GANESH INSTITUTE OF ENGINEERING AND TECHNOLOGY

Generation Transmission & Distribution

(Th- 04)

(As per the 2019-20 syllabus of the SCTE&VT, Bhubaneswar, Odisha)

Fourth Semester

Electrical Engg.

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Th4. GENERATION TRANSMISSION & DISTRIBUTION

SYLLABUS

1. GENERATION OF ELECTRICITY

Elementary idea on generation of electricity from Thermal, Hydel, Nuclear, Power station.
Introduction to Solar Power Plant (Photovoltaic cells).
Layout diagram of generating stations.

2. TRANSMISSION OF ELECTRIC POWER

Layout of transmission and distribution scheme.
Voltage Regulation & efficiency of transmission.
State and explain Kelvin's law for economical size of conductor.
Corona and corona loss on transmission lines.

3. OVER HEAD LINES

Types of supports, size and spacing of conductor.
Types of conductor materials.
State types of insulator and cross arms.
Sag in overhead line with support at same level and different level. (approximate formula effect of wind, ice and temperature on sag)
Simple problem on sag.

4. PERFORMANCE OF SHORT & MEDIUM LINES

4.1. Calculation of regulation and efficiency.

5. EHV TRANSMISSION

EHV AC transmission.
5.1..1. Reasons for adoption of EHV AC transmission.
5.1..2. Problems involved in EHV transmission.
HV DC transmission.
5.2..1. Advantages and Limitations of HVDC transmission system.

6. DISTRIBUTION SYSTEMS

Introduction to Distribution System.
Connection Schemes of Distribution System: (Radial, Ring Main and Inter connected system)
DC distributions.
  Distributor fed at one End.
  Distributor fed at both the ends.
  Ring distributors.
AC distribution system.
  Method of solving AC distribution problem.
  Three phase four wire star connected system arrangement.

7. UNDERGROUND CABLES

Cable insulation and classification of cables.
Types of L. T. & H.T. cables with constructional features.
Methods of cable lying.
Localization of cable faults: Murray and Varley loop test for short circuit fault / Earth fault.

8. ECONOMIC ASPECTS

Causes of low power factor and methods of improvement of power factor in power system.
Factors affecting the economics of generation: (Define and explain)
  Load curves.
  Demand factor.
  Maximum demand.
  Load factor.
  Diversity factor.
  Plant capacity factor.
Peak load and Base load on power station.

9. TYPES OF TARIFF

Desirable characteristic of a tariff.

Explain flat rate, block rate, two part and maximum demand tariff. (Solve Problems)

10. SUBSTATION

Layout of LT, HT and EHT substation.

Earthing of Substation, transmission and distribution lines.

BOOKS RECOMMENDED :

1. Principles of Power System V. K. Mehta S Chand
2. Power System Engineering D. P. Kothari, IJ Nagrath TMH

CHAPTERWISE EXPECTED MARK:

SL. NO	**TOPICS**	**EXPECTED MARK**
01	GENERATION OF ELECTRICITY	08
02	TRANSMISSION OF ELECTRIC POWER	06
03	OVER HEAD LINES	14
04	PERFORMANCE OF SHORT & MEDIUM LINES	14
05	EHV TRANSMISSION	12
06	DISTRIBUTION SYSTEMS	10
07	UNDERGROUND CABLES	06
08	ECONOMIC ASPECTS	10
09	TYPES OF TARIFF	06
10	SUBSTATION	14
TOTAL		100

CHAPTER-1
GENERATION OF ELECTRICITY

The conversion of energy available in different forms in nature into electrical energy is known as generation of electrical energy or electricity.

Generating Stations

1.1 Elementary idea on generation of electricity from Thermal, Hydel, Nuclear, Power station.

Bulk electric power is produced by special plants known as generating stations or power plants.

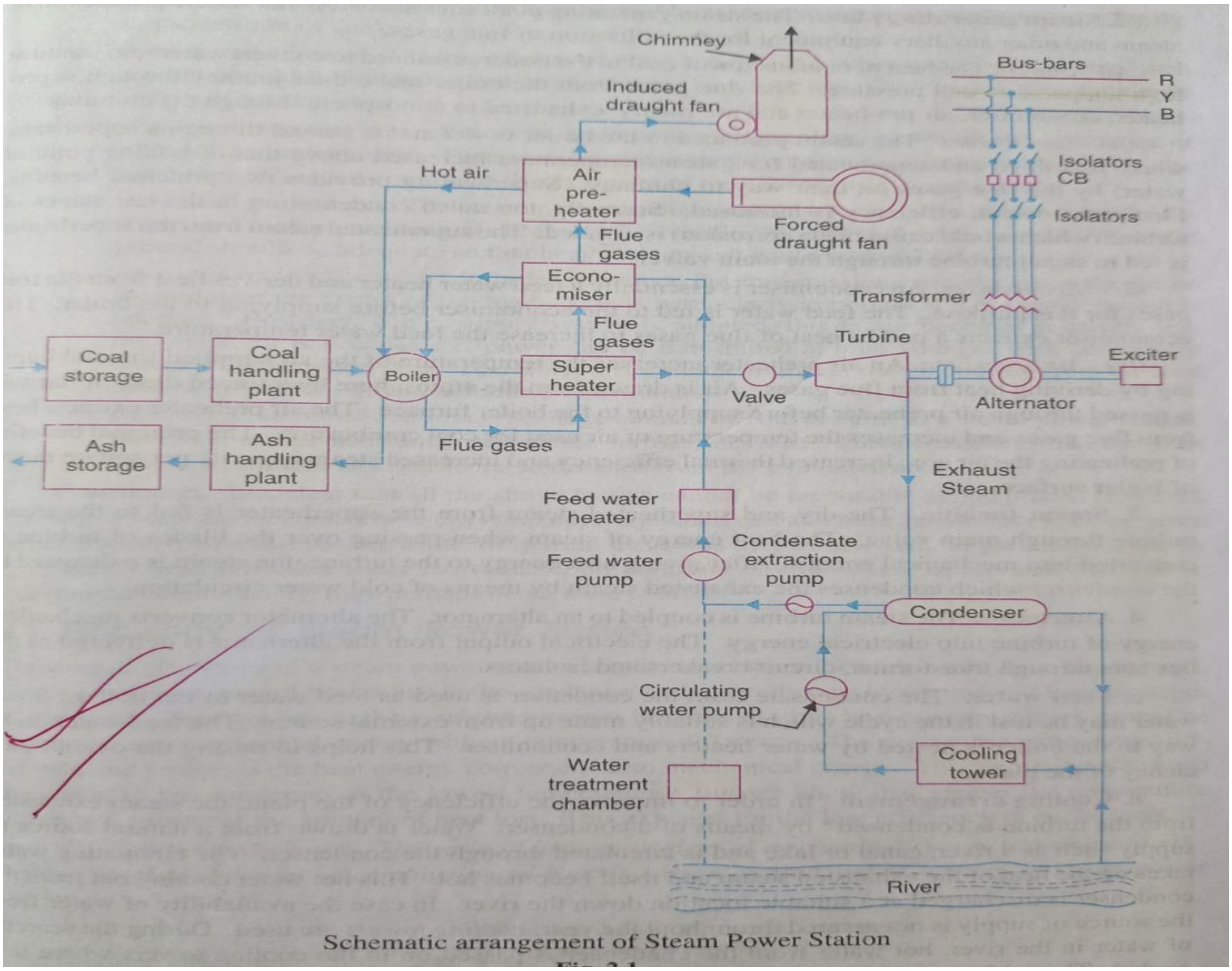
Depending upon the form of energy converted into electrical energy, the generating stations are classified as under :

(i) Steam power stations (Thermal power station) (ii) Hydroelectric power stations
(iii) Nuclear power stations

1. Steam power stations (Thermal power station)

A generating station which converts heat energy of coal combustion into electrical energy is known as a steam power station.

The schematic arrangement of steam Power station is drawn below



Schematic arrangement of Steam Power Station

The main units of plants are :

1. COAL STORAGE PLANT :- Coal is transported to the power station by road or rail and is stored in coal storage plant.

2. COAL HANDLING PLANT:- : From the coal storage plant coal is delivered to the coal handling plant where it is pulverized for rapid combustion with out using excess amount of air.

3. ASH STORAGE PLANT:- The coal is burnt in the boiler & the ash produced after the complete combustion of coal is removed to the ash handling plant.

4. ASH HANDLING PLANT:- the ash from ash handling plant is then delivered to the ash storage plant for subsequent use as fertilizer etc.

5. BOILER:- The heat of combustion of coal in the boiler is utilized to convert water into steam at very high temperature and pressure. The flue gases from the boiler makes their journey through super heater, economizer, air pre-heater & are finally exhausted to the atmosphere through the chimney.

6. SUPERHEATER:- The steam produced in the boiler is wet and is passed through super heater where it is dried and super heated.

7. ECONOMISER:- An economizer is essentially a feed water heater & derives heat from the flue gases to increase the feed water temperature.

8. AIR PREHEATER:- Air pre-heater increases the temperature of the air supplied for coal burning by deriving heat from flue gases.

9. FORCED DRAUGHT FAN :-It draws air from atomosphere which is supplied to the boiler for effective combustion.

10. INDUCED DRAUGHT FAN : it draws the flue gas and sends to chimney.

11. CHIMNEY:- The hot flue gases go to the atmosphere though chimney.

12. STEAM TURBINE:- The dry and super heated steam from the super heater is fed to the steam turbine which converts the heat energy of steam to mechanical energy.

13. ALTERNATOR:- The alternator converts the mechanical energy of steam turbine to electrical energy.

14. CONDENSER :- In order to improve the efficiency of the plant the steam exhausted from the turbine is condensed by means of a condenser. The condensate from the condenser is used as feed water to the boiler.

15. COOLING TOWER : The cooling tower provides a cooling arrangement for the feed water to be reused in boiler.

Working of Thermal power Plant :

When the water from condenser is fed to the Boiler through Economiser it remains a little hot .The Boiler is a extremely heated chamber because of a continuous burning of Coal in presence of air injected by F.D fan through pre-heater So the water gets converted to steam with very high temperature and pressure and reaches the Steam Turbine through Super-Heater. The Internal Energy of Steam gets converted to Mechanical Energy by Turbine and the Alternator converts the mechanical Energy of Turbine output to Electrical Energy .The Electrical Energy thus produced is supplied to the Bus-Bar for Power use.

CHOICE OF SITE SELECTION :

In order to achieve overall economy, the following points should be considered while selecting a site for a steam power station :

1. SUPPLY OF FUEL :- The steam power station should be located near coal mines so that transportation cost of fuel is minimum.

2. AVAILABILITY OF WATER:- A huge amount of water is required for the condenser for which it is it is essential that the plant should be located at the bank of a river or near a canal to ensure continuous supply of water.

3. TRANSPORTATION FACILITIES:- : A modern steam power station often requires the transportation of material and machinery. Therefore adequate transportation facilities by rail or Road should exist.

4. COST AND TYPE OF LAND:- The steam power station should be located at a place where land is cheap and further extension if necessary is possible.

5. NEARNESS TO LOAD CENTRES:- In order to reduce transmission cost the plant should be located near the center of load.

6. DISTANCE FROM POPULATED AREA :- As huge amount of coal is burnt in a steam power Plant due to which smoke and fumes pollutes the surrounding area. This necessitates that plant should be locate at a considerable distance from the populated areas.

ADVANTAGES :

1. The Fuel (i.e. Coal) used is quite cheap.
2. Less initial cost as compared to other generating stations.
3. It can be installed at any place & the coal can be transported by Rail / Road.
4. It requires less space as compared to hydro-electric Power Station.

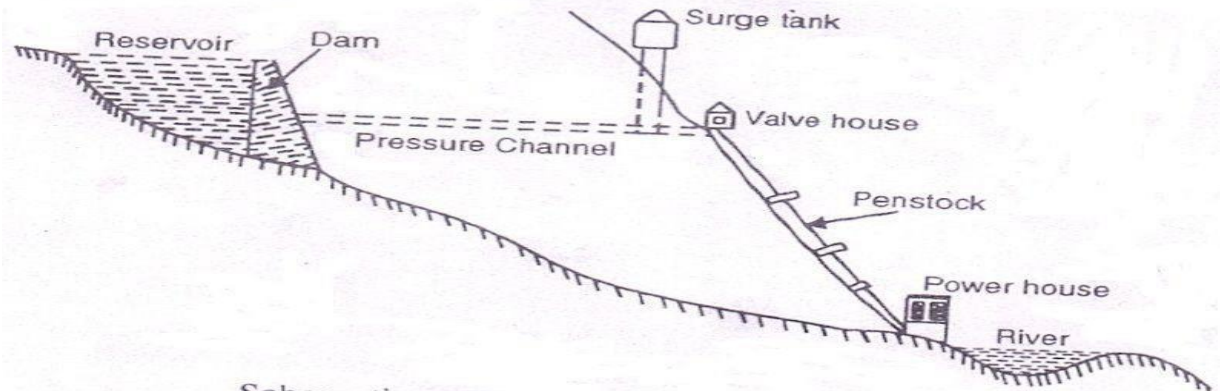
DISADVANTAGES :

1. It pollutes air or atmosphere due to smoke or fumes.
2. Running cost is higher than hydro power plant.

HYDRO-ELECTRIC POWER STATION:

A generating station which utilises the potential energy of water at a high level for the generation of electrical energy is known as a hydro-electric power station.

The schematic arrangement of hydro-electric power station is drawn below :



Schematic arrangement of a Hydro-electric plant

The main units or constituents of plants are :

1. DAM :- A Dam is a barrier which stores water & creates water head. Dams are built of concrete or stone masonry, earth or rock fill.

2. SPILWAYS :- There are times when the river flow exceeds the storage capacity of the reservoir. In order to discharge the surplus water from the storage reservoir into the river on the down-stream side of the dam, spill ways are used.

3. HEAD WORKS :-The head works consists of the diversion structures at the head of an intake. They generally include booms and racks for diverting floating debris, sluices for by-passing debris , sediments and valves for controlling the flow of water to the turbine.

4. SURGE TANK :-For close conduits abnormal pressure may cause damage to the conduit leading from head works to penstock. Surge tank acts as a protection for such situation.

5. PENSTOCKS :-Penstocks are open or close conduits which carry water to the turbines. They are generally made of reinforced concrete or steel.

6. WATER TURBINES :- Water turbines are used to convert the energy of falling water into mechanical energy.

7. ALTERNATOR :- The alternator converts the mechanical energy of turbine to electrical energy.

Working of Hydro-Electric Power Plant :

When the water from Reservoir is allowed to get released through pressure channel, it reaches the Valve house. Then the surge tank is provided in order to safe guard the extra back-thrust of water causing heavy damage to Penstock. The valve house controls the amount of water that will flow to the power house turbines through the Large sized Pen-stocks. Inside the power house the water Turbine convert the potential energy of water with sufficient head to Kinetic energy i.e. mechanical Energy which in turn actsas a prime-mover for the Alternator as before and generates Electrical Energy.

CHOICE OF SITE SELECTION :

In order to achieve overall economy, the following points should be considered while selecting a site for a Hydro-Electric Power Plant :

1. AVAILABILITY OF WATER:- Since the primary requirement of a hydro-electric power station is the availability of huge quantity of water at a good head this requirement is very essential.

2. STORAGE OF WATER:-There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a Dam in order to ensure the generation of power throughout the year.

3. COST & TYPE OF LAND :-The land for the construction of Plant should be available at a reasonable price. Further the bearing capacity of the ground should be adequate to withstand the weight of heavy equipment to be installed.

4. TRANSPORTATION FACILITY :The site selected should be accessible by Rail and Road so that necessary equipment and machineries be easily transported.

ADVANTAGES

1. It requires no fuel as water is used for the generation of Electrical Energy.
2. It is quite neat & clean as no smoke or ash is produced.
3. Running cost is very less as water is used.
4. It is simple in construction & requires less maintenance.

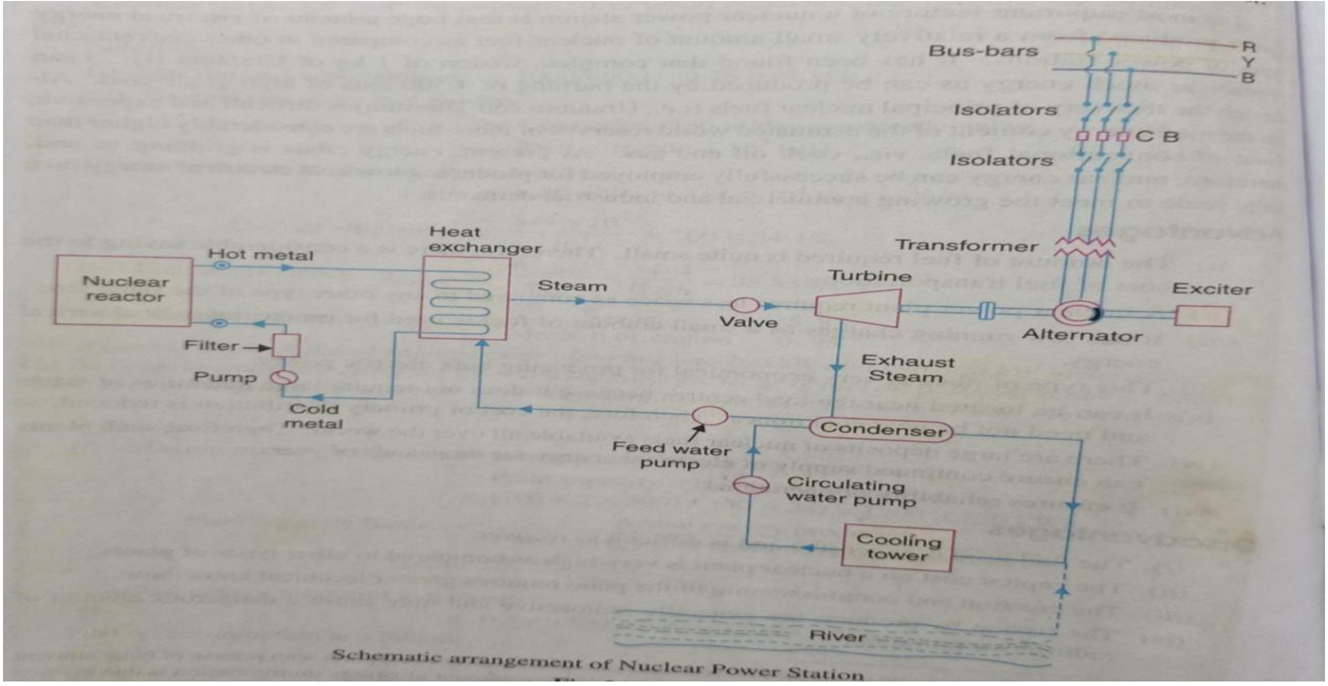
DISADVANTAGES

1. It involves high capital lost due to construction of dams.
2. Generation depends on average rainfall round the year.
3. High cost of transmission as these plants are located in hilly areas.

NUCLEAR POWER STATION :

A generating station in which nuclear energy is converted into electrical energy is known as a nuclear power station.

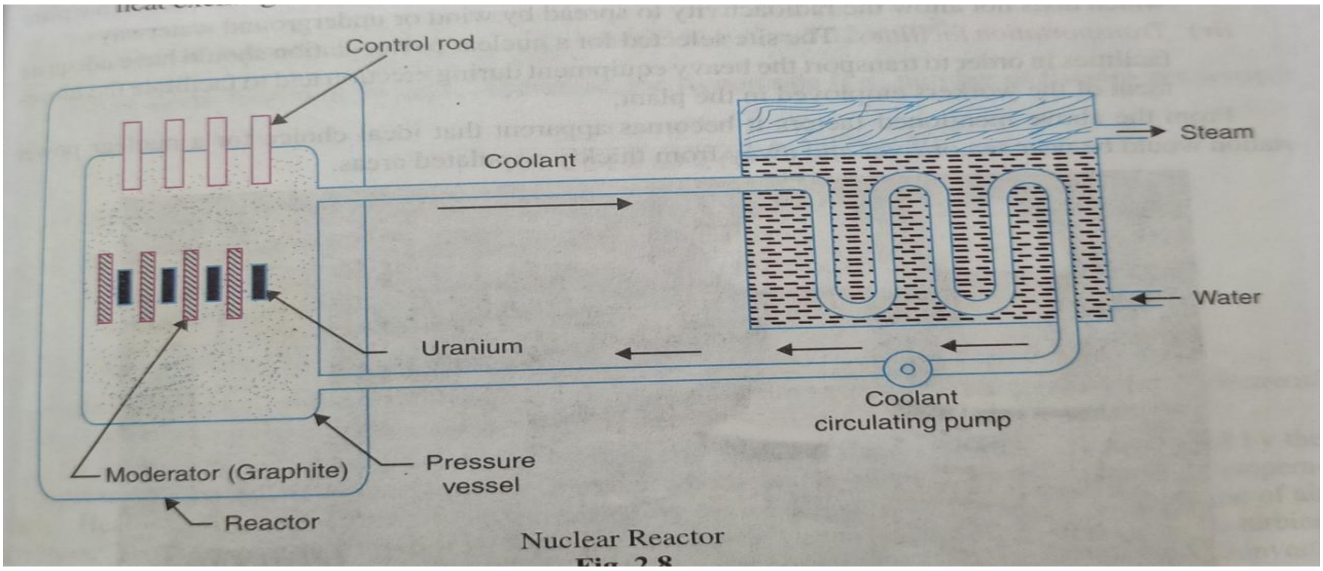
The schematic arrangement of nuclear power station is drawn below :



Schematic arrangement of Nuclear Power Station

The main units or constituents of plants are :

1. NUCLEAR REACTOR :-It is an apparatus in which the nuclear fuel(U^{235}) is subjected to nuclear fission.
2. HEAT EXCHANGER:-The coolant gives up heat to the heat exchanger which isutilized in raising the steam & after giving up heat the coolant is again fed to the reactor.
3. STEAM TURBINE:- The dry and super heated steam from the super heater is fed to thesteam turbine which converts the heat energy of steam to mechanical energy.
4. ALTERNATOR:- The alternator converts the mechanical energy ofturbine toElectrical Energy.



Working of Nuclear Power Plant : The chain reaction produces a huge amount of heat inside the Nuclear Reactor and requires a lot of care to control this reaction. The heat of the Reactor is carried to Heat-Exchanger by molten sodium which also heats the water injected into this Heat Exchanger chamber. After the water gets converted to steam with very high temperature and high pressure ,the Turbine converts the internal Energy of steam to Mechanical Energy and this is converted to Electrical Energy by Alternator as before.

NUCLEAR FUEL: URANIUM(U^{235}) , PLUTONIUM(Pu^{239}), THORIUM(Th^{232})

FISSION & CHAIN REACTION:

When a U-235 atom is struck by a slow neutron ,it will split into two or more fragments. This is called a nuclear fission .This splitting(fission) is accompanied by release of thermal energy in large quantity and two or three fast neutrons. These fast moving neutrons are slowed down by moderators so that they have high probability to hit other u- 235 atoms which in turn get fissioned and release heat and neutrons. This continuous self sustaining sequence of nuclear fissions is called CHAIN REACTION.

CHOICE OF SITE SELECTION :

In order to achieve overall economy, the following points should be considered while selecting a site for a Nuclear Power Plant :

1. AVAILABILITY OF WATER :- A huge amount of water is required for the condenser for which it is it is essential that the plant should be located at the bank of a river or near a canal to ensure continuous supply of water.

2. DISPOSAL OF WASTE :- The waste produced by fission in a nuclear power station is generally radio-active which must be disposed off properly to avoid health hazards for which it must be buried in deep trench.

3. DISTANCE FROM POPULATED AREA:- The site for setting up a nuclear power station should be quite away from populated areas.

4. TRANSPORTATION FACILITY:- The site selected for a nuclear power station should have adequate facilities in order to transport the heavy equipment during erection.

ADVANTAGES

1. There is saving in fuel transportation as amount of fuel required is less.
2. A Nuclear Power Plant requires less space as compared to other plants.
3. This type of plant is economical for producing bulk Electrical Energy.

DISADVANTAGES

1. Fuel is expensive and difficult to recover.
2. Capital lost is higher than other plants.
3. Experienced workman ship is required for plant erection & commissioning.
4. The Fission by-products are radio active & can cause dangerous radio-active pollution.The disposal of by-product is big problem.

SOLAR POWER PLANT:-

This is non-conventional energy source. On this planet, human life and all other forms of life are completely dependent on the daily flow of solar energy. The production of food and all other-life support systems of the natural environment are dependent on the sun.

Solar energy travels in small particles called photons. Converting even a part of the solar energy at even a very low efficiency can result in a far more energy that could conceivably be harnessed or utilized for power generation.

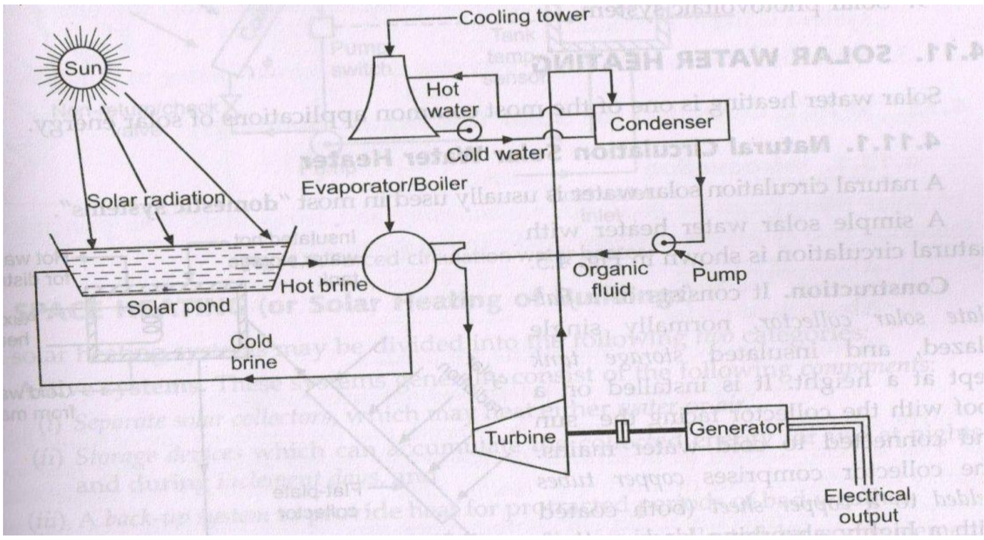
The amount of solar energy is expressed in solar constant. The solar constant is the total energy that falls on a unit area exposed normally to the rays of the sun, at the average sun-earth distance.

The most accepted value of solar constant is 1.353kW/m^2. A number of scattering and absorption processes in the atmosphere reduce the maximum heat flux reaching the earth's surface to avoid to around 1kW/m^2.

The heat flux reaches earth's surface by two modes: Direct & Diffuse.

It is the only direct heat energy which can be collected through a 'collector'. The ratio of direct to totally heat energy varies from place to place and depends on atmospheric conditions like dust , smoke, water vapor and other suspended matter. The ratio varies between 0.64 and 0.88 according to different investigators.

Since the altitude of the sun and length of day vary with the season, the solar energy received on a summer day is many times the energy received on a winter day. As a result the total energy for most of the area in plains in India is around 6000MJ/m^2per year .



ADVANTAGES:

1. It is a renewable source of energy.
2. It is free of cost.
3. Non-polluting source of energy.

DISADVANTAGES:

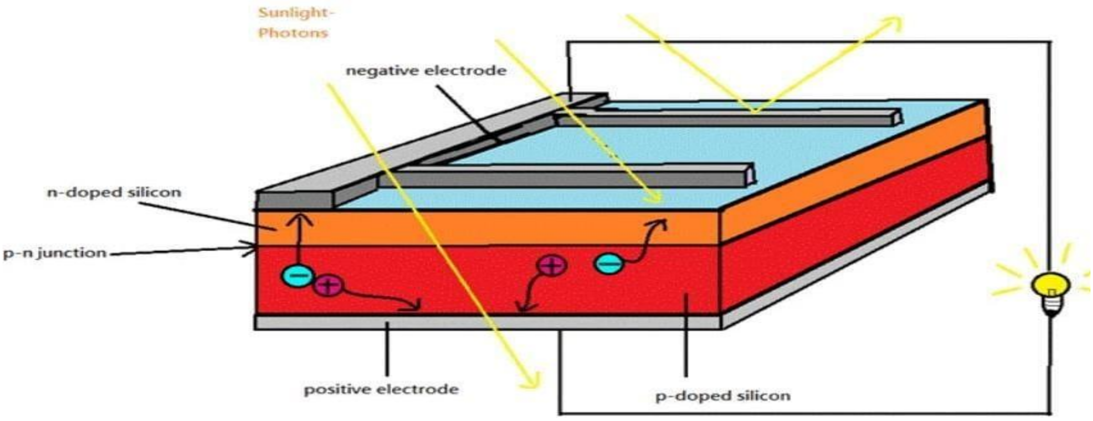
1. Low efficiency.
2. It is of intermittent type in nature, so for night hours this energy is not availed, and as such ,storage is required.

SOLAR PHOTO VOLTAIC SYSTEM

- Solar photovoltaic (PV) system convert solar energy directly into electrical energy.
- The basic conversion deice used is solar photo voltaic cell or solar cell.

OPERATING PRINCIPLE

- Semiconducting material in the PV cell are doped to form P-N structure as an internal electric field.
- The p-type(positive) silicon has a tendency to give up electrons and acquire holes, while n-type(negative) silicon accepts electrons. When sunlight hits the cell the electrons in the semiconductor gets excited to form electron-hole pair.
- Since there is an internal electric field, these pairs are induced to separate as a result the electrons move to negative electrodes while holes move to positive electrodes.
- A conducting wire connects the negative electrode, the load, and the positive electrode in series to form a circuit, as a result, an electric current is generated to supply the external load.



PHOTOVOLTAIC CELL

- Photovoltaic cell is a semiconductor device that converts light into electrical energy.
- The voltage induced by the PV cell depends upon the intensity of light incident on it.
- When the photons are incident on the electron they become energised and start emitting.
- The energised electrons are photoelectrons and the phenomenon of emission of electrons is photoelectric effect.

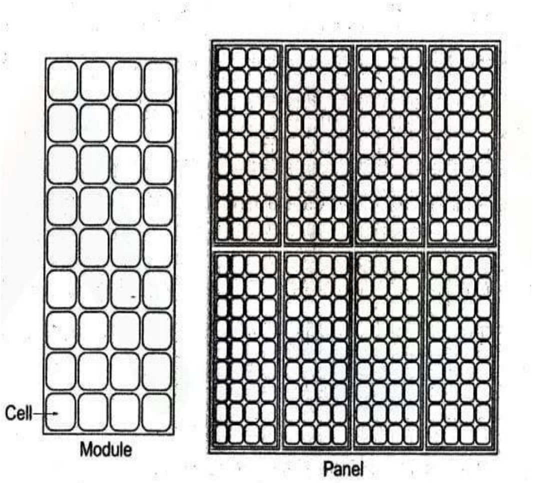
SOLAR CELL, MODULE, ARRAY

Solar Cell

- It is defined as an electrical device that converts light into electrical energy by photovoltaic effect.
- It is a form of photovoltaic cell whose electrical characteristics vary when exposed to light.

Solar PV Module

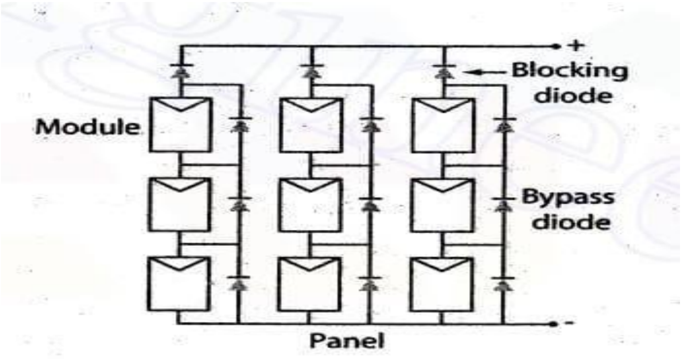
- It is an assembly of photovoltaic cells to achieve required voltage and current.
- A solar panel is group of several modules connected in series- parallel combination in a frame that can be mounted on a structure.



Solar PV Array

- A large number of interconnected solar panels is known as solar PV array.

SERIES AND PARALLEL CONNECTIONS



- The above figure shows the series -parallel connection of modules in a panel.
- In parallel connection blocking diodes are connected in series with each series string of modules. If any string fails the power output of remaining string is not absorbed by the failed string.
- Also bypass diodes are installed across each module, if one module fails, output of remaining modules in a string bypass the failed module.

SHORT QUESTIONS:

What is the function of an economizer ?

The function of an economizer to derives heat from the flue gases to increase the feed water temperature.

What is the function of an Air-preheater ?

The function of an Air-preheater to increases the temperature of the air supplied for coal burning by deriving heat from flue gases.

What is the function of surge tank ?

The function of surge tank for close conduits abnormal pressure may cause damage to the conduit leading from head works to penstock. Surge tank acts as a protection for such situation.

what are the advantages of solar power plant ?

The advantages of solar power plant are :

1. It is a renewable source of energy.
2. It is free of cost.
3. Non-polluting source of energy.

what are the advantages of Thermal power plant ?

The advantages of Thermal power plant are :

1. The Fuel (i.e. Coal) used is quite cheap.
2. Less initial cost as compared to other generating stations.
3. It can be installed at any place & the coal can be transported by Rail / Road.
4. It requires less space as compared to hydro-electric Power Station.

what are the advantages and disadvantages of Hydro-electric power plant ?

The advantages and disadvantages of Hydro-electric power plant are :

1. It requires no fuel as water is used for the generation of Electrical Energy.
2. It is quite neat & clean as no smoke or ash is produced.
3. Running cost is very less as water is used.
4. It is simple in construction & requires less maintenance.

The Disadvantages and disadvantages of Hydro-electric power plant are :

1. It involves high capital lost due to construction of dams.
2. Generation depends on average rainfall round the year.
3. High cost of transmission as these plants are located in hilly areas.

What is the function of Nuclear Reactor and Heat exchanger ?

NUCLEAR REACTOR :-It is an apparatus in which the nuclear fuel(U^{235}) is subjected to nuclear fission.

HEAT EXCHANGER:-The coolant gives up heat to the heat exchanger which isutilized in raising the steam & after giving up heat the coolant is again fed to the reactor.

Long Questions :

Explain with block diagram the working of a Thermal Power Plant .

Explain with block diagram the working of a Hydro-electric Power Plant .

Explain with block diagram the working of a Nuclear Power Plant .

Explain with block diagram the working of a Solar Power Plant .

CHAPTER-3

OVER HEAD LINES

Main Components of Overhead Lines :

An overhead line may be used to transmit or distribute electric power. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most probable weather conditions. In general, the main components of an overhead line are:

1. Conductors: which carry electric power from the sending end station to the Receiving end station.
2. Supports : which may be poles or towers and keep the conductors at a suitable level above the ground.
3. Insulators : which are attached to supports and insulate the conductors from the ground.
4. Cross arms : which provide support to the insulators.
5. Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Supports / Line Supports

The supporting structures for overhead line conductors are various types of poles and towers called line supports.

In general, the line supports should have the following properties :

(i) High mechanical strength to withstand the weight of conductors and wind loads etc.
(ii) Light in weight without the loss of mechanical strength.
(iii) Cheap in cost and economical to maintain.
(iv) Longer life.
(v) Easy accessibility of conductors for maintenance.

The line supports used for transmission and distribution of electric power are of various types including wooden poles, steel poles, R.C.C. poles and lattice steel towers.

The choice of supporting structure for a particular case depends upon the line span, X-sectional area, line voltage, cost and local conditions.

1. Wooden poles.

- These are made of seasoned wood (sal or chir) and are suitable for lines of moderate X-sectional area and of relatively shorter spans, up to 50 metres.
- Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas as an economical proposition. .

The main objections to wooden supports are : (i) tendency to rot below the ground level
(ii) comparatively smaller life (20-25 years) (iii) cannot be used for voltages higher than 20 kV
(iv) less mechanical strength and (v) require periodical inspection.

2. Steel poles.

- . They possess greater mechanical strength, longer life and permit longer spans to be used.
- Such poles are generally used for distribution purposes in the cities.
- This type of supports need to be galvanized or painted in order to prolong its life.
- The steel poles are of three types viz. (i) rail poles (ii) tubular poles and (iii) rolled steel joints.

3. RCC poles.

- The reinforced cement concrete poles have become very popular as line supports in recent years.
- They have greater mechanical strength, longer life and permit longer spans than steel poles , they give good outlook, require little maintenance and have good insulating properties.
- The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight.

4. Steel towers.

- In practice, wooden, steel and reinforced concrete poles are used for distribution purposes at low voltages, say up to 11 kV. However, for long distance transmission at higher voltage, steel towers are invariably employed.
- Steel towers have greater mechanical strength, longer life, can withstand most severe climatic conditions and permit the use of longer spans.
- This minimizes the lightning troubles as each tower acts as a lightning conductor.

Ground clearance on different voltages of different areas :

Line voltage in KV	**0.4**	**11**	**33**	**66**	**132**	**220**	**400**
Across the street	5.8	5.8	6.1	6.1	6.1	7.0	8.4
Along the street	5.5	5.5	5.8	6.1	6.1	7.0	8.4
Other areas	4.6	4.6	5.5	5.5	6.1	7.0	8.4

Conductor Materials :

The conductor is one of the important items of the overhead transmission line. The proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electric power should have the following properties :

(i) high electrical conductivity.

(ii) high tensile strength in order to withstand mechanical stresses.

(iii) low cost so that it can be used for long distances.

(iv) low specific gravity so that weight per unit volume is small.

The most commonly used conductor materials for overhead lines are copper, aluminum, steel-cored aluminum, galvanized steel and cadmium copper.

All conductors used for overhead lines are preferably stranded in order to increase the flexibility.

1. Copper.

- Copper is an ideal material for overhead lines owing to its high electrical conductivity and greater tensile strength.
- It is always used in the hard drawn form as stranded conductor.
- Copper has high current density i.e., the current carrying capacity of copper per unit of X-sectional area is quite large.
- copper is an ideal material for transmission and distribution of electric power. However, due to its higher cost and non-availability, it is rarely used for these purposes. Now-a-days the trend is to use aluminum in place of copper.

2. **Aluminium**.
    - Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength.
    - The relative comparison of the two materials is briefed below :
    - The conductivity of aluminium is 60% that of copper.
    - The increased X-section of aluminium exposes a greater surface to wind pressure and, therefore, supporting towers must be designed for greater transverse strength
    - Aluminium conductor being light, is liable to greater swings and hence larger cross-arms are required.
    - Due to lower tensile strength and higher co-efficient of linear expansion of aluminium, the sag is greater in aluminium conductors.
    - Considering the combined properties of cost, conductivity, tensile strength, weight etc., aluminium has an edge over copper.
    - it is being widely used as a conductor material
3. **Steel cored aluminium**.
    - Due to low tensile strength, aluminium conductors produce greater sag. This prohibits their use for larger spans and makes them unsuitable for long distance transmission. In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanized steel wires.
    - The composite conductor thus obtained is known as steel cored aluminium and is abbreviated as A.C.S.R. (aluminium conductor steel reinforced).
    - Steel-cored aluminium conductor consists of central core of galvanized steel wires surrounded by a number of aluminium strands.

The steel cored aluminium conductors have the following advantages :

(i) The reinforcement with steel increases the tensile strength but at the same time keeps the composite conductor light. Therefore, steel cored aluminium conductors will produce smaller sag and hence longer spans can be used.

(ii) Due to smaller sag with steel cored aluminium conductors, towers of smaller heights can be used.

4. **Galvanized steel**.
    - Steel has very high tensile strength. Therefore, galvanized steel conductors can be used for extremely long spans or for short line sections exposed to abnormally high stresses due to climatic conditions.
    - They have been found very suitable in rural areas where cheapness is the main consideration.
    - Due to poor conductivity and high resistance of steel, such conductors are not suitable for transmitting large power over a long distance..
5. **Cadmium copper**.
    - The conductor material now being employed in certain cases is copper alloyed with cadmium. An addition of 1% or 2% cadmium to copper increases the tensile strength by about 50% and the conductivity is only reduced by 15% below that of pure copper.
    - cadmium copper conductor can be useful for exceptionally long spans. However, due to high cost of cadmium, such conductors will be economical only for lines of small X-section.

Insulators

The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth. In general, the insulators should have the following desirable properties :

(i) High mechanical strength in order to withstand conductor load, wind load etc.
(ii) High electrical resistance of insulator material in order to avoid leakage currents to earth.
(iii) High relative permittivity of insulator material in order that dielectric strength is high.
(iv) The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.
(v) High ratio of puncture strength to flashover.

The most commonly used material for insulators of overhead line is porcelain but glass, steatite and special composition materials are also used to a limited extent.

Porcelain is produced by firing at a high temperature a mixture of kaolin, feldspar and quartz.

Causes of insulator failure.

- Insulators are required to withstand both mechanical and electrical stresses. The electrical breakdown of the insulator can occur either by flash-over or puncture.. The ratio of puncture strength to flashover voltage is known as safety factor i.e.,
- **Safety factor of insulator = Puncture strength / (Flash over voltage)**

Types of Insulators

There are several types of insulators but the most commonly used are pin type, suspension type, strain insulator, shackle insulator and egg insulator.

1. Pin type insulators.

- The pin type insulator is secured to the cross-arm on the pole. There is a groove on the upper end of the insulator for housing the conductor.
- The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor.
- Pin type insulators are used for transmission and distribution of electric power at voltages up to 33 kV.
- Beyond operating voltage of 33 kV, the pin type insulators become too bulky and hence uneconomical.

2. Suspension type insulators.

- The cost of pin type insulator increases rapidly as the working voltage is increased. For high voltages (>33 kV), it is a usual practice to use suspension type insulators .
- It consist of a number of porcelain discs connected in series by metal links in the form of a string.
- The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower.
- Each unit or disc is designed for low voltage, say 11 kV. if the working voltage is 66 kV, then six discs in series will be provided on the string.
- Depending upon the working voltage, the desired number of discs can be connected in series.
- If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.
- The suspension arrangement provides greater flexibility to the line.

- The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

3. Strain insulators.

- When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, strain insulators are used.
- For low voltage lines (< 11 kV), shackle insulators are used as strain insulators.
- The discs of strain insulators are used in the vertical plane.

4. Shackle insulators.

- This 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 to the cross arm.
- The conductor in the groove is fixed with a soft binding wire..

5. Stay or Egg insulator.

- This insulators are of egg shape and it also called as guy insulator.
- These insulators are provided height of about 3m from the ground.
- It is made up of porcelain and it have two holes right angles with each other.

Cross arms:

- Cross arms which provide support to the insulators.
- Cross arms are of various types such as MS channel, angle iron.
- These may be straight , U shaped , V shaped or Zig-Zag shaped.

Spacing of Conductor:

Line voltage in KV	0.4	11	33	66	132	220	400
Spacing in m.	0.2	1.2	2.0	2.5	3.5	6.0	11.5

String Efficiency :

The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency

i.e., String efficiency =Voltage across the string / (n * Voltage across disc nearest to conductor)

where n = number of discs in the string.

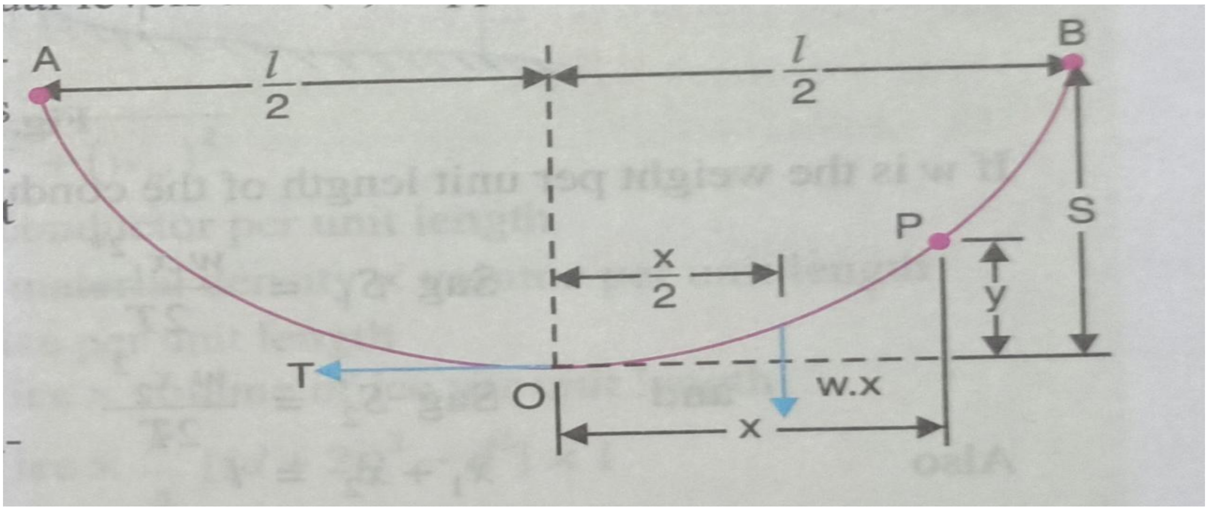
Sag in Overhead Lines

The difference in level between points of supports and the lowest point on the conductor is called sag.

Calculation of sag :

1. When supports are at equal levels:

Consider a conductor between two equilevel supports A and B with O as the lowest point will be at the mid-span.



Let l = length of span.
w= Weight per unit length of conductor.
T= Tension in the conductor.

Consider a point P on the conductor. Taking the lowest point O as the origin , let the co-ordinates of point P be x and y.

Assuming OP=x

The two forces acting on the portion OP of the conductor are

(a) The weight wx of conductor acting at a distance x/2 from O.
(b) The tension T acting at O.

Equating the moments of above two forces about point O, we get

$$Ty = wx * x/2$$

$$Y = \frac{wx^2}{2T}$$

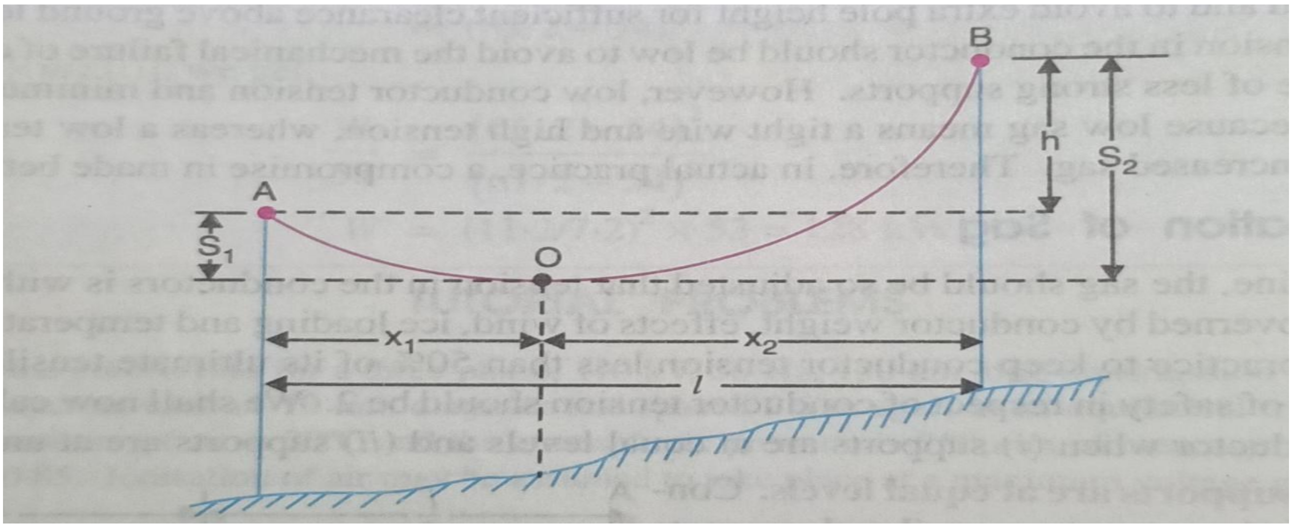
The maximum sag is represented by the value of y at either of the supports A and B.

At support A, x= l/2 and y=S.

$$\text{Sag, } S = \frac{w(l/2)^2)}{2T} = \frac{wl^2}{8T}$$

2. When supports are at unequal levels:

In hilly areas, we generally come across conductors suspended between supports are unequal levels. Let us consider two supports A and B having unequal levels, the lowest point on the conductor is O.



Let l = Span length.

h = Difference in levels between two supports.

x_1 = Distance of support at lower level from O.

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,

Sag, $S_1 = \frac{wx_1^2}{2T}$

and Sag, $S_2 = \frac{wx_2^2}{2T}$

also $x_1 + x_2 = l$........................ (i)

Now $S_2 - S_1 = \frac{wx_2^2}{2T} - \frac{wx_1^2}{2T} = \frac{w}{2T}(x_2^2 - x_1^2) = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$

$= \frac{wl}{2T}(x_2 - x_1)$

But $S_2 - S_1 = h$

So $h = \frac{(x_2 - x_1)}{2T}$

Or $({}_2 - x_1) = \frac{2Th}{wl}$

Solving equation (i) and (ii) we get,

$x_1 = \frac{l}{2} - \frac{Th}{wl}$

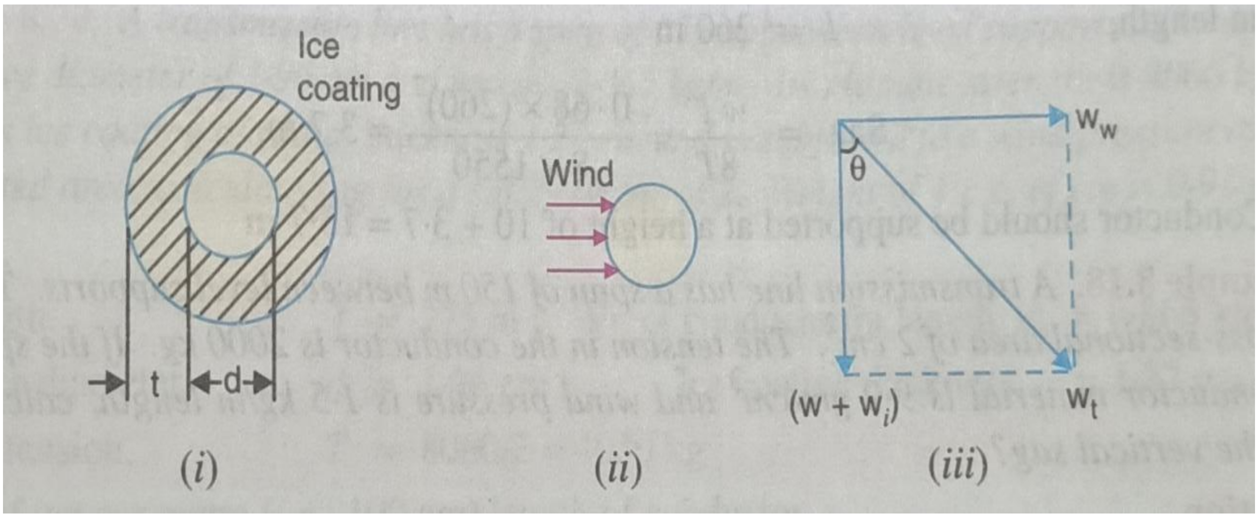
and

$x_2 = \frac{l}{2} + \frac{Th}{wl}$

Having found x_1 and x_2 values of S_1 and S_2 can be easily calculated.

EFFECT OF WIND AND ICE LOADING :

A conductor may have ice coating and simultaneously subjected to wind pressure. The weight of ice acts vertically downward and the force due to the wind is assumed to act horizontally. Hence, the total force on the conductor is the vector sum of horizontal and vertical forces as shown in figure.



Total weight of conductor per unit length is

$w_t = \sqrt{(w + w_i)^{2} + (w_w)^2}$

w = Weight of conductor per unit length.

= conductor material density * volume per unit length

W_i = weight of ice per unit length

= Density of ice * volume of ice per unit length

= density of ice * $\frac{\text{л}}{4}$ ((d+2t)^2 – d^2) *1

= density of ice * л t(d+t)

W_w = wind force per unit length

= wind pressure per unit area * projected area per unit length

= wind pressure * ((d+2t) * 1)

When the conductor has wind and ice loading also, the following points may be noted:

(i) The conductor sets itself in a plane at an angle Θ to the vertical where

$\tan\Theta = \frac{w_w}{w+w_i}$

(ii) The sag in the conductor is given by : $S = \frac{w_t l^2}{2T}$

Here S represents the slant sag in a direction making an angle Θ to the vertical.

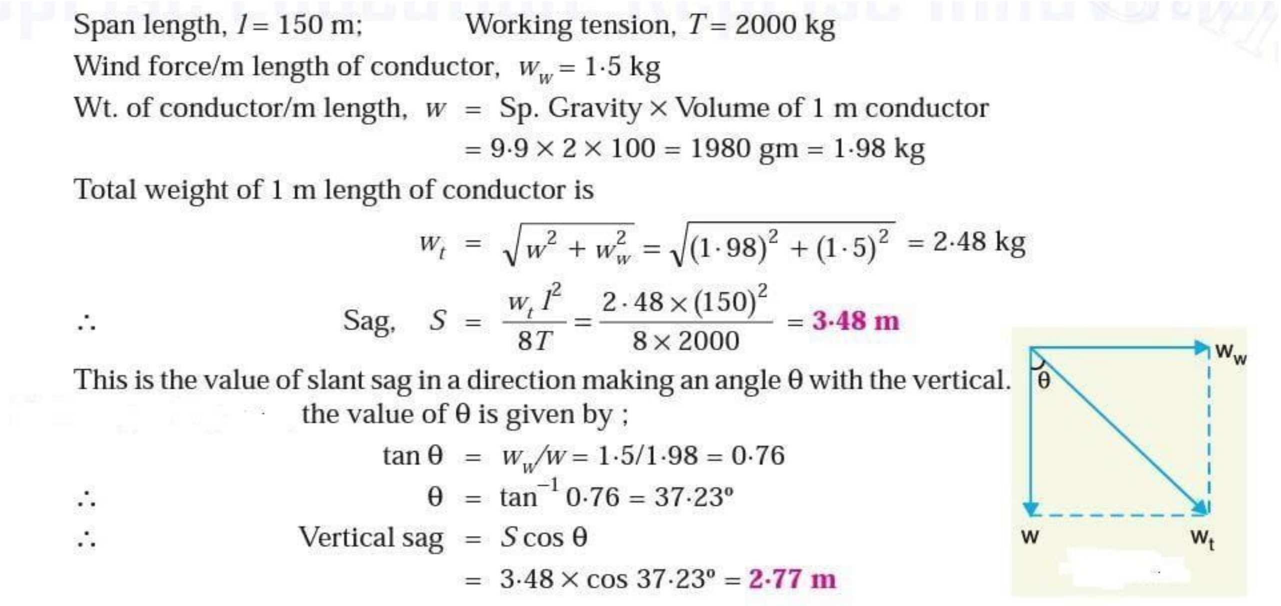
(iii) The vertical sag = S * cosΘ

Simple problem on sag.

Q.1

A transmission line has a span of 150 m between level supports. The conductor has a cross-sectional area of 2 cm2. The tension in the conductor is 2000 kg. If the specific gravity of the conductor material is 9·9 gm/cm3 and wind pressure is 1·5 kg/m length, calculate the sag. What is the vertical sag?

Ans :Given that :



Span length, l = 150 m; Working tension, T = 2000 kg

Wind force/m length of conductor, w_w = 1·5 kg

Wt. of conductor/m length, w = Sp. Gravity × Volume of 1 m conductor

= 9·9 × 2 × 100 = 1980 gm = 1·98 kg

Total weight of 1 m length of conductor is

$$w_t = \sqrt{w^2 + w_w^2} = \sqrt{(1\cdot98)^2 + (1\cdot5)^2} = 2\cdot48 \text{ kg}$$

$$\therefore \quad \text{Sag, } S = \frac{w_t l^2}{8T} = \frac{2\cdot48 \times (150)^2}{8 \times 2000} = \mathbf{3\cdot48\ m}$$

This is the value of slant sag in a direction making an angle θ with the vertical. the value of θ is given by ;

$$\tan\theta = w_w/w = 1\cdot5/1\cdot98 = 0\cdot76$$

$$\therefore \quad \theta = \tan^{-1} 0\cdot76 = 37\cdot23°$$

$$\therefore \quad \text{Vertical sag} = S\cos\theta$$

$$= 3\cdot48 \times \cos 37\cdot23° = \mathbf{2\cdot77\ m}$$

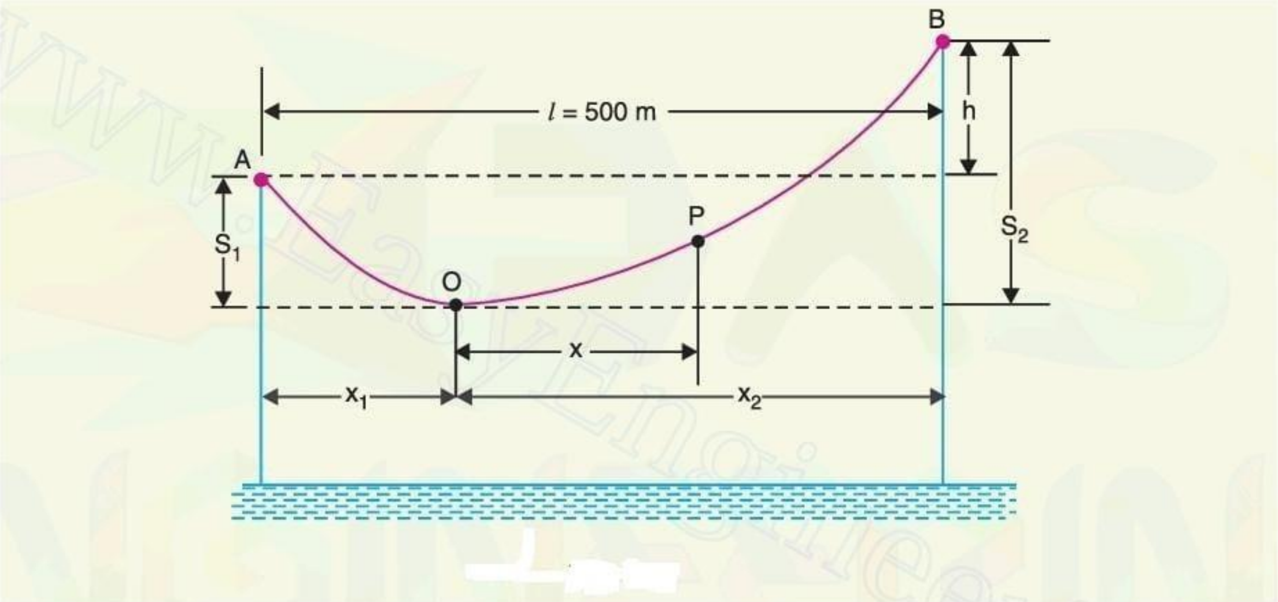
The towers of height 30 m and 90 m respectively support a transmission line conductor at water crossing. The horizontal distance betwen the towers is 500 m. If the tension in the conductor is 1600 kg, find the minimum clearance of the conductor and water and clearance mid-way betweenthe supports. Weight of conductor is 1·5 kg/m. Bases of the towers can be considered to be at water level.

Ans:

Given that : $l = 500$ m ; $w = 1{\cdot}5$ kg ; $T = 1600$ kg.

Difference in levels between supports, $h = 90 - 30 = 60$ m. Let the lowest point O of the conductor be at a distance x_1 from the support at lower level (*i.e.*, support A) and at a distance x_2 from the support at higher level (*i.e.*, support B).

Obviously, $x_1 + x_2 = 500$ m ...(*i*)



Now Sag $S_1 = \dfrac{w\,x_1^2}{2T}$ and Sag $S_2 = \dfrac{w\,x_2^2}{2T}$

$$\therefore \quad h = S_2 - S_1 = \frac{w\,x_2^2}{2T} - \frac{w\,x_1^2}{2T}$$

or
$$60 = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$\therefore \quad x_2 - x_1 = \frac{60 \times 2 \times 1600}{1\cdot 5 \times 500} = 256 \text{ m} \qquad \text{...}(ii)$$

Solving exps. (*i*) and (*ii*), we get, $x_1 = 122$ m; $x_2 = 378$ m

Now, $$S_1 = \frac{w\,x_1^2}{2T} = \frac{1\cdot 5 \times (122)^2}{2 \times 1600} = 7 \text{ m}$$

Clearance of the lowest point O from water level

$= 30 - 7 =$ **23 m**

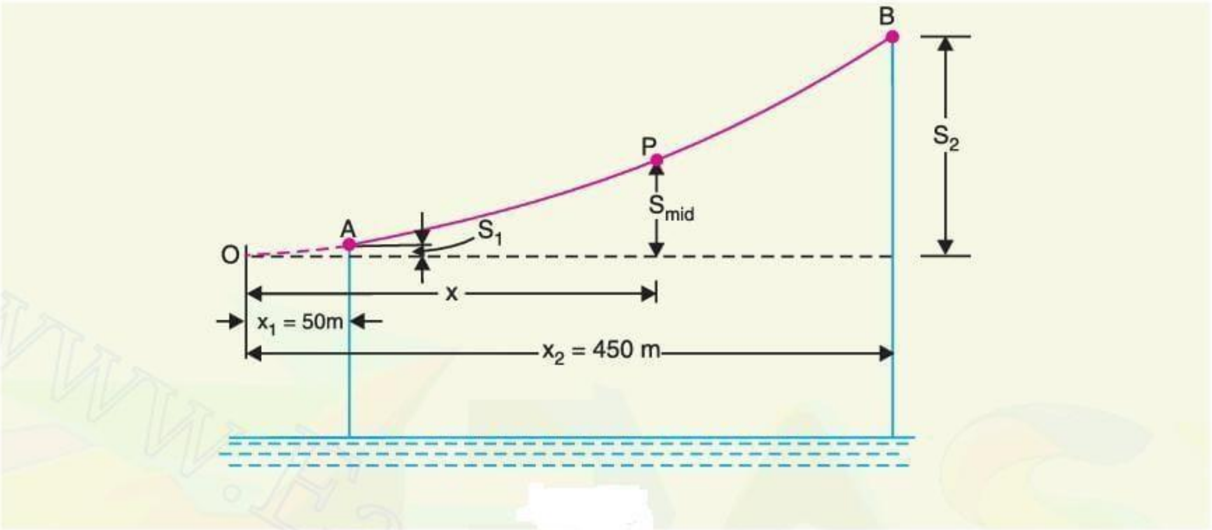
Let the mid-point P be at a distance x from the lowest point O.

Clearly, $x = 250 - x_1 = 250 - 122 = 128$ m

Sag at mid-point P, $$S_{mid} = \frac{w\,x^2}{2T} = \frac{1\cdot 5 \times (128)^2}{2 \times 1600} = 7\cdot 68 \text{ m}$$

An overhead transmission line at a river crossing is supported from two towers at heights of 40 m and 90 m above water level, the horizontal distance between the towers being 400 m. If the maximum allowable tension is 2000 kg, find the clearance between the conductor and water at a point mid-way between the towers. Weight of conductor is 1 kg/m.

Ans:



Here, $h = 90 - 40 = 50$ m; $l = 400$ m

$T = 2000$ kg; $w = 1$ kg/m

Obviously, $x_1 + x_2 = 400$ m ...(*i*)

Now $h = S_2 - S_1 = \frac{wx_2^2}{2T} - \frac{wx_1^2}{2T}$

or $50 = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$

$\therefore$ $x_2 - x_1 = \frac{50 \times 2 \times 2000}{400} = 500$ m ...(*ii*)

Solving exps. (*i*) and (*ii*), we get, $x_2 = 450$ m and $x_1 = -50$ m

Now x_2 is the distance of higher support *B* from the lowest point *O* on the conductor, whereas x_1 is that of lower support *A*. As the span is 400 m, therefore, point *A* lies on the same side of *O* as *B*

Horizontal distance of mid-point *P* from lowest point *O* is

x = Distance of *A* from *O* + 400/2 = 50 + 200 = 250 m

$\therefore$ Sag at point *P*, $S_{mid} = \frac{w\,x^2}{2T} = \frac{1 \times (250)^2}{2 \times 2000} = 15{\cdot}6$ m

Now Sag $S_2 = \frac{w\,x_2^2}{2T} = \frac{1 \times (450)^2}{2 \times 2000} = 50{\cdot}6$ m

Height of point *B* above mid-point *P*

$= S_2 - S_{mid} = 50{\cdot}6 - 15{\cdot}6 = 35$ m

$\therefore$ Clearance of mid-point *P* above water level

$= 90 - 35 =$ **55 m**

SHORT QUESTIONS:

Write the various type of supports are used in Overhead transmission line.

A. The various type of supports are used in Overhead transmission line are wooden poles, steel poles, R.C.C. poles and lattice steel towers.

What is String Efficiency **?**

A. The ratio of voltage across the whole string to the product of number of discs and the voltage across the disc nearest to the conductor is known as string efficiency
i.e., String efficiency =Voltage across the string / (n * Voltage across disc nearest to conductor)
where n = number of discs in the string.

Write the advantages of suspension type insulator.

A. The advantages of suspension type insulator are :

- Depending upon the working voltage, the desired number of discs can be connected in series.
- If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.
- The suspension arrangement provides greater flexibility to the line.

What is cross arm ?

A. The Cross arms which provide support to the insulators.

What is sag ?

A. The difference in level between points of supports and the lowest point on the conductor is called sag.

What are the factors affecting to the sag ?

A. The factors affecting to the sag are :

- Weight of the conductor.
- Span length.
- Working tensile strength.
- Temperature.

LONG QUESTION :

Name the important components of an overhead transmission line.
Discuss the various conductor materials used for overhead lines.
Discuss the various types of line supports.
Why are insulators used with overhead lines ? Discuss the desirable properties of insulators.
Discuss the advantages and disadvantages of (*i*) pin-type insulators (*ii*) suspension type insulators.
Deduce an approximate expression for sag in overhead lines when supports are at equal levels and unequal levels.
A transmission line has a span of 275 m between level supports. The conductor has an effective diameter of 1·96 cm and weighs 0·865 kg/m. Its ultimate strength is 8060 kg. If the conductor has ice coating of radial thickness 1·27 cm and is subjected to a wind pressure of 3·9 gm/ cm2 of projected area, calculate sag for a safety factor of 2. Weight of 1 c.c. of ice is 0·91 gm.

The towers of height 30 m and 90 m respectively support a transmission line conductor at water crossing. The horizontal distance betwen the towers is 500 m. If the tension in the conductor is 1600 kg, find the minimum clearance of the conductor and water and clearance mid-way betweenthe supports. Weight of conductor is 1·5 kg/m. Bases of the towers can be considered to be at water level.

An overhead transmission line at a river crossing is supported from two towers at heights of 40 m and 90 m above water level, the horizontal distance between the towers being 400 m. If the maximum allowable tension is 2000 kg, find the clearance between the conductor and water at a point mid-way between the towers. Weight of conductor is 1 kg/m.

CHAPTER-2

TRANSMISSION OF ELECTRIC POWER

Layout of transmission and distribution scheme. Or Electric supply system:

The conveyance of electric power from a power station to consumers Premises is known as electric supply system.

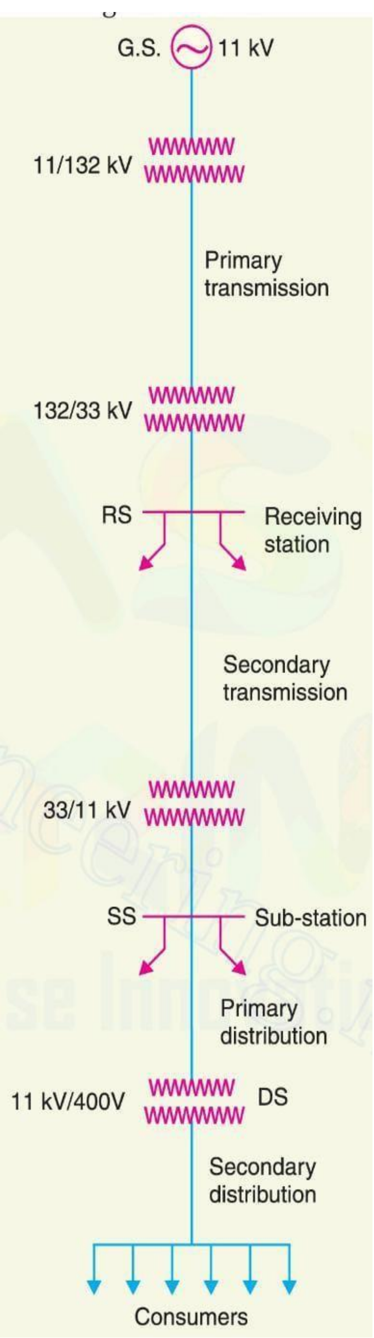
(i) Generating station : The generating station where electric power is produced by 3-phase alternators operating in parallel. The usual generation voltage is 11 kV. For economy in the transmission of electric power, the generation voltage (i.e., 11 kV) is stepped up to 132 kV (or more) at the generating station with the help of 3-phase transformers.

(ii) Primary transmission. The electric power at 132 Kv is transmitted by 3-phase, 3-wire overhead system to the outskirts of the city. This forms the primary transmission. Generally the primary transmission is carried at 66 kV, 132 kV, 220 kV or 400 kV.

(iii) Secondary transmission. At the receiving station, the voltage is reduced to 33kV by step-down transformers. From this station, electric power is transmitted at 33kV by 3-phase, 3-wire overhead system to various sub-stations (SS) located at the strategic points in the city. This forms the secondary transmission.

(iv) Primary distribution. The secondary transmission line terminates at the sub-station (SS) where voltage is reduced from 33 kV to 11kV, 3-phase, 3-wire. The 11 kV lines run along the important road sides of the city. This forms the primary distribution.

(v) Secondary distribution. The electric power from primary distribution line (11 kV) is delivered to distribution sub-stations (DS). These sub-stations are located near the consumers' localities and step down thevoltage to 400 V, 3-phase, 4-wire for secondary distribution.
The voltage between any two phases is 400 V and between any phase and neutral is 230 V. The single-phase residential lighting load is connected between any one phase and neutral, whereas 3-phase, 400 V motor load is connected across 3-phase lines directly.



Voltage Regulation :

The difference in voltage at the receiving end of a transmission line between conditions of no load and full load is called voltage regulation and is expressed as a percentage of the receiving end voltage.

Mathematically, % age Voltage regulation = $\frac{V_S - V_R}{V_R}*100$

Where Vs = Sending end voltage, V
V_R = Receiving end voltage, V

2.2 Transmission efficiency :

The ratio of receiving end power to the sending end power of a transmission line is known as the transmission efficiency of the line.

i.e. $$\%\text{ age Transmission efficiency, } \eta_T = \frac{\text{Receiving end power}}{\text{Sending end power}} \times 100$$
$$= \frac{V_R I_R \cos \phi_R}{V_S I_S \cos \phi_S} \times 100$$

where V_R, I_R and cos φ_R are the receiving end voltage, current and power factor while V_S, I_S and cos φ_S are the corresponding values at the sending end.

Kelvin's law for economical size of conductor. -

The most economical area of conductor is that for which the total annual cost of transmission line is minimum this is known as Kelvin's Law.

The cost of conductor material is generally a very considerable part of the total cost of a transmission line.

The total annual cost of transmission line can be divided broadly into two parts viz.,

i. Annual charge on capital outlay
ii. Annual cost of energy wasted in the conductor.

(i) Annual charge on capital outlay.

- This is on account of interest and depreciation on the capital cost of complete installation of transmission line.
- for an overhead line, insulator cost is constant, the conductor cost is proportional to the area of X-section and the cost of supports and their erection is partly constant and partly proportional to area of X-section of the conductor.
- Therefore, annual charge on an overhead transmission line can be expressed as :
  Annual charge = P1 + P2 a (i)
  where P_1 and P_2 are constants and "a" is the area of X-section of the conductor.

(ii) Annual cost of energy wasted.

- This is on account of energy lost mainly in the conductor due to I^2R losses.
- We know the energy lost in the conductor is inversely proportional to area of X-section. Thus, the annual cost of energy wasted in an overhead transmission line can be expressed as :

Annual cost of energy wasted = P3/a (ii)
where P3 is a constant.

Total annual cost, C = exp. (i) + exp. (ii)

$$= (P1 + P2\ a) + P3/a$$

$$C = P1 + P2\ a + P3/a \ldots \text{(iii)}$$

In eqn. (iii), only area of X-section a is variable. Therefore, the total annual cost of transmission line will be minimum if differentiation of C w.r.t. a is zero i.e.

$$\frac{d(c)}{da} = 0$$

$$\frac{d(P1 + P2\ a + P3/a)}{da} = 0$$

Or $P_2 – P_3/a = 0$

Or $P_2 = P_3/a$

or $P_2 = P_3/a$

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

Therefore Kelvin's Law can also be stated in an another way i.e. 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.

Corona and corona loss on transmission lines.

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

Factors Affecting Corona :

The following are the factors upon which corona depends :

(i) Atmosphere. As corona is formed due to ionization of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the stormy weather, the number of ions is more than normal and as such corona occurs at much less voltage as compared with fair weather.

(ii) Conductor size. The corona effect depends upon the shape and conditions of the conductors. The rough and irregular surface will give rise to more corona. A stranded conductor has irregular surface and hence gives rise to more corona that a solid conductor.

(iii) Spacing between conductors. If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect. It is because larger distance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.

(iv) Line voltage. The line voltage greatly affects corona. If it is low, there is no change in the condition of air surrounding the conductors and hence no corona is formed. However, if the line voltage has such a value that electrostatic stresses developed at the conductor surface make the air around the conductor conducting, then corona is formed.

Advantages:

(i) Due to corona formation, the air surrounding the conductor becomes conducting and hence virtual diameter of the conductor is increased. The increased diameter reduces the electrostatic stresses between the conductors.

(ii) Corona reduces the effects of transients produced by surges.

Disadvantages :

(i) Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.

(ii) Ozone is produced by corona and may cause corrosion of the conductor due to chemical action.

(iii) The current drawn by the line due to corona is non-sinusoidal and hence non-sinusoidal voltage drop occurs in the line. This may cause inductive interference with neighboring communication lines

Methods of Reducing Corona Effect :

The corona effects can be reduced by the following methods :

(i) By increasing conductor size. By increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. So ACSR conductors which have a larger cross-sectional area are used in transmission lines.

(ii) By increasing conductor spacing. By increasing the spacing between conductors, the voltage at which corona occurs is raised and hence corona effects can be eliminated.

Important terms:

Critical disruptive voltage: It is the minimum phase-neutral voltage at which corona occurs.

$$g = \frac{V}{r\log_e\frac{d}{r}}\ volts/cm$$

where g = potential gradient at the conductor surface or dielectric strength of air.
V= critical disruptive voltage.
d = space between conductors.
r = radius of conductor

and $g_o = \frac{VC}{r\log_e\frac{d}{r}}$

so $V_c = g_o r\log_e\frac{}{r}$ Kv/phase

where V_c = critical disruptive voltage.
G_o = break down strength of air at 76cm of mercury and 25c

$V_c = m_o g_o\,\delta r\log_e\frac{}{r}$ Kv/phase

Where m_o = irregularity factor of conductor.
= 1 for polished conductor
= 0.98 to 0.92 for dirty conductors
= 0.87 to 0.8 for stranded conductor.
δ= air density factor
= 1 for stranded conductor.

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

$$V_v = m_v g_o\,\delta\,r\left(1+\frac{0\cdot3}{\sqrt{\delta\,r}}\right)\log_e\frac{d}{r}\ \text{kV/phase}$$

m_o = irregularity factor of conductor.
= 1 for polished conductor
= 0.98 to 0.92 for dirty conductors
= 0.87 to 0.8 for stranded conductor.
δ= air density factor

Power loss due to corona. Formation of corona is always accompanied by energy loss which is dissipated in the form of light, heat, sound and chemical action.

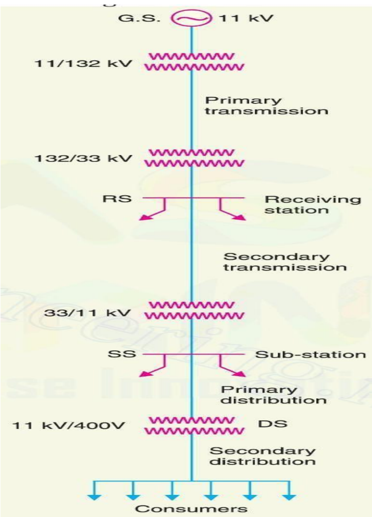
When disruptive voltage is exceeded, the power loss due to corona is given by :

$$P = 242\cdot2\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}\,(V-V_c)^2\times10^{-5}\ \text{kW / km / phase}$$

Where
f = supply frequency in Hz
V = phase-neutral voltage (r.m.s.)
V_c = disruptive voltage (r.m.s.) per phase

SHORT QUESTIONS:

Draw the lay out of electric supply system.



Define voltage regulation.

The difference in voltage at the receiving end of a transmission line between conditions of no load and full load is called voltage regulation and is expressed as a percentage of the receiving end voltage.

Mathematically, % age Voltage regulation = $\frac{V_S - V_R}{V_R} * 100$

Where Vs = Sending end voltage, V

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Define transmission efficiency.

The ratio of receiving end power to the sending end power of a transmission line is known as the transmission efficiency of the line.

i.e.

$$\% \text{ age Transmission efficiency, } \eta_T = \frac{\text{Receiving end power}}{\text{Sending end power}} \times 100$$

$$= \frac{V_R I_R \cos \phi_R}{V_S I_S \cos \phi_S} \times 100$$

where V_R, I_R and cos φ_R are the receiving end voltage, current and power factor while V_S, I_S and cos φ_S are the corresponding values at the sending end.

Q.4 What is corona ?

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

LONG QUESTIONS:

What is corona? What are the factors which affect corona ?

Discuss the advantages and disadvantages of corona.

Explain the following terms with reference to corona :

(i) Critical disruptive voltage

(ii) Visual critical voltage

(iii) Power loss due to corona

Describe the various methods for reducing corona effect in an overhead transmission line.

State and prove Kelvin’s law for size of conductor for transmission.

CHAPTER-4

PERFORMANCE OF SHORT & MEDIUM LINES

4.1 Classification of Overhead Transmission Lines

Depending upon the manner in which capacitance is taken into account, the overhead transmission lines are classified as :

(i) Short transmission lines.

- When the length of an overhead transmission line is upto about 50 km and the line voltage is comparatively low (< 20 kV) is called as short transmission line.
- Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected.
- Here only resistance and inductance of the line are taken into account.

(ii) Medium transmission lines.

- When the length of an overhead transmission line is about 50-150 km and the line voltage is moderaty high (>20 kV < 100 kV), it is considered as a medium transmission line.
- Due to sufficient length and voltage of the line, the capacitance effects are taken into account.
- Three parameters i.e Resistance, inductance and capacitance are taken into account while calculating performance of the transmission line.

(iii) Long transmission lines.

- When the length of an overhead transmission line is more than 150km and line voltage is very high (> 100 kV), it is considered as a long transmission line.
- For the treatment of such a line, the line constants are considered uniformly distributed over the whole length of the line and rigorous methods are employed for solution.

4.1 Important Terms

While studying the performance of a transmission line, it is desirable to determine its voltage regulation and transmission efficiency.

i. Voltage regulation.

The ratio between difference in voltage ($V_S - V_R$) to the receiving end voltage is called as voltage regulation.

Mathematically, % age Voltage regulation = $\frac{VS - VR}{VR}$ *100

Where Vs = Sending end voltage, V

V_R = Receiving end voltage, V

ii. Transmission efficiency :

The ratio of receiving end power to the sending end power of a transmission line is known as the transmission efficiency of the line.

i.e.

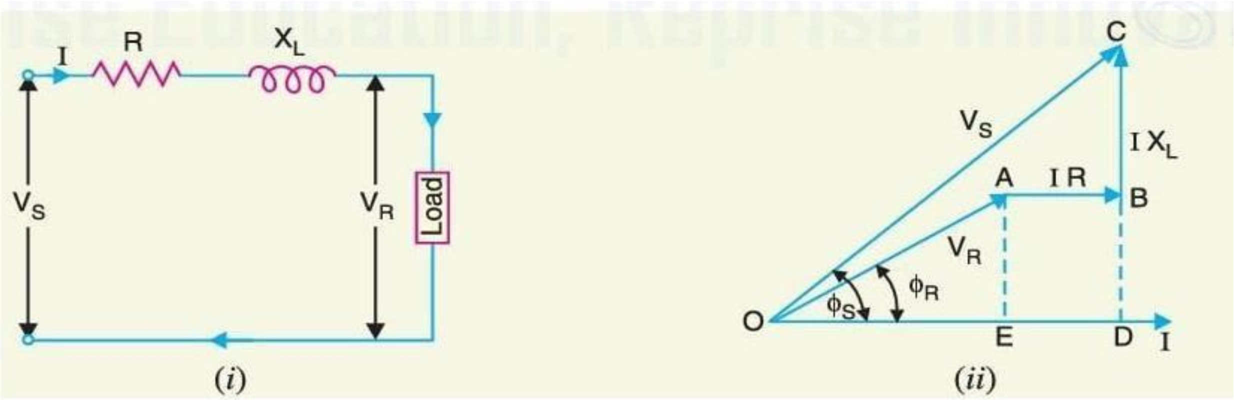
$$\%\text{ age Transmission efficiency, } \eta_T = \frac{\text{Receiving end power}}{\text{Sending end power}} \times 100$$

$$= \frac{V_R I_R \cos \phi_R}{V_S I_S \cos \phi_S} \times 100$$

where V_R, I_R and cos φ_R are the receiving end voltage, current and power factor while V_S, I_S and cos φ_S are the corresponding values at the sending end.

Performance of single phase short transmission line:

The equivalent circuit of a single phase short transmission line and the phasor diagram of the lagging load power factor are shown below :



let

I = load current

R = loop resistance *i.e.*, resistance of both conductors

X_L = loop reactance

V_R = receiving end voltage

$\cos \phi_R$ = receiving end power factor (lagging)

V_S = sending end voltage

$\cos \phi_S$ = sending end power factor

From the right angle triangle ODC, we get

$$(OC)^2 = (OD)^2 + (DC)^2$$

or

$$V_S^2 = (OE + ED)^2 + (DB + BC)^2$$

$$= (V_R \cos \phi_R + IR)^2 + (V_R \sin \phi_R + IX_L)^2$$

$$\therefore \quad V_S = \sqrt{\left(V_R \cos \phi_R + IR\right)^2 + \left(V_R \sin \phi_R + IX_L\right)^2}$$

(i) %age Voltage regulation $= \dfrac{V_S - V_R}{V_R} \times 100$

(ii) Sending end *p.f.*, $\cos \phi_S = \dfrac{OD}{OC} = \dfrac{V_R \cos \phi_R + IR}{V_S}$

(iii) Power delivered $= V_R I_R \cos \phi_R$

Line losses $= I^2 R$

Power sent out $= V_R I_R \cos \phi_R + I^2 R$

%age Transmission efficiency $= \dfrac{\text{Power delivered}}{\text{Power sent out}} \times 100$

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

Solution in complex notation. It is often convenient and profitable to make the line calculations in complex notation.

Taking $\vec{V_R}$ as the reference phasor, draw the phasor diagram as shown in Fig, It is clear that $\vec{V_S}$ is the phasor sum of $\vec{V_R}$ and $\vec{I}\,\vec{Z}$.

$$\begin{aligned}
\vec{V_R} &= V_R + j\,0 \\
\vec{I} &= \vec{I}\angle -\phi_R = I(\cos\phi_R - j\sin\phi_R) \\
\vec{Z} &= R + jX_L \\
\therefore \qquad \vec{V_S} &= \vec{V_R} + \vec{I}\,\vec{Z} \\
&= (V_R + j\,0) + I(\cos\phi_R - j\sin\phi_R)\,(R + j\,X_L)
\end{aligned}$$

Therefore, approximate expression for V_S becomes :

$$V_S = V_R + I\,R\cos\phi_R + I\,X_L\sin\phi_R$$

The expression for voltage regulation of a short transmission line is given by :

$$\%\text{age Voltage regulation} = \frac{I\,R\cos\phi_R + I\,X_L\sin\phi_R}{V_R}\times 100 \qquad (\textit{for lagging p.f.})$$

$$\%\text{age Voltage regulation} = \frac{I\,R\cos\phi_R - I\,X_L\sin\phi_R}{V_R}\times 100 \qquad (\textit{for leading p.f.})$$

The following conclusions can be drawn from the above expressions :

(i) When the load p.f. is lagging or unity or such leading that $I\,R\cos\phi_R > I\,X_L\sin\phi_R$, then voltage regulation is positive *i.e.*, receiving end voltage V_R will be less than the sending end voltage V_S.

(ii) For a given V_R and I, the voltage regulation of the line increases with the decrease in p.f. for lagging loads.

(iii) When the load p.f. is leading to this extent that $I\,X_L\sin\varphi_R > I\,R\cos\varphi_R$, then voltage regulation is negative *i.e.* the receiving end voltage V_R is more than the sending end voltage V_S.

(iv) For a given V_R and I, the voltage regulation of the line decreases with the decrease in p.f. for leading loads.

Problem-1:A single phase overhead transmission line delivers 1100 kW at 33 kV at 0·8 p.f. lagging. The total resistance and inductive reactance of the line are 10 Ω and 15 Ω respectively. Determine : (i) sending end voltage (ii) sending end power factor and (iii) transmission efficiency.

Solution.

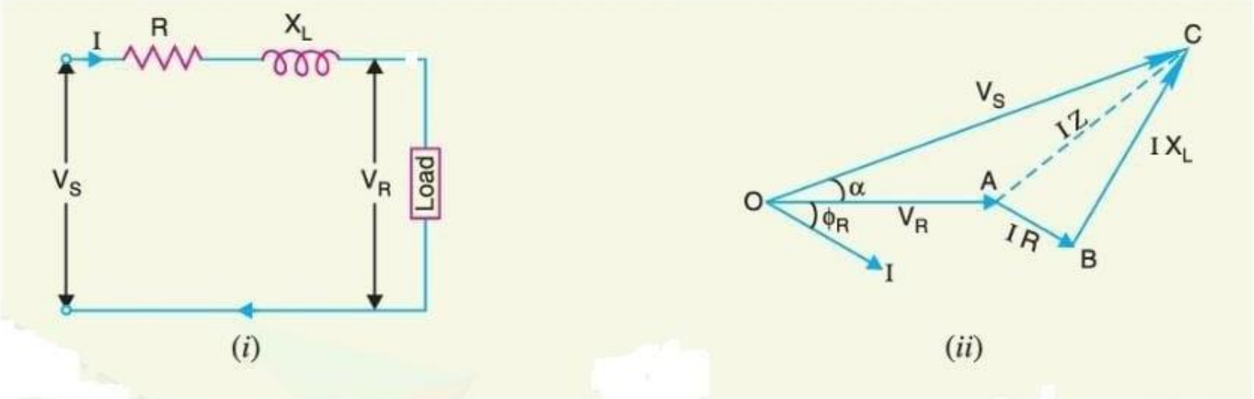
Load power factor, $\cos\phi_R = 0{\cdot}8$ lagging

Total line impedance, $\vec{Z} = R + jX_L = 10 + j\,15$

Receiving end voltage, $V_R = 33\text{ kV} = 33{,}000\text{ V}$

$$\therefore \quad \text{Line current, } I = \frac{kW \times 10^3}{V_R \cos\phi_R} = \frac{1100 \times 10^3}{33{,}000 \times 0{\cdot}8} = 41{\cdot}67\text{ A}$$

$$\text{As } \cos\phi_R = 0{\cdot}8 \quad \therefore \quad \sin\phi_R = 0{\cdot}6$$



(*i*) (*ii*)

The equivalent circuit and phasor diagram of the line are shown in Figs.

Taking receiving end voltage $\vec{V_R}$ as the reference phasor.

$$\vec{V_R} = V_R + j\,0 = 33000\text{ V}$$

$$\vec{I} = I(\cos\phi_R - j\sin\phi_R)$$

$$= 41{\cdot}67\,(0{\cdot}8 - j\,0{\cdot}6) = 33{\cdot}33 - j\,25$$

(*i*) Sending end voltage, $\vec{V_S} = \vec{V_R} + \vec{I}\,\vec{Z}$

$$= 33{,}000 + (33{\cdot}33 - j\,25{\cdot}0)\,(10 + j\,15)$$

$$= 33{,}000 + 333{\cdot}3 - j250 + j500 + 375$$

$$= 33{,}708{\cdot}3 + j\,250$$

$$\therefore \quad \text{Magnitude of } V_S = \sqrt{(33{,}708{\cdot}3)^2 + (250)^2} = \mathbf{33{,}709\text{ V}}$$

(*ii*) Angle between $\vec{V_S}$ and $\vec{V_R}$ is

$$\alpha = \tan^{-1}\frac{250}{33{,}708{\cdot}3} = \tan^{-1} 0{\cdot}0074 = 0{\cdot}42°$$

∴ Sending end power factor angle is

$$\phi_S = \phi_R + \alpha = 36{\cdot}87° + 0{\cdot}42° = 37{\cdot}29°$$

$$\therefore \quad \text{Sending end p.f., } \cos\phi_S = \cos 37{\cdot}29° = \mathbf{0{\cdot}7956\text{ lagging}}$$

(*iii*) Line losses $= I^2R = (41{\cdot}67)^2 \times 10 = 17{,}364\text{ W} = 17{\cdot}364\text{ kW}$

Output delivered = 1100 kW

Power sent = 1100 + 17·364 = 1117·364 kW

$$\therefore \quad \text{Transmission efficiency} = \frac{\text{Power delivered}}{\text{Power sent}} \times 100 = \frac{1100}{1117{\cdot}364} \times 100 = \mathbf{98{\cdot}44\%}$$

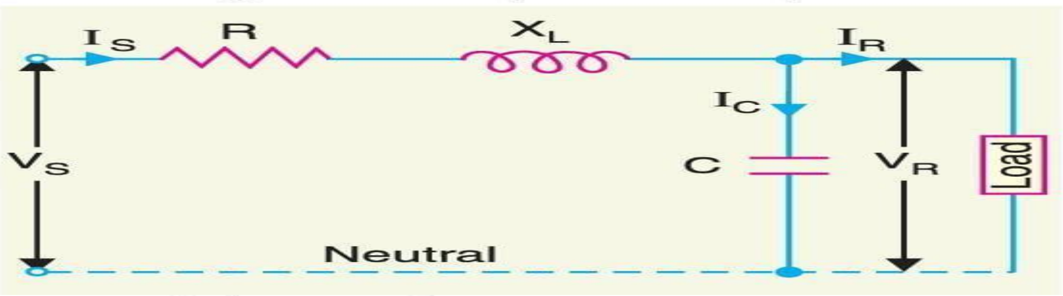
Performance of single phase medium transmission line:

There are three methods are used for the solution of medium transmission line, that are:

(i) End condenser method
(ii) Nominal T method
(iii) Nominal л method

1.End condenser method

The equivalent circuit of a single phase medium transmission line End condenser method are shown below :



Let I_R = load current per phase
R = resistance per phase
X_L = inductive reactance per phase
C = capacitance per phase
$\cos \phi_R$ = receiving end power factor (*lagging*)
V_S = sending end voltage per phase

The phasor diagram for the circuit is shown in Fig 1

Taking the receiving end voltage $\vec{V}_R$ as the reference phasor, we have, $\vec{V}_R = V_R + j\,0$

Load current, $\vec{I}_R = I_R\,(\cos \phi_R - j \sin \phi_R)$

Capacitive current, $\vec{I}_C = j\,\vec{V}_R\,\omega\,C = j\,2\,\pi\,f\,C\,\vec{V}_R$

The sending end current $\vec{I}_S$ is the phasor sum of load current $\vec{I}_R$ and capacitive current $\vec{I}_C$ *i.e.*,

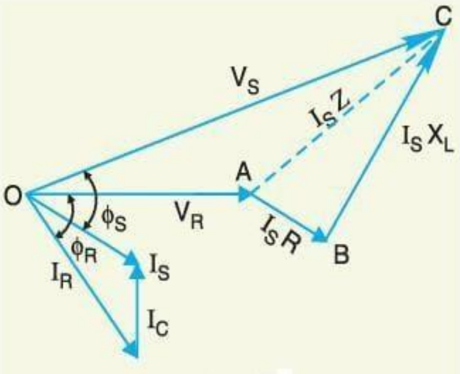


Fig. 1

$$\vec{I}_S = \vec{I}_R + \vec{I}_C$$
$$= I_R\,(\cos \phi_R - j \sin \phi_R) + j\,2\,\pi\,f\,C\,V_R$$
$$= I_R \cos \phi_R + j\,(-I_R \sin \phi_R + 2\,\pi\,f\,C\,V_R)$$

Voltage drop/phase $= \vec{I}_S\,\vec{Z} = \vec{I}_S\,(R + j X_L)$

Sending end voltage, $\vec{V}_S = \vec{V}_R + \vec{I}_S\,\vec{Z} = \vec{V}_R + \vec{I}_S\,(R + j\,X_L)$

Thus, the magnitude of sending end voltage V_S can be calculated.

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

$$\%\ \text{Voltage transmission efficiency} = \frac{\text{Power delivered / phase}}{\text{Power delivered / phase} + \text{losses / phase}} \times 100$$

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

Problem: 1 A (medium) single phase transmission line 100 km long has the following constants :

Resistance/km = 0·25ohm ; Reactance/km = 0·8ohm

Susceptance/km = 14 × 10−6 siemen ; Receiving end line voltage = 66,000 V

Assuming that the total capacitance of the line is localised at the receiving end alone, determine (i) the sending end current (ii) the sending end voltage (iii) regulation and (iv) supply power factor. The line is delivering 15,000 kW at 0.8 power factor lagging. Draw the phasor diagram to illustrate your calculations.

Solution: Total resistance, $R = 0{\cdot}25 \times 100 = 25\ \Omega$

Total reactance, $X_L = 0{\cdot}8 \times 100 = 80\ \Omega$

Total susceptance, $Y = 14 \times 10^{-6} \times 100 = 14 \times 10^{-4}\ S$

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

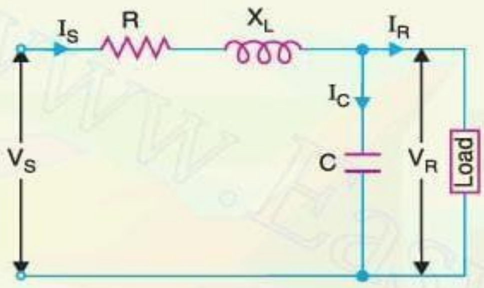
∴ Load current, $I_R = \dfrac{15{,}000 \times 10^3}{66{,}000 \times 0 \cdot 8} = 284$ A

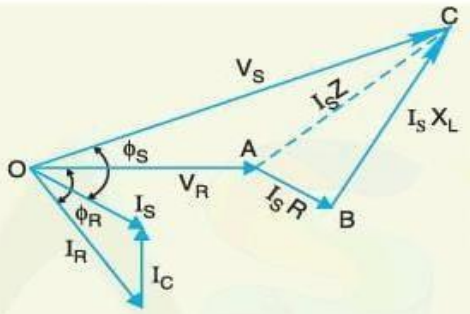
$\cos\phi_R = 0{\cdot}8\ ;\qquad \sin\phi_R = 0{\cdot}6$

Taking receiving end voltage as the reference phasor

$$\vec{V_R} = V_R + j0 = 66{,}000\,V$$

Load current, $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R) = 284\ (0{\cdot}8 - j0{\cdot}6) = 227 - j\,170$





Capacitive current, $\vec{I_C} = j\,Y \times V_R = j\,14 \times 10^{-4} \times 66000 = j\,92$

(i) Sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C} = (227 - j\,170) + j\,92$

$= 227 - j\,78$ ... (i)

Magnitude of $I_S = \sqrt{(227)^2 + (78)^2} =$ **240 A**

(ii) Voltage drop $= \vec{I_S}\,\vec{Z} = \vec{I_S}(R + j\,X_L) = (227 - j\,78)\ (25 + j\,80)$

$= 5{,}675 + j\,18,160 - j\,1950 + 6240$

$= 11{,}915 + j\,16{,}210$

Sending end voltage, $\vec{V_S} = \vec{V_R} + \vec{I_S}\,\vec{Z} = 66{,}000 + 11{,}915 + j\,16{,}210$

$= 77{,}915 + j\,16{,}210$ ...(ii)

Magnitude of $V_S = \sqrt{(77915)^2 + (16210)^2} =$ **79583V**

(iii) % Voltage regulation $= \dfrac{V_S - V_R}{V_R} \times 100 = \dfrac{79{,}583 - 66{,}000}{66{,}000} \times 100 =$ **20·58%**

(iv) phase angle between $\vec{V_R}$ and $\vec{I_R}$ is :

$\theta_1 = \tan^{-1} - 78/227 = \tan^{-1}(-0{\cdot}3436) = -18{\cdot}96°$

phase angle between $\vec{V_R}$ and $\vec{V_S}$ is :

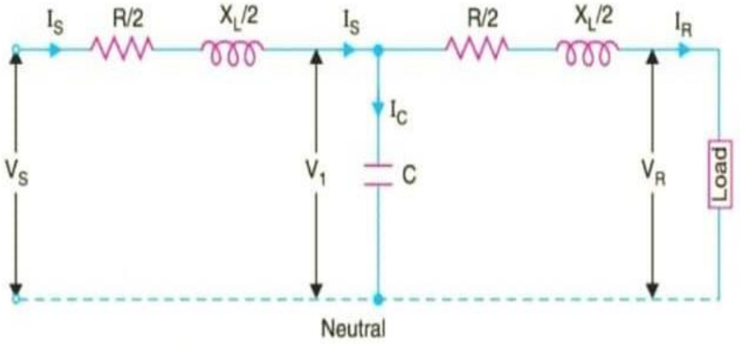
$\theta_2 = \tan^{-1}\dfrac{16210}{77915} = \tan^{-1}(0 \cdot 2036) = 11 \cdot 50°$

∴ Supply power factor angle, $\phi_S = 18{\cdot}96° + 11{\cdot}50° = 30{\cdot}46°$

∴ Supply p.f. $= \cos\phi_S = \cos 30{\cdot}46° =$ **0·86 lag**

2.Nominal T method:

The equivalent circuit of a single phase medium transmission line by nominal T method are shown below :



Let I_R = load current per phase ; R = resistance per phase

X_L = inductive reactance per phase ; C = capacitance per phase

$\cos\phi_R$ = receiving end power factor (*lagging*) ; V_S = sending end voltage/phase

V_1 = voltage across capacitor C

The phasor diagram for the circuit is shown in Fig. 1 . Taking the receiving end voltage $\vec{V_R}$ as the reference phasor, we have,

Receiving end voltage, $\vec{V_R} = V_R + j0$

Load current, $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

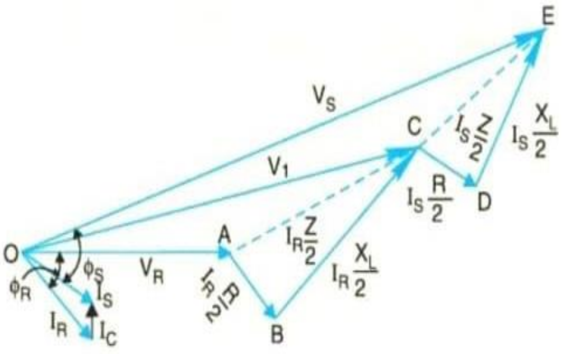


Fig. 1

Voltage across C,
$$\vec{V_1} = \vec{V_R} + \vec{I_R}\,\vec{Z}/2$$
$$= V_R + I_R(\cos\phi_R - j\sin\phi_R)\left(\frac{R}{2} + j\frac{X_L}{2}\right)$$

Capacitive current,
$$\vec{I_C} = j\omega C\vec{V_1} = j2\pi f C\,\vec{V_1}$$

Sending end current,
$$\vec{I_S} = \vec{I_R} + \vec{I_C}$$

Sending end voltage,
$$\vec{V_S} = \vec{V_1} + \vec{I_S}\,\frac{\vec{Z}}{2} = \vec{V_1} + \vec{I_S}\left(\frac{R}{2} + j\frac{X_L}{2}\right)$$

Problem: A 3-phase, 50 Hz transmission line 100 km long delivers 20 MW at 0·9 p.f. lagging and at 110 kV. The resistance and reactance of the line per phase per km are 0·2 Ω and 0·4 Ω respectively, while capacitance admittance is 2·5 × 10− 6 siemen/km/phase. Calculate : (i) the current and voltage at the sending end (ii) efficiency of transmission. Use nominal T method.

Solution.

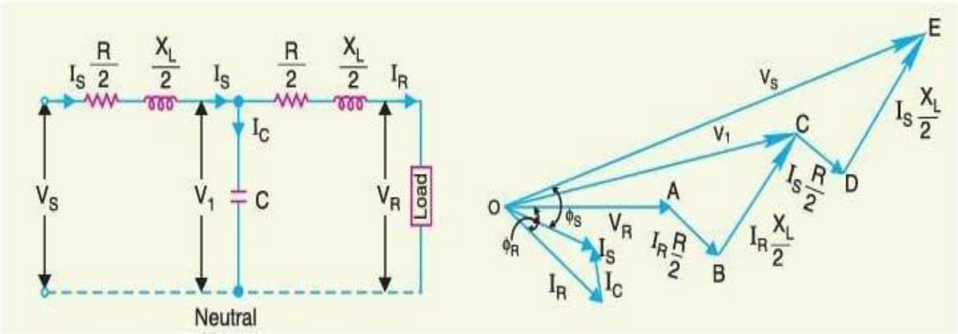
Given that

Total resistance/phase, $R = 0{\cdot}2 \times 100 = 20\ \Omega$

Total reactance/phase, $X_L = 0{\cdot}4 \times 100 = 40\ \Omega$

Total capacitance admittance/phase, $Y = 2{\cdot}5 \times 10^{-6} \times 100 = 2{\cdot}5 \times 10^{-4}$ S

Phase impedance, $\vec{Z} = 20 + j40$



Receiving end voltage/phase, $V_R = 110 \times 10^3/\sqrt{3} = 63508$ V

Load current, $I_R = \dfrac{20 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0{\cdot}9} = 116.6$ A

$\cos \phi_R = 0{\cdot}9\ ;\ \sin \phi_R = 0{\cdot}435$

(*i*) Taking receiving end voltage as the reference phasor

$\vec{V_R} = V_R + j0 = 63508$ V

Load current, $\vec{I_R} = I_R(\cos \phi_R - j \sin \phi_R) = 116{\cdot}6\ (0{\cdot}9 - j\,0{\cdot}435) = 105 - j50{\cdot}7$

Voltage across *C*, $\vec{V_1} = \vec{V_R} + \vec{I_R}\,\vec{Z}/2 = 63508 + (105 - j\,50{\cdot}7)\ (10 + j\,20)$

$= 63508 + (2064 + j1593) = 65572 + j1593$

Charging current, $\vec{I_C} = j\,Y\vec{V_1} = j\,2{\cdot}5 \times 10^{-4}\ (65572 + j1593) = -0{\cdot}4 + j\,16{\cdot}4$

Sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C} = (105 - j\,50{\cdot}7) + (-0{\cdot}4 + j16{\cdot}4)$

$= (104{\cdot}6 - j\,34{\cdot}3) = 110\ \angle -18°9'$ A

∴ Sending end current $=$ **110 A**

Sending end voltage, $\vec{V_S} = \vec{V_1} + \vec{I_S}\,\vec{Z}/2$

$= (65572 + j1593) + (104{\cdot}6 - j34{\cdot}3)\ (10 + j20)$

$= 67304 + j\,3342$

∴ Magnitude of $V_S = \sqrt{(67304)^2 + (3342)^2} = 67387\ V$

∴ Line value of sending end voltage

$= 67387 \times \sqrt{3} = 116717$ V $=$ **116·717 kV**

(*ii*) Total line losses for the three phases

$= 3\,I_S^2\,R/2 + 3I_R^2\,R/2$

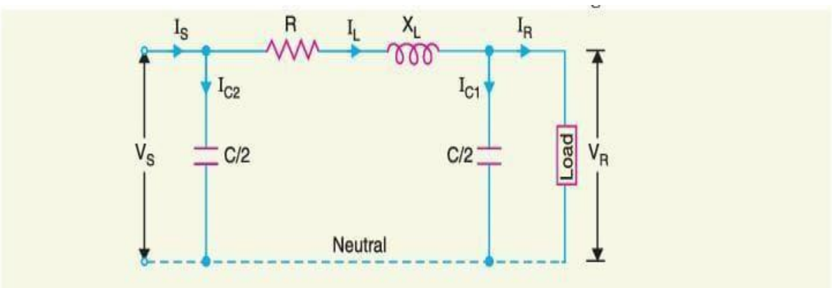
$= 3 \times (110)^2 \times 10 + 3 \times (116{\cdot}6)^2 \times 10$

$= 0{\cdot}770 \times 10^6$ W $= 0{\cdot}770$ MW

∴ Transmission efficiency $= \dfrac{20}{20 + 0{\cdot}770} \times 100 =$ **96·29%**

3.Nominal л method:

The equivalent circuit of a single phase medium transmission line by nominal л method are shown below :



let

I_R = load current per phase
R = resistance per phase
X_L = inductive reactance per phase
C = capacitance per phase
$\cos \phi_R$ = receiving end power factor (*lagging*)
V_S = sending end voltage per phase

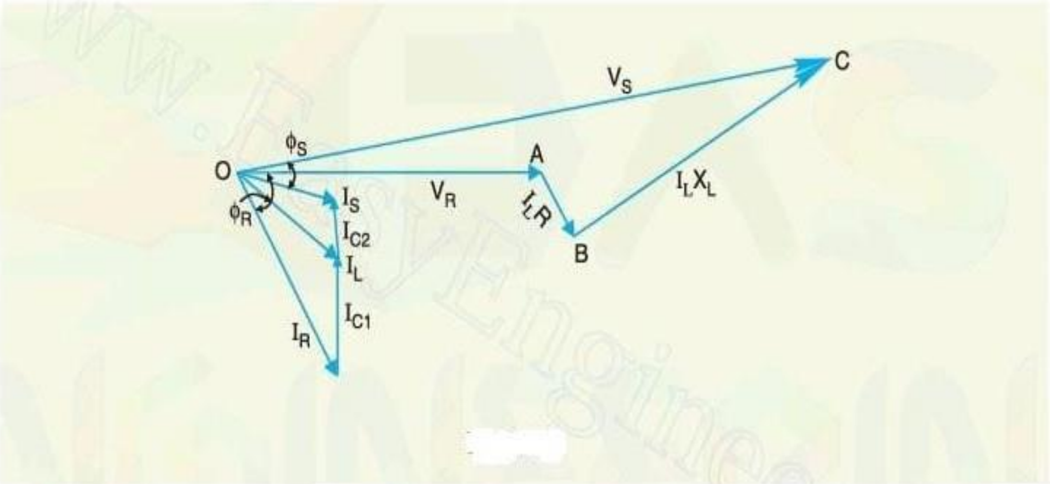
Taking the receiving end voltage as the reference phasor, we have,

$$\vec{V_R} = V_R + j0$$

Load current, $\vec{I_R} = I_R(\cos \phi_R - j \sin \phi_R)$

Charging current at load end is

$$\vec{I_{C1}} = j\omega(C/2)\vec{V_R} = j\pi f C \vec{V_R}$$



Line current, $\vec{I_L} = \vec{I_R} + \vec{I_{C1}}$

Sending end voltage, $\vec{V_S} = \vec{V_R} + \vec{I_L}\vec{Z} = \vec{V_R} + \vec{I_L}(R + jX_L)$

Charging current at the sending end is

$$\vec{I_{C2}} = j\omega(C/2)\vec{V_S} = j\pi f C \vec{V_S}$$

∴ Sending end current, $\vec{I_S} = \vec{I_L} + \vec{I_{C2}}$

Problem : A 3-phase, 50Hz, 150 km line has a resistance, inductive reactance and capacitive shunt admittance of 0·1 Ω, 0·5 Ω and 3 × 10−6 S per km per phase. If the line delivers 50 MW at 110 kV and 0·8 p.f. lagging, determine the sending end voltage and current. Assume a nominal π circuit for the line.

Solution:

Total resistance/phase, $R = 0{\cdot}1 \times 150 = 15\ \Omega$

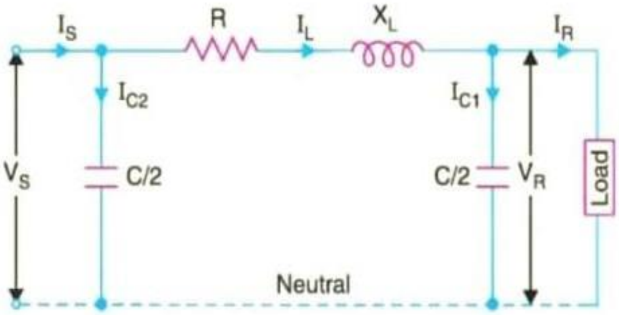
Total reactance/phase, $X_L = 0{\cdot}5 \times 150 = 75\ \Omega$

Capacitive admittance/phase, $Y = 3 \times 10^{-6} \times 150 = 45 \times 10^{-5}$ S

Receiving end voltage/phase, $V_R = 110 \times 10^3/\sqrt{3} = 63{,}508$ V

Load current, $I_R = \dfrac{50 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0{\cdot}8} = 328$ A

$\cos\phi_R = 0{\cdot}8\ ;\quad \sin\phi_R = 0{\cdot}6$



Taking receiving end voltage as the reference phasor, we have,

$$\vec{V}_R = V_R + j\,0 = 63{,}508 \text{ V}$$

Load current, $\vec{I}_R = I_R\,(\cos\phi_R - j\sin\phi_R) = 328\,(0{\cdot}8 - j0{\cdot}6) = 262{\cdot}4 - j196{\cdot}8$

Charging current at the load end is

$$\vec{I}_{C1} = \vec{V}_R\, j\,\frac{Y}{2} = 63{,}508 \times j\,\frac{45 \times 10^{-5}}{2} = j\,14{\cdot}3$$

Line current, $\vec{I}_L = \vec{I}_R + \vec{I}_{C1} = (262{\cdot}4 - j\,196{\cdot}8) + j\,14{\cdot}3 = 262{\cdot}4 - j\,182{\cdot}5$

Sending end voltage,
$$\begin{aligned}\vec{V}_S &= \vec{V}_R + \vec{I}_L\,\vec{Z} = \vec{V}_R + \vec{I}_L\,(R + j\,X_L)\\ &= 63,\,508 + (262{\cdot}4 - j\,182{\cdot}5)\;(15 + j\,75)\\ &= 63{,}508 + 3936 + j\,19{,}680 - j\,2737{\cdot}5 + 13{,}687\\ &= 81{,}131 + j\,16{,}942{\cdot}5 = 82{,}881\ \angle\ 11°47'\text{ V}\end{aligned}$$

∴ Line to line sending end voltage = 82,881 × √ 3 = 1,43,550 V = **143·55 kV**

Charging current at the sending end is

$$\begin{aligned}I_{C2} &= j\vec{V}_S\; Y/2 = (81{,}131 + j\,16{,}942\cdot 5)\; j\,\frac{45 \times 10^{-5}}{2}\\ &= -\,3{\cdot}81 + j\,18{\cdot}25\end{aligned}$$

Sending end current,
$$\begin{aligned}\vec{I}_S &= \vec{I}_L + \vec{I}_{C_2} = (262{\cdot}4 - j\,182{\cdot}5) + (-\,3{\cdot}81 + j\,18{\cdot}25)\\ &= 258{\cdot}6 - j\,164{\cdot}25 = 306{\cdot}4\ \angle -32{\cdot}4°\text{ A}\end{aligned}$$

∴ Sending end current = **306·4 A**

SHORT QUESTION:

Define voltage regulation.

The difference in voltage at the receiving end of a transmission line between conditions of no load and full load is called voltage regulation and is expressed as a percentage of the receiving end voltage.

Mathematically, % age Voltage regulation = $\frac{V_S - V_R}{V_R}$*100

Where Vs = Sending end voltage, V
V_R = Receiving end voltage, V

Define transmission efficiency.

The ratio of receiving end power to the sending end power of a transmission line is known as the transmission efficiency of the line.

i.e.

$$\text{\% age Transmission efficiency, } \eta_T = \frac{\text{Receiving end power}}{\text{Sending end power}} \times 100$$

$$= \frac{V_R I_R \cos\phi_R}{V_S I_S \cos\phi_S} \times 100$$

where V_R, I_R and cos φ_R are the receiving end voltage, current and power factor while V_S, I_S and cos φ_S are the corresponding values at the sending end.

LONG QUESTIONS:

A single phase overhead transmission line delivers 1100 kW at 33 kV at 0·8 p.f. lagging. The totalresistance and inductive reactance of the line are 10 Ω and 15 Ω respectively. Determine : (i) sending end voltage (ii) sending end power factor and (iii) transmission efficiency.

A (medium) single phase transmission line 100 km long has the following constants :
Resistance/km = 0·25ohm ; Reactance/km = 0·8ohm
Susceptance/km = 14 × 10–6 siemen ; Receiving end line voltage = 66,000 V
Assuming that the total capacitance of the line is localised at the receiving end alone, determine (i) the sending end current (ii) the sending end voltage (iii) regulation and (iv) supply power factor. The line is delivering 15,000 kW at 0.8 power factor lagging. Draw the phasor diagram to illustrate your calculations.

Problem: A 3-phase, 50 Hz transmission line 100 km long delivers 20 MW at 0·9 p.f. lagging and at 110 kV. The resistance and reactance of the line per phase per km are 0·2 Ω and 0·4 Ω respectively, while capacitance admittance is 2·5 × 10– 6 siemen/km/phase. Calculate : (i) the current and voltage atthe sending end (ii) efficiency of transmission. Use nominal T method.

A 3-phase, 50Hz, 150 km line has a resistance, inductive reactance and capacitive shunt admittance of 0·1 Ω, 0·5 Ω and 3 × 10–6 S per km per phase. If the line delivers 50 MW at 110 kVand 0·8 p.f. lagging, determine the sending end voltage and current. Assume a nominal π
circuit for the line

CHAPTER-5
EHV AC TRANSMISSION

EHV AC transmission :

- A transmission system is to transfer electrical power from one place to another or from one network to another network.
- In order to transmit large amounts of electric power over long distances extra high voltage (EVH) transmission lines are adopted.
- Extra-high voltage (EHV) facilitate transmission at 300Kv to 765KV.
- High voltage up to 300KV.
- Ultra high voltage(UHV) above 765KV.
- In India the transmission voltages in use are 33, 66, 110, 132, 220 and 400KV.

5.1..1. Reasons for adoption of EHV AC transmission.

The reasons for adoption of EHV AC transmission line are :

- Increase in transmission efficiency.
- Reduction of electrical power loss.
- Decrease in voltage drop and Improvement of voltage regulation.
- Reduction in conductor material requirement.
- Flexibility for future system growth.
- Increase in transmission capacity of the line.
- Possibility of interconnections of power systems.

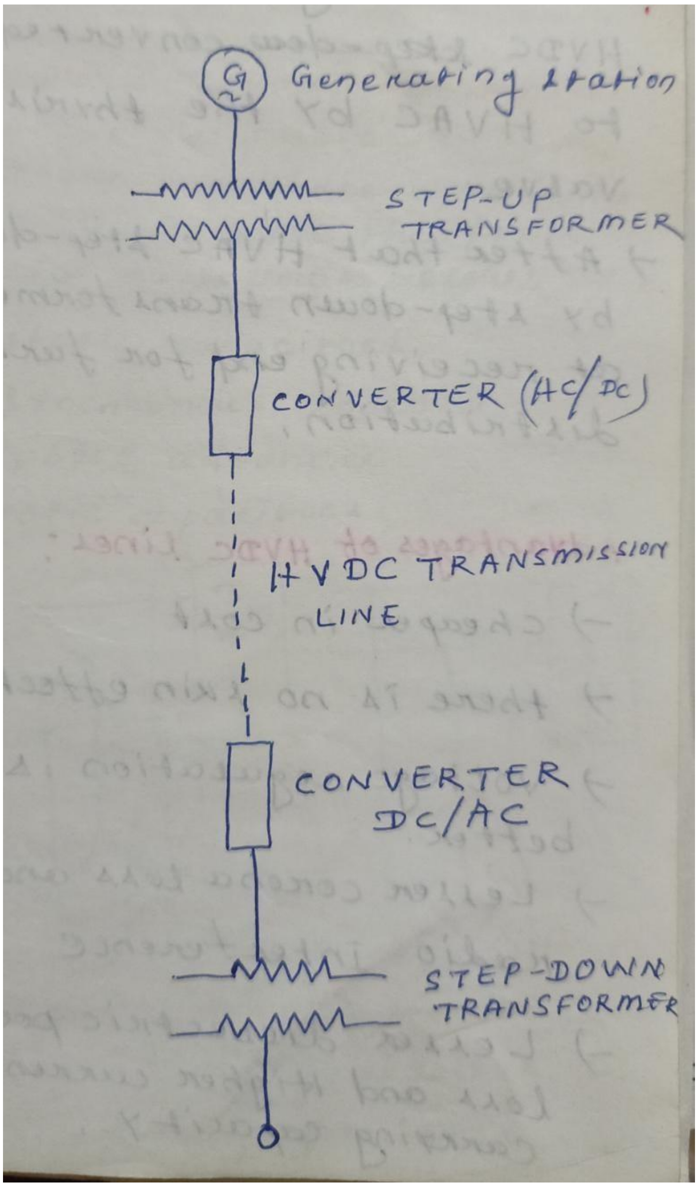
5.1..2. Problems involved in EHV transmission.

The problem associated with EHV transmission line are :

- There is high amount of power loss due to corona.
- Radio – interference occurs in EHV transmission line.
- Heavy supporting structure and erection difficulties arises.
- Level of insulation requirement increases.
- Erection difficulties.
- The cost of transformers, switchgear equipments and protective equipments increases with increase in transmission line voltage.
- The EHV lines generates electrostatic effects which are harmful to human beings and animals.

HVDC transmission line.

The single line diagram of HVDC transmission line is drawn below:



For HVDC transmission line the following points should be noted,

- The generating station generates 11KV AC voltage.
- The 11KV voltage is step up to 132KV(AC) by step up transformer.
- Then the high voltage AC is converted to high voltage DC by converter(rectifier).
- The HVDC power transmitted by bipolar lines called as HVDC transmission line.
- At the receiving end the HVDC converted to HVAC by the converter(inverter).
- After that HVAC stepped down by step-down transformer at receiving end for further distribution.

5.2..1. Advantages of HVDC transmission system.

The advantages of HVDC transmission system are:

- These systems are economical for bulk transmission of power for long distances as the cost of conductor reduces since d.c. system requires only two conductors.
- The cost of supporting towers and insulation is also reduced.

- The transmission losses are reduced.
- There are no stability problems with d.c. system. Hence asynchronous operation of transmission link is possible.
- Skin effect is also low in d.c. system.
- Greater power transmission per conductor is possible with d.c. system.
- The corona loss is low in d.c. systems.
- The radio interference with HVDC is less.
- Voltage regulation is better.
- The losses are less in transmission with d.c.
- With HVDC link there is easy reversibility and controllability of power flow.
- Intermediate substations are not required with HVDC transmission.
- Greater reliability than HVAC line.

5.2..1. Limitations of HVDC transmission system.

The limitation or dis-advantages of HVDC transmission system are:

- With multi terminal d.c. the circuit breaking is difficult and expensive.
- Overload capacity of HVDC converters is low.
- The maintenance of insulators in HVDC system is more.
- Voltage transformation is not easier in case of dc.
- There are additional losses in converter transformers and valves.

SHORT QUESTIONS :

Write the advantages of EHV AC transmission system.

The advantages of EHV AC transmission system are :

- Increase in transmission efficiency.
- Reduction of electrical power loss.
- Decrease in voltage drop and Improvement of voltage regulation.
- Reduction in conductor material requirement.

What are the problems involved with EHV transmission line ?The problem associated with EHV transmission line are :

- There is high amount of power loss due to corona.
- Radio – interference occurs in EHV transmission line.
- Heavy supporting structure and erection difficulties arises.
- Level of insulation requirement increases.

Write the advantages and disadvantages of HVDC transmission system.The advantages of HVDC transmission system are:

- These systems are economical for bulk transmission of power for long distances as the cost of conductor reduces since d.c. system requires only two conductors.
- The cost of supporting towers and insulation is also reduced.

The dis-advantages of HVDC transmission system are:

- With multi terminal d.c. the circuit breaking is difficult and expensive.
- Overload capacity of HVDC converters is low.

Long question

Q.1 With neat diagram explain about HVDC transmission line.

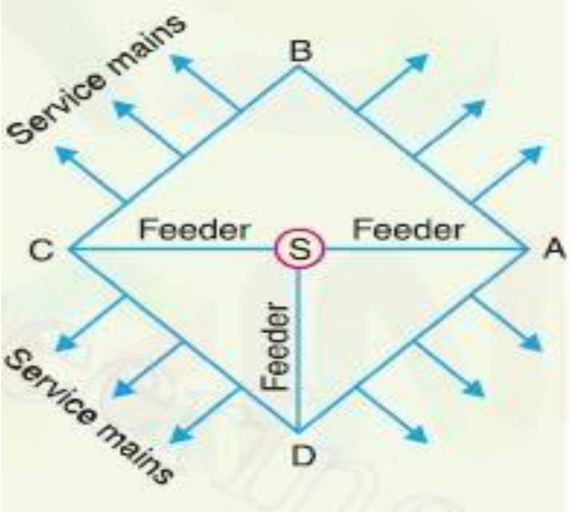
CHAPTER-6

DISTRIBUTION SYSTEMS

Introduction to Distribution System.

That part of power system which distributes electric power for local use is known as distribution system.

- It generally consists of feeders, distributors and the service mains.
- The single line diagram of a typical low tension distribution system is shown below.



(i) *Feeders.*

- A feeder is a conductor which connects the sub-station to the area where power is to be distributed.
- Generally, no tappings are taken from the feeder so that current in it remains the same throughout.
- The main consideration in the design of a feeder is the current carrying capacity.

(ii) *Distributor.*

- A distributor is a conductor from which tappings are taken for supply to the consumers.
- In above Fig. *AB*, *BC*, *CD* and *DA* are the distributors. The current through a distributor is not constant because tappings are taken at various places along its length.
- A distributor is designed from the point of view of the voltage drop in it.
- Here the limit of voltage variations is ± 6% of rated value at the consumers' terminals.

(iii) *Service mains.*

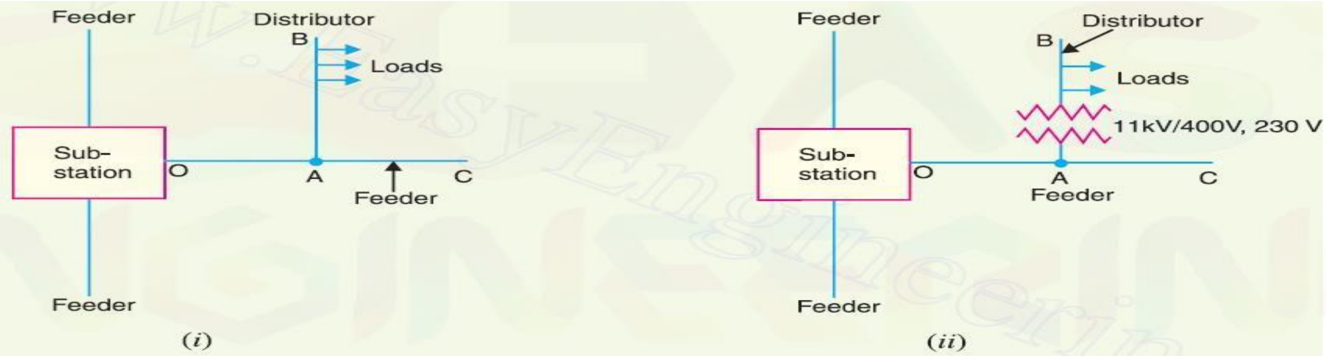
- A service mains is generally a small cable which connects the distributor to the consumers' terminals.

Connection Schemes of Distribution System:

All distribution of electrical energy is done by constant voltage system. The following distribution circuits are generally used :

(i) Radial System.

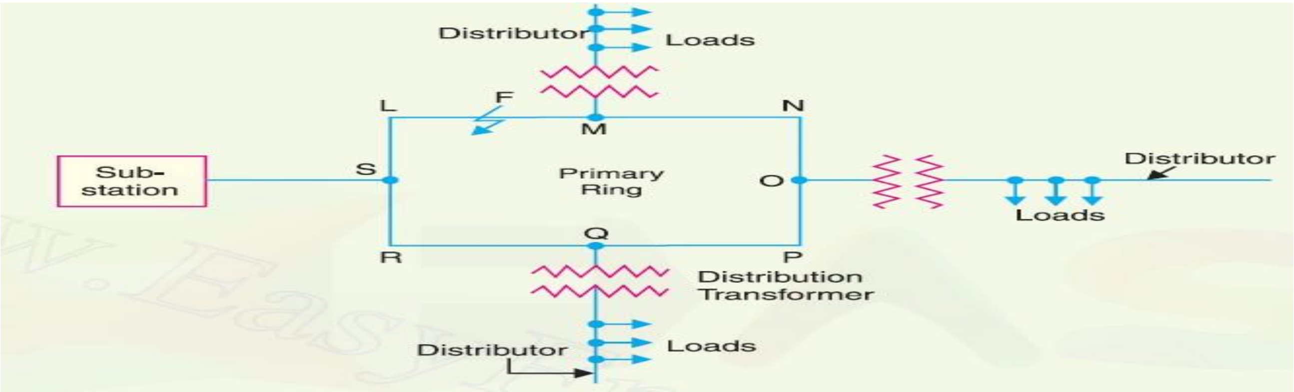
- In this system, separate feeders radiate from a single substation and feed the distributors at one end only.
- The single line diagram of a radial system for d.c. distribution where a feeder OC supplies a distributor AB at point A is shown in fig.-(i).
- The single line diagram of radial system for a.c. distributor is fed at one end only is shown in fig.(ii)
- The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.
- This is the simplest distribution circuit and has the lowest initial cost.
- The end of the distributor nearest to the feeding point will be heavily loaded.
- This system is used for short distances only.



(i) (ii)

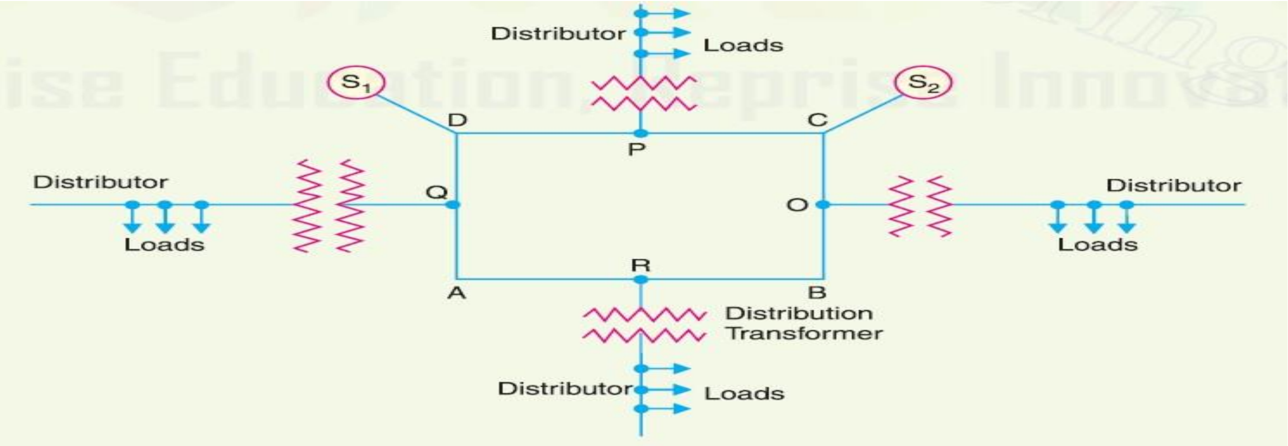
(ii) Ring main system.

- In this system, the primaries of distribution transformers form a loop.
- The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation.
- The single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS is shown below.
- The distributors are tapped from different points M, O and Q of the feeder through distribution transformers.
- There are less voltage fluctuations at consumer’s terminals.
- The system is very reliable as each distributor is fed via two feeders.



(iii) Interconnected system.

- When the feeder ring is energised by two or more than two generating stations or substations, it is called inter-connected system.
- The single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two substations S1 and S2 at points D and C respectively shown below.
- Distributors are connected to points O, P, Q and R of the feeder ring through distribution transformers.
- It increases the service reliability.



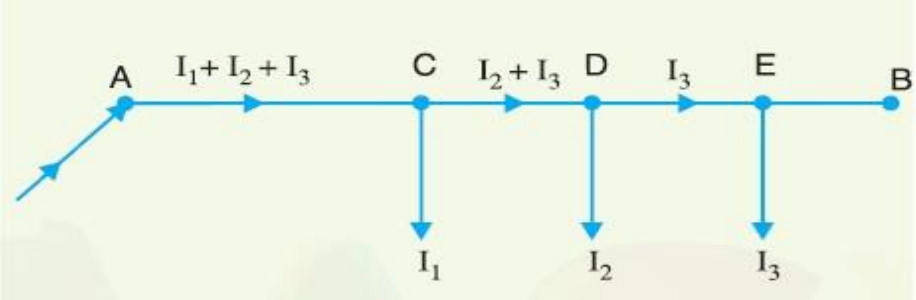
DC distributions.

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) Distributor fed at one end
(ii) Distributor fed at both ends
(iii) Distributor fed at the centre
(iv) Ring distributor.

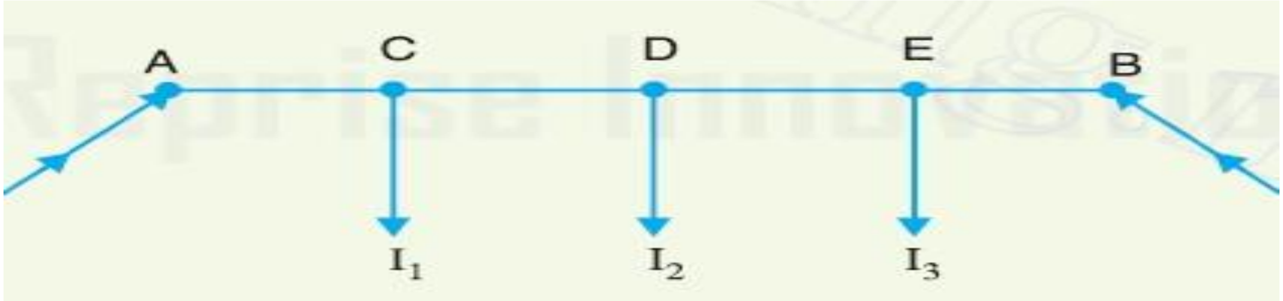
Distributor fed at one End.

- 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 single line diagram of a d.c. distributor AB fed at the end A and loads I_1, I_2 and I_3 tapped off at points C, D and E respectively.
- The current in the various sections of the distributor away from feeding point goes on decreasing.
- The voltage across the loads away from the feeding point goes on decreasing.
- In case a fault occurs on any section of the distributor, the whole distributor will have to be disconnected from the supply mains.



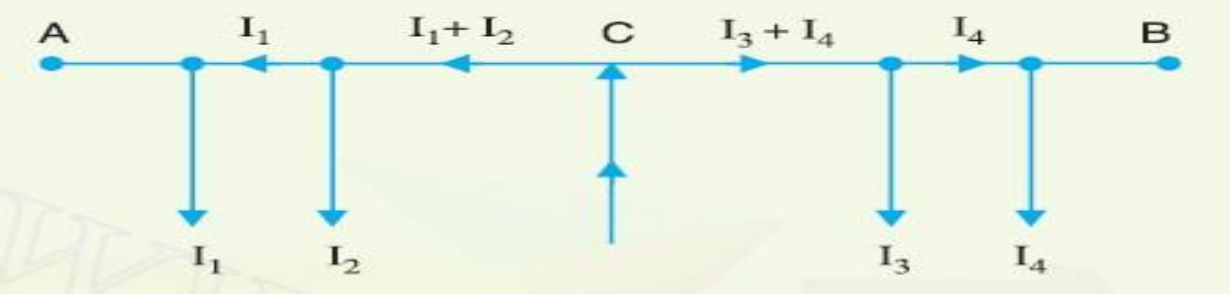
Distributor fed at both the ends.

- 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.
- The voltage at the feeding points may or may not be equal.
- The single line diagram of a distributor AB fed at the ends A and B and loads of I_1, I_2 and I_3 tapped off at points C, D and E respectively are shown below.
- 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.
- If a fault occurs on any feeding point of the distributor, the continuity of supply is maintained from the other feeding point.



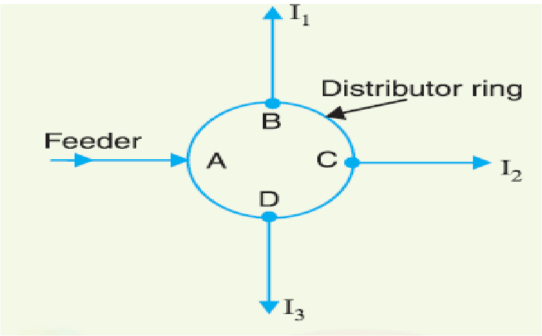
Distributor fed at the centre.

- 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.
- The single line diagram is shown below



Ring distributors.

- In this type, the distributor is in the form of a closed ring as shown in Fig. below.
- 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.

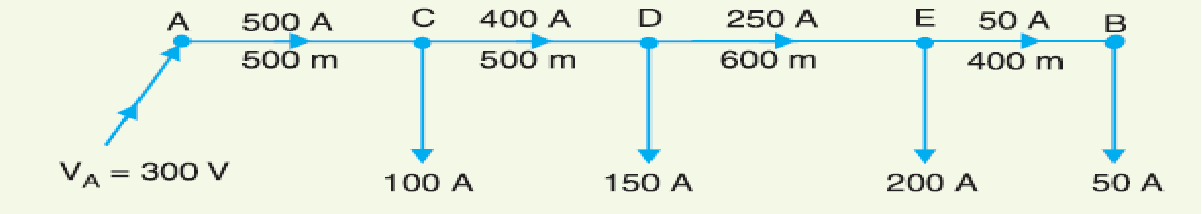


Problem-1

A 2-wire d.c. distributor cable AB is 2 km long and supplies loads of 100A,150A,200A and 50A situated 500 m, 1000 m, 1600 m and 2000 m from the feeding point A. Each conductor has a resistance of 0·01 Ω per 1000 m. Calculate the p.d. at each load point if a p.d. of 300 V is maintained at point A.

Solution.

The single line diagram of the distributor with its tapped currents are drawn below.



Resistance per 1000 m of distributor = 2 × 0·01 = 0·02 Ω

Resistance of section AC, $R_{AC} = 0{\cdot}02 \times 500/1000 = 0{\cdot}01\ \Omega$

Resistance of section CD, $R_{CD} = 0{\cdot}02 \times 500/1000 = 0{\cdot}01\ \Omega$

Resistance of section DE, $R_{DE} = 0{\cdot}02 \times 600/1000 = 0{\cdot}012\ \Omega$

Resistance of section EB, $R_{EB} = 0{\cdot}02 \times 400/1000 = 0{\cdot}008\ \Omega$

The currents in the various sections of the distributor are :

$I_{EB} = 50$ A

$I_{DE} = 50 + 200 = 250$ A

$I_{CD} = 250 + 150 = 400$ A

$I_{AC} = 400 + 100 = 500$ A

P.D. at load point C, V_C = Voltage at A − Voltage drop in AC

$= V_A - I_{AC} R_{AC}$

$= 300 - 500 \times 0{\cdot}01 = 295$ V

P.D. at load point D, $V_D = V_C - I_{CD} R_{CD}$

$= 295 - 400 \times 0{\cdot}01 = 291$ V

P.D. at load point E, $V_E = V_D - I_{DE} R_{DE}$

$= 291 - 250 \times 0{\cdot}012 = 288$ V

P.D. at load point B, $V_B = V_E - I_{EB} R_{EB}$

$= 288 - 50 \times 0{\cdot}008 = 287{\cdot}6$ V

Problem-2

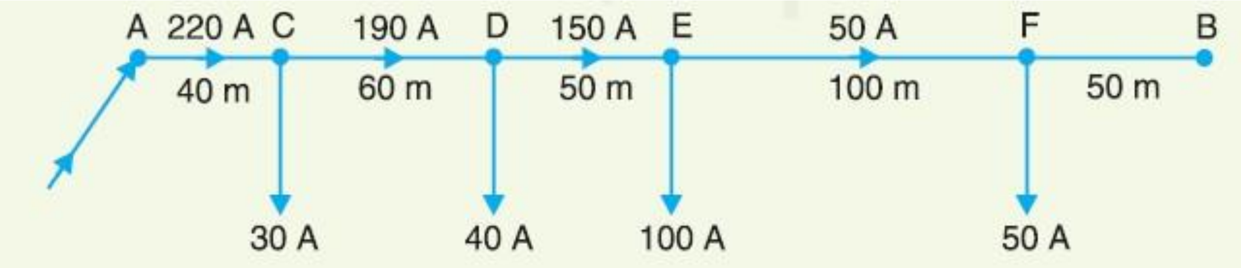
A 2-wire d.c. distributor AB is 300 metres long. It is fed at point A. The various loads and their positions are given below :

At point	distance from A in metres	concentrated load in amperes
C	40	30
D	100	40
E	150	100
F	250	50

If the maximum permissible voltage drop is not to exceed 10 V, find the cross-sectional area of the distributor. Take ρ = 1·78 × 10−8 Ωm.

Solution.

The single line diagram of the distributor along with its tapped currents is shown below.



Let resistance of 100 m length of the distributor is r ohms.
Then resistance of various sections of the distributor is :
$R_{AC} = 0\cdot4r\ \Omega$; $R_{CD} = 0\cdot6r\ \Omega$; $R_{DE} = 0\cdot5r\ \Omega$; $R_{EF} = r\ \Omega$
The currents in the various sections of the distributor are :
$I_{AC} = 220$ A ; $I_{CD} = 190$ A ; $I_{DE} = 150$ A ; $I_{EF} = 50$ A
Total voltage drop over the distributor = $I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE} + I_{EF} R_{EF}$
$= 220 \times 0\cdot4r + 190 \times 0\cdot6r + 150 \times 0\cdot5r + 50 \times r$
$= 327\ r$
As the maximum permissible drop in the distributor is 10 V,
$\therefore\ 10 = 327\ r$

Or $r = 10/327 = 0\cdot03058\ \Omega$

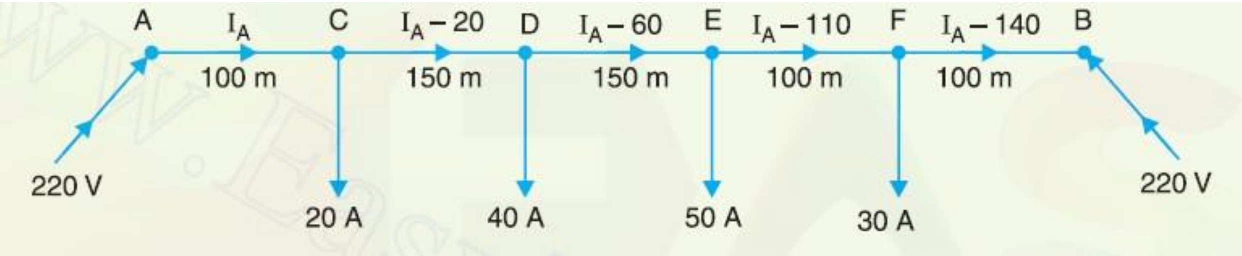
X-sectional area of conductor = $\dfrac{\rho l}{r/2} = \dfrac{1.78\times10^{-8}\times100}{\frac{0.03058}{2}} = 116.4\times10^{-6}\ \text{m}^2 = 1.164\ \text{cm}^2$

Problem-3

A 2-wire d.c. street mains AB, 600 m long is fed from both ends at 220 V. Loads of 20 A, 40 A, 50 A and 30 A are tapped at distances of 100m, 250m, 400m and 500 m from the end A respectively. If the area of X-section of distributor conductor is 1cm2, find the minimum consumer voltage. Take Take ρ = $1\cdot78 \times 10^{-6}$ Ωcm.

Solution.

Let I_A amperes be the current supplied from the feeding end A.
The currents in the various sections of the distributor are as shown in Fig. given below.



Resistance of 1 m length of distributor = $2 \times \frac{1.7\times10^{-6}\times100}{1} = 3.4 \times 10^{-4}\ \Omega$

Resistance of section AC, $R_{AC} = (3\cdot4 \times 10^{-4}) \times 100 = 0\cdot034\ \Omega$

Resistance of section CD, $R_{CD} = (3\cdot4 \times 10^{-4}) \times 150 = 0\cdot051\ \Omega$

Resistance of section DE, $R_{DE} = (3\cdot4 \times 10^{-4}) \times 150 = 0\cdot051\ \Omega$

Resistance of section EF, $R_{EF} = (3\cdot4 \times 10^{-4}) \times 100 = 0\cdot034\ \Omega$

Resistance of section FB, $R_{FB} = (3\cdot4 \times 10^{-4}) \times 100 = 0\cdot034\ \Omega$

Voltage at B = Voltage at A – Drop over length AB

or $V_B = V_A - [I_A R_{AC} + (I_A - 20) R_{CD} + (I_A - 60) R_{DE} + (I_A - 110) R_{EF} + (I_A - 140) R_{FB}]$

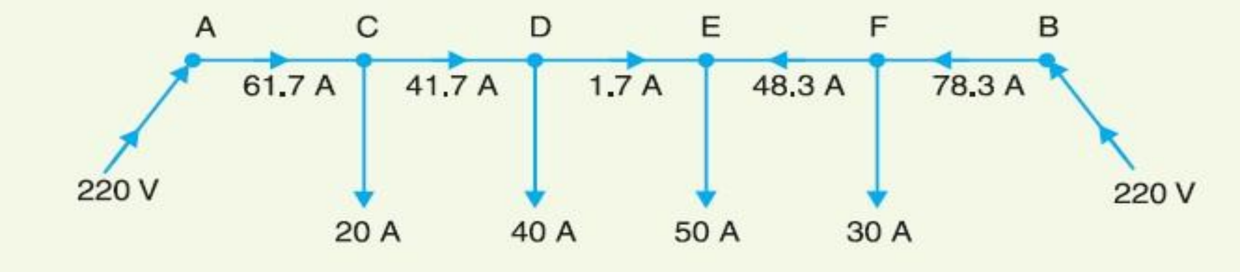
or $220 = 220 - [0\cdot034\ I_A + 0\cdot051\ (I_A - 20) + 0\cdot051\ (I_A - 60) + 0\cdot034\ (I_A - 110) + 0\cdot034\ (I_A - 140)]$

$= 220 - [0\cdot204\ I_A - 12\cdot58]$

or $0\cdot204\ IA = 12\cdot58$

$I_A = 12\cdot58/0\cdot204 = 61\cdot7$ A

The actual distribution of currents in the various sections of the distributor is shown in Fig.below



It is clear that currents are coming to load point E from both sides i.e. from point D and point F. Hence, E is the point of minimum potential.

Minimum consumer voltage,

$$V_E = V_A - [I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE}]$$

$$= 220 - [61\cdot7 \times 0\cdot034 + 41\cdot7 \times 0\cdot051 + 1\cdot7 \times 0\cdot051]$$

$$= 220 - 4\cdot31 = 215\cdot69\ V$$

Problem-4

A two-wire d.c. distributor AB, 600 metres long is loaded as under :

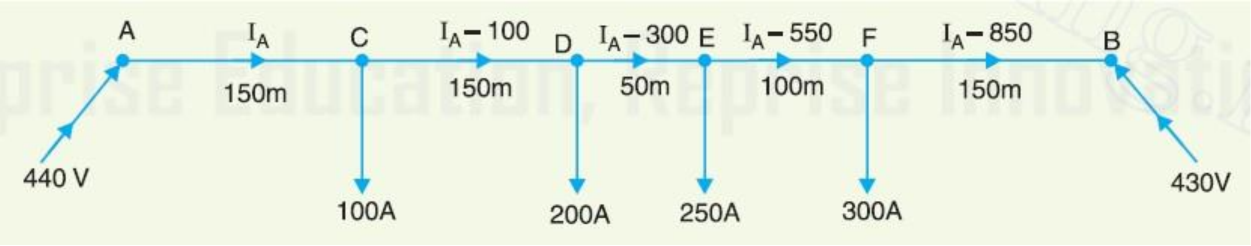
Distance from A (metres) :	150	300	350	450
Loads in Amperes :	100	200	250	300

The feeding point A is maintained at 440 V and that of B at 430 V. If each conductor has a resistance of 0·01 Ω per 100 metres, calculate :

(i) the currents supplied from A to B, (ii) the power dissipated in the distributor.

Solution.

Let I_A amperes be the current supplied from the feeding point A. Then currents in the various sections of the distributor are shown in Fig. below



Resistance of 100 m length of distributor (both wires) = 2 × 0·01 = 0·02 Ω

Resistance of section AC, R_{AC} = 0·02 × 150/100 = 0·03 Ω

Resistance of section CD, R_{CD} = 0·02 × 150/100 = 0·03 Ω

Resistance of section DE, R_{DE} = 0·02 × 50/100 = 0·01 Ω

Resistance of section EF, R_{EF} = 0·02 × 100/100 = 0·02 Ω

Resistance of section FB, R_{FB} = 0·02 × 150/100 = 0·03 Ω

Voltage at B = Voltage at A — Drop over AB

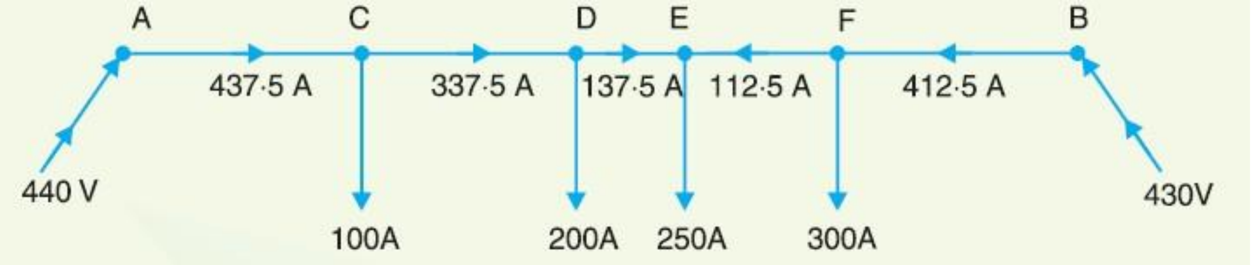
or $V_B = V_A - [I_A R_{AC} + (I_A - 100) R_{CD} + (I_A - 300) R_{DE} + (I_A - 550) R_{EF} + (I_A - 850) R_{FB}]$

$430 = 440 - [0{\cdot}03\, I_A + 0{\cdot}03\, (I_A - 100) + 0{\cdot}01\, (I_A - 300) + 0{\cdot}02\, (I_A - 550) + 0{\cdot}03\, (I_A - 850)]$

or $430 = 440 - [0{\cdot}12\, I_A - 42{\cdot}5]$

$$\therefore IA = \frac{482.5 - 430}{0.12} = 437{\cdot}5 \text{ A}$$

The actual distribution of currents in the various sections of the distributor is shown in Fig.below and E is the point of minimum potential.



(i) From the Fig. Current supplied from end A, I_A = 437·5 A

Current supplied from end B, I_B = 412·5 A

(ii) Power loss in the distributor

$= I^2_{AC} R_{AC} + I^2_{CD} R_{CD} + I^2_{DE} R_{DE} + I^2_{EF} R_{EF} + I^2_{FB} R_{FB}$

= (437·5)2 × 0·03 + (337·5)2 × 0·03 + (137·5)2 × 0·01 + (112·5)2 × 0·02 + (412·5)2 × 0·03

= 5742 + 3417 + 189 + 253 + 5104 = 14,705 watts = 14·705 Kw

A.C distribution system.

- The electrical energy produced at the power station is transmitted at very high voltages by 3-phase, 3-wire system to step-down sub-stations for distribution.
- The distribution system consists of two parts i.e. primary distribution and secondary distribution.
- The primary distribution circuit is 3-phase, 3-wire and operates at voltages (3·3 or 6·6 or 11kV) somewhat higher than general utilization levels.
- It delivers power to the secondary distribution circuit through distribution transformers situated near consumers' localities. Each distribution transformer steps down the voltage to 400 V and power is distributed to ultimate consumers' by 400/230 V, 3-phase, 4-wire system.

A.C. Distribution Calculations :

A.C. distribution calculations differ from those of d.c. distribution in the following respects :

(i) In case of d.c. system, the voltage drop is due to resistance alone. However, in a.c. system, the voltage drops are due to the combined effects of resistance, inductance and capacitance.

(ii) In a d.c. system, additions and subtractions of currents or voltages are done arithmetically but in case of a.c. system, these operations are done vectorically.

(iii) In an a.c. system, power factor (p.f.) has to be taken into account.

Method of solving AC distribution problem.

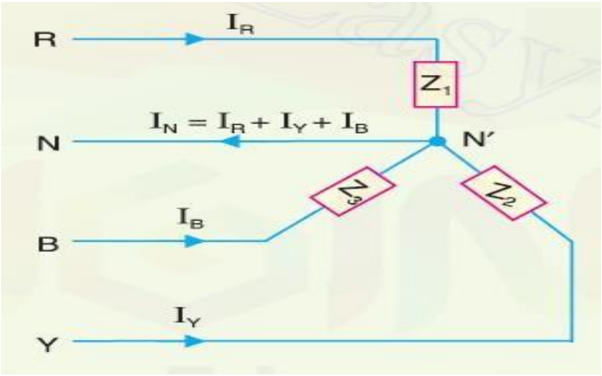
In a.c. distribution calculations, power factors of various load currents have to be considered since currents in different sections of the distributor will be the vector sum of load currents and not the arithmetic sum. The power factors of load currents may be given (i) w.r.t. receiving or sending end voltage or (ii) w.r.t. to load voltage itself.

(i) Power factors referred to receiving end voltage.

(ii) Power factors referred to respective load voltage.

Three phase four wire star connected system arrangement.

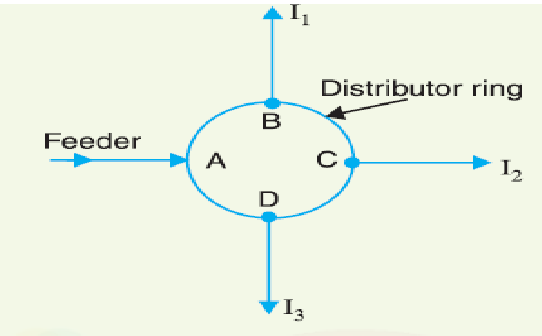
- In the Star Connection, the similar ends (either start or finish) of the three windings are connected to a common point called star or neutral point.
- This system uses star connected phase windings and the fourth wire or neutral wire is taken from the star point.
- If the voltage of each winding is V, then the line-to-line voltage (line voltage) is √3V and the line-to-neutral voltage (phase voltage) is V.



- The voltage across each impedance is equal to the phase voltage of the supply. However, current in each phase (or line) will be different due to unequal impedances.
- The amount of current flowing in the neutral wire will depend upon the magnitudes of line currents and their phasor relations. The neutral current is equal to or smaller than one of the line currents.

SHORT QUESTIONS:

Draw the single line diagram of ring main system ?



What are the various methods adopted for DC distribution system ?The various methods adopted for DC distribution system are:

(i) Distributor fed at one end
(ii) Distributor fed at both ends
(iii) Distributor fed at the centre
(iv) Ring distributor.

Define feeder and Distributor.

A feeder is a conductor which connects the sub-station to the area where power is to be distributed.

A distributor is a conductor from which tappings are taken for supply to the consumers.

Write the advantages of interconnection of power system.The advantages of interconnection of power system are:

- Exchange of power can be possible at peak load.
- Economical operation can be ensured.
- Diversity factor will increase.
- Plant reserve capacity will be reduced.

LONG QUESTIONS:

Write short notes on Ring main distribution system.

A 2-wire d.c. distributor cable AB is 2 km long and supplies loads of 100A,150A,200A and 50A situated 500 m, 1000 m, 1600 m and 2000 m from the feeding point A. Each conductor has a resistance of 0·01 Ω per 1000 m. Calculate the p.d. at each load point if a p.d. of 300 V is maintained at point A.

A 2-wire d.c. distributor AB is 300 metres long. It is fed at point A. The various loads and their positions are given below :

At point	distance from A in metres	concentrated load in amperes
C	40	30
D	100	40
E	150	100
F	250	50

If the maximum permissible voltage drop is not to exceed 10 V, find the cross-sectional area of the distributor. Take ρ = 1·78 × 10−8 Ωm.

A 2-wire d.c. street mains AB, 600 m long is fed from both ends at 220 V. Loads of 20 A, 40A, 50 A and 30 A are tapped at distances of 100m, 250m, 400m and 500 m from the end A respectively. If the area of X-section of distributor conductor is 1cm2, find the minimum consumer voltage. Take Take $\rho = 1 \cdot 78 \times 10^{-6}$ Ωcm.

A two-wire d.c. distributor AB, 600 metres long is loaded as under :

Distance from A (metres) :	150	300	350	450
Loads in Amperes :	100	200	250	300

The feeding point A is maintained at 440 V and that of B at 430 V. If each conductor has a resistance of 0·01 Ω per 100 metres, calculate :

(i) the currents supplied from A to B, (ii) the power dissipated in the distributor.

CHAPTER-7
UNDERGROUND CABLES

Underground Cables :

An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.

The type of cable to be used will depend upon the working voltage and service requirements.

A cable must fulfil the following necessary requirements :

- (i) The conductor used in cables should be tinned stranded copper or aluminium of high conductivity.
- (ii) Stranding is done so that conductor may become flexible and carry more current.
- (iii) The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.
- (iv) The cable must have proper thickness of insulation in order to give high degree of safety and reliability.
- (v) The cable must be provided with suitable mechanical protection .

Cable insulation :

In general, the insulating materials used in cables should have the following properties :

- ***(i)*** High insulation resistance to avoid leakage current.
- ***(ii)*** High dielectric strength to avoid electrical breakdown of the cable.
- ***(iii)*** High mechanical strength to withstand the mechanical handling of cables.
- ***(iv)*** Non-hygroscopic *i.e.*, it should not absorb moisture from air or soil.
- ***(v)*** Non-inflammable.
- ***(vi)*** Low cost .
- ***(vii)*** Unaffected by acids and alkalis to avoid any chemical action.

The principal insulating materials used in cables are :

1. Rubber
2. Vulcanized India Rubber (*V.I.R.*).
3. Impregnated paper.
4. Varnished cambric.
5. Polyvinyl chloride (*PVC*).

Classification of Cables

Cables for underground service may be classified in two ways according to (i) the type of insulating material (ii) the voltage for which they are manufactured. according to which cables can be divided into the following groups :

(i) Low-tension (L.T.) cables — up to 1000 V
(ii) High-tension (H.T.) cables — up to 11,000 V
(iii) Super-tension (S.T.) cables — from 22 kV to 33 kV
(iv) Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
(v) Extra super voltage cables — beyond 132 kV

- A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (i) single-core (ii) two-core (iii) three-core (iv) four-core etc.

Types of L. T. & H.T. cables with constructional features.

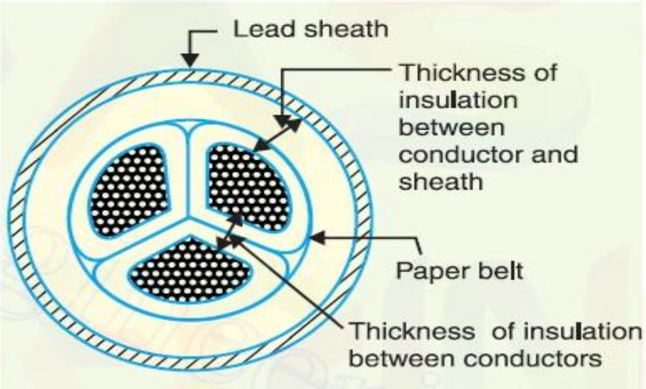
Underground cables are generally deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used.

The following types of cables are generally used for 3-phase service :

1. Belted cables — up to 11 kV
2. Screened cables — from 22 kV to 66 kV
3. Pressure cables — beyond 66 kV.

1. Belted cables.

- These cables are used for voltages up to 11kV but in extraordinary cases, their use may be extended upto 22kV.
- The cores are insulated from each other by layers of impregnated paper.
- Another layer of impregnated paper tape, called paper belt is wound round the grouped insulated cores.
- The gap between the insulated cores is filled with fibrous insulating material (jute etc.) so as to give circular cross-section to the cable.
- The belt is covered with lead sheath to protect the cable against ingress of moisture and mechanical injury.



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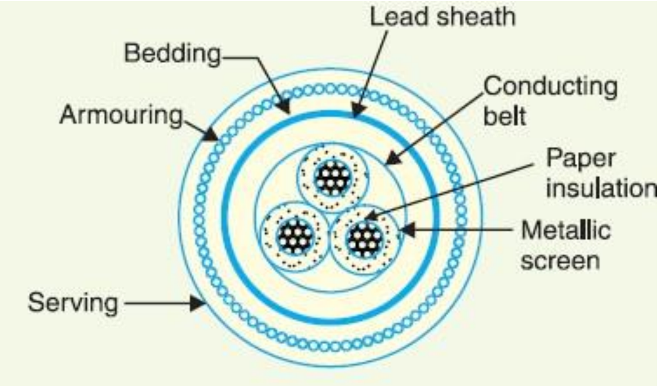
2. Screened cables.

- These cables are meant for use up to 33 kV, but in particular cases their use may be extended to operating voltages up to 66 kV.
- Two principal types of screened cables are H type cables and S.L. type cables.

(i) H-type cables.

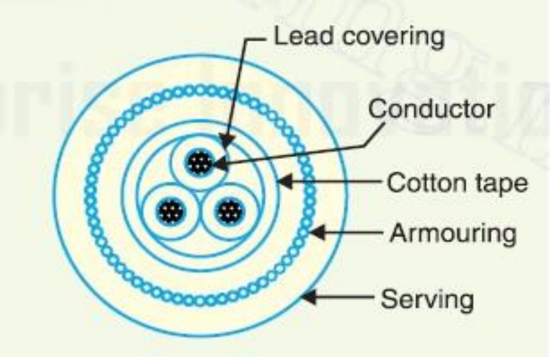
- This type of cable was first designed by H. Hochstadter and hence the name.
- Each core is insulated by layers of impregnated paper.
- The insulation on each core is covered with a metallic screen which usually consists of a perforated aluminium foil.
- The cores are laid in such a way that metallic screens make contact with one another.
- The cable has no insulating belt but lead sheath, bedding, armouring and serving follow as usual.



(H-Type)

(ii) S.L. type cables.

- It is basically H-type cable but the screen round each core insulation is covered by its own lead sheath.
- There is no overall lead sheath but only armouring and serving are provided.
- The three lead sheaths of S.L. cable are much thinner than the single sheath of H-cable .



(S.L Type)

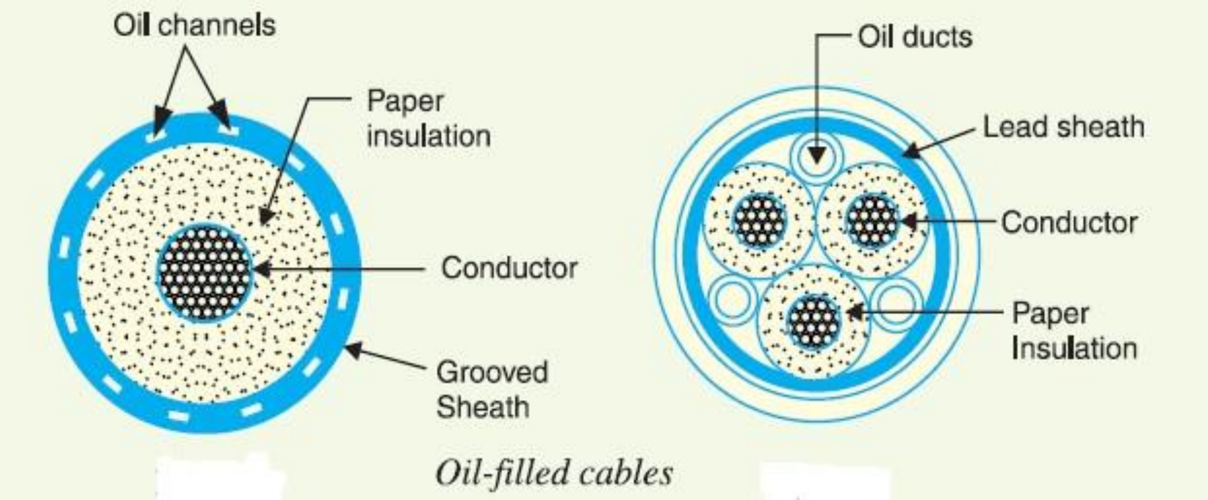
3. Pressure cables

- When the operating voltages are greater than 66 kV, pressure cables are used.
- In such cables, voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables.

Two types of pressure cables i.e oil-filled cables and gas pressure cables.

(i) Oil-filled cables.

- In such types of cables, channels or ducts are provided in the cable for oil circulation.
- The oil under pressure is kept constantly supplied to the channel by means of external reservoirs placed at suitable distances (say 500 m) along the route of the cable.
- Oil under pressure compresses the layers of paper insulation and is forced into any voids that may have formed between the layers.
- Due to the elimination of voids, oil-filled cables can be used for higher voltages, the range being from 66 kV upto 230 kV.
- Oil-filled cables are of three types i.e single-core conductor channel, single-core sheath channel and three-core filler-space channels.

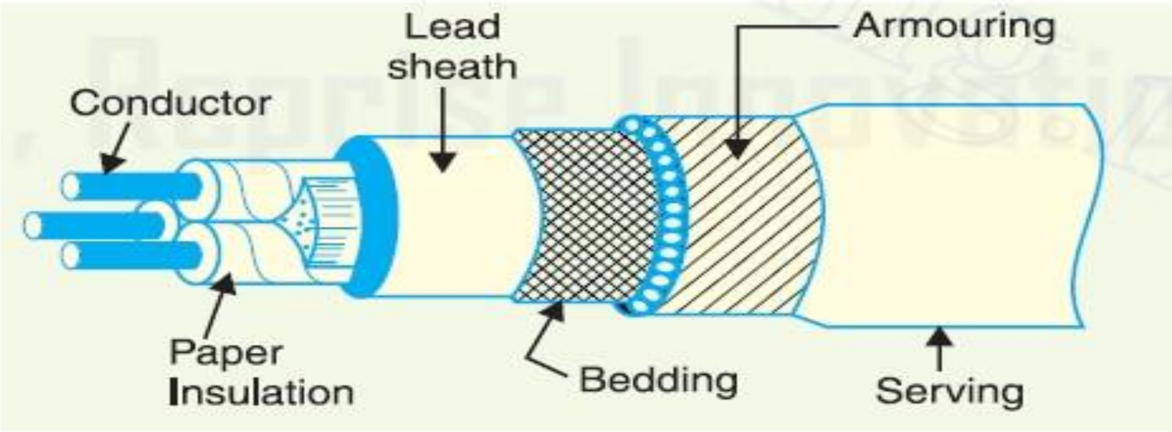


Oil-filled cables

(ii) Gas pressure cables.

- The voltage required to set up ionisation inside a void increases as the pressure is increased. Therefore, if ordinary cable is subjected to a sufficiently high pressure, the ionisation can be altogether eliminated.
- The increased pressure produces radial compression which tends to close any voids. This is the underlying principle of gas pressure cables.
- The construction of the cable is similar to that of an ordinary solid type except that it is of triangular shape and thickness of lead sheath is 75% that of solid cable.
- The triangular section reduces the weight and gives low thermal resistance but the main reason for triangular shape is that the lead sheath acts as a pressure membrane.
- The sheath is protected by a thin metal tape.
- The cable is laid in a gas-tight steel pipe.
- The pipe is filled with dry nitrogen gas at 12 to 15 atmospheres.

Construction of Cables



The various parts of construction of a 3-conductor cable are :

1) Cores or Conductors.

- A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended.
- The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable.

2) Insulatian.

- Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable.
- The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound.

3) Metallic sheath.

- In order to protect the cable from moisture, gases or other damaging liquids (acids or alkalies) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation.

4) Bedding.

- Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape.
- The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

5) Armouring.

- Over the bedding, armouring is provided which consists of one or two layers of galvanised steel wire or steel tape.
- Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling.
- Armouring may not be done in the case of some cables.

6) Serving.

- In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring is known as serving.

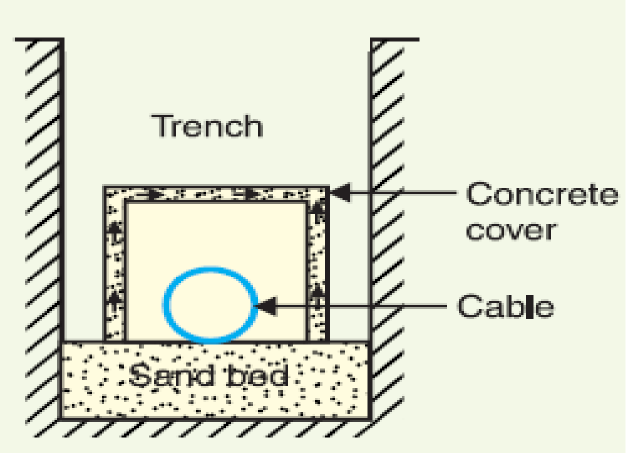
7.3 Methods of cable lying.

The reliability of underground cable network depends to a considerable extent upon the proper laying and attachment of fittings i.e., cable end boxes, joints, branch connectors etc.

There are three main methods of laying underground cables i.e, direct laying, draw-in system and the solid system.

1. Direct laying. .

- In this method, a trench of about 1·5 meter deep and 45 cm wide is dug.
- The trench is covered with a layer of fine sand and the cable is laid over this sand bed.
- The sand prevents the entry of moisture from the ground and thus protects the cable from decay.
- The trench is then covered with bricks and other materials in order to protect the cable from mechanical injury. When more than one cable is to be laid in the same trench, a horizontal or vertical inter axial spacing of at least 30 cm is provided in order to reduce the effect of mutual heating.



Advantages

(i) It is a simple and less costly method.

(ii) It gives the best conditions for dissipating the heat generated in the cables.

(iii) It is a clean and safe method as the cable is invisible and free from external disturbances.

Disadvantages

(i) The alterations in the cable network cannot be made easily.

(ii) The maintenance cost is very high .

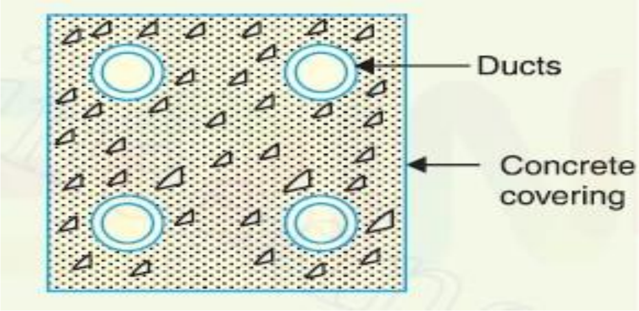
(iii) Localisation of fault is difficult.

(iv) It cannot be used in congested areas where excavation is expensive and inconvenient.

- This method of laying cables is used in open areas where excavation can be done conveniently and at low cost.

2. Draw-in system.

- In this method, conduit or duct of glazed stone or cast iron or concrete are laid in the ground with manholes at suitable positions along the cable route.
- The diagram shows four-way underground duct line. Three of the ducts carry transmission cables and the fourth duct carries relay protection connection, pilot wires.
- The duct line changes direction ; depths, dips and offsets be made with a very long radius.
- The distance between the manholes should not be too long so as to simplify the pulling in of the cables.
- The cables to be laid in this way need not be armoured but must be provided with serving of hessian and jute in order to protect them when being pulled into the ducts.



Advantages

- **(i)** Repairs, alterations or additions to the cable network is easy.
- **(ii)** As the cables are not armoured, therefore, joints become simpler and maintenance cost is low.
- **(iii)** There are very less chances of fault occurrence due to strong mechanical protection provided by the system.

Disadvantages

- **(i)** The initial cost is very high.
- **(ii)** The current carrying capacity of the cables is reduced.

- This method is generally used for short length cable routes such as in workshops, road crossings where frequent digging is costlier or impossible.

3. Solid system.

- In this method of laying, the cable is laid in open pipes or troughs dug out in earth along the cable route.
- The toughing is of cast iron, stoneware, asphalt or treated wood.
- When the cable is laid in position, the toughing is filled with a bituminous or asphaltic compound and covered over.
- Cables laid in this manner are usually plain lead covered because toughing affords good mechanical protection.

Disadvantages

- **(i)** It is more expensive than direct laid system.
- **(ii)** It requires skilled labour and favourable weather conditions.
- **(iii)** Due to less heat dissipation facilities, the current carrying capacity of the cable is reduced.

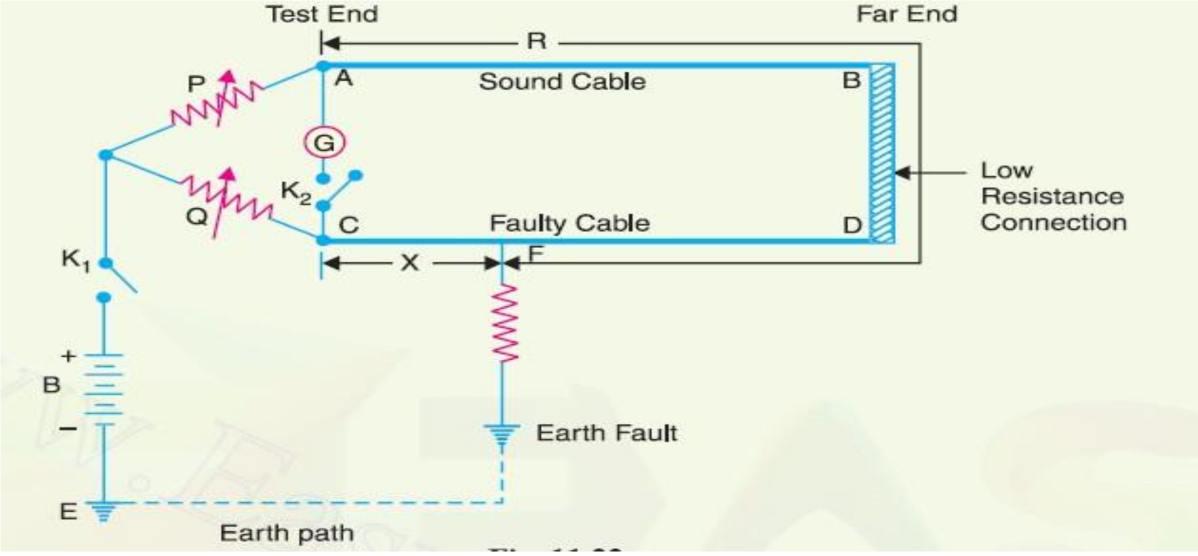
Localization of cable faults: Murray loop test for short circuit fault / Earth fault.

The Murray loop test is the most common and accurate method of locating earth fault or short-circuit fault in underground cables.

(i) Earth fault :

The circuit diagram for locating the earth fault by Murray loop test are shown below. Here AB is the sound cable and CD is the faulty cable, the earth fault occurring at point F. The far end D of the faulty cable is joined to the far end B of the sound cable through a low resistance link.

Two variable resistances P and Q are joined to ends of A and C respectively and serve as the ratio arms of the Wheatstone bridge.



Let R = resistance of the conductor loop up to the fault from the test end

X = resistance of the other length of the loop

Let P, Q, R and X are the four arms of the Wheatstone bridge.

The resistances P and Q are varied till the galvanometer indicates zero deflection.

In the balanced position of the bridge, we have,

$$\frac{P}{Q} = \frac{R}{X}$$

$$\frac{P}{Q} + 1 = \frac{R}{X} + 1$$

$$\frac{P + Q}{Q} = \frac{R + X}{X}$$

If r is the resistance of each cable, then R+X = 2r

$$\frac{P + Q}{Q} = \frac{2r}{X}$$

$$X = \frac{Q}{P+Q} \times 2r$$

If l is the length of each cable in metres, then resistance per metre length of cable = $\frac{r}{l}$

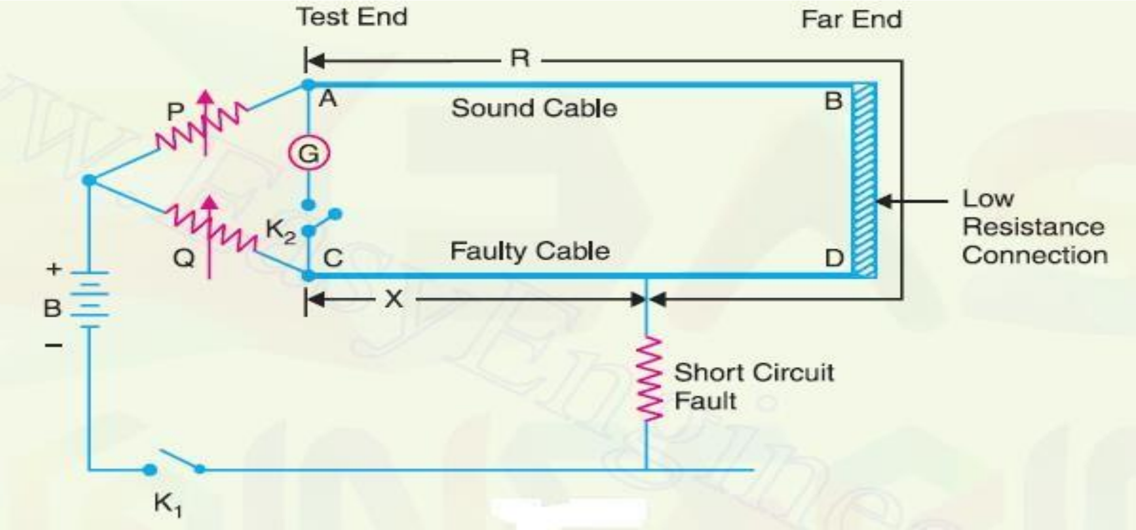
$$d = \frac{X}{r/l} = \frac{Q}{P+Q} \times 2r \times \frac{l}{r} = \frac{Q}{P+Q} \times 2l$$

$$d = \frac{Q}{P+Q} \times (loop\ length)$$

Thus the position of the fault is located. that resistance of the fault is in the battery circuit and not in the bridge circuit. Therefore, fault resistance does not affect the balancing of the bridge. However, if the fault resistance is high, the sensitivity of the bridge is reduced.

(ii) Short-circuit fault :

The circuit diagram for locating the short-circuit fault by Murray loop test are shown below.



P, *Q*, *R* and *X* are the four arms of the bridge.

Fault resistance is in the battery circuit and not in the bridge circuit.

The bridge in balanced by adjusting the resistances *P* and *Q*.

In the balanced position of the bridge :

$$\frac{P}{Q} = \frac{R}{X}$$

$$\frac{P+Q}{Q} = \frac{R+X}{X} = \frac{2r}{X}$$

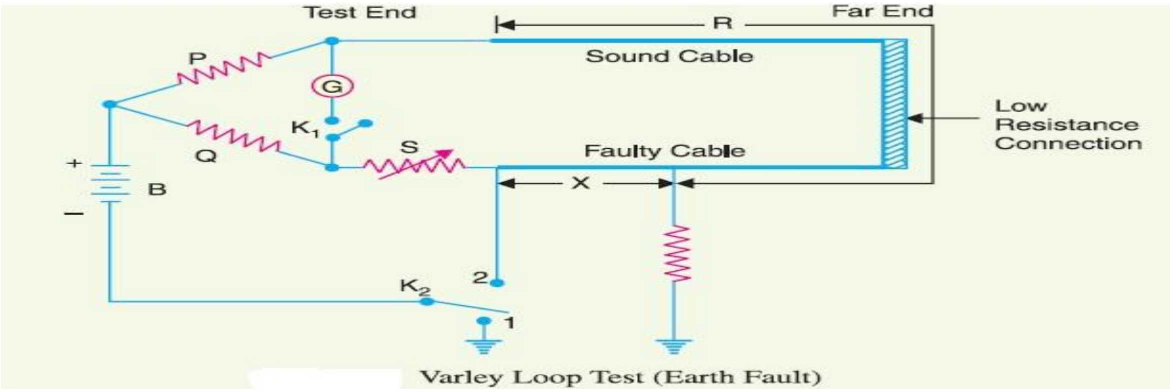
$$X = \frac{Q}{P+Q} \times 2r$$

$$X = \frac{Q}{P+Q} \times (loop\ length)$$

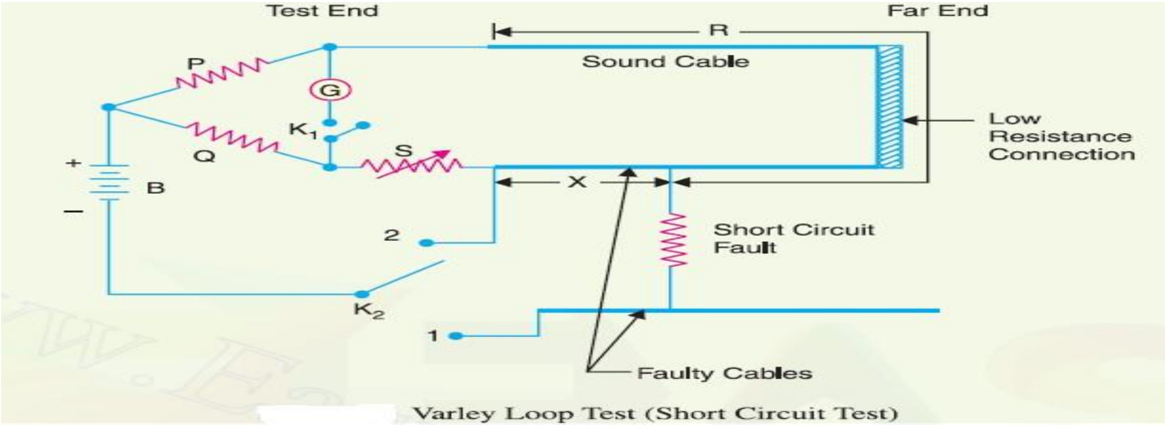
Thus the position of the fault is located

Localization of cable faults: Varley loop test for short circuit fault / Earth fault.

- The Varley loop test is also used to locate earth fault or short-circuit fault in underground cables. This test also employs Wheatstone bridge principle.
- It differs from Murray loop test in that here the ratio arms *P* and *Q* are fixed resistances. Balance is obtained by adjusting the variable resistance S connected to the test end of the faulty cable.
- The connection diagrams for locating the earth fault and short-circuit fault by Varley loop test are shown in Fig below.



Varley Loop Test (Earth Fault)



Varley Loop Test (Short Circuit Test)

For earth fault or short-circuit fault, the key $K2$ is first thrown to position 1. The variable resistance S is varied till the bridge is balanced for resistance value of $S1$. Then,

$$\frac{p}{Q} = \frac{R}{X + S_1}$$

$$\frac{p}{Q} = \frac{R + X + S_1}{X + S_1}$$

$$X = \frac{(R+X)-P\ S_1}{P+Q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Now key $K2$ is thrown to position 2 (for earth fault or short-circuit fault) and bridge is balanced with new value of resistance $S2$. Then,

$$\frac{P}{Q} = \frac{R + X}{S_2}$$

or $$(R + X)\ Q = PS_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

From eqs. (i) and (ii), we get,

$$X = \frac{(S_2 - S_1)}{P+Q}$$

Since the values of P, Q, $S1$ and $S2$ are known, the value of X can be determined.

Loop resistance = $R + X = \frac{P}{Q} S_2$

If r is the resistance of the cable per metre length, then,

Distance of fault from the test end is

$d = \frac{X}{r}$ metres.

Problem -1

Murray loop test is performed on a faulty cable 300 m long. At balance, the resistance connected to the faulty core was set at 15 Ω and the resistance of the resistor connected to the sound core was 45 Ω. Calculate the distance of the fault point from the test end.

Solution.

Distance of the fault point from test end is

$d = \frac{Q}{P+Q} \times \text{loop length}$

Here $Q = 15\ \Omega$; $P = 45\ \Omega$; loop length = 2 × 300 = 600 m

$\therefore\ d = \frac{15}{45+15} \times 600 = 150$ m.

Problem-2

In a test by Murray loop for ground fault on 500 m of cable having a resistance of 1·6 Ω/km, the faulty cable is looped with a sound cable of the same length and area of crosssection. If the ratio of the other two arms of the testing network at balance is 3 : 1, find the distance of the fault from the testing end of cables.

Solution.

$\frac{P}{Q} = 3$ or $\frac{P+Q}{Q} = 4$

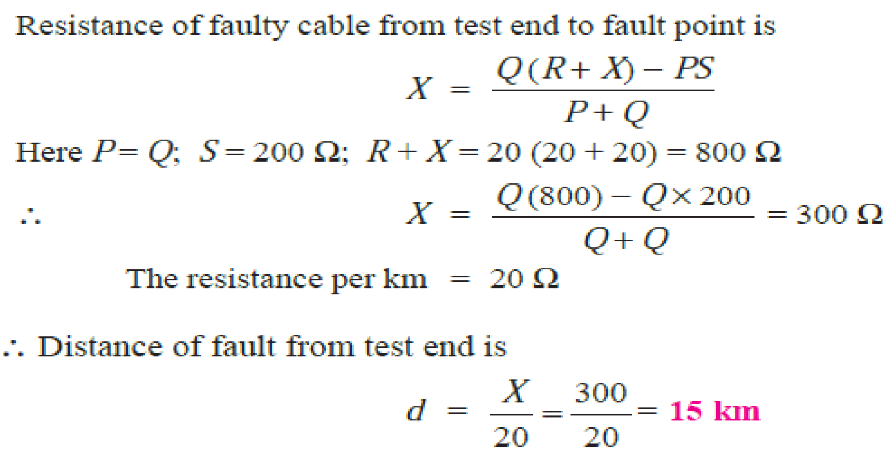
Distance of fault from test end is

$d = \frac{Q}{P+Q} \times loop\ length = \frac{1}{4} \times (2 \times 500) = 250$m.

Problem-3

Varley loop test is performed to locate an earth fault on a 20 km long cable. The resistance per km of the single conductor is 20 Ω. The loop is completed with a similar healthy conductor. At balance, the variable resistance connected to the faulty conductor is 200 Ω. The fixed resistors have equal values. Calculate the distance of the fault from the test end.

Solution.



Resistance of faulty cable from test end to fault point is

$$X = \frac{Q(R+X) - PS}{P+Q}$$

Here $P = Q$; $S = 200\ \Omega$; $R + X = 20\ (20 + 20) = 800\ \Omega$

$$\therefore \quad X = \frac{Q(800) - Q \times 200}{Q+Q} = 300\ \Omega$$

The resistance per km = 20 Ω

∴ Distance of fault from test end is

$$d = \frac{X}{20} = \frac{300}{20} = \textbf{15 km}$$

SHORT QUESTIONS :

what are the insulating materials are used in underground cable?The principal insulating materials used in cables are :

1. Rubber
2. Vulcanized India Rubber (*V.I.R.*).
3. Impregnated paper.
4. Varnished cambric.
5. Polyvinyl chloride (*PVC*).

Classify the cable depending upon line voltage.

(i) Low-tension (L.T.) cables — up to 1000 V
(ii) High-tension (H.T.) cables — up to 11,000 V
(iii) Super-tension (S.T.) cables — from 22 kV to 33 kV
(iv) Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
(v) Extra super voltage cables — beyond 132 kV

What is armouring and why it is used ?

A. Over the bedding, armouring is provided which consists of one or two layers of galvanised steel wire or steel tape.

Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling.

what is grading of cable ?

A. The process of achieving uniform electrostatic stress in the dielectric of cables is known as grading of cables.

Why metallic sheathing is provided in underground cable ?

A. In order to protect the cable from moisture, gases or other damaging liquids (acids or alkalies) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation.

LONG QUESTIONS :

Explain the various methods of cable laying.

With necessary circuit explain Murray loop test for earth fault and short circuit test in under ground cable.

Give in details the general construction of a cable.

Classify the LT & HT cables.

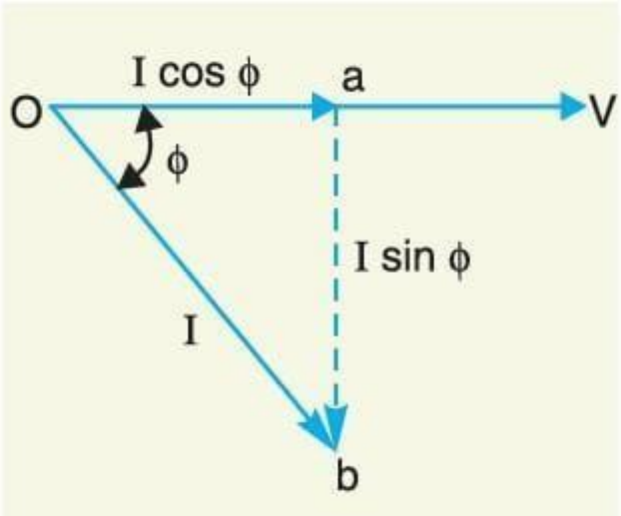
Briefly describe about cable laying.

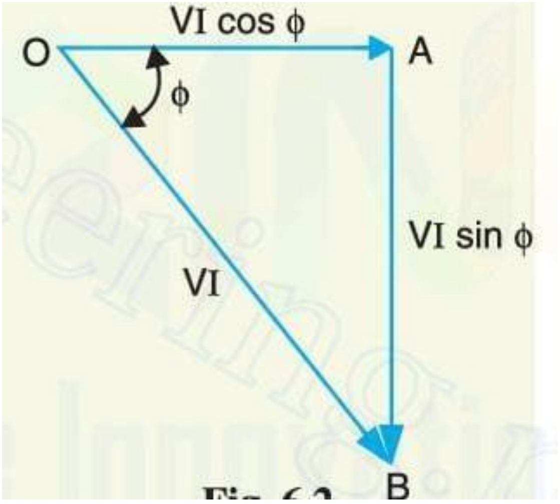
CHAPTER-8

ECONOMIC ASPECTS

Power Factor

The cosine of angle between voltage and current in an a.c. circuit is known as power factor.





The power factor of a circuit can be defined in one of the following three ways :

(a) Power factor = cos φ = cosine of angle between *V* and *I*

(b) Power factor = *R/Z* = Resistance / Impedance

(c) Power factor = VIcosϕ / VI = Active power / Apparent Power

(d) The reactive power is neither consumed in the circuit nor it does any useful work. It merely flows back and forth in both directions in the circuit. A wattmeter does not measure reactive power.

From the above right angle triangle we get

OA = VI cosϕ and represents the active power in watts or kW

AB = VI sinϕ and represents the reactive power in VAR or kVAR

OB = VI and represents the apparent power in VA or kVA

The apparent power in an a.c. circuit has two components viz., active and reactive power at right angles to each other.

$OB^2 = OA^2 + AB^2$

or (apparent power)2 = (active power)2 + (reactive power)2

or $(kVA)^2 = (kW)^2 + (kVAR)^2$

Disadvantages of Low Power Factor

We know that $P = V_L I_L \cos\varphi$ (For single phase supply)

$$\therefore\ I_L = \frac{P}{V_L \cos\varphi} \quad \text{……… …...(i)}$$

$P = \sqrt{3} V_L I_L \cos\varphi$ (For 3 phase supply)

$$\therefore\ I_L = \frac{P}{\sqrt{3} V_L\, I_L \cos\varphi} \quad \text{…………..(ii):}$$

(i) Large kVA rating of equipment.

$$\text{kVA} = \frac{\text{kW}}{\cos \varphi}$$

It is clear that kVA rating of the equipment is inversely proportional to power factor. The smaller the power factor, the larger is the kVA ratings and hence equipment larger and expensive.

(ii) Greater conductor size.

To transmit or distribute a fixed amount of power at constant voltage, the conductor will have to carry more current at low power factor, it necessitates large conductor size.

(iii) Large copper losses.

The large current at low power factor causes more I^2R losses in all the elements of the supply system. This results in poor efficiency.

(iv) Poor voltage regulation.

The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors hence the voltage regulation decreases.

(v) Reduced handling capacity of system.

The lagging power factor reduces the handling capacity of all the elements of the system. It is because the reactive component of current prevents the full utilisation of installed capacity.

8.1 Causes of low power factor

The following are the causes of low power factor:

(i) Most of the a.c. motors are of induction type (1φ and 3φ induction motors) which have low lagging power factor.

(ii) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.

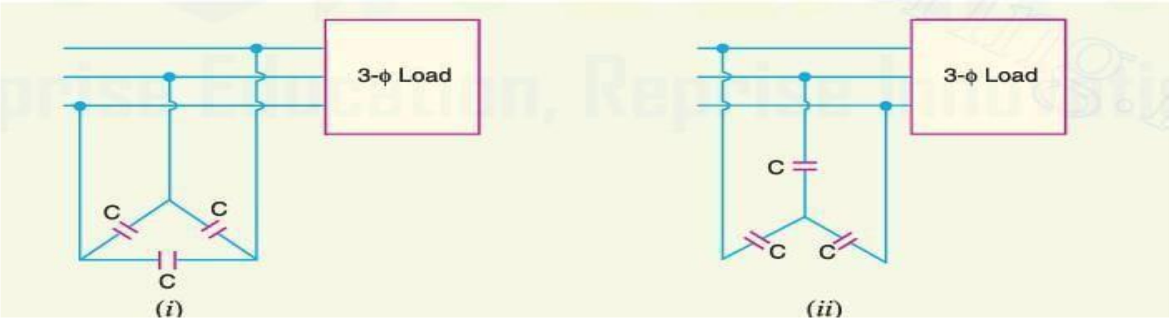
(iii) The load on the power system is varying ; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetization current. This results in the decreased power factor.

Methods of improvement of power factor in power system.

The low power factor is mainly due to the fact that most of the power loads are inductive and, therefore, take lagging currents. In order to improve the power factor, there are three methods are applied that are :

1. Static capacitors.
2. Synchronous condenser.
3. Phase advancers.

1. Static capacitor.



- The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor.
- The capacitor is generally known as static capacitor which draws a leading current and partly or completely neutralises the lagging reactive component of load current.
- This raises the power factor of the load. For three-phase loads, the capacitors can be connected in delta or star.
- Static capacitors are invariably used for power factor improvement in factories.

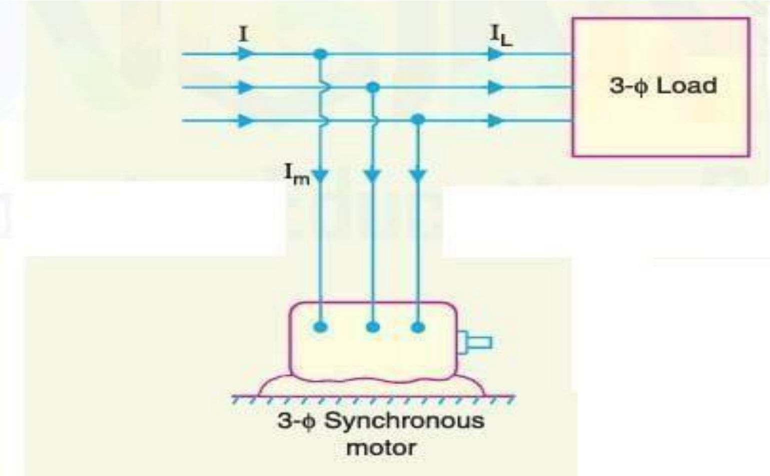
Advantages

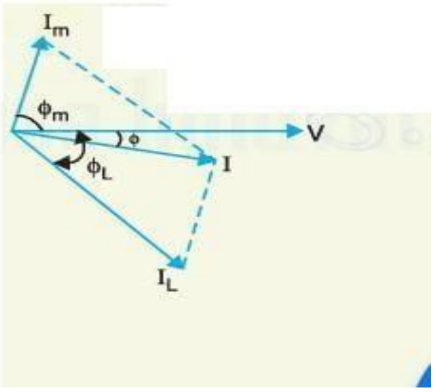
(i) They have low losses.
(ii) They require little maintenance as there are no rotating parts.
(iii) They can be easily installed as they are light and require no foundation.
(iv) They can work under ordinary atmospheric conditions.

Disadvantages

(i) They have short service life ranging from 8 to 10 years.
(ii) They are easily damaged if the voltage exceeds the rated value.
(iii) Once the capacitors are damaged, their repair is uneconomical.

2. Synchronous condenser.





- An over-excited synchronous motor running on no load is known as synchronous condenser.
- When it is connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved.
- The 3φ load takes current I_L at low lagging power factor cos φ_L. The synchronous condenser takes a current Im which leads the voltage by an angle φ_m.
- The resultant current I is the phasor sum of Im and I_L and lags behind the voltage by an angle φ.
- It is clear that φ is less than φ_L so that cos φ is greater than cos φ_L. Thus the power factor is increased from cos φ_L to cos φ.
- Synchronous condensers are generally used at major bulk supply substations for power factor improvement.

Advantages

(i) This helps in achieving step less control of power factor.
(ii) The motor windings have high thermal stability to short circuit currents.
(iii) The faults can be removed easily.

Disadvantages

(i) There are considerable losses in the motor.
(ii) The maintenance cost is high.
(iii) It produces noise.
(iv) Except in sizes above 500 kVA, the cost is greater than that of static capacitors of the same rating.

3. Phase advancers.

- Phase advancers are used to improve the power factor of induction motors.
- The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags behind the supply voltage by 90^0.
- If the exciting ampere turns can be provided from some other a.c. source, then the stator winding will be relieved of exciting current and the power factor of the motor can be improved. This job is accomplished by the phase advancer which is simply an a.c. exciter.
- The phase advancer is mounted on the same shaft as the main motor and is connected in the rotor circuit of the motor.
- It provides exciting ampere turns to the rotor circuit at slip frequency.
- By providing more ampere turns than required, the induction motor can be made to operate on leading power factor like an over-excited synchronous motor.

Advantages

(i) as the exciting ampere turns are supplied at slip frequency, therefore, lagging kVAR drawn by the motor are considerably reduced.
(ii) phase advancer can be conveniently used where the use of synchronous motors is unadmissible.

Disadvantages

1. They are not economical for motors below 200 H.P.

Factors affecting the economics of generation:

The art of determining the per unit (i.e., one kWh) cost of production of electrical energy is known as economics of power generation.

To deduce the power generation economics effectively we should know the structure of annual expenditure of the plant and the factors affecting them. The total annual expenditure of the plant can be classified into several subheadings namely,

1. Fixed Cost / charges
2. Semi fixed Cost /Charges
3. Running Cost/ Charges

(i) Fixed cost.

- It is the cost which is independent of maximum demand and units generated.
- The fixed cost is due to the annual cost of central organisation, interest on capital cost of land and salaries of high officials.
- The annual expenditure on the central organisation and salaries of high officials is fixed since it has to be met whether the plant has high or low maximum demand or it generates less or more units.
- The capital investment on the land is fixed and hence the amount of interest is also fixed.

(ii) Semi-fixed cost.

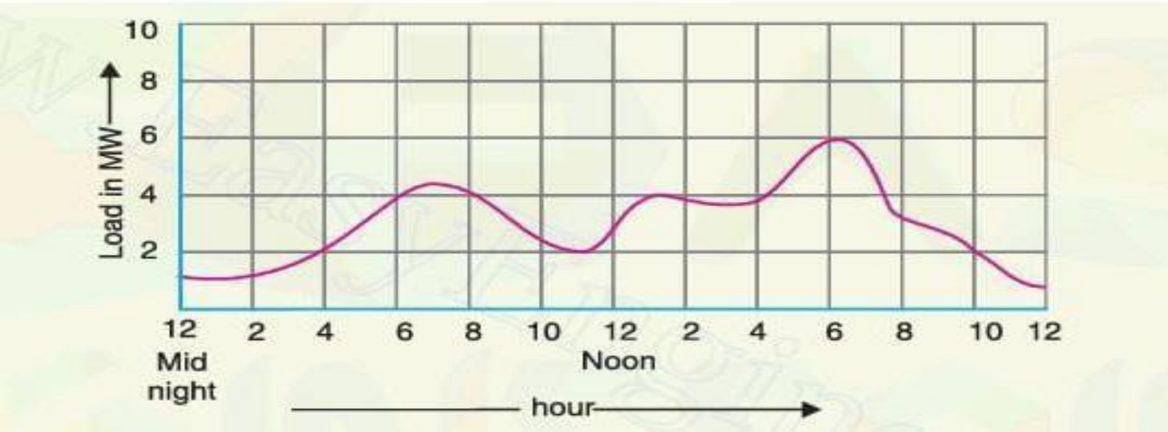
- It is the cost which depends upon maximum demand but is independent of units generated.
- The semi-fixed cost is directly proportional to the maximum demand on power station and is on account of annual interest and depreciation on capital investment of building and equipment, taxes, salaries of management and clerical staff.
- The maximum demand on the power station determines its size and cost of installation.
- The greater the maximum demand on a power station, the greater is its size and cost of installation.

(iii) Running cost.

- It is the cost which depends only upon the number of units generated.
- The running cost is on account of annual cost of fuel, lubricating oil, maintenance, repairs and salaries of operating staff.
- Since these charges depend upon the energy output, the running cost is directly proportional to the number of units generated by the station.
- if the power station generates more units, it will have higher running cost and vice-versa.

Load curves.

The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a load curve.



- The curve showing the variation of load on the power station with respect to whole day is known as daily load curve.
- The monthly load curve can be obtained from the daily load curves of that month.
- The yearly load curve is obtained by considering the monthly load curves of that particular year.
- The yearly load curve is generally used to determine the annual load factor.
- The daily load curve shows the variations of load on the power station during different hours of the day.
- The area under the daily load curve gives the number of units generated in the day.
- Units generated/day = Area (in kWh) under daily load curve.
- The highest point on the daily load curve represents the maximum demand on the station on that day.
- The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

  Average load = Area (in kWh) under daily load curve/24 hours
- The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor.

  Load factor = Average load / Max. demand.

Connected load.

It is the sum of continuous ratings of all the equipments connected to supply system.

8.2.3Maximum demand :

It is the greatest demand of load on the power station during a given period.

It helps to determine the installed capacity of the station.

Demand factor.

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

$$\text{i.e., Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

- The value of demand factor is usually less than 1.
- It is expected because maximum demand on the power station is generally less than the connected load.
- If the maximum demand on the power station is 80 MW and the connected load is 100 MW, then demand factor = 80/100 = 0·8.
- The value of demand factor helps determining the capacity of the plant equipment.

Average load.

The average of loads occurring on the power station in a given period (day or month or year) is known as average load or average demand.

$$\text{Daily average load} = \frac{\text{No.of units (kWh) generated in a day}}{\text{24 hours}}$$

$$\text{Monthly average load} = \frac{\text{No.of units (kWh) generated in a month}}{\text{Number of hours in a month}}$$

$$\text{Yearly average load} = = \frac{\text{No.of units (kWh) generated in a year}}{\text{8760 hours}}$$

Load factor.

The ratio of average load to the maximum demand during a given period is known as load factor

$$\text{i.e., Load factor} = \frac{\text{Average load}}{\text{Max.demand}}$$

If the plant is in operation for T hours,

$$\text{Load factor} = \frac{\text{Average load x T}}{\text{Max.demand x T}}$$

$$\text{Load factor} = \frac{\text{Units generated in T hours}}{\text{Max.demand x T hours}}$$

- The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year.
- Load factor is always less than 1 because average load is smaller than the maximum demand.

Diversity factor.

- The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor.

$$\text{i.e., Diversity factor} = \frac{\text{Sum of individual max.demands}}{\text{Max.demand on power station}}$$

- The maximum demand on the power station is always less than the sum of individual maximum demands of the consumers.
- Diversity factor will always be greater than 1.
- The greater the diversity factor, the lesser is the cost of generation of power.

Plant capacity factor.

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

$$\text{i.e., Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max.energy that could have been produced}}$$

$$= \frac{\text{Average demand x T}}{\text{Plant capacity x T}}$$

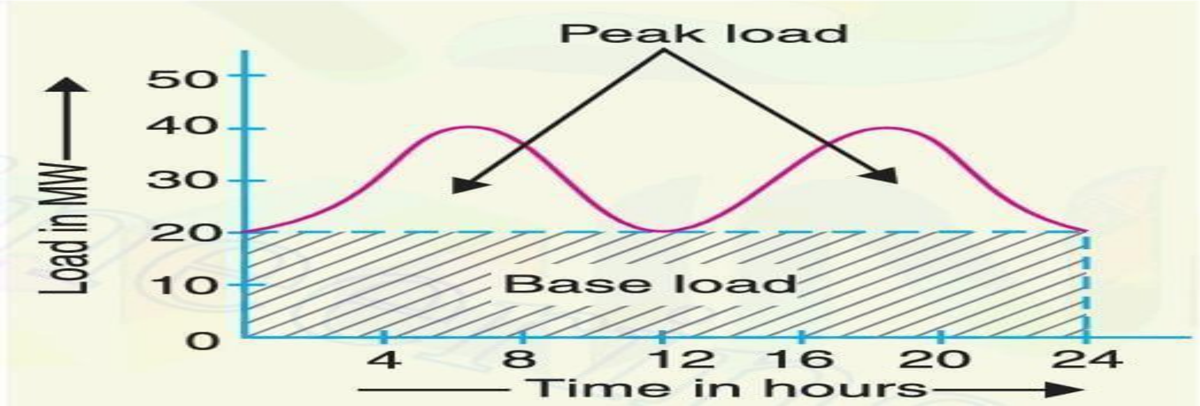
$$= \frac{\text{Average demand}}{\text{Plant capacity}}$$

For a period of one year , Annual plant capacity factor $= \frac{\text{Annual kWh output}}{\text{Plant capacity x 8760}}$

Peak load and Base load on power station.

Load on the power station can be considered in two parts.

1. Base load.
2. Peak load.



1. Base load.

- The unvarying load which occurs almost the whole day on the station is known as base load.
- Referring to the load curve of the above Fig., it is clear that 20 MW of load has to be supplied by the station at all times of day and night i.e. throughout 24 hours. Therefore, 20 MW is the base load of the station.

2. Peak load.

- The various peak demands of load over and above the base load of the station is known as peak load.
- Referring to the load curve of the above Fig. , it is clear that there are peak demands of load excluding base load.
- These peak demands of the station generally form a small part of the total load and may occur throughout the day.

Problem-1

A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being 61·5 × 106 per annum. Calculate (i) the demand factor and (ii) load factor.

Solution.

(i) Demand factor = Max. demand / Connected load

= 20/ 43 = 0·465

(ii) Average demand = Units generated per annum / Hours in a year

= (61.5×10^6) / 8760 = 7020 kW

∴ Load factor = Average demand / Max. demand

=7020 / (20×10^3) = 0·351 or 35·1%

SHORT QUESTIONS:

What is Maximum demand ?

A. The greatest demand of load on the power station during a given period is called as maximum demand. It helps to determine the installed capacity of the station.

What is Demand factor ?

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

$$\text{i.e., Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

The value of demand factor is usually less than 1.

Defin Load factor.

A. The ratio of average load to the maximum demand during a given period is known as load factor

$$\text{i.e., Load factor} = \frac{\text{Average load}}{\text{Max.demand}}$$

Define diversity factor.

A. The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor.

$$\text{i.e., Diversity factor} = \frac{\text{Sum of individual max.demands}}{\text{Max.demand on power station}}$$

Diversity factor will always be greater than 1.

What is Plant capacity factor ?

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

$$\text{i.e., Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max.energy that could have been produced}}$$

Define Base load and Peak load.

Base load.

The unvarying load which occurs almost the whole day on the station is known as base load.

Peak load.

The various peak demands of load over and above the base load of the station is known as peak load.

Define load curve.

The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a load curve.

LONG QUESTIONS :

Write are the various causes of low power factor and how it can be improved ?

Write short notes on load curve.

A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being 61·5 × 106 per annum. Calculate (i) the demand factor and (ii) load factor.

CHAPTER-9

TYPES OF TARIFF

Tariff :

The rate at which electrical energy is supplied to a consumer is known as tariff.

Objectives of tariff:

Electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items :

(i) Recovery of cost of producing electrical energy at the power station.

(ii) Recovery of cost on the capital investment in transmission and distribution systems.

(iii) Recovery of cost of operation and maintenance of supply of electrical energy e.g., metering equipment, billing etc.

(iv) A suitable profit on the capital investment.

Desirable Characteristics of a Tariff

A tariff must have the following desirable characteristics :

(i) Proper return :

- The tariff should be such that it ensures the proper return from each consumer.
- In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit.

(ii) Fairness :

- The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy.
- A big consumer should be charged at a lower rate than a small consumer.
- It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy.

(iii) Simplicity :

- The tariff should be simple so that an ordinary consumer can easily understand it.
- A complicated tariff may cause an opposition from the public which is generally distrustful of supply companies.

(iv) Reasonable profit :

- The profit element in the tariff should be reasonable.
- An electric supply company is a public utility company and generally enjoys the benefits of monopoly.

(v) Attractive :

- The tariff should be attractive so that a large number of consumers are encouraged to use electrical energy.
- Efforts should be made to fix the tariff in such a way so that consumers can pay easily.

Types of Tariff

There are several types of tariff. However, the following are the commonly used types of tariff :

1. Simple tariff.

- When there is a fixed rate per unit of energy consumed, it is called a simple tariff or uniform rate tariff.
- In this type of tariff, the price charged per unit is constant i.e., it does not vary with increase or decrease in number of units consumed.
- The consumption of electrical energy at the consumer's terminals is recorded by means of an energy meter.
- This is the simplest of all tariffs and is readily understood by the consumers.

Disadvantages

(i) There is no discrimination between different types of consumers since every consumer has to pay equitably for the fixed charges.
(ii) The cost per unit delivered is high.
(iii) It does not encourage the use of electricity.

2. Flat rate tariff.

- When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.
- In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate.
- For example, the flat rate per kWh for lighting load may be 60 paise, whereas it may be slightly less(say 55 paise per kWh) for power load.

Advantages

(i) it is more fair to different types of consumers.
(ii) It is quite simple in calculations.

Disadvantages

(i) Separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.
(ii) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

3. Block rate tariff.

- When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff.
- In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block.
- The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy.

- For example, the first 30 units may be charged at the rate of 60 paise per unit ; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.
- It is used for majority of residential and small commercial consumers.

Advantages

- The consumer gets an incentive to consume more electrical energy.
- It increases the load factor of the system and hence the cost of generation is reduced.

Disadvantages

- It lacks a measure of the consumer's demand.

4. Two-part tariff.

- When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part tariff.
- In this tariff, the total charge to be made from the consumer is split into two components viz., fixed charges and running charges.
- The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer.
- The consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed.

  i.e.,Total charges = Rs ($b \times$ kW + $c \times$ kWh)

  where, b = charge per kW of maximum demand

  c = charge per kWh of energy consumed
- It is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages

(i) It is easily understood by the consumers.

(ii) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantages

(i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.

(ii) There is always error in assessing the maximum demand of the consumer.

5. Maximum demand tariff.

- It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer.
- It removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rate able value.
- This type of tariff is mostly applied to big consumers.
- It is not suitable for a small consumer (*e.g.*, residential consumer) as a separate maximum demand meter is required.

6. **Power factor tariff.**
   - The tariff in which power factor of the consumer's load is taken into consideration is known as power factor tariff.
7. **Three-part tariff.**
   - When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a three-part tariff.

     i.e., Total charge = Rs (a + b × kW + c × kWh)

     where a = fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues,

     b = charge per kW of maximum demand,

     c = charge per kWh of energy consumed.

Problem-1

The maximum demand of a consumer is 20 A at 220 V and his total energy consumption is 8760 kWh. If the energy is charged at the rate of 20 paise per unit for 500 hours use of the maximum demand per annum plus 10 paise per unit for additional units, calculate : (i) annual bill (ii) equivalent flat rate.

Solution.

Assume the load factor and power factor to be unity.

$$\therefore \text{ Maximum demand } = \frac{220*20*1}{1000} = 4.4 \text{ Kw}$$

(i) Units consumed in 500 hrs = 4·4 × 500 = 2200 kWh

Charges for 2200 kWh = Rs 0·2 × 2200 = Rs 440

Remaining units = 8760 − 2200 = 6560 kWh

Charges for 6560 kWh = Rs 0·1 × 6560 = Rs 656

∴ Total annual bill = Rs (440 + 656) = **Rs. 1096**

(ii) Equivalent flat rate = Rs 1096/8760

= Re 0 ·125 = **12.5 paise**

Problem-2.

Two systems of tariff are available for a factory working 8 hours a day for 300 working days in a year.

(i) High-voltage supply at 5 paise per unit plus Rs 4·50 per month per kVA of maximum demand.

(ii) Low-voltage supply at Rs 5 per month per kVA of maximum demand plus 5·5 paise per unit.

The factory has an average load of 200 kW at 0·8 p.f. and a maximum demand of 250 kW at the same p.f. The high voltage equipment costs Rs 50 per kVA and the losses can be taken as 4%. Interest and depreciation charges are 12%. Calculate the difference in the annual costs between the two systems.

Solution.

(i) High voltage supply

Max. demand in kVA = 250/0·8 = 312·5

As the losses in h.v. equipment are 4%, therefore, capacity of h.v. equipment

= 312·5/0·96 = 325·5 kVA

Capital investment on h.v. equipment = Rs 50 × 325·5 = Rs 16,275

Annual interest and depreciation = Rs 16,275 × 0·12 = Rs 1953

Annual charge due to maximum kVA demand

= Rs 325·5 × 4·5 × 12 = Rs 17,577

Units consumed/year =(200 * 8 *300) / 0.96 = 5 × 10^5 kWh

Annual charge due to kWh consumption = Rs 0·05 × 5 × 10^5 = Rs 25,000

Total annual cost = Rs (1953 + 17,577 + 25,000) = Rs 44,530

(ii) Low voltage supply. There is no loss of energy as no equipment is used.

Max. demand in kVA = 250/0·8 = 312·5

Annual charge due to maximum kVA demand = Rs 312·5 × 5 × 12 = Rs 18,750

Units consumed/year = 200 × 8 × 300 = 48 × 10^4 kWh

Annual charge due to kWh consumption = Rs 0·055 × 48 × 10^4 = Rs 26,400

Total annual cost = Rs (18,750 + 26,400) = Rs 45,150

Difference in the annual costs of two systems = Rs (45,150 − 44,530) = Rs 620

Hence, high-voltage supply is cheaper than low-voltage supply by Rs 620.

Problem-3

A factory has a maximum load of 240 kW at 0·8 p.f. lagging with an annual consumption of 50,000 units. The tariff is Rs 50 per kVA of maximum demand plus 10 paise per unit. Calculate the flat rate of energy consumption. What will be annual saving if p. f. is raised to unity?

Solution.

Maximum demand in kVA at a p.f. of 0·8 = 240/0·8 = 300

Annual bill = Demand charges + Energy charges

= Rs 50 × 300 + Rs 0·1 × 50,000

= Rs 15,000 + Rs 5000 = Rs 20,000

∴ Flat rate/unit = Rs 20 000/ 50 000 = Rs0.40 =40 paise

When p.f. is raised to unity, the maximum demand in kVA

= 240/1 = 240

Annual bill = Rs 50 × 240 + Rs 0·1 × 50,000

= Rs 12,000 + Rs 5,000 = Rs 17,000

Annual saving = Rs (20,000 − 17,000) = Rs 3000

Problem-4

A consumer has a maximum demand of 200 kW at 40% load factor. If the tariff is Rs. 100 per kW of maximum demand plus 10 paise per kWh, find the overall cost per kWh.

Solution.

Units consumed/year = Max. demand × L.F. × Hours in a year

= (200) × (0·4) × 8760 = 7,00,800 kWh

Annual charges = Annual M.D. charges + Annual energy charges

= Rs (100 × 200 + 0·1 × 7,00,800)

= Rs 90,080

∴ Overall cost/kWh = Rs 90080/700800

= Re 0·1285 = 12·85 paise

SHORT QUESTIONS :

What is Simple tariff ?

A. When there is a fixed rate per unit of energy consumed, it is called a simple tariff or uniform rate tariff. In this type of tariff, the price charged per unit is constant i.e., it does not vary with increase or decrease in number of units consumed.

What is Flat rate tariff ?

A. When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff. In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate.

What is Block rate tariff ?

A. When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff.

In this tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy.

What is Two-part tariff ?

A. When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part tariff.

In this tariff, the total charge to be made from the consumer is split into two components viz., fixed charges and running charges.

The consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed.

i.e.,Total charges = Rs (b × kW + c × kWh)

where, b = charge per kW of maximum demand

c = charge per kWh of energy consumed

What is Maximum demand tariff ?

A. It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer.

It removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rate able value.

LONG QUESTIONS :

Define tariff and briefly describe about various types of tariff.

The maximum demand of a consumer is 20 A at 220 V and his total energy consumption is 8760 kWh. If the energy is charged at the rate of 20 paise per unit for 500 hours use of the maximum demand per annum plus 10 paise per unit for additional units, calculate : (i) annual bill (ii) equivalent flat rate.

A factory has a maximum load of 240 kW at 0·8 p.f. lagging with an annual consumption of 50,000 units. The tariff is Rs 50 per kVA of maximum demand plus 10 paise per unit. Calculate the flat rate of energy consumption. What will be annual saving if p. f. is raised to unity?

CHAPTER-10
SUBSTATION

Sub-Station

The assembly of apparatus used to change some characteristic (e.g. voltage, a.c. to d.c., frequency, p.f. etc.) of electric supply is called a sub-station.

The following are the important points which must be kept in view while laying out a sub-station :

(i) It should be located at a proper site.
(ii) It should provide safe and reliable arrangement.
(iii) It should be easily operated and maintained.
(iv) It should involve minimum capital cost.

Classification of Sub-Stations

There are several ways of classifying sub-stations. However, the two most important ways of classifying them are according to (1) service requirement and (2) constructional features.

1. According to service requirement.

According to the service requirement, sub-stations may be classified into :

(i) Transformer sub-stations.

Those sub-stations which change the voltage level of electric supply are called transformer sub-stations.

(ii) Switching sub-stations.

These sub-stations do not change the voltage level i.e. incoming and outgoing lines have the same voltage. However, they simply perform the switching operations of power lines.

(iii) Power factor correction sub-stations.

Those sub-stations which improve the power factor of the system are called power factor correction sub-stations.

(iv) Frequency changer sub-stations.

Those sub-stations which change the supply frequency are known as frequency changer sub-stations.

(v) Converting sub-stations.

Those sub-stations which change a.c. power into d.c. power are called converting sub-stations.

(vi) Industrial sub-stations.

Those sub-stations which supply power to individual industrial concerns are known as industrial sub-stations.

2. According to constructional features.

According to constructional features, the sub-stations are classified as :

(i) Indoor sub-station (ii) Outdoor sub-station
(iii) Underground sub-station (iv) Pole-mounted sub-station

(i) Indoor sub-stations.

For voltages upto 11 kV, the equipment of the sub-station is installed Indoor.

(ii) Outdoor sub-stations.

For voltages beyond 66 kV, equipment is invariably installed outdoor.

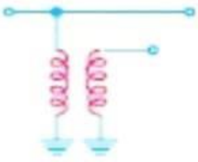
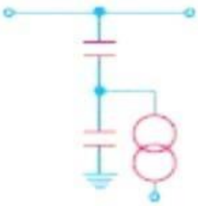
(iii) Underground sub-stations.

In thickly populated areas, the space available for equipment and building is limited and the cost of land is high. Under such situations, the sub-station is created underground.

(iv) Pole-mounted sub-stations.

This is an outdoor sub-station with equipment installed overhead on H-pole or 4-pole structure.

Circuit element symbol :

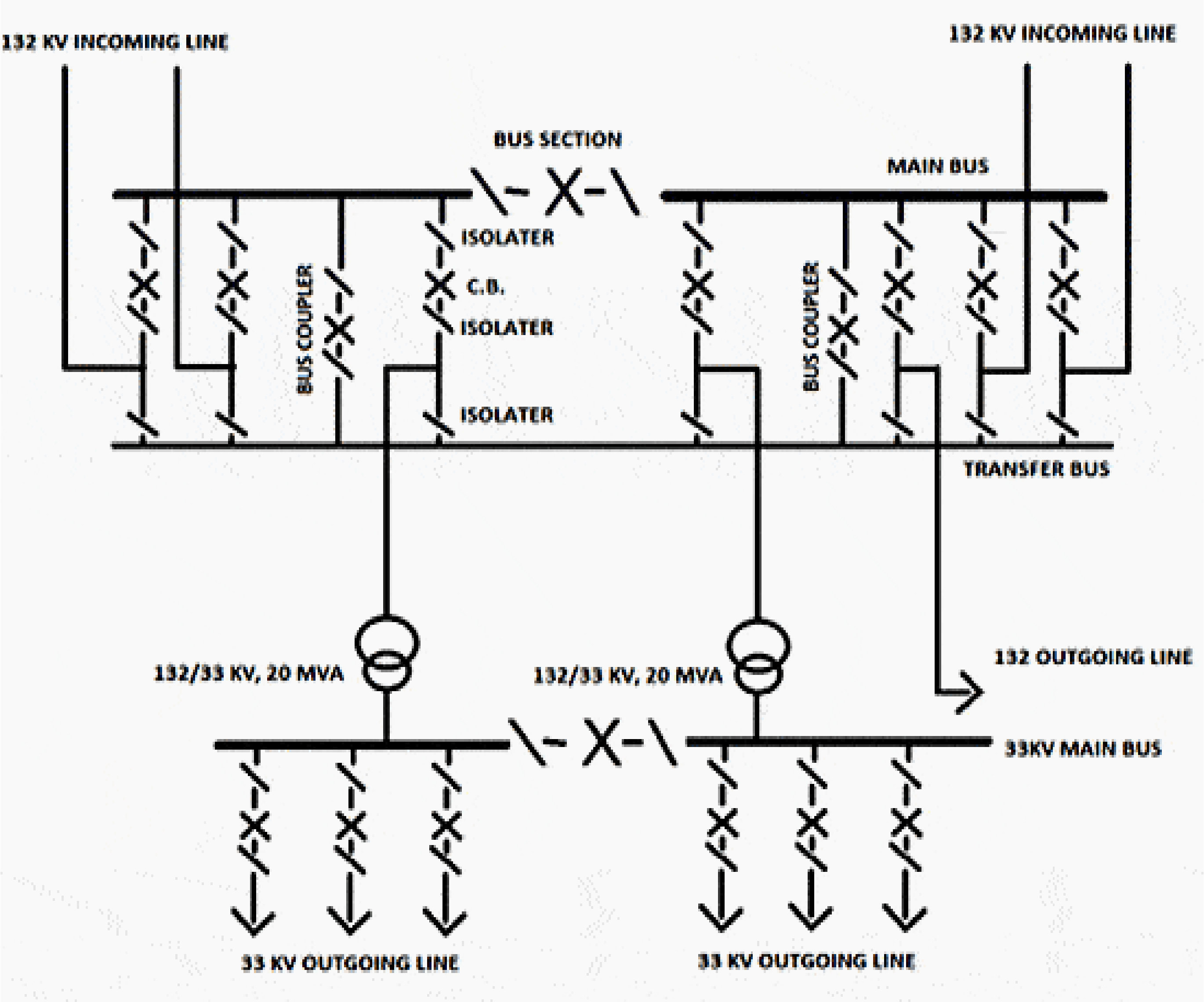
S.No.	Circuit element	Symbol
1	Bus-bar	
2	Single-break isolating switch	
3	Double-break isolating switch	
4	On load isolating switch	
5	Isolating switch with earth Blade	
6	Current transformer	
7	Potential transformer	
8	Capacitive voltage transformer	
9	Oil circuit breaker	
10	Air circuit breaker with overcurrent tripping device	
11	Air blast circuit breaker	
12	Lightning arrester (active gap)	
13	Lightning arrester (valve type)	

Layout of LT, HT and EHT substation.

1. Layout of EHT substation

From the generating station sub-station, electric power at 220 kV/ 132 kV is transmitted by 3-phase, 3-wire overhead system to the outskirts of the city. Then the electric power is received by the primary grid (EHT) sub-station which reduces the voltage level to 66 KV/ 33 KV for secondary transmission.

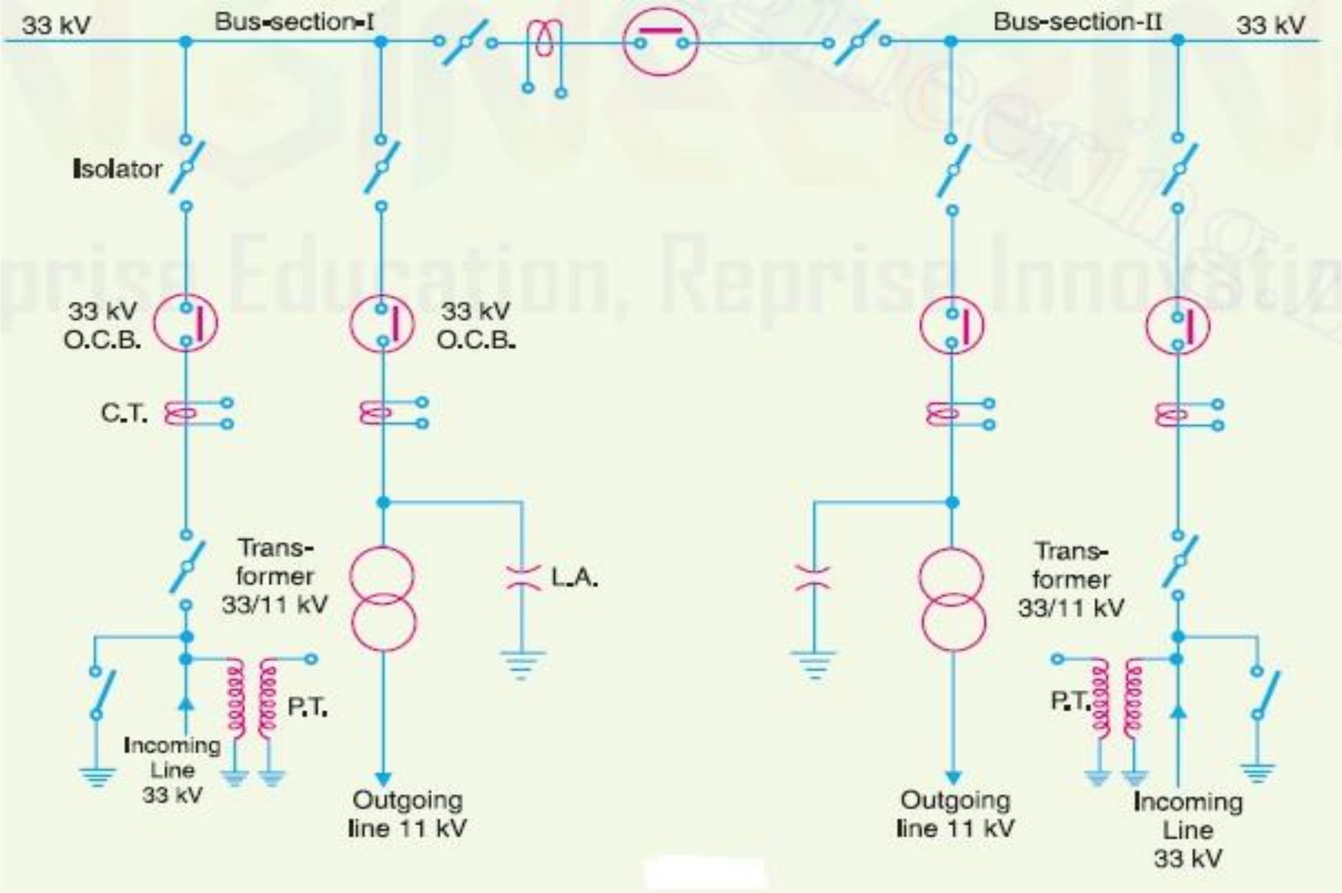
The layout of 132KV/ 33KV EHT substation are drawn below.



2. Layout of HT substation:

From the primary grid sub-station, electric power is transmitted at 66 kV 0r 33kV by 3-phase, 3-wire system to various secondary sub-stations located at the strategic points in the city. At a secondary sub-station, the voltage is further stepped down to 11 kV.

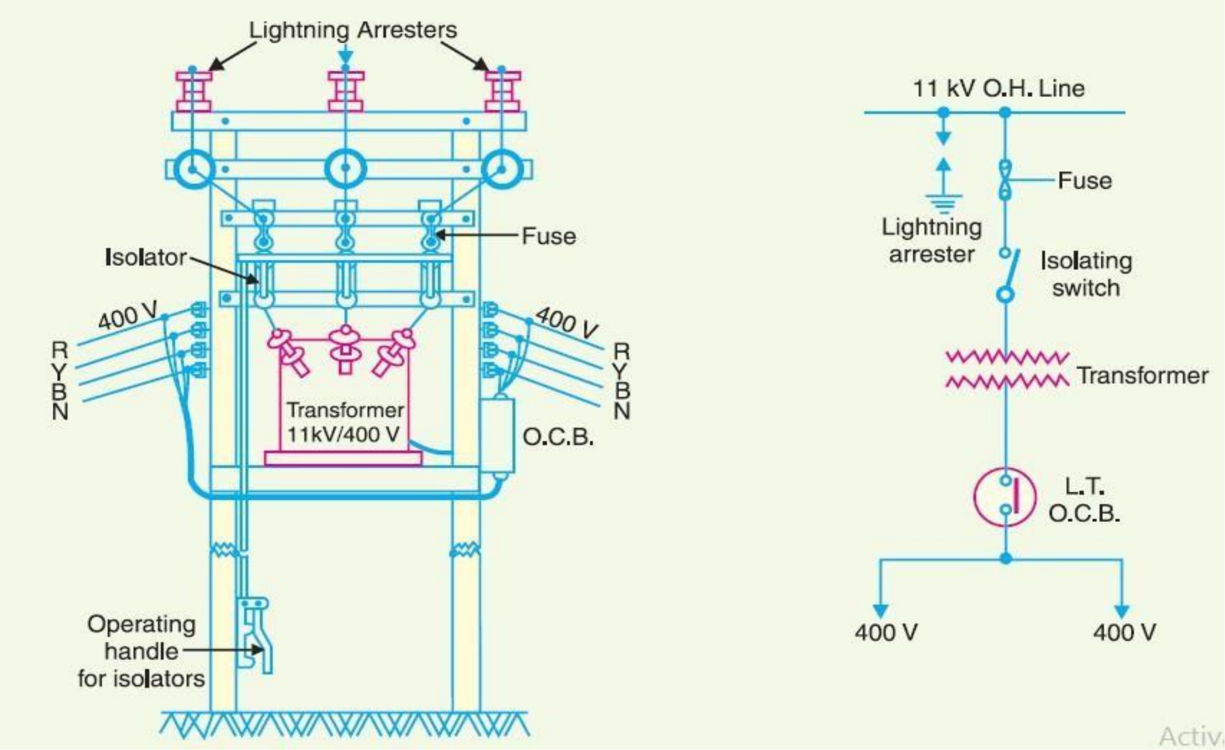
The single line diagram of 33KV/ 11KV HT substation are drawn below.



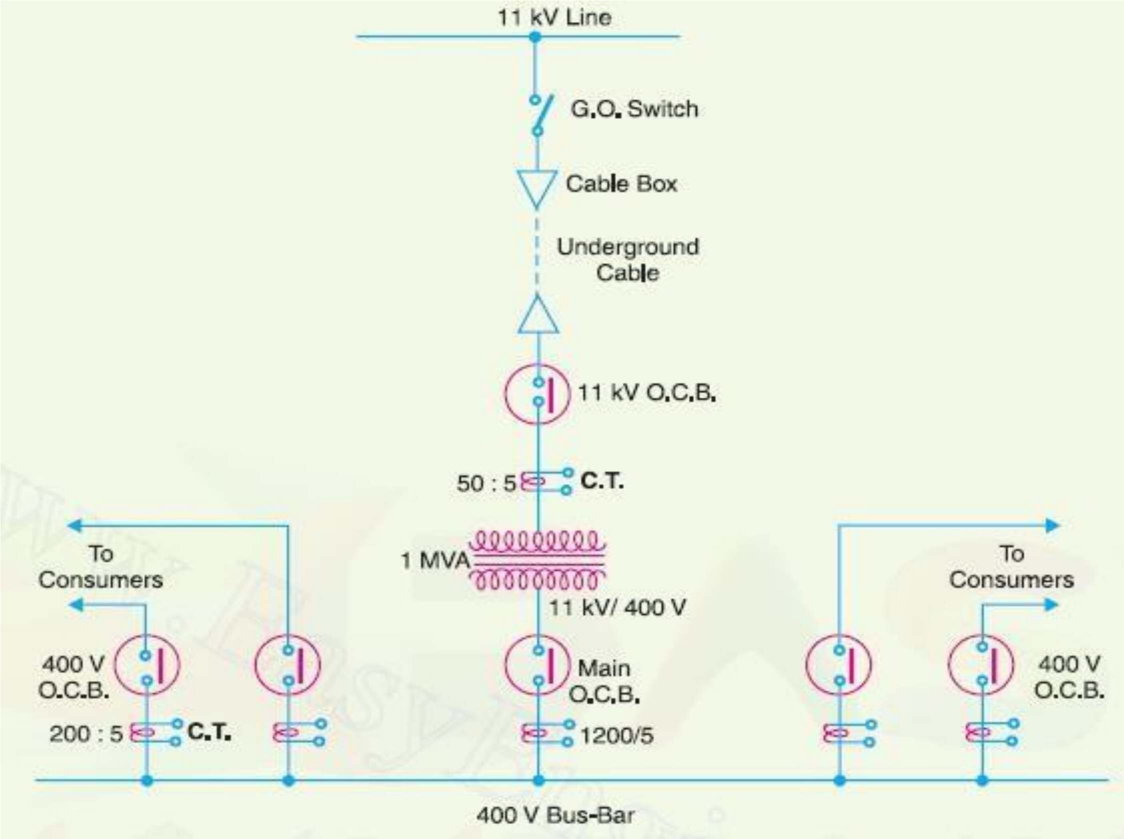
3. Layout of LT substation:

The electric power from 11 kV lines is delivered to distribution sub-stations. These sub stations are located near the consumers localities and step down the voltage to 400 V, 3 phase, 4-wire for supplying to the consumers. The voltage between any two phases is 400V and between any phase and neutral it is 230 V.

The single line diagram of 11KV/ 0.4KV outdoor type LT substation are drawn below.



The single line diagram of 11KV/ 0.4KV in-door type LT substation are drawn below.



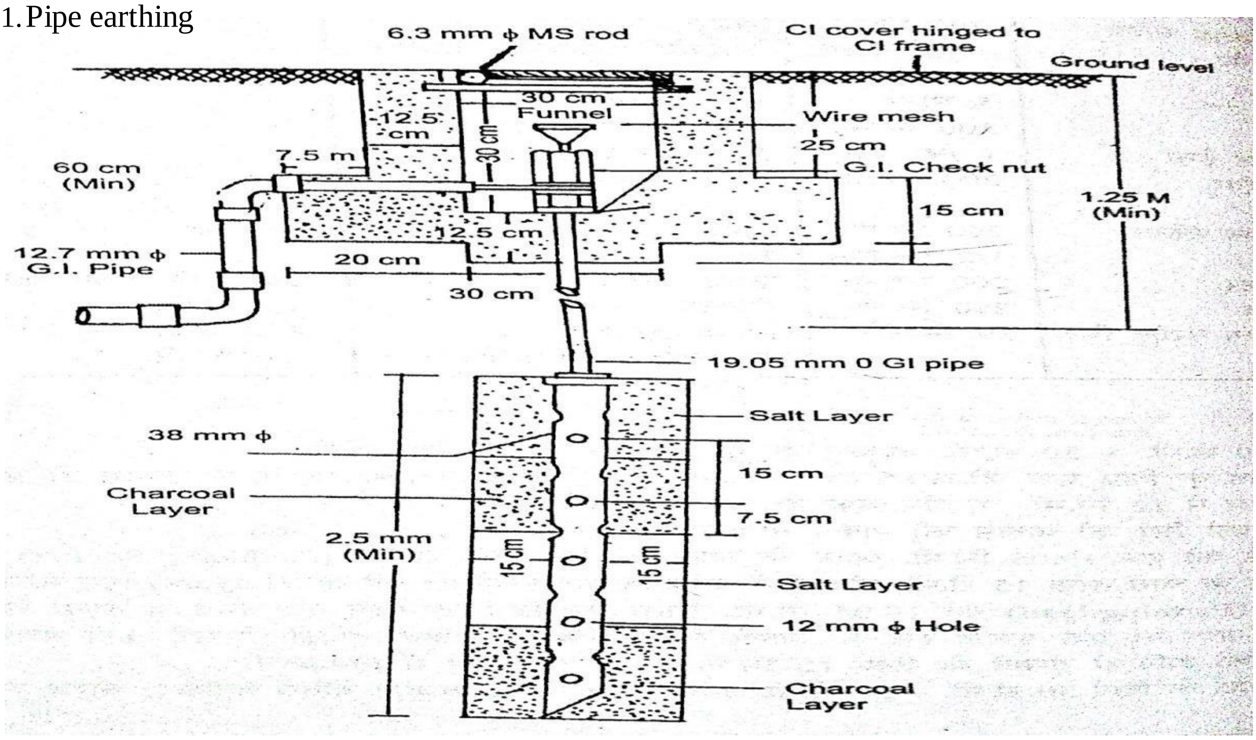
Earthing of Substation, transmission and distribution lines.

Grounding or Earthing

The process of connecting the metallic frame (i.e. non-current carrying part) of electrical equipment or some electrical part of the system (e.g. neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth (i.e. soil) is called grounding or earthing.

Generally two types of earthing systems are used in substation , transmission and distribution line.

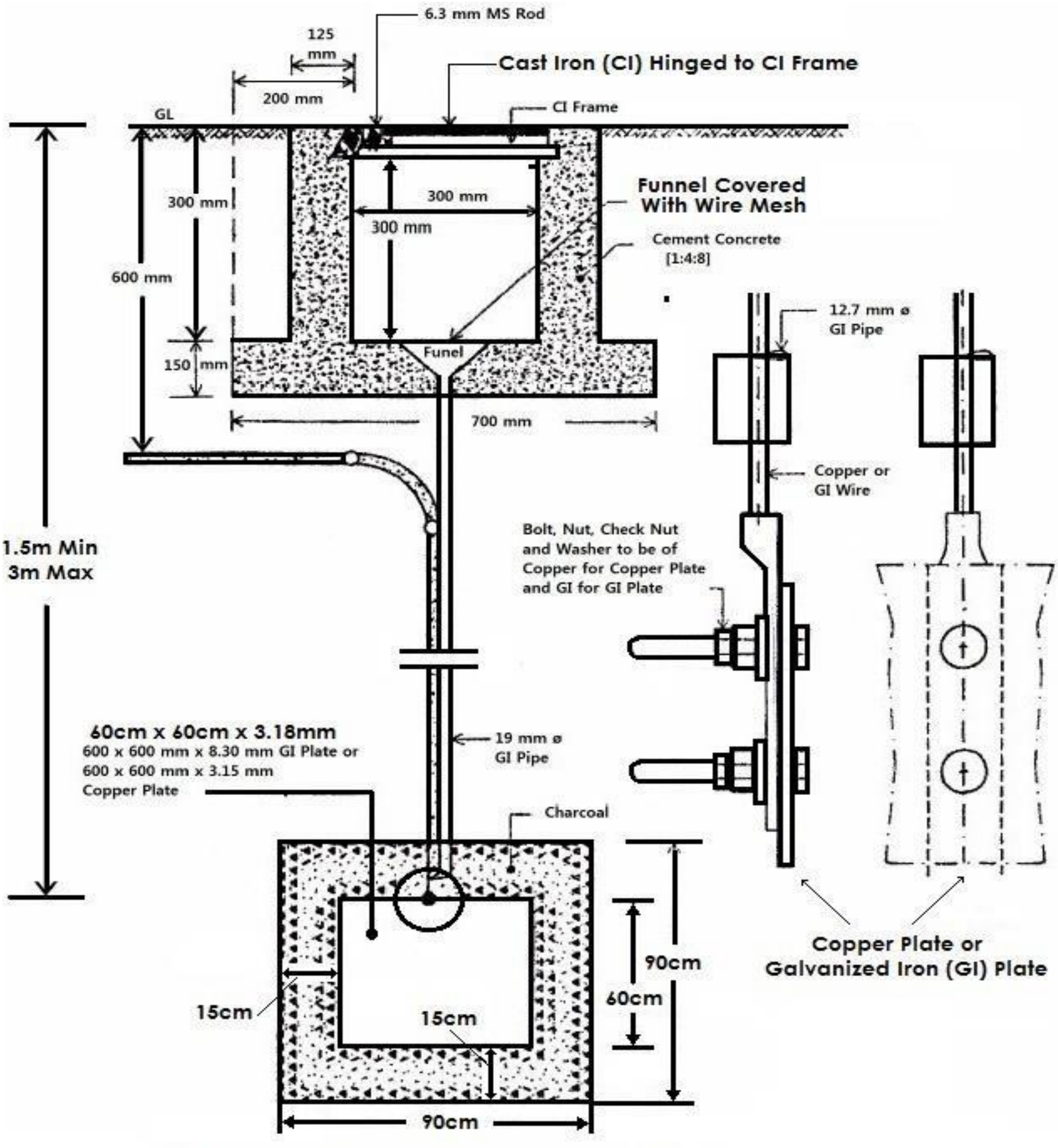
1. Pipe earthing



Material table

Si no	Description	specification	Quanity
01	G.I pipe	38mm dia,2.5 m long	01 no
02	G.I pipe for watering	19mm dia,1.5m long	01 no
03	G.I pipe	13mm dia ,4.5m long	01 no
04	G.I wire	6SWG	12m
05	G.I lugs	G.I type	02 nos
06	G.I nut bolt	10 mm dia ,16mm dia	04 nos
07	G.I bends	13mm dia	02 nos
08	Cast iron frame	30cm *30 cm	01 no
09	Cast iron cover	30 cm * 30 cm	01 no
10	Funnel	-	01 no
11	Channel	-	10kg
12	Common salt	-	10kg
13	Sundries to complete the whole job	-	As per required

2. Plate earthing.



Material table

Si no	Description	specification	Quanity
01	Copper plate	60cm* 60cm*3mm	01 no
02	G.I pipe for watering	19mm dia,1.5m long	01 no
03	G.I pipe	13mm dia ,4.5m long	01 no
04	G.I wire	6SWG	12m
05	G.I lugs	G.I type	02 nos
06	G.I nut bolt	10 mm dia ,16mm dia	04 nos
07	G.I bends	13mm dia	02 nos
08	Cast iron frame	30cm *30 cm	01 no
09	Cast iron cover	30 cm * 30 cm	01 no
10	Funnel	-	01 no
11	Channel	-	10kg
12	¤ Common salt	-	10kg
13	Sundries to complete the whole job	-	As per required

SHORT QUESTIONS

What is substation?

The assembly of apparatus used to change some characteristic (e.g. voltage, a.c. to d.c., frequency, p.f. etc.) of electric supply is called a sub-station.

Why earthing is necessary in a substation ?

Earthing is necessary for a substation to protect the equipments, devices, switch gears from damage or accidents like lighting, short circuit faults etc.

Classify the substation on constructional features.

According to constructional features, the sub-stations are classified as :
(i) Indoor sub-station (ii) Outdoor sub-station
(iii) Underground sub-station (iv) Pole-mounted sub-station

LONG QUESTIONS

Draw the key diagram of 11kv/400v substation.

Draw the layout of HT substation.

Draw the layout of EHT substation.

Draw the diagram of pipe earthing and also prepare the list of equipments required.

Q.4 Draw the diagram of plate earthing and also prepare the list of equipments required.