}{3} I_b (\alpha^2 - \alpha) = \frac{1}{3} \times 30.3 \times (-\sqrt{3}) = -17.5 \text{ A}$$

$$\text{Neutral Resistance } (R_n)_{pu} = 0.968$$

$$\text{Neutral Resistance } (R_u) \text{ in ohms} = 14.43 \Omega$$

148.

Sol. $\left. \begin{array}{l} \text{MVA rating of alternator} = 50 \text{ MVA} \\ \text{Voltage rating} = 11 \text{ kV} \end{array} \right\} \text{Base value}$

∴ Base impedance = $\frac{(kV)^2}{\text{MVA}}$

∴ $Z_B = \frac{11^2}{50} = 2.42 \Omega$

for 3-phase fault, fault current $I_f = 1870 \text{ A}$
 fault current in case of line to line fault

$$I_{f(L-L)} = 2590 \text{ A}$$

and $I_{f(L-L)} = 4130 \text{ A}$

Let X_1, X_2, X_0 be the positive, negative and zero sequence reactances for 3-phase fault,

∴ for 3-phase fault, $|I_f| = \frac{V_{ph}}{X_1}$

$$\Rightarrow 1870 = \frac{11 \times 10^3}{\sqrt{3} X_1}$$

$$\therefore X_1 = 3.396 \Omega$$

$$\therefore X_{1(p.u.)} = \frac{3.396}{2.42} = 1.403$$

for L-L fault, $|I_{f(L-L)}| = 2590 \text{ A}$

$$\Rightarrow \frac{\sqrt{3} V_{ph}}{X_1 + X_2} = 2590 \text{ A}$$

$$\Rightarrow X_1 + X_2 = \frac{11,000}{2590} = 4.247 \Omega$$

$$\therefore X_1 + X_2 = 4.247 \Omega$$

$$\Rightarrow X_2 = 4.247 - X_1 = 4.247 - 3.396 = 0.8511 \Omega$$

$$\therefore X_{2(p.u.)} = \frac{0.8511}{2.42} = 0.3516 \text{ p.u.}$$

For line to ground fault, $|I_{f(L-G)}| = \frac{3 V_{ph}}{X_1 + X_2 + X_0}$

$$\Rightarrow 4130 = \frac{3 \times \frac{11 \times 10^3}{\sqrt{3}}}{X_1 + X_2 + X_0}$$

$$\therefore X_1 + X_2 + X_0 = 4.6132$$

$$X_{0(p.u.)} = 4.6132 - 0.8511 - 3.396$$

$$X_0 = 0.366 \Omega$$

$$X_{0(p.u.)} = \frac{0.366}{2.42} = 0.151 \text{ p.u.}$$

149.

Sol. The transient stability refers to the maximum flow of power possible through a point without losing the stability with sudden and large changes in the network conditions which can occur due to faults, by sudden large increment of loads etc.

When synchronous machines are operated along with fast acting voltage regulator, the stability limits of the system are higher than when rather slow acting regulator are used. Dynamic stability also corresponds to slow changes in load as in the case of steady state stability but the main difference between the two is that dynamic stability is made possible by the action of fast acting voltage regulators which are capable of changing the flux at a faster rate than caused by the system in falling out of step, whereas in steady state stability the assumption is that, the regulator acts slowly in order to adjust the terminal voltage to the prescribed value.

Recent means for maintaining and improving transient stability is given below:

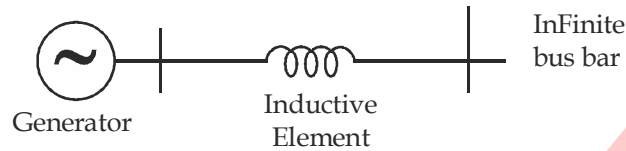
- (i) **HVDC links:** A DC link is asynchronous i.e. the two AC system at either end do not have to be controlled in phase or even be at exactly the same frequency as they do for an AC link and the power transmitted can be readily controlled. There is no risk of a fault on one system causing loss of stability in the other system.
- (ii) **Braking Resistors :** For improving stability where clearing is delayed or large load is suddenly lost, a resistive load called a braking resistor is connected at or near the generator bus. This load

compensates for at least some of the reduction of load on the generators and hence reduces the acceleration.

- (iii) **Turbine fast valving or Bypass valving:** The mechanical input power to turbine by the help of fast valving is one other way of improving stability. Here the difference between mechanical input and reduced electrical output of a generator under a fault, as sensed by a control scheme initiates the closing of a turbine valve to reduce the power input.

150.

Sol. Equal area criterion :



Consider the swing equation:

$$\frac{d^2\delta}{dt^2} = \frac{1}{m}(P_m - P_e) = \frac{P_a}{M}$$

where

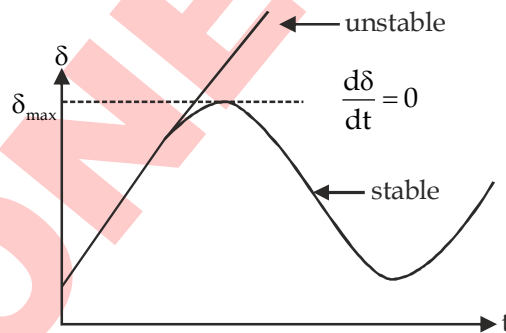
P_m = mechanical power

P_e = electrical power

P_a = accelerating power

$$M = \frac{H}{\pi f}$$

Now if δ continues to increase indefinitely with time, the machine will lose synchronism & system is said to be unstable. On the other hand, if $\frac{d\delta}{dt} = 0$. It implies that δ increases to a certain value then decreases or vice versa; in other words, the system is oscillating is said to be stable.



thus:

$$\frac{d\delta}{dt} = 0 \text{ space system is stable}$$

& $\frac{d\delta}{dt} > 0$ space for sufficiently long time ($> 1s$)

Now, solving equation (i) to calculate $\left(\frac{d\delta}{dt}\right)$.

$$\frac{d^2\delta}{dt^2} = \frac{P_a}{M}$$

$$2 \frac{d\delta}{dt} \cdot \frac{d^2\delta}{dt^2} = 2 \frac{d\delta}{dt} \cdot \frac{P_a}{M}$$

Multiplying both sides by $\frac{2d\delta}{dt}$

$$\frac{d}{dt} \left(\frac{d\delta}{dt} \right)^2 = \frac{2}{M} P_a \frac{d\delta}{dt}$$

Integrating,

$$\left(\frac{d\delta}{dt} \right)^2 = \frac{2}{M} \int_{\delta_0}^{\delta} P_a d\delta$$

$$\frac{d\delta}{dt} = \left(\frac{2}{M} \int_{\delta_0}^{\delta} P_a d\delta \right)^{1/2}$$

δ_0 - initial rotor angle before disturbance.

Now for stability,

$$\frac{d\delta}{dt} = 0$$

or

$$\left(\frac{2}{M} \int_{\delta_0}^{\delta} P_a d\delta \right)^{1/2} = 0$$

or

$$\int_{\delta_0}^{\delta} P_a d\delta = 0$$

This (equation (ii)) implies that the total area under P_a (accelerating power) - δ curve reduces to zero at some value of δ . (Or) the negative area should be equal to positive area.

negative area $\rightarrow$ decelerating area

positive area $\rightarrow$ accelerating area

Hence, the name equal area criterion.

Limitations of Equal Area Criterion

- (i) Its a graphical method/study, so its unable to provide the corresponding critical time for the critical clearing angle.
- (ii) The EAC is applicable only for two m/c system or for m/c connected to infinite bus.
- (iii) EAC provides the solution for the single machine only instead of two machine system.

151.

Sol.

$$Y_{bus} = j \begin{bmatrix} -3.78 & 1.25 & 2.50 & 0 \\ 1.25 & -3.42 & 1.11 & 1.00 \\ 2.50 & 1.11 & -4.89 & 1.25 \\ 0 & 1.00 & 1.25 & -2.31 \end{bmatrix}$$

We know that,

$$Y_{ik} = y_{ik} = -(\text{the admittance between } i \text{ and } k)$$

$$\therefore y_{ik} = -Y_{ik}$$

$$\therefore y_{12} = -j1.25 = y_{21} \Rightarrow Z_{12} = \frac{1}{y_{12}} = j0.8 = Z_{21}$$

$$y_{13} = -j2.50 = y_{31} \Rightarrow Z_{13} = \frac{1}{y_{13}} = j0.4 = Z_{31}$$

$$y_{14} = 0 \Rightarrow Z_{14} = \infty \text{ (no lines between 1 and 4)}$$

$$y_{23} = j1.11 \Rightarrow Z_{23} = Z_{32} = j0.9$$

$$y_{24} = -j1.00 \Rightarrow Z_{24} = j1.00$$

$$y_{34} = -j1.25 \Rightarrow Z_{34} = j0.8$$

And

$$y_{ii} = y_{i0} + y_{i1} + y_{i2} + \dots$$

= Total admittance connected at i^{th} bus

$$y_{11} = y_{10} + y_{12} + y_{13} + y_{14}$$

$\therefore$

$$y_{10} = y_{11} + y_{12} + y_{13} + y_{14}$$

$$= j3.78 + j1.25 + j2.5 + 0 \text{ (sum of first row)}$$

$$= j3.78 + j3.75 = j0.03$$

$$Z_{10} = \frac{1}{y_{10}} = j \frac{100}{3} = j33.33$$

152.

Sol. (a) Let, load shared by generator 1 = x
then, load shared by generator 2 = $300 - x$

$\therefore$ for generator 1,

$$\frac{\Delta f}{x} = \frac{50 - 48}{200}$$

$$\Delta f = \frac{2}{200}(x)$$

$$\Delta f = \frac{1}{100}x \quad \dots(1)$$

for generator,

$$\frac{\Delta f}{300 - x} = \frac{50 - 47}{200}$$

$$\Delta f = \frac{3}{200}(300 - x) \quad \dots(2)$$

from (1) and (2),

$$\frac{x}{100} = \frac{3}{200}(300 - x)$$

$$2x = 900 - 3x$$

$$5x = 900$$

$$x = \frac{900}{5} = 180 \text{ MW} = P_1$$

$\therefore$ $300 - x = 120 \text{ MW} = P_2$

(b) Let generator 1 works on max load then $P_1 = 200 \text{ MW}$ (at upf rating of generator = 200 MW)

153.

Sol. Given data

fuel costs $F_1 = 0.2P_1^2 + 40P_1 + 120 \text{ Rs / hr.} \quad \dots(i)$

$$F_2 = 0.25P_2^2 + 30P_2 + 150 \text{ Rs / hr.} \quad \dots(ii)$$

where $25 \text{ MW} \leq P_1 \leq 100 \text{ MW}$, $25 \text{ MW} \leq P_2 \leq 100 \text{ MW}$

the incremental fuel cost can be obtained by differentiating equation (i) and (ii)

$$\frac{\partial F_1}{\partial P_1} = 0.4 P_1 + 40 \text{ Rs / MWhr} \quad \dots(iii)$$

$$\frac{\partial F_2}{\partial P_2} = 0.5 P_2 + 30 \text{ Rs / MWhr} \quad \dots(iv)$$

For economic load dispatch incremental fuel costs should be equal.

$$0.4P_1 + 40 = 0.5P_2 + 30$$

$$0.4P_1 - 0.5P_2 = -10 \quad \dots(v)$$

given $P_1 + P_2 = 180 \quad \dots(vi)$

solving equating (v) and (vi) we get, $P_1 = 88.89$ MW

$$P_2 = 91.11 \text{ MW}$$

cost of generation

$$(F_{EC}) = F_1 + F_2$$

$$F_1 = 0.2(88.89)^2 + 40(88.89) + 120 = 5255.88 \text{ Rs/hr}$$

$$F_2 = 0.25(91.11)^2 + 30(91.11) + 150 = 4958.55 \text{ Rs/hr}$$

$$F = 5255.88 + 4958.55$$

$$F_T = 10214.43 \text{ Rs/hr}$$

When load is equally shared

That is $P_1 = 90$ MW, $P_2 = 90$ MW

cost of generation $(F_{EL}) = F_1 + F_2$

$$F_1 = 0.2(90)^2 + 40(90) + 120 = 5340 \text{ Rs/hr}$$

$$F_2 = 0.25(90)^2 + 30(90) + 150 = 4875 \text{ Rs/hr}$$

$$F_{EL} = 10215 \text{ Rs/hr}$$

Saving in fuel cost = (cost due to equal loading) - (cost due to economic load dispatch)

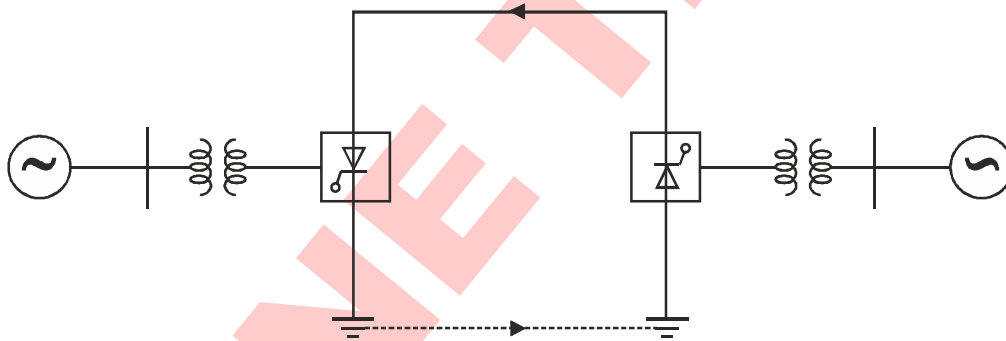
$$F_{EL} - F_{EC} = 10215 - 10214.43$$

$$= 0.57 \text{ Rs/hr}$$

154.

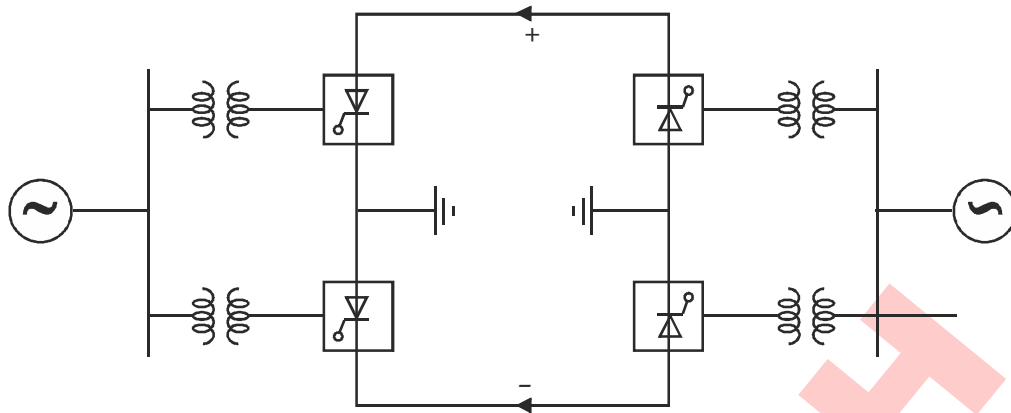
Sol. There are three types of HVDC links and they are listed below:

(i) **Monopolar HVDC link:**



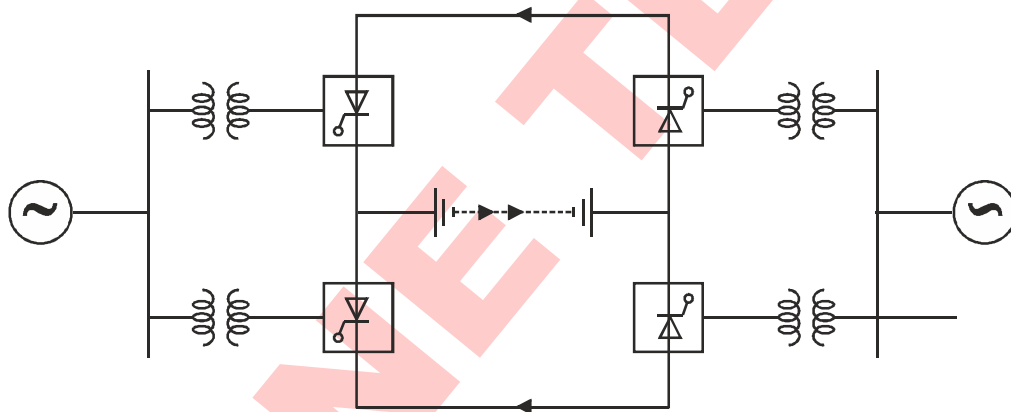
- In this type of HVDC system one conductor is only used with negative polarity with respect to earth.
- Negative polarity is used to reduce corona loss and radio interference.
- This type of links are used in HVDC submarine cables.
- Power rating is half of that of bipolar dc link.

(ii) **Bipolar DC link:**



- In this type of system one conductor has positive polarity and other conductor has negative polarity with respect to earth.
- The earth electrodes are located about 25 km away from terminals.
- During fault on any one of the line it works as monopolar link with reduced power flow.

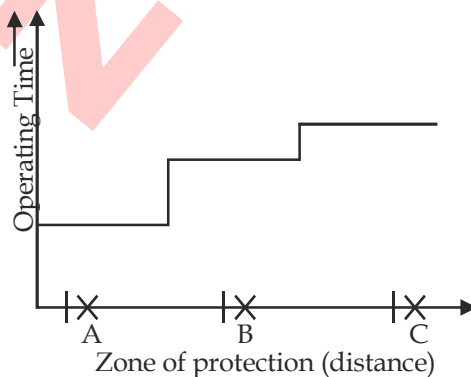
(iii) Homopolar DC link:



- In this type of system both the conductors are having same polarity with respect to earth.
- In this type of system earth is used as the return conductor.
- This type of system are used to combine cable and over head line.

155.

Sol.



The principle of operation of a distance protection scheme is as follows:

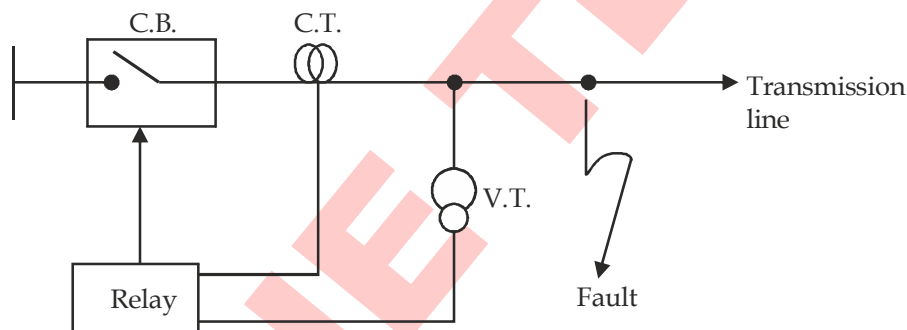
- The diagram shows the stepped time-distance characteristics of the relays.

- Impedance relays are used for the protection of transmission lines.
- The entire zone of protection is divided into three zones-
 (i) **Zone 1 :**
 - The first relay unit is adjusted to protect only upto 80% of the transmission line. It is a high speed unit and is used for primary protection.
 - It has the minimum time of operation equal to about 1 or 2 cycles of operation.
 (ii) **Zone 2 :**
 - The main purpose of the second unit is to protect the rest of the line which is beyond the reach of the first unit.
 - To operate even for the arcing faults, this relay is set to reach beyond the line.
 - It takes care of the under reach caused by arc resistance.
 - Its operating time is between 0.25 sec. to 0.5 sec. and reaches till 50% of the adjoining line.
 (iii) **Zone 3 :**
 - It is used to provided back-up protection.
 - It's reach extends beyond the end of the adjoining line.
 - It's reach is equal to the given line plus the adjoining line plus extra 25% of the third line.
 - It's operating time is between 0.4 sec. to 1 sec.

Hence, 3 units of relays are required for a complete protection scheme.

Connection of CT and VT

The current and voltage transformers are connected with the relay and the circuit breaker as shown below:



- The C.T. is connected in series with the transmission line to sense over-current.
- The V.T. is connected across the transmission line to detect over-voltage.
- The relay senses the output of C.T. and V.T. and operates the circuit breaker accordingly.