

Subject - GTD

Generation Of electricity

Hydro electric power plant: -

Hydro electric power? -

The power obtained from energy of falling water is known as hydro electric power.

Hydro electric power plant: -

The power plant which generates electrical energy by utilizing the potential energy of water at high level called hydro electric power plant i.e. the potential energy stored in water is converted to kinetic energy again that kinetic energy is converted to mechanical energy by allowing water through hydraulic turbine runner and finally mechanical energy is used to run generator or alternator, which coupled with turbine shaft.

Mathematically

$$\text{Electric power (P)} = WQH\eta \times 9.81 \times 10^{-3} \text{ KW}$$

W = Sp. weight of water in kg/m^3

Q = rate of flow of water m^3/sec

H = Height or head in meter

η = Efficiency of power plant

Hydrological cycle: -

The process by which moistures from the surface of water bodies covering the earth surface

transferred to the land and back to the water bodies again called hydrological cycle.

Hydrology :-

The study of hydrological cycle is called hydrology i.e. Hydrology deals with occurrence & distribution of water over & under the earth surface.

(a) Precipitation :-

It may be defined as the total condensation of the moisture that reach the earth surface in any form i.e. ice, hail, sleet dew & forestation etc.

(b) Evaporation :-

The process by which all the rainfall is return to the atmosphere from the land & water surfaces called evaporation.

Evaporation includes evaporation from land & water surface. Evaporation by transmission and atmospheric evaporation.

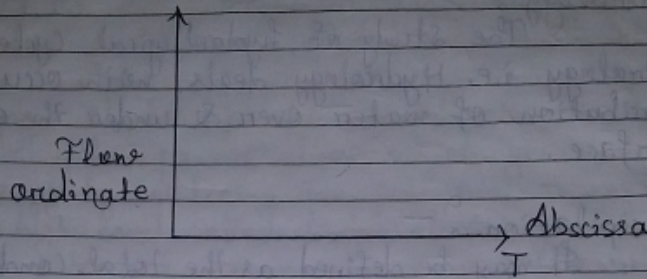
(c) Runoff :-

It may be defined as the part of precipitation which is available as stream flow i.e. $\text{Runoff} = \text{Total precipitation} - \text{Total evaporation}$

Hydro Graph :-

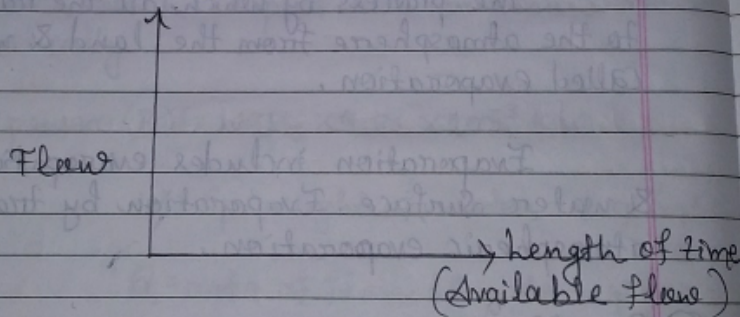
It is graphical representation of discharge or flow with the time. Here flow is in ordinates in

height number of $m^3/sec \times km^3$ or K. watt. & time as abscissa in hour, day, week, month or year.



Flow duration curve :-

It is the graph between flows and length during which they are available.



Mass curve :-

The curve which indicates the total volume of run-off in M^3 at a certain time.

Storage :-

Generally water flows excess during one seasons and less during another. So it is

provide water constantly.

Pondage :-

The water storage if present at far away from power plant then a small pond is required near the power plant to provide hourly changes in power demand.

Hydro electric power station :-

The power station which converts the kinetic energy of water in electrical energy are called hydro electric power station.

Elements of hydro electric power plant :-

(a) Storage reservoir :-

It stores water during excess flow periods (Rainy Seasons) & supplied the same during least flow of periods i.e. (dry seasons).

It can be either ~~natural~~ natural i.e. lake or artificial made by construction dam across the river.

(b) Dam :-

It is the most expensive and important part which is built up concrete or stone masonry earth or rock fill. It is not only raise the water surface by creating artificial head but provide pondage or storage.

③ Forebay :-

It serves as regulating reservoir storing water temporarily during light load period and providing same during increased load period i.e. it is either a pond behind the diversion dam or an enlarged section of canal spread out to accommodate required width of intake.

④ Spillway :-

These are constructed to discharge the over flow water to the downstream when the reservoir is full. Generally it acts as safety valve during flood situation.

⑤ Intake :-

Generally intake includes head works i.e. structure at the intake the conduits & tunnel or flumes which are responsible for diverting and preventing entry of debris and ice into the turbines. These structures include booms, screens, racks or sluices.

Surge tank :-

Surge tank regulates and maintains required pressure in the penstock. Because during light load pressure in the penstock becomes more even if which can burst the penstock but surge tank reduces the pressure by raising water level inside it. Similarly during the low pressure additional water flows provided by it. So surge tank stabilizes the velocity & pressure in the penstock.

Valve and Gates? —

Generally these are fitted at Entrance to the turbine during in section and repairing these are shut off.

Tail race? —

The water from turbine is discharged to the tail race generally tail race may be same stream or another one but design & size of tail race should be search that water are free exist.

Prime movers / water turbines? —

In hydro power plant water turbines are used as prime movers which convert kinetic energy of water into mechanical energy which is further utilized to drive the alternators generating electric energy.

Selection of site for hydro electric power plant?

These are some factors which are taken in to consideration for the selection of site for hydro electric power plant i.e.

① Availability of water? —

Hydro electric power plant should be built where there adequate water available at huge quantity of water is flowing across a given point.

Water storage? —

For continuous supply of water. The water storage in suitable reservoir at height or

building of dam across the river is essential. So convenient accommodation for the erection of a dam per reservoir must be available.

Water head :-

It has a considerable effect on the cost & economy of power generation i.e. an increasing effective head reduces the quantity of storage water & handle by pen stock screens & turbine resulting reduction in cost.

Distance from load centre :-

Generally these plant locate far away from load center so roots & distances affects on economical transmission.

Accessibility of size :-

It requires adequate transportation facilities for easy transportation required equipment & machine.

Availability of land :-

The land available must be cheap & rocky to with stand large building & machinery.

Merits :-

- ① No fuel is required by such plant because water is the source of energy.
- ② It is highly reliable & cheapest & operation & maintenance.

- ⑤ No. stand by loss & variable load demand can meet easily.
- ④ Good longer life & robust.
- ③ Efficiency does not fall with age & it has neat & clean environment due to absence of smoke & ash.
- ⑥ In addition to generation of provides irrigation flood control on navigation.

Demerits :-

- ① It covers large area.
- ② Constructional cost is very high along with it requires long transmission line as it far away from load centre.
- ③ Its O/P is uncertain.

Steam power plant or thermal power plant :-

The power plant which generates electrical energy from the combustion of coal called steam power plant.

Elements of thermal power plant :-

- ① Steam generating equipment :-
- ② Boiler :-

It is a major part of thermal power plant which convert water into steam. It is of two types fire tube boilers & water tube boilers in fire tube boilers the tubes containing hot gasses of combustion

Surrounded with water while in water tubes
water inside the tube while hot gases outside.

(b) Boiler furnace :-

Boiler furnace is a chamber in which fuel is burnt to liberate the heat energy it also provides support & enclosures for combustion equipment i.e. burner.

(c) Super heater & re-heater :-

A superheater is a device which removes the last traces of moisture from saturated steam leaving a boiler tubes & also increase its temp. above the saturation temp.

Re-heater :-

It re-super heat the partly expanded steam from the turbine resulting dryness of steam up to last stage of turbine.

(d) Economizer & Air pre-heater :-

These are such devices which recover the heat from the flue gases on their way to chimney & raise the temp. of feed water & air supplied for combustion.

(2) Condenser :-

Steam after expansion through prime mover goes through condenser which condenses the exhaust steam & also removes air & other unwanted gases from steam while

passing through them.

It is up two types.

(1) Jet or Contact Condenser
& Surface Condenser

(3) Evaporator :-

These are employed for feeding pure water to steam power plant by evaporating raw water.

(4) Feed water heater :-

These heat the feed water by means of bled steam before supply to the boiler which improves efficiency.

(5) Prime mover :-

It converts the stored energy in steam into rotational mechanical energy. It is either reciprocating or turbines. Now raises only steam turbine are use as prime movers.

Working principle of steam power plant :-

The working of thermal power plant can be summarized as follows.

Fuel & Ash Ckt :-

Generally heavy amount of fuel i.e. coal is stored in coal storage his again transfer to boiler furnace through coal handling plant, where gets pulverization. After combustion the resulting ash get transfer to ash storage to ash handling plant.

Air and flue gas Ckt? —

Here, atmospheric air is drawn by forced draught fan or induced draught fan through air preheater in which air is heated by heat of flue gases passing to chimney & finally air is passed to furnace. Similarly, flue gas after passing through boiler & super heater drawn by induced draught fan via dust collector (precipitator), Economizer & Air pre heater) finally exhausted to the atmosphere to the chimney.

Feedwater and Steam Ckt? —

Generally steam coming from boiler is wet and having high pressure, which again dried & further super heated by super heater & supply to steam turbine through main valve where it gives heat energy and passes through Condenser.

Now, the condensate steam is extracted from the condenser to the low pressure feed water by condensate extraction pump.

where it gets heated up at low pressure & pump to high pressure water heater through deaerator & finally to boiler through economizer where it gets again heat of flue gas passing it on the way to chimney.

Here the function deaerator reduces dissolved oxygen in the condensate steam.

Generally a small part of steam & water is passing through different components are losses. So water is added to feed water as make up water by make up water treatment.

Cooling water (kt) :-

The cooling water is supply from the natural source of supply i.e. river, lake canal etc through screens to remove the matter that might choke condenser tube. The circulation of cooling water maintain low pressure in condenser.

Selection of Site for thermal power plant :-

There are different factors which govern the site selection.

① Near to the load center :-

It locates near the load center resulting less transmissions cost & loss.

② Supply of water :-

Large quantity of water is required.

① To raise steam in boilers

② For cooling

③ For carrying disposal of Ash

④ For drinking

③ Availability of coal :-

It required huge amount of coal. So plants are

located near the coal mines to avoid the transport of coal & ash.

④ Land requirement :-

Land is required not only for setting of plant but also other purposes for staff colony, coal storage, ash disposal etc.

Transportation facilities :-

These facilities must be available for transportation of heavy equipment & fuels i.e. near railway station.

Merits :-

- ① The fuel (i.e. coal) used is quite cheap.
- ② Cheaper in initial cost in comparison to the other plant.
- ③ Less space is required in comparison to hydro power plant.
- ④ Such plant can be installed at any place where as hydro electric plants can only be developed at source of water.
- ⑤ A portion of steam raised can be used as process steam in various industries like paper mill, sugar mill, chemical etc.

Demerits :-

- ① High maintenance & operating cost.
- ② Pollution of atmosphere due to fumes & residues.

- ③ Consumption of huge amount of water.
- ④ Handling of coal & disposal of ash is quite difficult.
- ⑤ Troubles from smoke & heat from the plant.

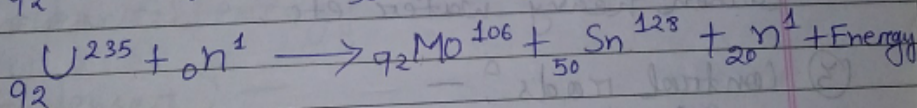
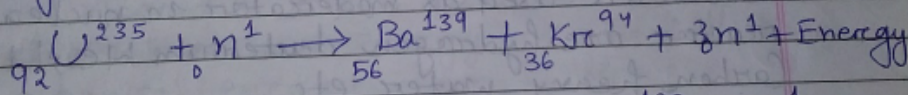
Nuclear power plant :-

The power plant which generates electricity by utilizing the vast energy released from nuclear fission reaction is known as nuclear power.

Nuclear fission :-

The nuclear reaction in which a heavy nucleus is split into small nucleus is split into small nuclei with liberation of vast energy by bombardment of neutron is known as nuclear fission reaction.

Eg - Chemical reaction.



Note :-

1 kg of natural uranium give energy equivalent to combustion of 10,500 Kg of coal i.e.
 $0.7/100 \times 3 \times 10^6 \times 0.5$ joule

Nuclear chain reaction :-

It may be defined as a fission reaction where the neutrons from a previous step continuity propagate &

repeat the reaction i.e.

Components of nuclear power plant:-

(a) Nuclear Reactor:-

It is the main part of nuclear power plant which is very similar to boilers of thermal power plant. It has following component.

(1) Reactor Core:-

It contains a number of fuel rods made of U^{235} , U^{234} , U^{233} etc. as Uranium gets oxidised rapidly so fuel rods clad with aluminium, stainless steel or Zirconium.

(2) Moderator:-

The moderators moderate or reduces the neutrons speed to a value that increase the probability of fission reaction. The elements which are used as moderator in nuclear reactor are hydrogen, deuterium, He, Li, Oxygen, Carbon, heavy water etc.

(3) Control rods:-

The control rods which are made of Boron, Cadmium or Hafnium are inserted in to nuclear reactor from the top of reactor vessels. The control rods control rate of the nuclear fission reaction by absorbing neutrons. It can be inserted or taken out as according to requirement i.e. if we need increased rate of reaction we have to taken out & vice versa.

(a) Coolant :-

It is the medium through which heat generated in the reactor is transferred to the heat exchanger & it also keeps the reactor at desired temp.

(a) The material like air, He, H₂ & CO₂ amongst the gases, light or heavy water amongst the liquids or molten sodium or lithium amongst the metal used as coolant.

(b) Heat exchanger :-

In heat exchanger the gas is heated or steam is generated by utilizing heat from nuclear reactor, here heat is connected by heat exchanger tube by circulation.

(c) Steam turbine :-

The steam produced in heat exchanger is transferred to steam turbines through steam valve where heat energy is converted into mechanical energy.

(d) Condenser :-

The exhausted steam from steam turbine is condensed by condenser & again feed to heat exchanger by feed water pump.

(e) Alternator :-

It is coupled to steam turbine & it generates electricity by converting mechanical energy to convert into electrical energy.

Selection of site for nuclear power plant
The factors to be considered while selecting a site for nuclear power plant for economical efficient generation.

Availability of water supply:—

① It requires more water i.e. ~~ten~~ times of thermal power plant of same rating, so it is located near the river, sea side or lake.

② Distance from populated area:—

Generally these are located far away from populated area due to danger of radioactivity.

③ Nearness to load center:—

These plants can be located near the load center because of absence of transportation.

④ Availability of space for disposal of water:—

There should have adequate space & arrangement for the disposal of radioactivity waste.

⑤ Types of land:—

The land should be strong enough to support the heavy reactor i.e. 10,000 tonnes weight with imposed bearing pressure around 50 tonnes/m².

Merits :-

- ① It requires very small fuel.
- ② It requires less area as compared to in other plant.
- ③ In addition to generating power it produces variable fissile material.
- ④ It can be located at load center resulting reduction in primary distribution cost.
- ⑤ It has most economical & flexible o/p.
- ⑥ The operating cost quite low after installation.

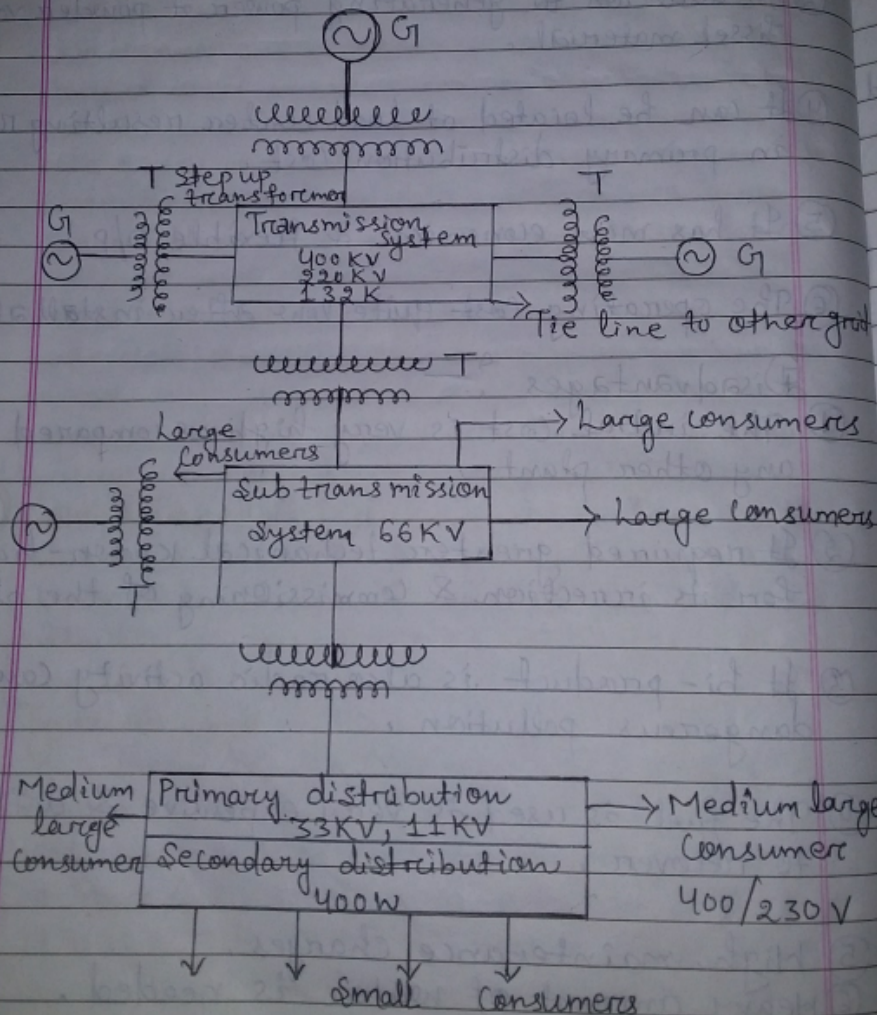
Disadvantages :-

- ① The initial cost is very high as compared to any other plant.
- ② It required greater technical know-how for its inspection & commissioning of the plant.
- ③ Its by-product is also radioactive activity causing dangerous pollution.
- ④ The fuel is used is very expensive & difficult to recover.
- ⑤ High maintenance charges.
- ⑥ Heavy amount of water is needed.

Transmission of Electric power

Draw layout of transmission and distribution scheme.

Generally generating stations are situated far away from load centre hence a power supply network connects the generating stations to load centre. As followed



Here power system generally composed of transmission system and distribution system, which again divided in to primary and secondary (or sub) generally voltage is generated in 33KV (in advanced countries) 11KV (in india) which if transmitted results heavy current and power loss.

which if transmitted results heavy current and power losses. So there are stepped up to a higher value i.e. 66KV 132KV 220KV/230KV and 400KV step up transformer present near generating station and transfer to primary transmission system. where it step down and transmitted to secondary transmission. Again voltage is step down to 33KV or 11KV and transmitted to primary distribution system from where medium large consumers connected and finally voltage step down to 400V at secondary distribution system and fed to small consumers.

Voltage regulation -

It is defined as the difference of supply end voltage and receiving end voltage to the receiving end voltage in other word.

The voltage drop i.e. difference of secondary end voltage and receiving end voltage expressed as a percentage of receiving end voltage called regulation.

Mathematically,

$$\% \text{ voltage regulation} = \frac{V_s - V_R}{V_R} \times 100$$

V_s = Supply end voltage

V_R = Receiving end voltage

Efficiency^Q —

It is defined as the ratio of power delivered at the receiving end to the power sent from the sending end.

$$\text{Mathematically } \eta = \frac{P_R}{P_S} \times 100$$

$$= \frac{P_R}{P_R + P_L} \times 100$$

where $P_R = V_R \cdot I_R \cos \phi_R$ = Receiving end power

$P_S = V_s \cdot I_s \cos \phi_s$ = Sending end power

Q. An overhead 3- ϕ transmission line delivers 5000 kW at 22 kV at 0.8 P.f lagging with resistance and reactance of 4- Ω and 6- Ω respectively. Calculate (1) percentage regulation (2) efficiency.

Solution^Q —

$$V_R = 22 \text{ kV}$$

$$V_{PH} = \frac{22}{\sqrt{3}} = 12700 \text{ V}$$

$$Z_{PM} = 4 + j6 \Omega$$

Here sending voltage / phase $V_s = V_{ph} + I_{ph} Z_{PM}$

$$\text{Here } I = \frac{5000 \times 10^3}{\sqrt{3} \times 22 \times 10^3 \times 0.8} = 164 \text{ A}$$

$$I = 164 - 36.86$$

$$\begin{aligned}
 \text{So } V_S &= 12700 + 164 - 3686 \times 7.2 \times 56.31 \\
 &= 12700 + 1180.8 - 19.45 \\
 &= 12700 + 1113.41 + j393.6 \\
 &= 13813.4 + j393.6 \\
 &= 13819.16
 \end{aligned}$$

$$\begin{aligned}
 \text{Voltage regulation} &= \frac{V_S - V_R}{V_R} \times 100 \\
 &= \frac{13819 - 12700}{12700} \times 100 \\
 &= 8.825\%
 \end{aligned}$$

$$\text{Efficiency} = \frac{PR}{PR + 3I^2R} = \frac{5000 \times 100}{5000 + (3 \times 164^2 \times 4)} = 93.94\%$$

PI = Line losses

Kelvin's law^a -

The law states that the most economical area of conductor is that for which the total annual cost of transmission is minimum.

Generally annual cost split into two part.

(a) Annual charge on Capital out lay i.e. $P_1 + P_2 a$

(b) Annual cost of energy wasted i.e. P_3/a
 where P_1 , P_2 and P_3 are constants and 'A' area of X-Section of the conductor.

So, total annual cost (C) = $P_1 + P_2 a + P_3/a$

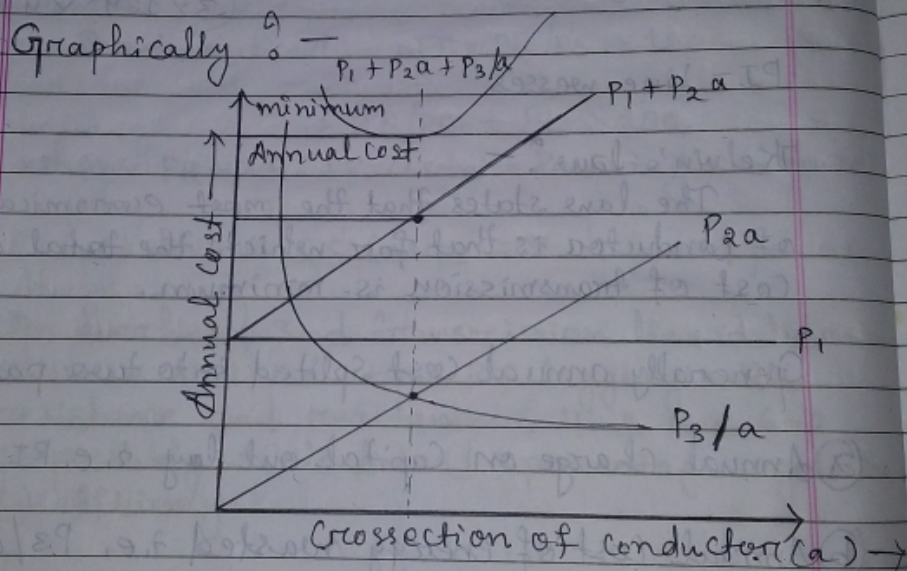
For minimum
 $DC/DA = 0$ i.e. $D/DA (P_2 a + P_3/A) = 0$

$$= P_2 - P_3/a^2 = 0$$

$$= P_2 \cdot a = P_3/a$$

i.e. variable part of annual charge = Annual cost of energy wasted.

In other word it can be started that the most economical area of conductor is that for which the variable part of annual charge is equal to the cost of energy losses per year.



Limitation ^a —

- (i) Difficult to estimate the energy loss in the line without load curve, which is not available at the time of estimation.

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(ii) Annual charge on capital outlay i.e. $P_1 + P_2 \propto$ not true Eq. - neither the cost of cable dielectric and heat in underground cables the cost of laying vary in this manner.

(iii) Current density, mechanical strength, corona loss are not considered.

(iv) By this low conductor size may be too small to carry the necessary current safely.

(v) Interest and depreciation not determined accurately.

Corona :-

The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona.

The phenomenon of corona is accompanied by a hissing sound and production of ozone gas due to corona also increases.

In case of polished and smooth, the corona glow will be uniform throughout the length of the conductor, otherwise the rough points will appear brighter.

In case of D.C. supply the +ve wire has uniformly glow, while the -ve conductor has spotty glow.

Formation of corona? -

Under normal condition, the air around the conductors contain some ionized particles like free electrons and free ions and neutral molecules. Due to ultra-violet ray and radioactivity applied, the potential is setup in the air. When the potential gradient at the conductor surface reaches about 30 kV per cm the velocity acquired by the free electrons is sufficient to strike a neutral molecule with enough force to dislodge one or more electrons from it. This produce another ion and one or more free electrons. These electrons again collides with the other neutral molecules and produces other ions. This process of ionization is cumulative. As a result corona is formed.

Factor affecting Corona? -

① Atmosphere? -

In stormy weather corona occurs more than in normal weather due to more ions than the normal weather.

② Conductor Size? -

The rough and irregular surface will produce more corona.

③ Spacing between conductors? -

If the spacing between the conductors is made very large as compare to their diameter there may not be any corona effect.

④ Line voltage: -

In low voltage no corona is formed.

Critical disruptive voltage: -

It is the minimum phase to neutral voltage at which corona occurs.

Visual critical voltage: -

It is the minimum phase neutral voltage at which corona glow appears all along the line conductors.

Power loss due to corona: -

Due to corona electric energy is lost, which is dissipated in the form of light, heat, sound and chemical action. Power loss due to corona is

$$P = 242.2 (F + 25/6) \sqrt{R/D} (V - V_c)^2 \times 10^{-5} \text{ kW/km/PH}$$

V_c = disruptive voltage / phase

② Advantages: -

- (i) Reduces electro static stress between the conductors.
- (ii) Reduces transient due to surges.

③ Disadvantages: -

- (i) It reduces transmission efficiency.
- (ii) Corrosion of conductor occurs due to ozone.
- (iii) Inductive interference due to non-sinusoidal voltage.

② Methods reducing Corona? —

- ① Large dia conductor
- ② Hollow conductors
- ③ Bundled conductors

①

②

③

④

⑤

Due to corona electric energy is lost which is dissipated in the form of light, heat, sound and chemical action. Power loss due to corona is given by the following formula:

$$P = 24.5 \times 10^{-5} \times \sqrt{f} \times L \times (V - V_0)^2 \times 10^{-2} \text{ kW}$$

VC = disruptive voltage (phase to phase)

③ Advantages —

① Reduces electric stress between the conductors.

② Reduces transmission loss.

③ It reduces transmission efficiency.

④ Corrosion of conductors occurs due to corona.

⑤ Inductive interference due to corona is reduced.

Advantages

Chapter-3 Line Supports

The line supports should have the following properties,

- ① High mechanical strength to withstand the weight of conductors and wind loads.
- ② Light in weight.
- ③ Long life
- ④ Cheap in cost
- ⑤ Easy accessibility of conductors maintenance

The line supports used for transmission and distribution of electric power are made in either wood, steel, R.C.C. or lattice steel.

Wooden pole? -

Wooden poles are made of woods. This type of poles are used for shorter spans up to 50 meters. These are mainly used in rural areas.

② Shackle insulators? -

For low voltage line less than 11 kV shackle insulators are used as strain insulators. This is also known as spool insulators. It is used in low voltage distribution lines. Such insulators can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or cross arm. The conductor in the groove is fixed with soft binding wire.

Creosote oil are impregnated in the ground level of the wooden pole for better foundation. These wooden poles has smaller life 20 to 25 years. Also it has less mechanical strength. It can't be used for voltage higher than 20 KV.

Steel poles :-

The steel poles are used generally for the distribution purpose in the city areas. It has high mechanical strength with longer life poles. The outer surface of the pole is painted for longer life.

These poles are three types.

- ① Rail poles
- ② Tabular Poles
- ③ Rolled steel joints

R.C.C. poles :-

These poles are very popular in recent days. They provide longer span than steel and wood poles. They have greater mechanical strength with longer life.

These type of pole require less maintenance. It has good insulating properties.

These poles are heavy weights. So the cost of transportation is high.

Steel Towers :-

For long distance transmission at higher voltage steel towers are used. These steel towers have longer life, great mechanical strength. It is suitable for severe climate condition these type of steel towers are used for longer spans. Tower footings are grounded by driving rods into the earth. This minimizes the lightning troubles as each tower acts as a lightning conductor it can also be used as double circuit tower which allows continuity of supply in case of one circuit break down.

Types of Insulator

Insulators :-

An electrical insulator is a material whose internal electric charges do not flow freely.

In overhead transmission or distribution lines insulators are used to insulate the current flowing in the conductor to earth through the poles or towers.

The most commonly used materials for insulator of overhead line is porcelain.

Types of insulator in overhead lines :-

There are mainly three types of insulator used overhead lines for high voltage.

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- ① Pin type insulator
 - ② Suspension type insulator
 - ③ Strain type insulator

There are two other type insulators are used for low voltage overhead lines. These are

- ① Stay type insulators
- ② Shackle type insulators

① Pin type insulators :-

This type of insulator is popularly used in power network up to 33kV system. The pin type insulator is secured to the cross arm on the pole. The live conductor attached to the top of the pin insulator the shortest distance between conductor and earth, surrounding the insulator body along which electrical discharge may take place through air is known as flash over distance.

When the insulator is wet, its outer surface becomes almost conducting. Hence the flash over distance of insulator is decreased. So the design of the electrical insulator (pin type) is umbrella type on the upper part, so that it can protect the rest lower part of the insulator from rain.

② Suspension type insulator : —

This type of insulator is used beyond the voltage 33KV. The pin type insulator is not economical for beyond the voltage 33KV. In this type of insulator number of insulators are connected in series to form a string and the line conductor is carried by the bottom most insulator. Each insulator of a suspension string is called disc insulator because of their disc shape. Each disc is designed for 11KV the number of disc in series would depend upon the working voltage. If any of the disc is damaged, then that disc can be replaced. There is no need to change the whole string. If the line voltage will increase, then that can be insulated by adding more disc in string. This type of insulators are mainly used with steel towers. As the conductors run below the earthed cross arm of the tower, therefore this arrangement provides partial protection from lightning. The spacing between the conductors is more when suspension type insulator is used in overhead lines.

③ Strain insulator : —

When there is a dead end of the line or there is a sharp curve the line is subjected to greater tension.

In order to relieve the line of excessive tension, strain insulators are used. Strain insulator consists of an assembly of suspension

insulators. It has considerable mechanical strength.

Low voltage application insulators? —

① Stay insulator? —

For low voltage range lines, the stays are to be insulated from ground at a height.

Stay insulator? —

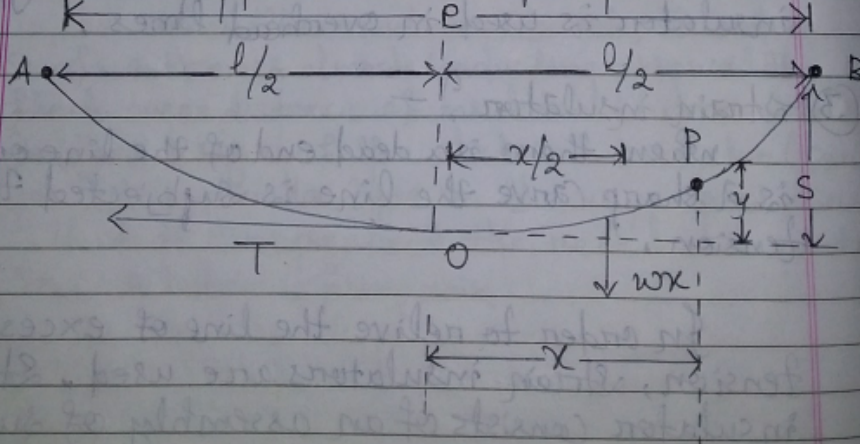
This insulator used in the stay wire is called as the stay insulator.

Calculation of sag? —

The sag should be so adjusted that tension in the conductor is within safe limits.

The tension is governed by conductor weight, effects of wind, ice loading and temperature variations.

① when supports are at equal parts? —



The above figure shows a conductor is placed between two equilevel supports A and B. The point O is the lowest point.

If L = length of span

w = weight per unit length of conductor

T = Tension in the conductor

Consider point 'P' on the conductor let the distance between point 'O' and P in horizontal projection is x .

There are two forces acting on the conductor portion 'OP'.

- ① The weight w_x of the conductor acting at a distance $x/2$ from 'O'.
- ② Tension T acting at 'O'.

If we equate the two forces on the conductor at point 'O'.

we get $T_y = w_x (x/2)$

$$y = wx^2/2T$$

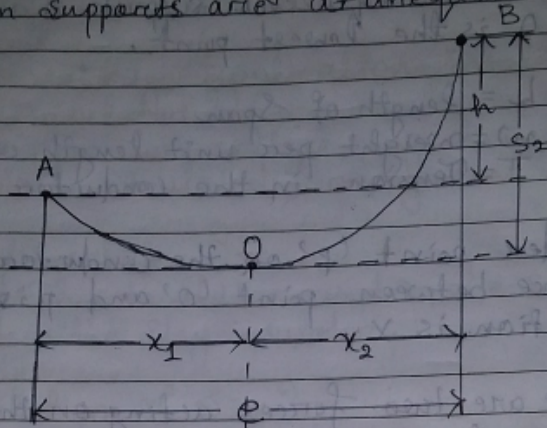
If the sag is represented by the value of ' y '.

At support 'A' $x = L/2$ and $y = s$

Then sag $S = w(L/2)^2/2T$

$$S = wL^2/8T$$

Calculation of sag¹ —
when supports are at unequal levels² —



Unequal level supports are normally found in hilly areas. The above figure shows a conductor suspended between two supports A and B at different levels. Consider the lowest point is 'O'.

Let L = span length

H = difference in levels between two supports.

x_1 = distance of support at lower level from

x_2 = distance of support at higher level from 'O'.

T = Tension in the conductor.

If " w " is the weight per unit length of the conductor, then

$$\text{Sag } S_1 = \frac{w x_1^2}{2T} \quad \left(\gamma = \frac{w x^2}{2T} \right)$$

$$\text{Sag } S_2 = \frac{w x_2^2}{2T}$$

From the figure $x_1 + x_2 = L$

By subtracting S_2 from S_1

$$S_2 - S_1 = W/2T (x_2^2 - x_1^2)$$

$$S_2 - S_1 = W/2T (x_2 + x_1) \times (x_2 - x_1)$$

We know $x_2 + x_1 = L$

$$\text{Then } S_2 - S_1 = WL/2T (x_2 - x_1)$$

From the figure $S_2 - S_1 = H$

Equation - 3 becomes

$$S_2 - S_1 = H = WL/2T (x_2 - x_1)$$

$$x_1 - x_2 = 2TH/WL$$

By solving eqⁿ - (3) & (5), we will get

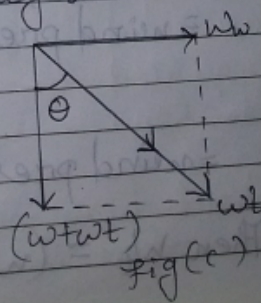
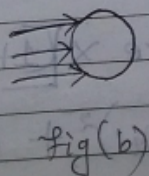
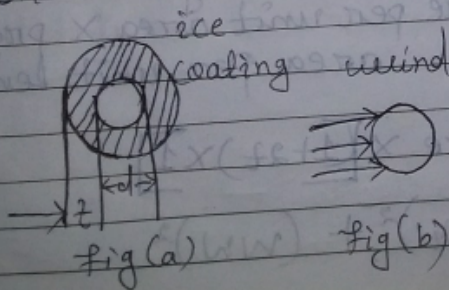
$$x_1 = L/2 - TH/WL \text{ and}$$

$$x_2 = L/2 + TH/WL$$

Putting the values of x_1 and x_2 in eqⁿ (1) & (2)

we can calculate sag S_1 and S_2 .

The effect of wind and ice loading? —
On the calculation of sag? —



In some cases the conductor may have ice coating and simultaneously subjected to wind pressure - At this time the weight of the ice acts vertically down ~~normal~~ as the same direction as the weight of conductor the force due to the wind is assumed to act horizontally as shown fig. 'b'.

The total force on the conductor due to wind and ice coating is the vector sum of horizontal and vertical forces as shown in fig 'c'.

If w = weight of the conductor per unit length
 $=$ Conductor material density $\times$ volume per unit length

w_i = weight of ice per unit length
 $=$ density of ice $\times$ volume of ice per unit length.

Density of ice $\times$ at $(d+t)$

w_w = wind force per unit length
 $=$ wind pressure per unit area $\times$ projected area per unit length

$=$ wind pressure $\times [(1+2t) \times 1]$

Then $w_t = (w + w_i)^2 + (w_w)^2$

If the conductor sets it self in a plane at an angle to the vertical then

$$\tan \theta = W_w / W + W_e$$

Then the sag of in the conductor is given

$$\text{By } S = W_e L^2 / 2T$$

$$\text{The vertical sag} = S \cos \theta$$

Chapter - 4

Performance of Short & Medium lines

Performance of Short & Medium lines :-
Generally transmission lines are classified according to their length at the power frequency $f = 50\text{ Hz}$ as follows.

Short transmission lines :-

Transmission lines of length up to 80 km are classified as short lines. Effect of Capacitance is ignored in these lines.

Medium transmission lines :-

Transmission lines of length between 80 km to 160 km are classified as medium transmission lines. Here effect of Capacitance is not ignored but Capacitance is assumed to be lumped in the middle or at the ends of transmission lines. Here effect of Capacitance is not ignored but Capacitance is assumed to be lumped in the middle or at the ends of transmission lines. Accordingly transmission lines are analysed using nominal- π & nominal T method.

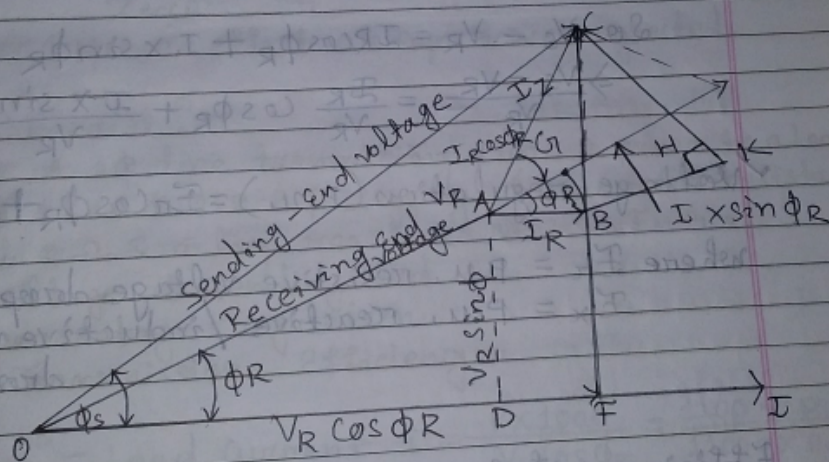
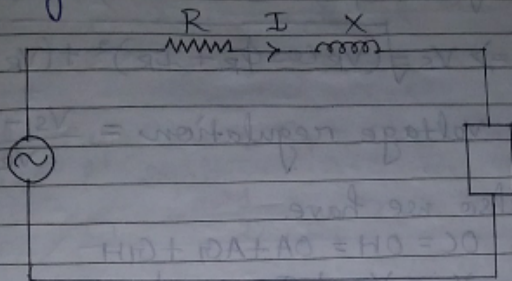
Long transmission lines :-

Parameters in this type line cannot be assumed lumped & rigorous calculations are required to analyse. Here length of line $> 160\text{ km}$.

Short transmission lines :-

Here shunt conductance & shunt capacitance

are neglected & series resistance & inductive reactance to be considered. It has following ckt diagram.



Here R = resistance of both the conductors (i.e. go & return)

X = Inductive reactance of both conductors (i.e. go & return)

V_R = receiving end voltage

V_S = Sending end voltage

$\cos(\phi)_R$ = receiving end power factor

$\cos(\phi)_S$ = Sending end power factor

From phasor diagram we have

$$OC = \sqrt{(OD+DE)^2 + (FB+BC)^2}$$

$$\Rightarrow V_s = \sqrt{(V_R \cos \phi_R + IR)^2 + (V_R \sin \phi_R + IX)^2}$$

$$\text{Now \% voltage regulation} = \frac{V_s - V_R}{V_R} \times 100$$

Here, also we have

$$OC = OH = OA + AG + GH$$

$$V_s = V_R + IR \cos \phi_R + IX \sin \phi_R$$

$$\text{So } V_s - V_R = IR \cos \phi_R + IX \sin \phi_R$$

$$\Rightarrow \frac{V_s - V_R}{V_R} = \frac{IR}{V_R} \cos \phi_R + \frac{IX \sin \phi_R}{V_R}$$

$$\checkmark \text{ Voltage regulation (P.u.)} = \frac{IR \cos \phi_R}{V_R} + \frac{IX \sin \phi_R}{V_R}$$

where $I_R =$ P.u. resistive voltage drop

$I_X =$ P.u. reactive / inductive voltage drop

Efficiency of transmission line (η_1) =

$$\frac{\text{Power delivered to load}}{\text{Power supplied from supply end}} \times 100$$

$$\% \eta_1 = \frac{V_R I \cos \phi_R}{V_R I \cos \phi_R - I^2 R}$$

Note:-

(i) For leading power factor.

$$\% \text{ voltage regulation} = \frac{I_R \cos \phi_R - I_X \sin \phi_R}{V_R} \times 100$$

(ii) Total capacitance $C_T = C \times l$ C_T is small because l is small.

$$X_{CT} = \frac{1}{2\pi f C_T} \quad X_{CT} \text{ is so large.}$$

Hence charging current $I_c = \frac{V}{X_{CT}}$ is nearly zero.

Hence effect of capacitance neglected.

✓ Numerical:-

A 1 ϕ line transmitting 1100 kW power to a load at 11 kV & 0.8 P.F lagging. It has total resistance of 2 Ω & a loop reactance of 3 Ω . Evaluate.

(i) voltage at sending end.

(ii) percentage regulation

(iii) Transmission efficiency.

Solution:- Load current $I = \frac{P \times 1000}{V_R \cos \phi_R} = \frac{1100 \times 1000}{11000 \times 0.8} = 125 \text{ A}$

(i) voltage at sending end $V_s = \sqrt{(V_R \cos \phi_R + I_R)^2 + (V_R \sin \phi_R + I_X)^2}$

$$= \sqrt{(11000 \times 0.8 + 125 \times 2)^2 + (11000 \times 0.6 + 125 \times 3)^2}$$

$$= \sqrt{(9050)^2 + (6975)^2} = 11426 \text{ V}$$

$$\checkmark \text{ (ii) percentage regulation} = \frac{V_s - V_R}{V_R} \times 100$$

$$= \frac{11426 - 11,000}{11,000} \times 100 = 3.873\%$$

$$\text{Line losses} = I^2 R = (125)^2 \times R = 31250 \text{ W} \\ 31.25 \text{ kW}$$

$$\checkmark \text{ (iii) Transmission Efficiency } (\eta) =$$

$$\frac{\text{Power delivered}}{\text{Power delivered} + \text{line losses}} \times 100$$

$$= \frac{1100 \times 100}{11,00 + 31.25} = 47.24\%$$

Numerical :-

An overhead 3ϕ transmission line delivers 5MW at 22 kV at 0.8 lagging P.f. The resistance & reactance of each conductor is 4Ω & 6Ω respectively. Evaluate:-

- (i) Sending end voltage
- (ii) percentage regulation
- (iii) Total line losses
- (iv) Transmission efficiency

$$\text{Solution :- phase voltage at receiving end} = \frac{22 \times 1000}{\sqrt{3}} \\ = 12,702 \text{ V}$$

$$\text{Load delivered } P = 5 \text{ MW} = 5 \times 10^6 \text{ W}$$

$$\text{Load P.F } \cos \phi_R = 0.8 \text{ lagging}$$

Line Current $I = \frac{\text{Load delivered in watts}}{3 \times V_R \cos \phi}$

$$= \frac{5 \times 10^6}{3 \times 12.702 \times 0.8} = 164 \text{ A}$$

Sending End voltage per phase $V_s = V_R + I R \cos \phi + I X \sin \phi$

$$= 12.702 + (164 \times 4 \times 0.8) + (164 \times 6 \times 0.6)$$

$$= 13.8172 \text{ V}$$

(i) Line Sending - End voltage $V_{SL} = \sqrt{3} V_s =$

$$= \sqrt{3} \times 13.817.2$$

$$= 23.932 \text{ V or } 23.932 \text{ kV}$$

(ii) percentage regulation $= \frac{V_{SL} - V_{RL}}{V_{RL}} \times 100$

$$= \frac{23.932 - 22}{22} \times 100 = 8.782\%$$

(iii) Total line losses $= \frac{3 I^2 R}{1000} = \frac{3 \times (164)^2 \times 4}{1000} \text{ kW}$

$$= 322.752 \text{ kW}$$

(iv) Transmission Efficiency (η_1) =

$$\frac{\text{Output power}}{\text{Output power} + \text{line losses}} \times 100$$

$$= \frac{5000}{5000 + 322.762} \times 100 = 93.936\%$$

ABCD parameter :-

$$\text{Here } V_s = V_R + I_z$$

$$I_s = I_R \text{ so, comparing with}$$

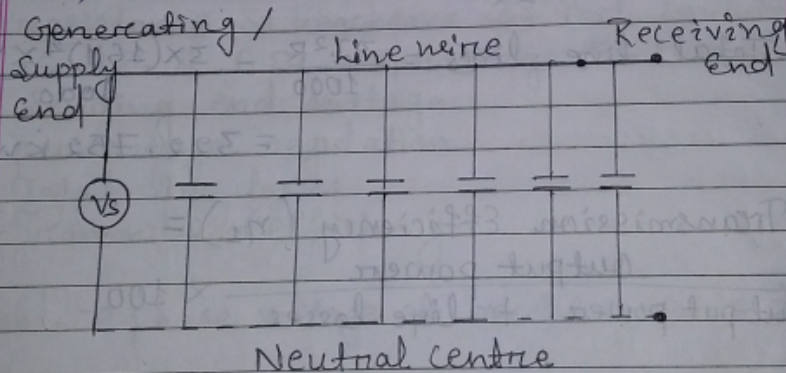
$$V_s = A V_R + B I_R$$

$$I_s = C V_s + D I_R$$

we have, $A=1, B=Z$ i.e. $\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$
 $C=0, D=1$

① Medium transmission lines :-

These are transmission lines of length 80 km to 160 km & operate on voltage below 20 kV. Effect of capacitance are taken into consideration. The capacitance of the line is uniformly distributed over its entire length as follows.



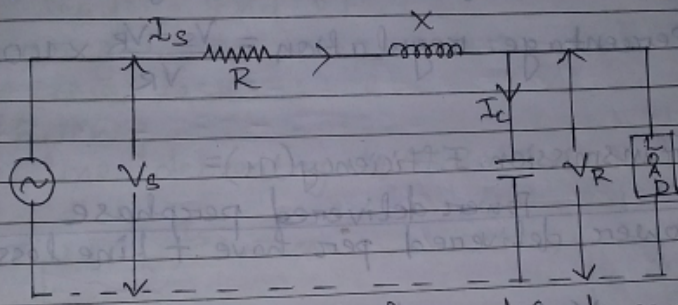
But for simple calculation, the capacitance of the system is assumed to be divided up & lumped in the form of capacitors shunted across the line at one or more points. The most common methods of

representation localised Capacitance method
i.e.

- (i) End Condenser method.
- (ii) Nominal T method (middle condenser method)
- (iii) Nominal π method (split condenser method)

② End condenser method? —

Here capacitance of the line is assumed to be lumped at the load end i.e as follows.



(Equivalent ckt for end Condenser method)

Let

R = resistance of line per phase

X = reactance of the line per phase

C = Capacitance per phase of line in Farad.

Receiving End / Load. End current = I_R
Receiving End voltage V_R (phase)

$\cos(\phi_R)$ = receiving end P.F. lagging Now.
we have

$$V_R = V_R(1 + j0)$$

$$I_R = I_R(\cos\phi_R - j\sin\phi_R)$$

Capacitive current $I_c = I_{VR} \omega C = I 2\pi f C V_R$

Sending end current $-(I_s) = I_R + I_c$

$I_R (\cos \phi_R - j \sin \phi_R) + j 2\pi f C V_R$

Voltage drop per phase $= I_s Z = I_s (R + jX)$

Phase voltage at the sending end $V_s = V_R + I_s Z$

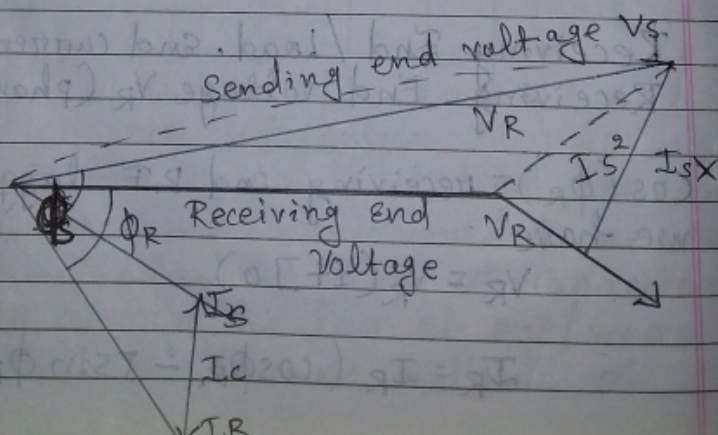
Percentage regulation $= \frac{V_s - V_R}{V_R} \times 100$

Transmission Efficiency (η_1) =

$\frac{\text{Power delivered per phase}}{\text{Power delivered per phase} + \text{Line losses/phase}}$

$= \frac{V_R I_R \cos \phi_R}{V_R I_R \cos \phi_R + I_s^2 R} \times 100$

Now, we can draw phasor diagram for End Condenser method as follows.



(i) the Sending - End current
 and receiving - End voltage

(ii) The Sending - End voltage

(iii) The Sending End P.F.

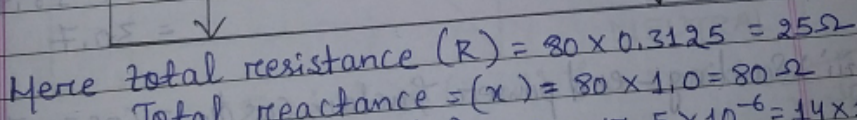
(iv) the regulation

(v) the line losses

(vi) Efficiency

the line delivering 15 Mw at 0.8 p.f. lagging

Solution,



Total reactance $= (X) = 80 \times 1.0 = 80 \Omega$

Total reactance $= (x) = 80 \times 1.0 = 80 \Omega$
Total susceptance $= (y) = 80 \times 17.5 \times 10^{-6} = 14 \times 10^{-4} S$
Voltage $V_B = 66 KV = 66,000 V$

Receiving end voltage $V_R = 66 \text{ kV} = 66,000 \text{ V}$

Load current $I_R = \frac{15 \times 10^6}{66,000 \times 0.8} = 284 \text{ A}$

power factor at receiving end $\cos \phi_R = 0.8$
 $\sin \phi_R = 0.6$

Taking receiving end voltage V_R as reference phaser

$$\text{we have, } V_R = 66,000 (1 + j0)$$

$$\text{Load current } (I_R) = 28 + (0.8 - 0.6j) \\ = 2272 - j170.44$$

$$\text{charging current } I_C = jYV_R = j \times 0.0014 \times 66,000 \\ = j92.4A$$

$$(i) \text{ Sending - end current } (I_S) = I_R + I_C \\ = (2272 - j170.4) + j92.4 \\ = 227.2 - j78 = 240.2 \angle -18.94A$$

(ii) Sending end voltage

$$V_S = V_R + I_S (R + jX) \\ = 66,000 + (227.2 - j78)(25 + j80) \\ = 77,920 + j16,226 \\ = 79,592 \angle 11.76V$$

$$\text{Sending end power factor angle } \phi_s = 11.76 - (-18.94) \\ = 30.7$$

$$(iii) \text{ Sending - end power factor } \cos \phi_s = \cos 30.7 \\ = 0.86 (\text{lag})$$

$$(iv) \text{ Regulation} = \frac{V_S - V_R}{V_R} = \frac{79,592 - 66,000}{66,000} \\ = 0.206 / 20.6\%$$

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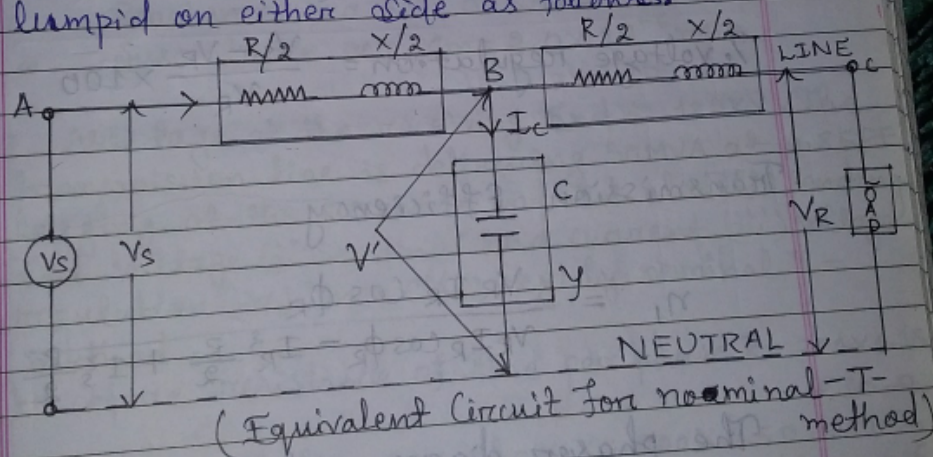
$$(v) \text{ line losses} = \frac{I^2 R}{1000} = \frac{(2+0.2)^2 \times 25}{1000} = 1442.4 \text{ W}$$

$$(vi) \text{ Transmission Efficiency } (\eta) = \frac{\text{Power o/p}}{\text{Power o/p} + \text{line losses}} \times 100$$

$$= \frac{15,000}{15,000 + 1442.4} \times 100 = 91.23\%$$

(ii) Nominal T method :-

In this method the whole of the line capacitance is assumed to be connected at the middle point of the line & half of the line resistance & reactance (i.e. $\frac{R}{2}$ & $\frac{X}{2}$) to be lumped on either side as follows.



Here I_R = Receiving end current
 I_c = Charging or Capacitance current
 V_R = Receiving end voltage
 V_s = Sending end voltage

Now we have

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$$I_s = I_R + I_c$$

where $I_R = I_R (\cos \phi_R - j \sin \phi_R)$

$$I_c = I_w c v' = j 2\pi F c v'$$

v' = voltage across capacitor

$$v' = V_R + I_R \cdot \frac{Z}{2}$$

So, $I_s = I_R + j 2\pi F c v'$

$$V_s = v' + I_s \times \frac{Z}{2} = v' + I_s \frac{R + jX}{2}$$

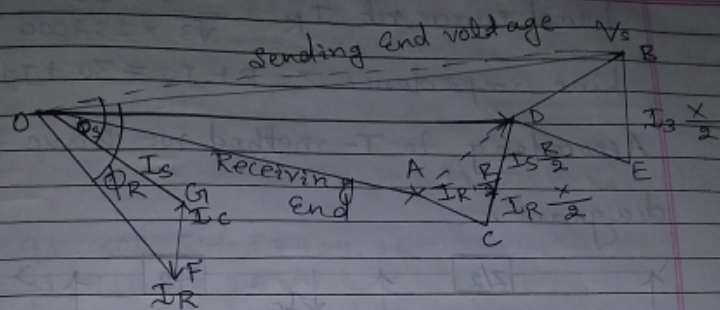
$$\Rightarrow V_s = v' + I_s \left(\frac{R + jX}{2} \right)$$

$$\% \text{ voltage regulation} = \frac{V_s - V_R}{V_R} \times 100$$

Transmission Efficiency

$$\eta_1 = \frac{V_R I_R \cos \phi_R}{V_R I_R \cos \phi_R - I_R^2 \frac{R}{2} + I_s^2 \frac{R}{2}}$$

The phasor diagram of Nominal-T method can be drawn as follows by taking V_R as reference.



Numerical problem :-

A transmission line 280km long has the following constants,

Resistance per km = 0.15Ω

Reactance per km = 0.50Ω

Susceptance per km = $2.0 \times 10^{-6} \text{ mho}$

Voltage at the receiving End is 132KV. The transmission line is delivering 50MVA at 0.85PF lagging at the receiving end. Calculate (i) Sending End voltage (ii) Sending End current (iii) voltage regulation (iv) line efficiency by nominal T-method.

Solⁿ :- Here resistance of line per phase $R = 280 \times 0.15 = 30 \Omega$

Reactance of line per phase $X = 280 \times 0.50 = 100 \Omega$

Capacitive Susceptance per phase $Y = 280 \times 2.0 \times 10^{-6} = 4 \times 10^{-4} \text{ S}$

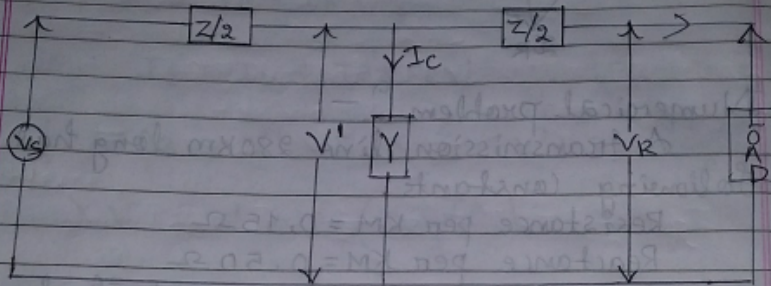
Receiving end line voltage = 132KV

Receiving end phase voltage = $\frac{132 \text{KV}}{\sqrt{3}} = 76210 \text{V}$

Load current $I_R = \frac{50 \times 10^6}{\sqrt{3} \times 132000} = 218.7 \text{ A}$

Line impedance $Z = R + jX = 30 + j100 \Omega$

According to T-method we have following diagram.



Here $V_R = 76210 + j0$

$\cos \phi = 0.85 \sin \phi = \sqrt{1 - 0.85^2} = 0.5268$

So, $I_R = 218.7 (0.85 - j0.5268) = (185.9 - j115.2) \text{ A}$

Phase voltage across condenser $V' = V_R + \frac{Z}{2} \times I_R$

$V' = (76210 + j0) + (185.9 - j115.2) \times \left(\frac{30 + j100}{2} \right)$
 $= 84,758.5 + j7,567 \text{ V}$

Charging Current $I_c = V' \times Y = (84,758.5 + j7,567) \times j4 \times 10^{-4}$
 $= -3.0268 + j33.9 \text{ A}$

Sending End Current $I_s = I_c + I_R$

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$$I_s = (185.9 - j115.2) + (-3.0268 + j33.9) \\ = 182.8732 - j81.3 = 200.13 \angle -23.97^\circ$$

(ii) Sending end voltage $V' + I_s \times \frac{Z}{2} =$

$$= (84,758.5 + j7,567) + \frac{1}{2} (182.87 - j81.3j) (30 + j40) \\ = 91,566.6 + j7924.16 \\ = 91,910 \angle 4.95^\circ$$

(iii) Sending end line voltage $= \sqrt{3} \times 91,910 \\ = 1,59191 \text{ V} = 159.2 \text{ KV}$

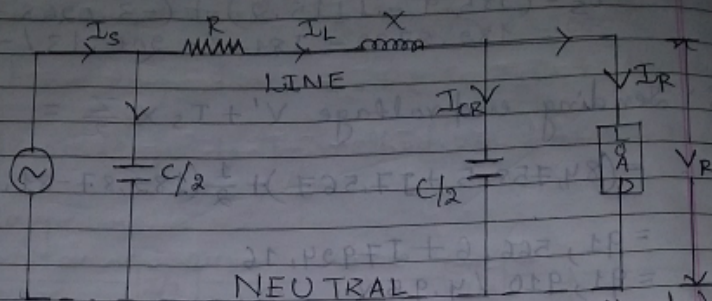
(iv) Voltage regulation $= \frac{V_{SL} - V_{RL}}{V_{RL}} \times 100 \\ = \frac{159.2 - 132}{132} \times 100 = 20.6 \%$

(v) Line Efficiency $\eta = \frac{\sqrt{3} V_{RL} \times I_{RL} \cos \phi_R \times 100}{\sqrt{3} V_{RL} I_{SL} \cos \phi_S}$

$$\eta = \frac{\sqrt{3} \times 132 \times 218.7 \times 0.85}{\sqrt{3} \times 159.2 \times 200.13 \cos [4.95 - (-23.97)]} \\ = 87.99\%$$

Nominal π method

In this method capacitance is divided & placed at beginning & ending of the line & resistance & inductive reactance is lumped in middle of the line as follows.



(Equivalent circuit of π method)
taking V_s as reference we have

Here,

$$I_{CR} = j\omega \frac{C}{2} V_R = j2\pi f \frac{C}{2} V_R$$

$$I_{CR} = I_R + I_{CR}, \quad I_R = I_{CR} \angle -\phi_R$$

where I_{CR} = Current through receiving end

ϕ_R = Angle between V_R & I_{CR}

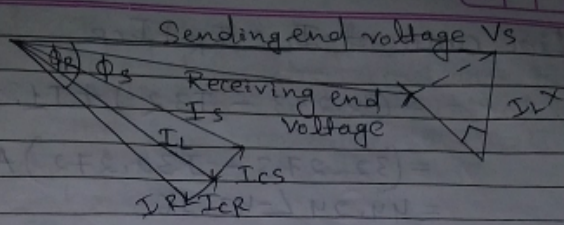
$$I_L = \text{Line Current}, \quad I_{CS} = j\omega \frac{C}{2} V_s$$

I_{CS} = Charging Current at the Sending end

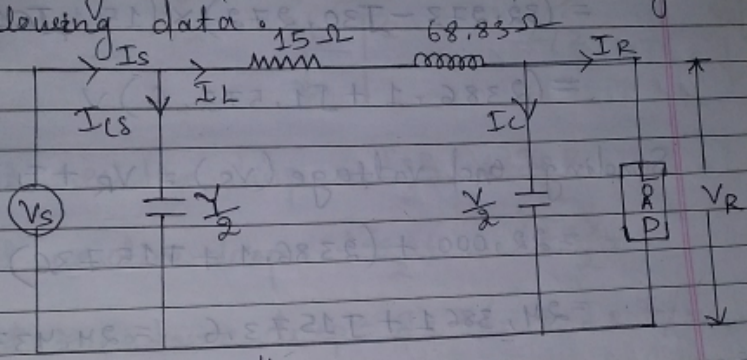
$$V_s = V_R + I_L Z = V_R + I_L (R + jX)$$

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

Now phasor diagram can be Sending end voltage.



Q. Find out the voltage regulation & efficiency following a network of 1 ϕ having following data.



$$Y = 1.5708 \times 10^{-4} S$$

$$V_R = 22 \text{ KV}$$

$$\cos \phi_R = 0.71 \text{ lagging}$$

$$S_R = 10^3 \text{ KVA}$$

Solution:- Here $V_R = 22000 + j0$

$$I_R = \frac{S_R}{V_R} = \frac{10^3}{22} = 45.55 \text{ A}$$

$$\Rightarrow I_R = 45.55 (0.71 - j0.7042) \\ = (32.273 - j32) \text{ A}$$

$$I_{CR} = \frac{1}{2} Y_{VR} = \frac{1}{2} \times (22000 \times j1.5708 \times 10^{-4}) \\ = j1.728$$

Line current $I_L = I_R + I_{CR}$

$$= (32.273 - j32) + j1.728$$

$$= (32.273 - j30.272) \text{ A}$$

$$= 44.24 \angle -43.16^\circ$$

Impedance drop in line $= I_L Z$

$$= (32.273 - j30.272) \times (15 + j62.83)$$

$$= (2386.1 + j1573.6) \text{ V}$$

Sending end voltage (V_s) $= V_R + I_L Z$

$$= 22,000 + (2386.1 + j1573.6)$$

$$= 24,386.1 + j1573.6 = 24,437 \angle 3.69^\circ$$

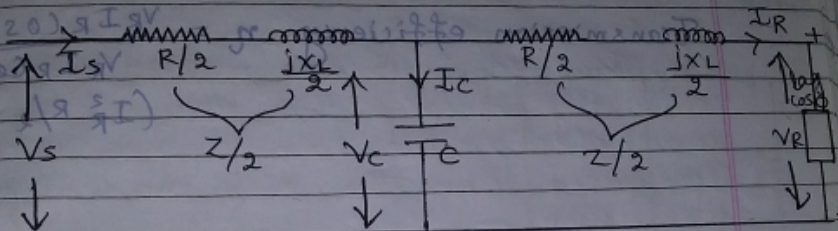
% Voltage regulation $= \frac{V_s - V_R}{V_R} \times 100$

$$= \frac{24,437 - 22,000}{22,000} \times 100 = 11\%$$

$$\eta = \frac{10^3 \times 1000 \times 0.71}{10^3 \times 100 \times 0.71 + (44.24)^2 \times 15} = 96.02\%$$

Nominal T method

The whole of the line capacitance is assumed to be connected at the middle point of the line & half of the line resistance & reactance ($R/2, X/2$) to be lumped on either side.



$$\text{Total resistive drop} = \frac{I_S R}{2} + \frac{I_R R}{2}$$

$$\text{Total reactive drop} = \frac{j I_S X_L}{2} + \frac{j I_R X_L}{2}$$

$$\text{Total impedance drop} = I_S Z/2 + I_R Z/2$$

$$I_S = I_C + I_R$$

$$V_C (\text{Capacitor voltage}) = V_S + \frac{I_S R}{2} + \frac{j I_S X_L}{2}$$

$$\text{Receiving end voltage } (V_R) = V_C + \frac{I_R R}{2} + \frac{j I_R X_L}{2}$$

$$I_S = I_R + I_C$$

KVL in input loop

$$-V_S + I_S R/2 + \frac{j I_S X_L}{2} + V_C = 0$$

$$V_S = V_C + \frac{I_S R}{2} + \frac{j I_S X_L}{2}$$

KVL in output loop

$$-V_c + \frac{I_R R}{2} + \frac{j I_R X_L}{2} + V_R = 0$$

$$V_c = \frac{I_R R}{2} + \frac{j I_R X_L}{2} + V_R$$

Transmission efficiency $\eta = \frac{V_R I_R \cos \phi_R}{V_R I_R \cos \phi_R - (I_R^2 R/2 + I_S^2 R/2)}$

Total resistive drop $= \frac{I_1 R}{2} + \frac{I_2 R}{2}$

Total reactive drop $= \frac{j I_1 X_L}{2} + \frac{j I_2 X_L}{2}$

Total impedance drop $= \frac{I_1}{2} \sqrt{R^2 + X_L^2} + \frac{I_2}{2} \sqrt{R^2 + X_L^2}$
 $I_2 = I_1 + I_R$

V_c (applied voltage) $= V_2 + \frac{I_2 R}{2} + \frac{j I_2 X_L}{2}$

Receiving end voltage (V_R) $= V_c + \frac{I_R R}{2} + \frac{j I_R X_L}{2}$

$I_2 = I_R + I_1$

KVL in input loop

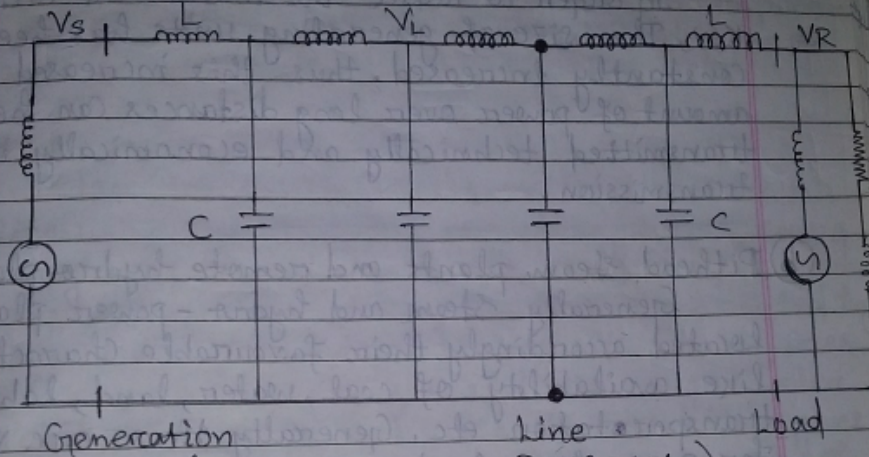
$$0 = -V_2 + \frac{I_2 R}{2} + \frac{j I_2 X_L}{2} + V_c$$

$$V_c = V_2 + \frac{I_2 R}{2} + \frac{j I_2 X_L}{2}$$

EHV TRANSMISSION

Explain EHV AC TRANSMISSION

Generally the voltages of 300 KV ^{to 765 KV} are considered as extra high voltage (EHV) transmission line. Generally EHV AC lines are selected for long distances 250 km and above and high power 500 MW and above. Electrical 3- ϕ EHV-AC line as follows.



(EHV-AC LINE DIAGRAM)

In EHV-AC line series inductance (L) and shunt capacitance C influence the performance of line (voltage regulation power flow, stability etc). Significantly and they can't be neglected. Here the surge impedance of the line is as follows

$$Z_s = \sqrt{L/C} \Omega$$

Eg:-

400 KV - EHV-AC line has been installed in India in 1974 but recently 765 EHV AC line installed i.e. in 1992.

Explain reasons for adoption of EHV AC Transmission. —

There are different reasons for adoption of EHV-AC transmission line as follows. —

(a) Increase in size of generating units? —

In order to reduce the investment cost per kW, the size of generating units has been constantly increased, thus this increased large amount of power over long distances can be transmitted technically and economically in EHV transmission.

(b) Pithead steam plants and remote hydro plants? —

Generally steam and hydro-power plants are located accordingly their favourable characteristics like availability of coal, water, land, labour, transportation etc. Generally these are very far away from load centre. Hence transmission of large amount of power over long distances can only be technically and economically possible by EHV-Transmission.

(c) Surge Impedance loading? —

Surge impedance loading is the power that line carries when each phase terminated by a load equal to surge impedance of the line i.e. $Z_c = \sqrt{L/C}$

where L = Series inductance per unit length

C = Shunt capacitance per unit length

Hence,

$$SIL = 3V^2/Z_c$$

Therefore voltage at higher value makes large power transmission at economic.

(d) Transmission :-

The number of circuits and the land requirement for transmission decreases with adoption of EHV AC transmission.

E.g. :-

For transmitting 600 MW over 250 km at 480 line using two conductor per phase and requiring a right of way of about 40 m giving $600/40 = 15$ mw per meter right of way but if it is transmitted by two double circuit lines at 200 kV then it requires a right of 60 m giving $600/60 = 10$ mw per meter right of way. So double circuit 400 kV line gives this ratio as about 30 mw per meter right of way. Hence EHV line reduces right of way requirement quite substantially.

(e) Line cost :-

The line installation cost per MW per km decreases with increase in voltage level. Moreover the impact of the cost of losses on the overall transmission costs can be substantially different at different voltage levels. The total line cost including the cost of losses per mw per km decreases considerably by use of EHV AC transmission.

Problems involved in EHV transmission :-
There are different major problems associated with EHV transmission line as follows :-

(a) Corona loss and radio Interference :-

Generally corona appears in high voltage transmission line which not only a source of power loss but it is also a source of interference with radio and television.

(b) Heavy Supporting structure and erection difficulties :-

Generally EHV-AC transmission uses bundle conductor, which results large mechanical loading on towers. Similarly large air and ground clearances, dynamic forces due to broken conductors etc makes large mechanical load. Hence strength of tower should be heavy.

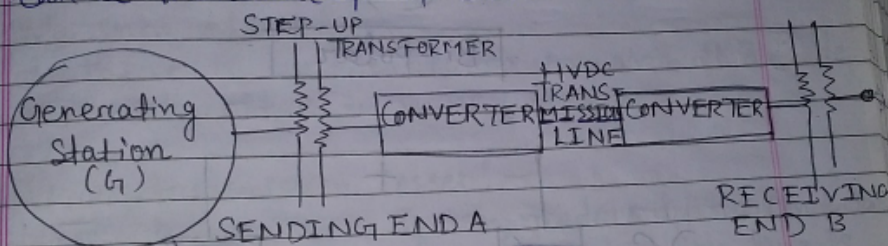
(c) Insulation requirement :-

Generally EHV-AC transmission requires high insulation to withstand the voltage surges due to internal sources, i.e. switching operation or due to external sources, i.e. lightning etc, which produces very high voltage generally 2-3 times of normal voltage. Hence insulation level depends upon switching over-voltages, temporary over-voltages and atmospheric over-voltages.

transient - sudden change

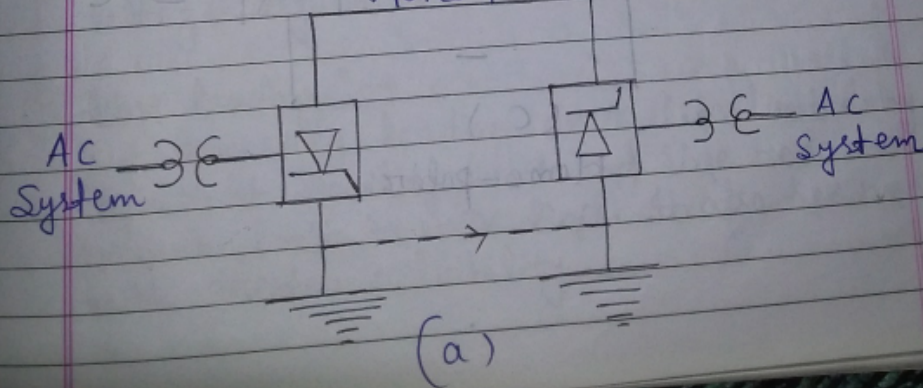
HVDC Transmission

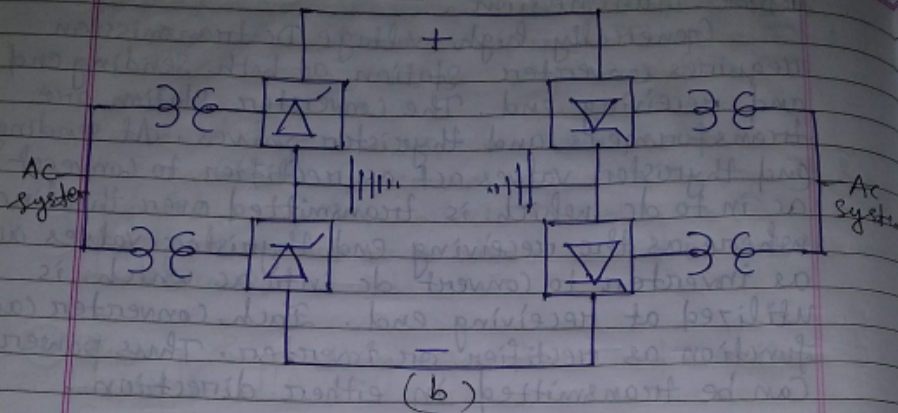
Generally high voltage Dc transmission requires converter station at both sending end and receiving end. The converter station are transformers and thyristor valves. At sending end thyristor valves act as rectifier to convert ac into dc which is transmitted over the line, where as the receiving end thyristor valves act as inverter, to convert dc into ac which is utilized at receiving end. Each converter can function as rectifier or inverter. Thus power can be transmitted in either direction.



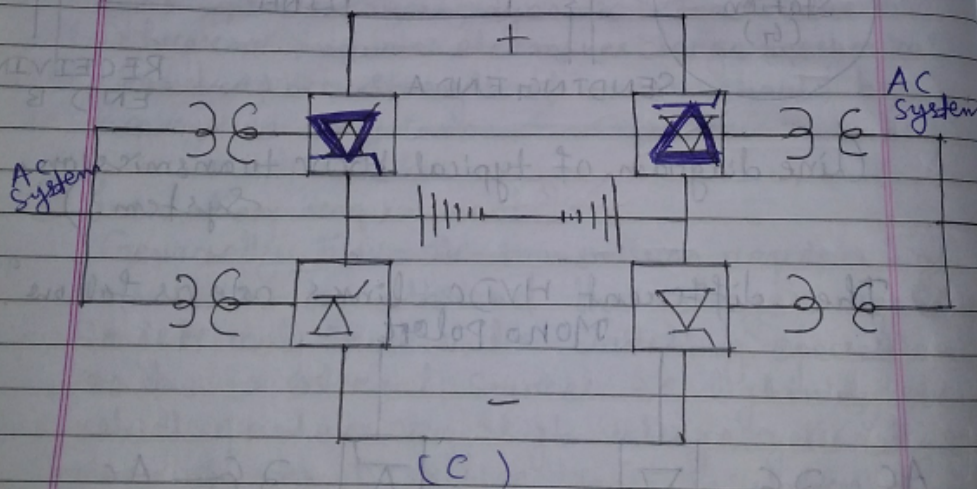
(Line diagram of typical HVDC transmission system)

The different HVDC links are as follows:-
Mono Pole





Bi-polar



Homopolar

Advantages and Limitations of HVDC Transmission System:

③ Advantages:-

HVDC transmission has many technical and Economic advantages over ac transmission as follows:-

① Cheaper in cost:-

Bipolar HVDC Transmission lines require two pole conductors which is very cheap.

② No skin effect:-

As there is uniform current distribution in dc so no skin effect in HVDC.

③ Lower transmission losses:-

HVDC transmission system needs only two conductors and therefore the power losses in a dc line is less.

④ Voltage regulation:-

Due to absence of inductance it has better voltage regulation.

⑤ Line loading:-

Generally loading on ac line limited by transient stability limit and line reactance but no such limit in HVDC lines. It also has no SIL with greater reliability.

⑥ Low short circuit current:—
It has no short circuit.

⑦ Lesser corona loss and radio interference:—
It has lesser corona loss due to zero frequency.

⑧ Higher operating voltages and no reactive power compensation:—
Generally HVDC system has high operating voltage with absence of reactive power compensation.

⑨ No stability limit:—
There is no stability limit in HVDC transmission system.

Limitations of HVDC transmission:—

HVDC transmission system has following limitations as follows:—

① Costly terminal equipment:—

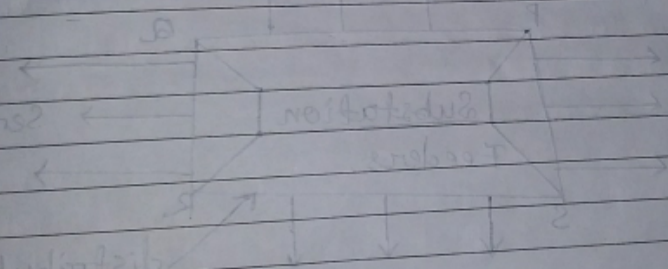
The converters used in HVDC are very costly along with the converters produce lot of harmonics both on dc and ac sides, which requires filtering and smoothing equipment resulting extra additional expense. It also requires complex cooling system and circuit breaker, which again adds cost.

(2) More maintenance of line insulators! —
It requires more maintenance for in insulation

(3) Circuit breaking in multi terminal dc system is difficult and costlier.

(4) Voltage transformer: —

Voltage transformation is not easier in case of dc and hence it has to be accomplished on the ac side of the system. Dc system can't be employed for distribution sub transmission and back bone transmission.



Distribution System

Introduction to distribution system :-

An electric power distribution system is the final stage in the delivery of electric power. It carries electricity from transmission system to individual consumer. Distribution lines mainly subdivided into two types.

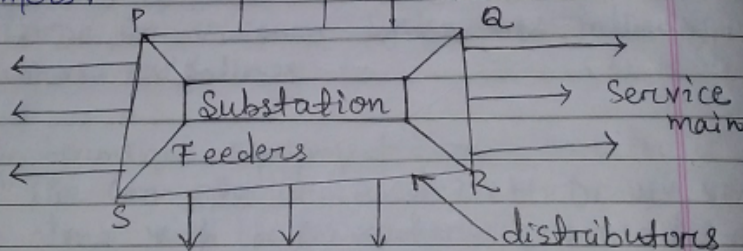
- (a) primary distribution lines
- (b) Secondary distribution lines

(a) Primary distribution lines :-

Carry the medium voltage power to distribution transformers located near the customer's premises.

(b) Secondary distribution lines :-

Carry the step down voltage from the transformer located near the customer's premises to the customers.



(1) Feeders :-

It is a conductor which conduct electricity from substation to the area where the power is to be distributed. The feeders carries same current because no tapping are taken from the feeder. The feeder is designed according to the

Current Carrying Capacity.

(2) Distributors? —

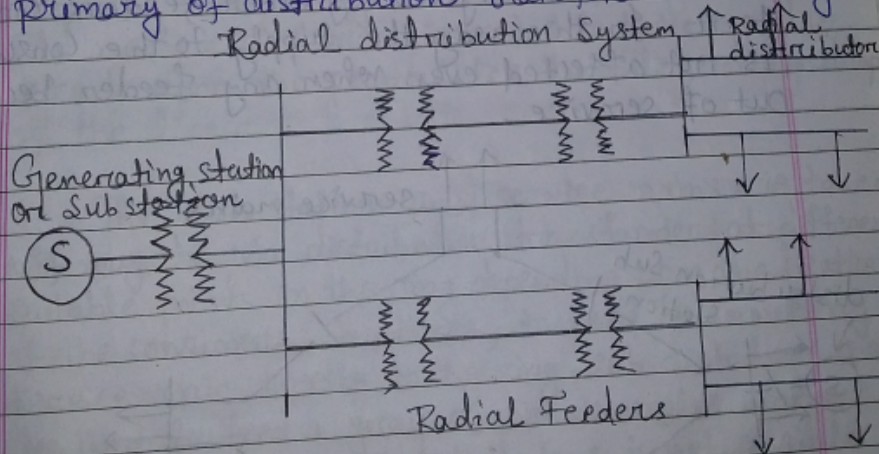
Consumers take supply from the distributor by tapping. In the above figure PQ, QR, RS and PS are the distributors. The voltage drop along its length is considered before designing a distributor.

(3) Service mains? —

It is a cable which connects the distributor to the consumer's energy meter.

Radial Electrical power distribution system? —

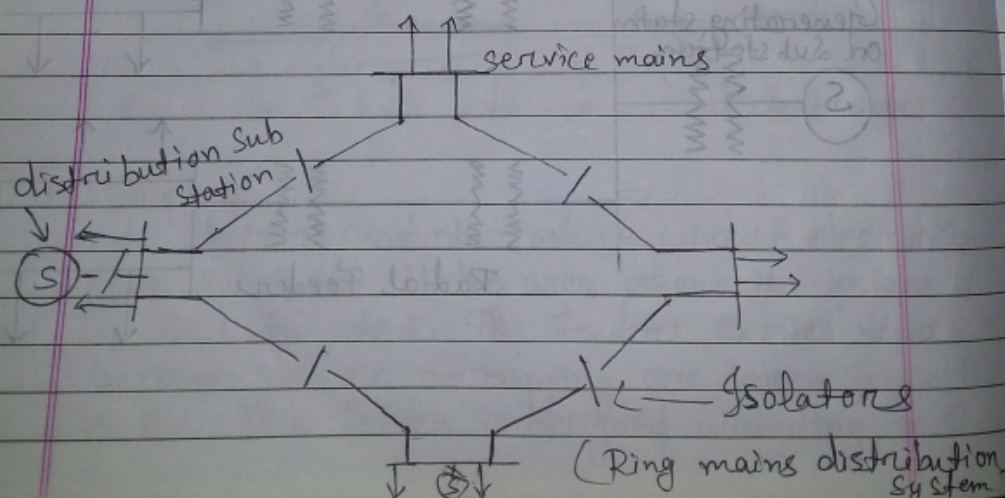
In early days of electrical power distribution system, different feeders were radially come out from the substation and connected to the primary of distribution transformer directly.



But radial electrical power distribution system has one major drawback that in case of any feeder failure, the associated consumers would not get any power as there was no alternative path to feed the transformer. In case of transformer failure also, the power supply is interrupted. In other words the consumer in the radial electrical distribution system would be in darkness until the feeder or transformer was rectified.

Ring main Electrical power distribution system:

The drawback of radial electrical power distribution system can be overcome by introducing a ring main electrical power distribution system. Here one ring network of distributors is fed by more than one feeder. In this case if one feeder is under fault or maintenance, the ring distributor is still energized by other feeders connected to it. In this way the supply to the consumers is not affected even when any feeder becomes out of service.



In this way, supply to the consumers connected to the healthy zone of the ring can easily be maintained even when one section of the ring is shutdown. The number of feeders connected to the ring main electrical power distribution system depends upon the following factors.

① Maximum demand of the system. —

If it is more, then more numbers of feeders feed the ring.

② Total length of the ring main distributors. —

If it is more, then more numbers of —

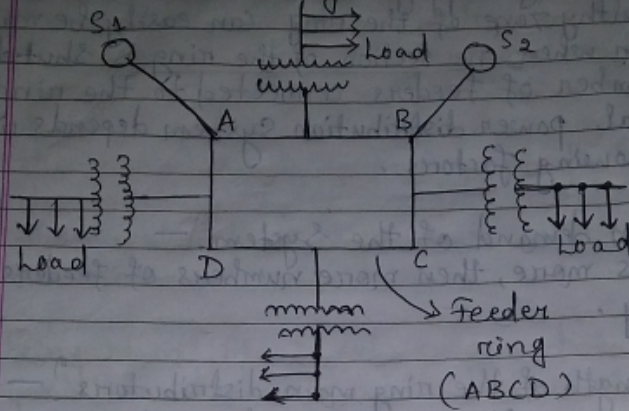
If its length is more, to compensate the voltage drop in the line, more feeders to be connected to the ring system.

③ Required voltage regulation. —

The number of feeders connected to the ring also depends upon the permissible allowable voltage drop of the line.

The sub stations and service mains are taken off may be via distribution transformer at different suitable points on the ring depending upon the location of the consumers. Sometimes, instead of connecting service main directly to the ring, sub distributors are also used to feed a group of service mains where direct access of ring distributors is not possible.

Inter Connected System⁹ -



In this type of system two or more than two generating station or substation are energizing station or substation are energizing the feeder ring. In this system any area from one generating station during peak load hours can be fed from other generating station which increase the efficiency of the system. Now a days electrical energy is generated, transmitted and distributed in the form of a.c. But for certain applications D.C. supply is necessary. The D.C. supply from the substations fed to the load through distributors.

Types of D.C. distributors - In Short⁹ -

The most general method of classifying d.c. distributors is the way they are fed by the feeders. On this basis, d.c. distributors are classified as:-

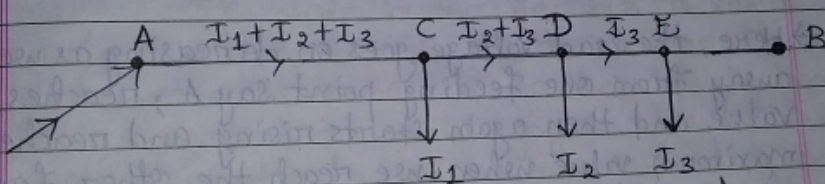
- (i) Distributors fed at one end
- ii) Distributors fed at both ends

- (iii) Distributor fed at the centre
(iv) Ring distributor

Distributor fed at one end:-

In this type of feeding, the distributor is connected to the supply at one end and loads are taken at different points along the length of the distributor.

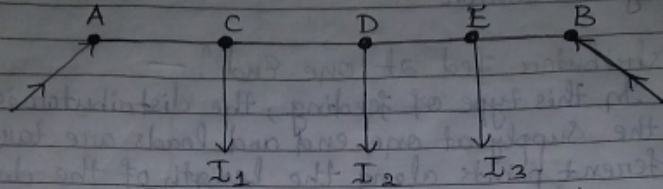
The current in the various sections of the distributor away from feeding point goes on decreasing. Thus current in section AC is more than the current in section CD and current in section CD is more than the current in section DE.



DC distributor fed at one end

The voltage across the loads away from the feeding point goes on decreasing. In case a fault occurs in any section of the distributor the whole distributor will have to be disconnected from the supply mains. Therefore, continuity of supply is interrupted.

Distributor fed at both ends.

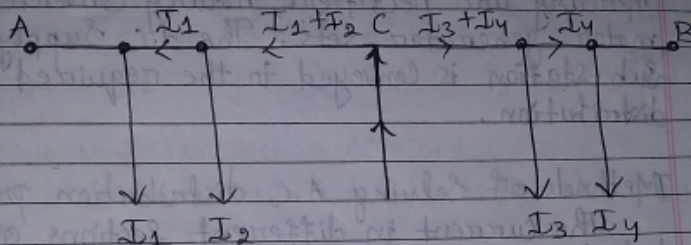


DC distributor fed at both ends

- In this type of feeding, the distributor is connected to the supply mains at both ends and loads are tapped off at different points along the length of the distributor.
- Here, the load voltage goes on decreasing as we move away from one feeding point say A, reaches minimum value and then again starts rising and reaches maximum value when we reach the other feeding point B. The minimum voltage occurs at some load point and is never fixed. It is shifted with the variation of load on different sections of the distributor.
- If a fault occurs on any feeding point of the distributor, the continuity of supply is maintained from the other feeding point.
- In case of fault on any section of the distributor, the continuity of supply is maintained from the other feeding point.

→ The area of x-section required for a doubly fed distributor is much less than that of a singly fed distributor.

Distributor fed at the centre : —

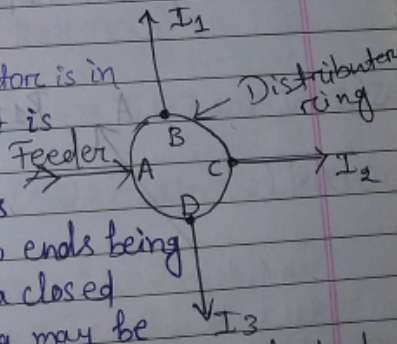


DC distributor fed at centre

In this type of feeding, the centre of the distributor is connected to the supply mains. It is equivalent to two singly fed distributors, each distributor having a common feeding point and length equal to half of the total length.

Ring mains : —

In this type, the distributor is in the form of a closed ring. It is equivalent to a straight distributor fed at both ends with equal voltages, the two ends being brought together to form a closed ring. The distributor ring may be fed at one or more than one point.



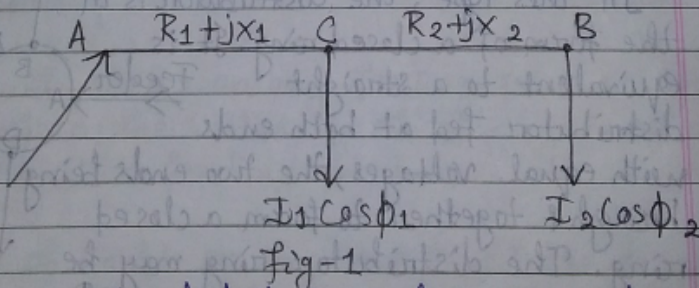
Use of DC distributor? —

D.C. Supply is required for the operation of variable speed machinery (e.g. d.c. motors), electrochemical work and electric traction. For this purpose, a.c. power is converted into d.c. power at the sub-station by using converting machinery e.g. mercury arc rectifiers, rotary converters and motor-generator sets. The d.c. supply from the sub-station is conveyed to the required places for distribution.

Methods of Solving A.C. distribution problems, —

The current in different sections of the distributor will be the vector sum of load currents and not the arithmetic sum in a.c. distribution. Hence the power factor of various load currents have to be considered when solving A.C. distribution problems.

① Power factor referred to receiving end voltage, —



AB is an AC distributor where I_1 and I_2 are the loads taken from the point 'C' and 'B' as shown in fig-1, V_B is the receiving end voltage. The

Lagging power factor at point 'C' is $\cos \phi_1$ and
 the lagging power factor at point B is $\cos \phi_2$
 w.r.t. V_B . The Section AC has impedance $= R_1 + jX_1$
 and the Section CB has the impedance $= R_2 + jX_2$.
 The load current at point 'C' $= I_1 = I_1(\cos \phi_1 - j \sin \phi_1)$
 The load current at point 'B' is equal to current
 in section CB is equal to $I_{CB} = I_2 = I_2(\cos \phi_2 - j \sin \phi_2)$
 The current in section AC $= I_1 + I_2$
 $= I_1(\cos \phi_1 - j \sin \phi_1) + I_2(\cos \phi_2 - j \sin \phi_2)$

The current in section AC $= I_1 + I_2$
 $= I_1(\cos \phi_1 - j \sin \phi_1) + I_2(\cos \phi_2 - j \sin \phi_2)$

The load current at point 'B' is equal to current
 in section CB is equal to $I_{CB} = I_2 = I_2(\cos \phi_2 - j \sin \phi_2)$

The current in section AC $= I_1 + I_2$
 $= I_1(\cos \phi_1 - j \sin \phi_1) + I_2(\cos \phi_2 - j \sin \phi_2)$

The voltage drop in Section CB $= V_{CB} = I_{CB} Z_{CB}$
 $= I_2(\cos \phi_2 - j \sin \phi_2)(R_2 + jX_2)$

Voltage drop in Section AC, $V_{AC} = I_{AC} Z_{AC} = (I_1 + I_2) Z_{AC}$
 $= [I_1(\cos \phi_1 - j \sin \phi_1) + I_2(\cos \phi_2 - j \sin \phi_2)] \times (R_1 + jX_1)$

The sending end voltage $V_A = V_B + V_{CB} + V_{AC}$
 Sending end current $= I_A = I_1 + I_2$
 The vector diagram of a.c. distribution when power
 factor referred to receiving end voltage is
 $V_C = V_B + (I_2 R_2)^2 + (I_2 X_2)^2$
 $V_A = V_B + (I_{AC} R_1)^2 + (I_{AC} X_1)^2$