LECTURE NOTES
ON

GENERATION, TRANSMISSION AND DISTRIBUTION
(Th. 4)

A COURSE IN 4TH SEMESTER OF DIPLOMA IN ELECTRICAL ENGINEERING

Department of Electrical Engineering
GOVT. POLYTECHNIC, NABARANGPUR

DISCLAIMER

SYLLABUS

OBJECTIVES :

After completion of this subject the student will be able to:

(i) Different schemes of power generation with their block diagram.
(ii) Mechanical and electrical design of transmission lines and numerical problems.
(iii) Types of cables and their methods of laying and testing.
(iv) Different schemes of distribution with problem solving
(v) Different types of sub-stations.

(vi) Economic aspects of power supply system with problem and type of tariff of electricity.

Course content

1. GENERATION OF ELECTRICITY

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

1.2 Introduction to Solar Power Plant (Photovoltaic cells).

1.3 Layout diagram of generating stations.

2. TRANSMISSION OF ELECTRIC POWER

2.1Layout of transmission and distribution scheme.

2.2Voltage Regulation & efficiency of transmission.

2.3State and explain Kelvin's law for economical size of conductor.

2.4Corona and corona loss on transmission lines.

3. OVER HEAD LINES

3.1 Types of supports, size and spacing of conductor.

3.2 Types of conductor materials.

3.3 State types of insulator and cross arms.

3.4 Sag in overhead line with support at same level and different level. (Approximate formula effect of wind, ice and temperature on sag)

3.5 Simple problem on sag.

4. PERFORMANCE OF SHORT & MEDIUM LINES

4.1. Calculation of regulation and efficiency.

5. EHV TRANSMISSION

5.1 EHV AC transmission.

5.1.1. Reasons for adoption of EHV AC transmission.

5.1.2. Problems involved in EHV transmission.

5.2 HV DC transmission.

5.2.1. Advantages and Limitations of HVDC transmission system.

6. DISTRIBUTION SYSTEMS

6.1 Introduction to Distribution System.

6.2 Connection Schemes of Distribution System: (Radial, Ring Main and Inter connected system)

6.3 DC distributions.

6.3.1 Distributor fed at one End.

6.3.2 Distributor fed at both the ends.

6.3.3 Ring distributors.

6.4 AC distribution system.

6.4.1. Method of solving AC distribution problem.

6.4.2. Three phase four wire star connected system arrangement.

7. UNDERGROUND CABLES

7.1 Cable insulation and classification of cables.

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

7.3 Methods of cable lying.

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

8. ECONOMIC ASPECTS

8.1 Causes of low power factor and methods of improvement of power factor in power system.

8.2 Factors affecting the economics of generation: (Define and explain)

8.2.1 Load curves.

8.2.2 Demand factor.

8.2.3 Maximum demand.

8.2. Load factor.

8.2.5 Diversity factor.

8.2.6 Plant capacity factor.

8.3 Peak load and Base load on power station.

9 TYPES OF TARIFF

9.1. Desirable characteristic of a tariff.

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

10 SUBSTATION

10.1 Layout of LT, HT and EHT substation.

10.2 Earthing of Substation, transmission and distribution lines.

Learning resources:

Sl.No	Title of the Book	Name of Author	Publisher
1.	Principles of Power System	V. K. Mehta	S Chand
2.	A text book of Power System Engineering	A Chakrabarti, M L Soni, P V Gupta, U S Bhatnagar	Dhanpat Rai & Co
3.	A course of electrical power system	S. L. Uppal	Khanna publisher
4.	Power System Engineering	D. P. Kothari, IJ Nagrath	TMH

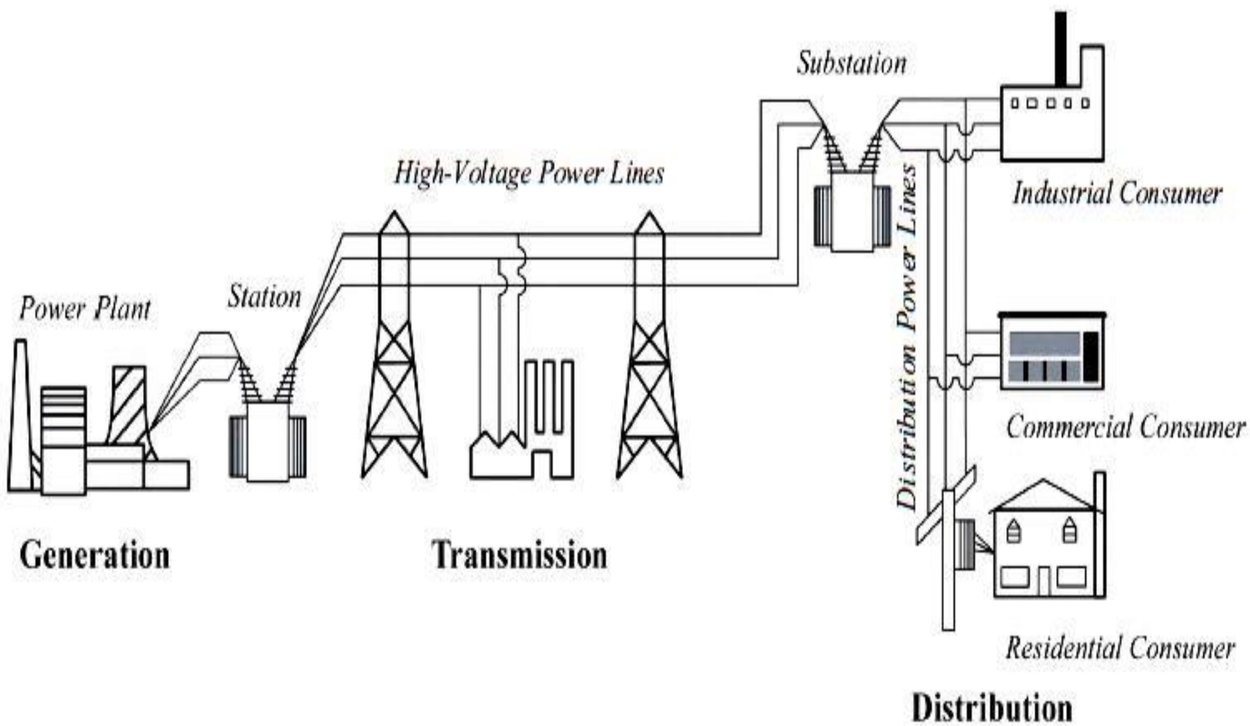
INTRODUCTION TO POWER SYSTEM

BASIC OF ELECTRIC POWER

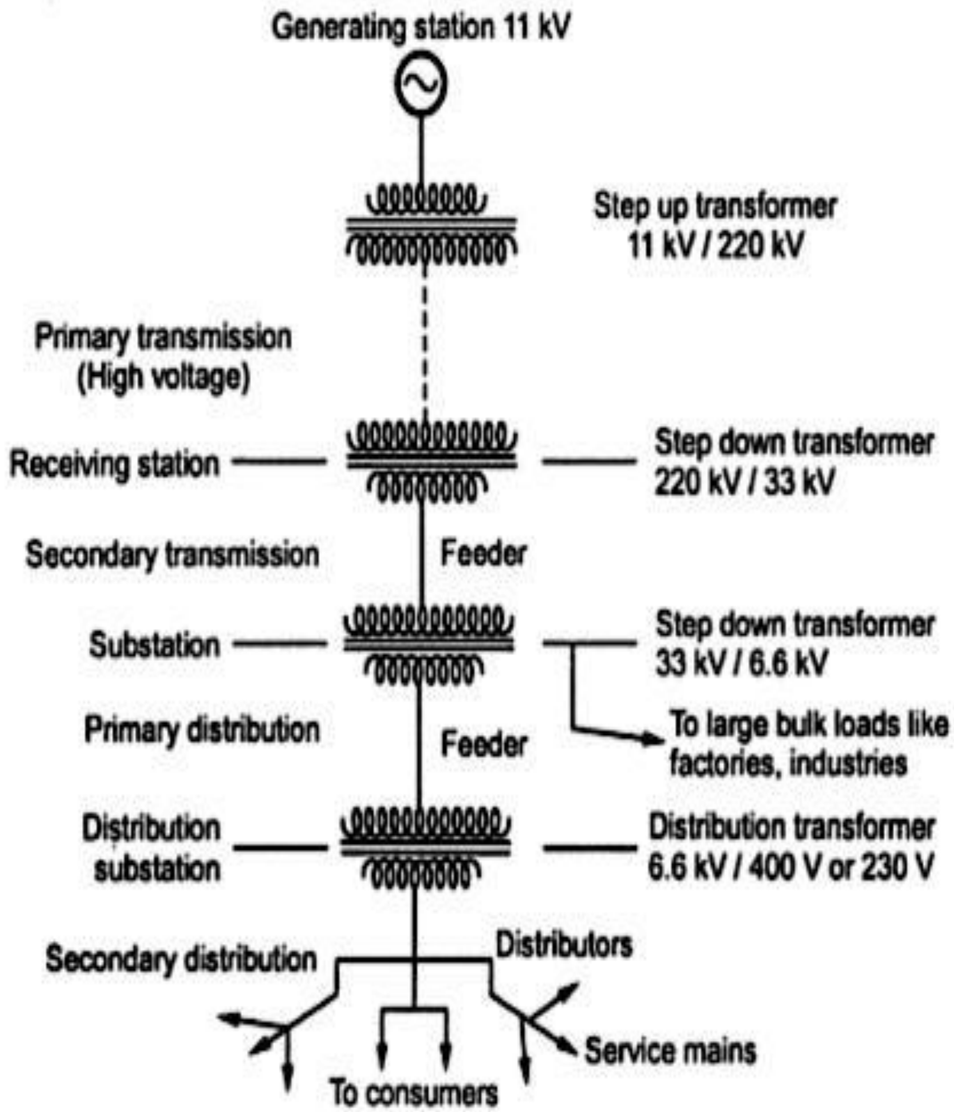
Electric power is the product of two quantities: current and voltage. These two quantities can vary with respect to time (AC power) or can be kept at constant levels (DC power).Most refrigerators, air conditioners, pumps and industrial machinery use AC power whereas most computers and digital equipment use DC power.

AC power has the advantage of being easy to transform between voltages and is able to be generated and utilised by brushless machinery. DC power remains the only practical choice in digital systems and can be more economical to transmit over long distances at very high voltages (see HVDC)

The ability to easily transform the voltage of AC power is important for two reasons: Firstly, power can be transmitted over long distances with less loss at higher voltages. So in power systems where generation is distant from the load, it is desirable to step-up (increase) the voltage of power at the generation point and then step-down (decrease) the voltage near the load. Secondly, it is often more economical to install turbines that produce higher voltages than would be used by most appliances.



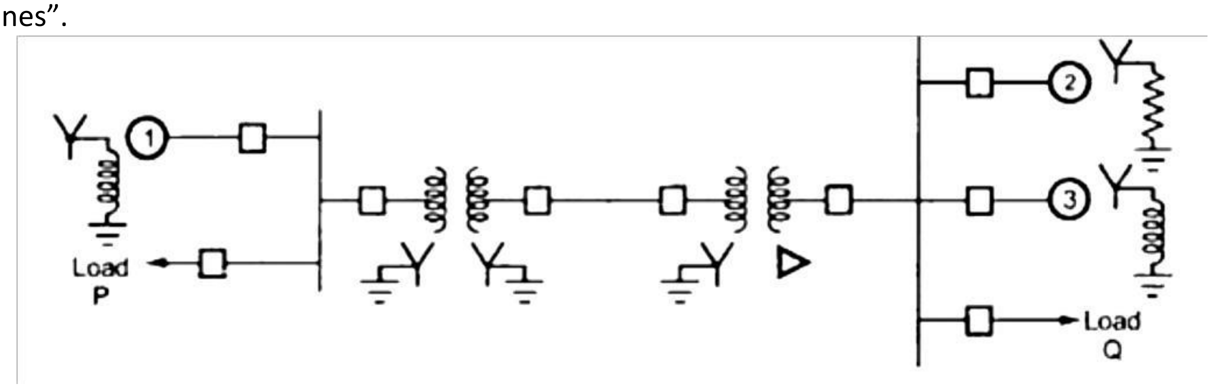
STRUCTURE OF POWER SYSTEM



COMPONENTS OF POWER SYSTEM

Single Line Diagram:

"A single line diagram is diagrammatic of power system in which the components are represented by their symbols and the interconnection between them is shown by straight lines".



ELEMENTS OF POWER SYSTEM

Power transformers:

Power transformers are used generation and transmission network for stepping-up the voltage at generating station and stepping-down the voltage for distribution. Auxiliary transformers supply power to auxiliary equipments at the substations.

Current transformers (CT):

The lines in substations carry currents in the order of thousands of amperes. The measuring instruments are designed for low value of currents. Current transformers are connected in lines to supply measuring instruments and protective relays.

Potential transformers (PT):

The lines in substations operate at high voltages. The measuring instruments are designed for low value of voltages. Potential transformers are connected in lines to supply measuring instruments and protective relays. These transformers make the low voltage instruments suitable for measurement of high voltages. For example a 11kV/110V PT is connected to a power line and the line voltage is 11kV then the secondary voltage will be 110V.

Circuit breaker (CB):

Circuit breakers are used for opening or closing a circuit under normal as well as abnormal (faulty) conditions. Different types of CBs which are generally used are oil circuit breaker, air-blast circuit breaker, and vacuum circuit breaker and SF6 circuit breaker.

Isolators or Isolating switches:

Isolators are employed in substations to isolate a part of the system for general maintenance. Isolator switches are operated only under no load condition.

GENERATION OF ELECTRICAL ENERGY

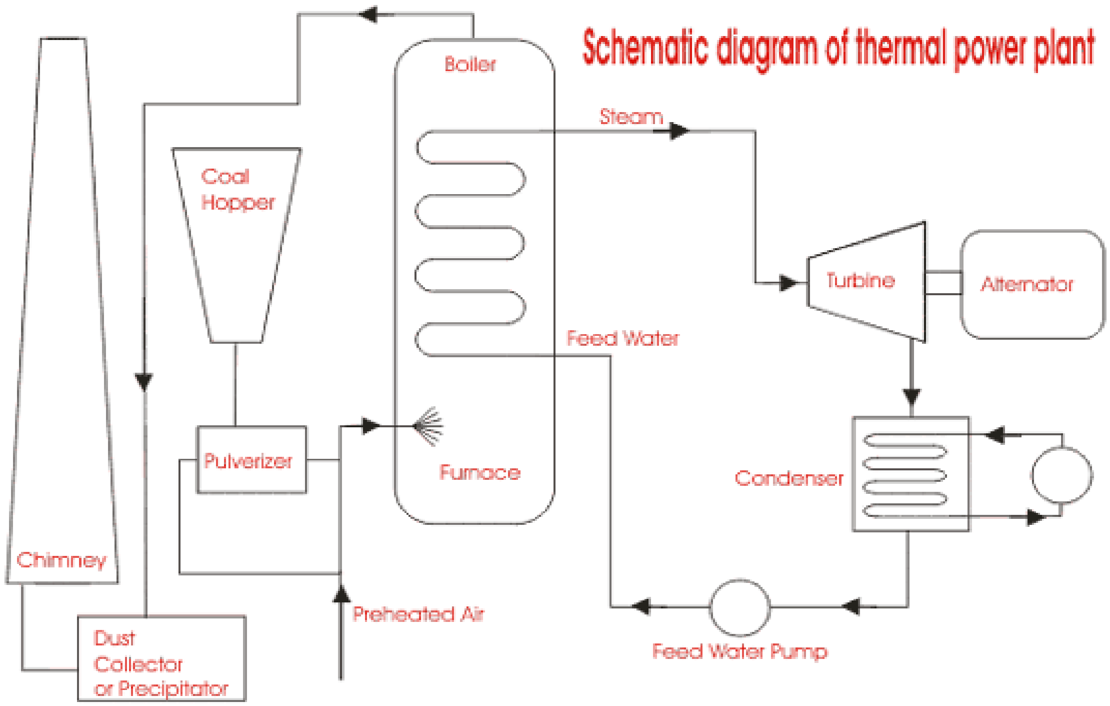
Three most widely found generating stations – thermal, hydel and nuclear plants in our country and elsewhere.

THERMAL POWER PLANT

The theory of **thermal power station** or **working of thermal power station** is very simple. A **power generation plant** mainly consists of alternator runs with help of steam turbine. The steam is obtained from high pressure boilers. Generally in India, bituminous coal, brown coal and peat are used as fuel of boiler.

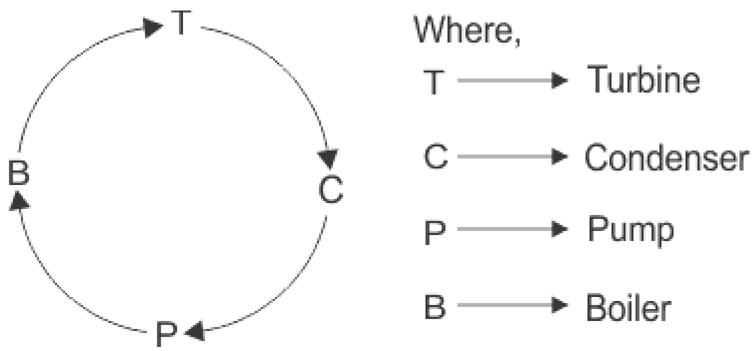
For better understanding we furnish every step of function of a thermal power station as follows,

1. First the pulverized coal is burnt into the furnace of steam boiler.
2. High pressure steam is produced in the boiler.
3. This steam is then passed through the super heater, where it further heated up.
4. This supper heated steam is then entered into a turbine at high speed.
5. In turbine this steam force rotates the turbine blades that means here in the turbine the stored potential energy of the high pressured steam is converted into mechanical energy.



1. After rotating the turbine blades, the steam has lost its high pressure, passes out of turbine blades and enters into a condenser.
2. In the condenser the cold water is circulated with help of pump which condenses the low pressure wet steam.
3. This condensed water is then further supplied to low pressure water heater where the low pressure steam increases the temperature of this feed water, it is then again heated in a high pressure heater where the high pressure of steam is used for heating.
4. The turbine in thermal power station acts as a prime mover of the alternator.

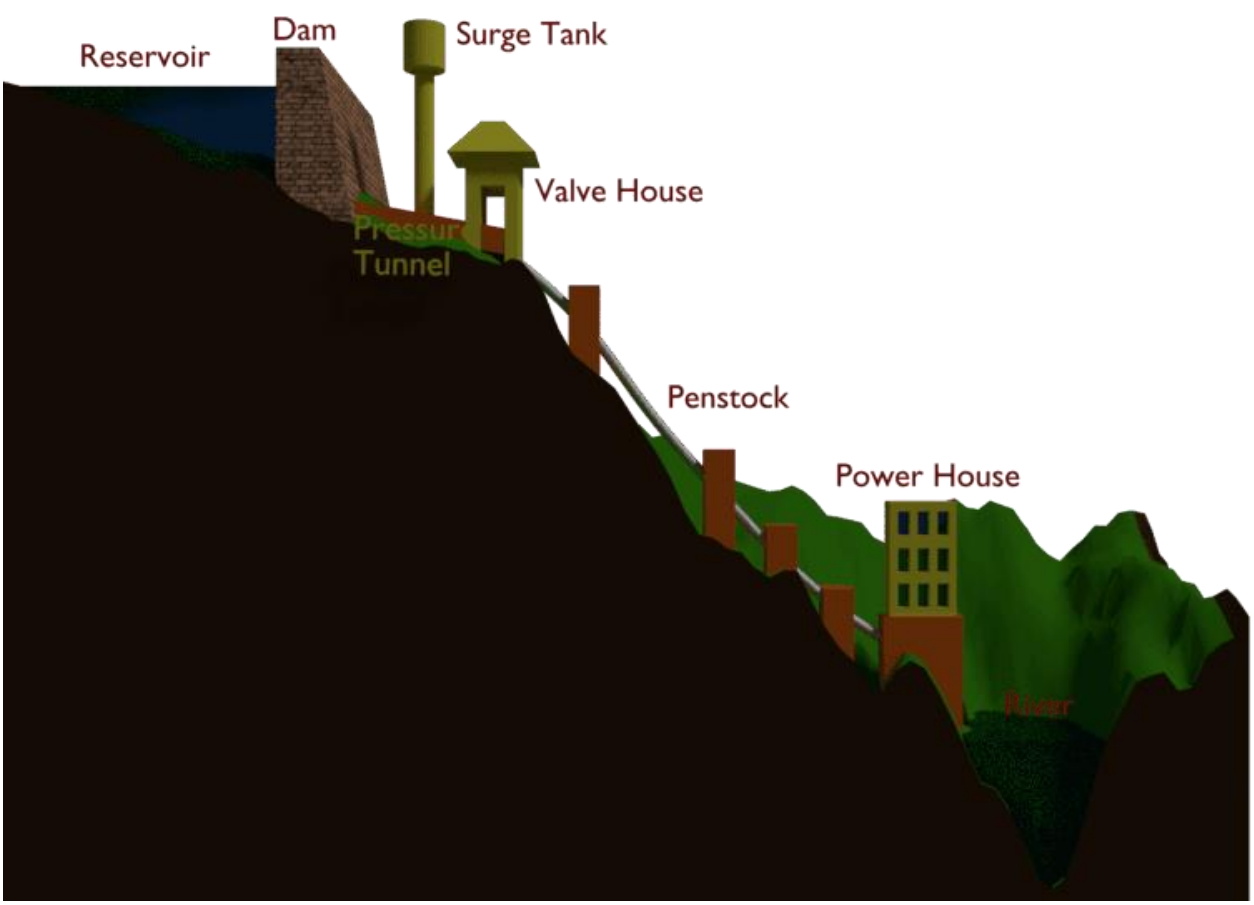
A typical Thermal Power Station Operates on a Cycle which is shown below.



The working fluid is water and steam. This is called feed water and steam cycle. The ideal Thermodynamic Cycle to which the operation of a **Thermal Power Station** closely resembles is the RANKINE CYCLE.

HYDEL POWER PLANT

In **hydroelectric power station** the kinetic energy developed due to gravity in a falling water from higher to lower head is utilised to rotate a turbine to produce electricity. The potential energy stored in the water at upper water level will release as kinetic energy when it falls to the lower water level. This turbine rotates when the following water strikes the turbine blades. To achieve a head difference of water **hydroelectric electric power station** are generally constructed in hilly areas.



There are only six primary components required to construct a hydroelectric power plant. These are dam, pressure tunnel, surge tank, valve house, penstock, and powerhouse.

1. The dam is an artificial concrete barrier constructed across the way of the river. The catchment area behind the dam creates a huge water reservoir.
2. The pressure tunnel takes water from the dam to the valve house.
3. In the valve house, there are two types of valves available. The first one is main sluicing valve and the second one is an automatic isolating valve. The sluicing valves control the water flowing to the downstream and automatic isolating valves stop the water flow when the electrical load is suddenly thrown off from the plant.
4. The penstock is a steel pipeline of suitable diameter connected between the valve house and powerhouse. The water flows down from upper valve house to lower powerhouse through this penstock only.
5. In the powerhouse there are water turbines and alternators with associated step up transformers and switchgear systems to generate and then facilitate transmission of electricity.
6. At last, we will come to the surge tank. The surge tank is also a protective accessory associated with **hydroelectric power plant**. It is situated just before the valve house. The height of the tank must be greater than the head of the water stored in the water reservoir behind the dam. This is an open top water tank.

The purpose of this tank is to protect the penstock from bursting out when suddenly turbine refuses to take water

The main advantage of an electric power plant is that it does not require any fuel.

It only requires water head which is naturally available after the construction of the required dam.

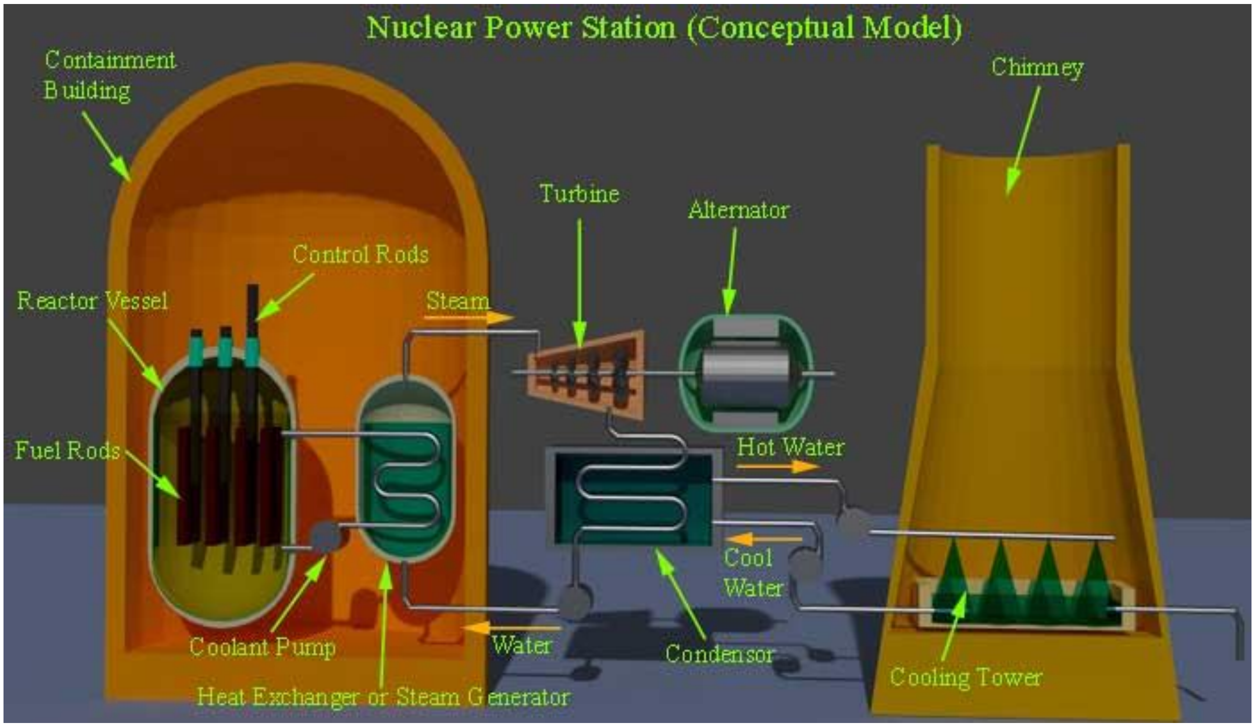
No fuel means no fuel cost, no combustion, no generation of flue gases, and no pollution in the atmosphere.

Due to the absence of fuel combustion, the **hydroelectric power plant** itself is very neat and clean.

NUCLEAR POWER PLANT

We can generate electrical power by means of nuclear power. In **nuclear power station**, generates electrical power by nuclear reaction. Here, heavy radioactive elements such as Uranium (U_{235}) or Thorium (Th_{232}) are subjected to nuclear fission. This fission is done in a special apparatus called reactor.

The basic principle of a nuclear power station is the same as a conventional thermal power station. The only difference is that, instead of using heat generated due to coal combustion, here in a nuclear power plant, the heat generated due to nuclear fission.



A nuclear power station has mainly four components.

1. Nuclear reactor

In a nuclear reactor, Uranium 235 is subjected to nuclear fission. It controls the chain reaction that starts when the fission is done. The chain reaction must be controlled otherwise the rate of energy released will be fast, there may be a high chance of explosion.

The heat released during a nuclear reaction is carried to the heat exchanger by means of coolant consist of sodium metal.

2. Heat exchanger

In a heat exchanger, the heat carried by sodium metal is dissipated in water and water is converted to high-pressure steam here. After releasing heat in water the sodium metal coolant comes back to the reactor by means of a coolant circulating pump.

3. Steam turbine

In a nuclear power plant, the steam turbine plays the same role as a coal power plant. The steam drives the turbine in the same way. After doing its job, the exhaust steam comes into a steam condenser where it is condensed to provide space to the steam behind it.

4. Alternator

An alternator, coupled with a turbine, rotates and generates electrical power, for utilization. The output from the alternator is delivered to the bus-bars through a transformer, circuit breakers, and isolators.

Advantages of Nuclear Power Station

1. As we said, the fuel consumption in this power station is quite low and hence, the cost for generating a single unit of energy is quite less than other conventional power generation methods. The amount of nuclear fuel required is also less.
2. A nuclear power station occupies a much smaller space compared to other conventional power stations of the same capacity.
3. This station does not require plenty of water, hence it is not essential to construct plant near-natural sources of water. This also does not require a huge quantity of fuel; hence it is also not essential to construct the plant near a coal mine or the place where good transport facilities are available. Because of this, the nuclear power station can be established very near to the load center.
4. There are large deposits of nuclear fuel globally therefore such plants can ensure the continued supply of electrical energy for coming thousands of years.

Disadvantages of Nuclear Power Plant

1. The fuel is not easily available and it is very costly.
2. The initial cost of constructing a nuclear power station is quite high.
3. Erection and commissioning of this plant are much complicated and sophisticated than other conventional power stations.
4. The fission by-products are radioactive in nature, and it may cause high radioactive pollution.
5. The maintenance cost is higher and the manpower required to run a nuclear power plant is quite higher since specialist trained people are required.
6. The sudden fluctuation of load cannot be met up efficiently by the nuclear plants.
7. As the by-products of the nuclear reactions are highly radioactive, it is a very big problem for the disposal of these by-products. It can only be disposed of deep inside the ground or in a sea away from the seashore.

SOLAR POWER PLANT

A solar power plant is any type of facility that converts sunlight either directly, like Photovoltaic, or indirectly, like Solar Thermal plants, into electricity.

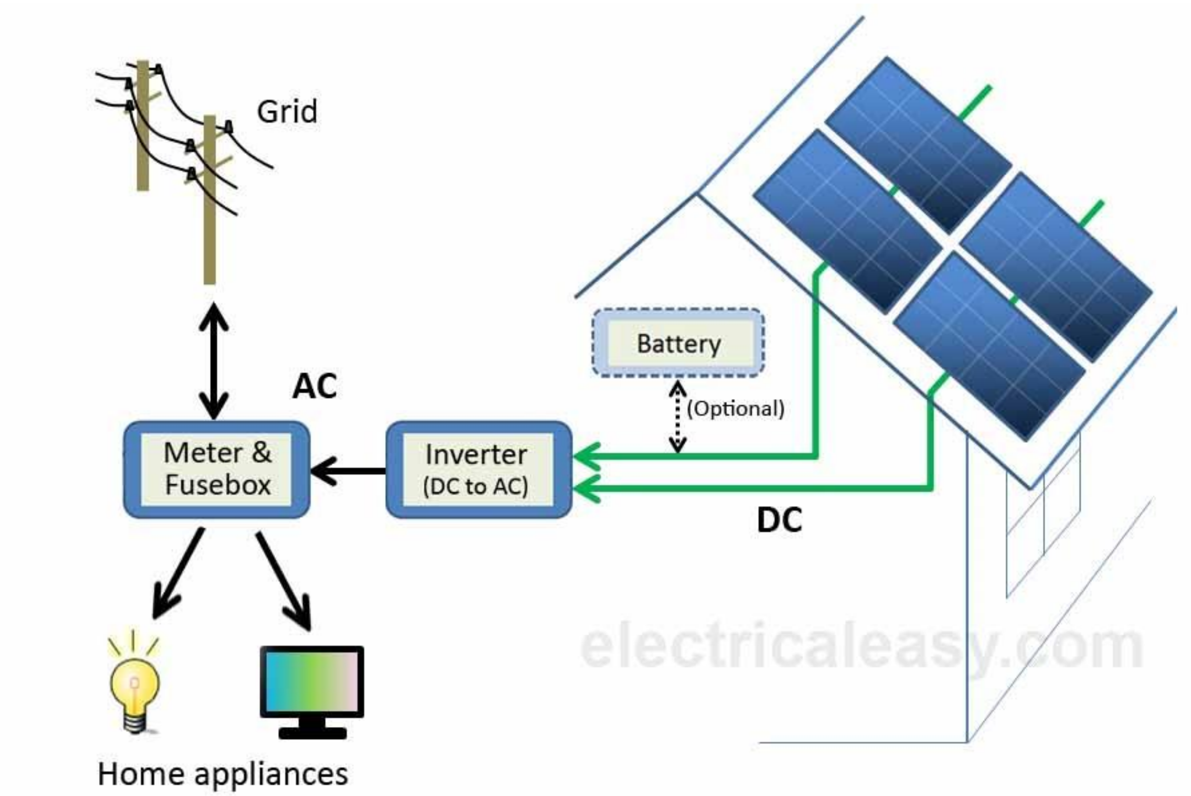
Photovoltaics

Photovoltaic power plants use large areas of photovoltaic cells, known as PV or solar cells, to directly convert sunlight into usable electricity. These cells are usually made from silicon alloys and are the technology most people have become familiar with - chances are you may have one on your roof.

The panels themselves come in various forms:

- Crystalline solar panels - As the name suggests these types of panels are made from crystalline silicon. They can be either monocrystalline or poly- or multi-crystalline. As a rule of thumb monocrystalline versions are more efficient (**about 15-20%**) but more expensive than their alternatives (tend to be **13-16% efficient**) but advancements are closing the gap between them over time.

- Thin-film solar panels - These types of panels consist of a series of films that absorb light in different parts of the EM spectrum. They tend to be made from amorphous silicon (aSi), cadmium telluride (CdTe), cadmium sulfide (CdS), and copper indium (gallium) diselenide.



Working Principle

Most solar PV panels are made from semiconductor materials, usually some form of silicon. When photons from sunlight hit the semiconductor material free electrons are generated which can then flow through the material to produce a direct electrical current. This is known as the photo-effect in physics. The DC current then needs to be converted to alternating current (AC) using an inverter before it can be directly used or fed into the electrical grid.

TRANSMISSION OF ELECTRIC POWER

MOST ECONOMICAL SIZE OF CONDUCTOR

It has already been shown that maximum stress in a cable occurs at the surface of the conductor. For safe working of the cable, dielectric strength of the insulation should be more than the maximums tress. Rewriting the expression for maximum stress, we get,

$$g_{max} = \frac{2V}{d \log_e \frac{D}{d}} \text{ volts/m}$$

The values of working voltage V and internal sheath diameter D have to be kept fixed at certain values due to design considerations. This leaves conductor diameter d to be the only variable in exp.(i). For given values of V and D, the most economical conductor diameter will be one for which gmax has a minimum value. The value of gmax will be minimum when d loge D/d is maximum i.e.

$$\frac{d}{dd}\left[d \log_e \frac{D}{d}\right] = 0$$

$$\text{or} \quad \log_e \frac{D}{d} + d.\frac{d}{D}.\frac{-D}{d^2} = 0$$

$$\text{or} \quad \log_e (D/d) - 1 = 0$$

$$\text{or} \quad \log_e (D/d) = 1$$

$$\text{or} \quad (D/d) = e = 2{\cdot}718$$

Most economical conductor diameter is

$$d = \frac{D}{2.718}$$

and the value of *gmax* under this condition is

$$g_{max} = \frac{2V}{d} \text{ volts/m} \qquad [\text{Putting } \log_e D/d = 1 \text{ in exp. } (i)]$$

CORONA

When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low. However, when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called corona.

The phenomenon of corona is accompanied by a hissing sound, production of ozone, power loss and radio interference.

The higher the voltage is raised, the larger and higher the luminous envelope becomes, and greater are the sound, the power loss and the radio noise.

Factors Affecting Corona

The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends:

(i)Atmosphere

As corona is formed due to ionisation 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 because unevenness of the surface decreases the value of breakdown voltage. Thus 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.

Important Terms

The phenomenon of corona plays an important role in the design of an overhead transmission line. Therefore, it is profitable to consider the following terms much used in the analysis of corona effects:

(i)Critical Disruptive Voltage

It is the minimum phase-neutral voltage at which corona occurs. Consider two conductors of radii r cm and spaced d cm apart. If V is the phase-neutral potential, then potential gradient at the conductor surface is given by:

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

In order that corona is formed, the value of g must be made equal to the breakdown strength of air. The breakdown strength of air at 76 cm pressure and temperature of 25ºC is 30 kV/cm (max) or 21·2 kV/cm (r.m.s.) and is denoted by go. If Vc is the phase-neutral potential required under these conditions, then,

(ii) Visual critical voltage

It is the minimum phase-neutral voltage at which corona glow appears all along the line conductors. It has been seen that in case of parallel conductors, the corona glow does not begin at the disruptive voltage Vc but at a higher voltage Vv, called visual critical voltage. The phase-neutral effective value of visual critical voltage is given by the following empirical formula : where mV is another irregularity factor having a value of 1·0 for polished conductors and 0·72 to 0·82 for rough conductors.

(iii) 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:

$$P = 242{\cdot}2\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}\,(V-V_c)^2 \times 10^{-5}\ \text{kW / km / phase}$$

where f = supply frequency in Hz

V = phase-neutral voltage (*r.m.s.*)

V_c = disruptive voltage (*r.m.s.*) per phase

Advantages and Disadvantages of Corona

Corona has many advantages and disadvantages. In the correct design of a high voltage overhead line, a balance should be struck between the advantages and disadvantages.

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

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

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

(ix) The current drawn by the line due to corona is non-sinusoidal and hence no sinusoidal voltage drop occurs in the line. This may cause inductive interference with neighbouring communication lines.

Methods of Reducing Corona Effect

It has been seen that intense corona effects are observed at a working voltage of 33 kV or above. Therefore, careful design should be made to avoid corona on the sub-stations or bus-bars rated for 33 kV and higher voltages otherwise highly ionized air may cause flash-over in the insulators or between the phases, causing considerable damage to the equipment. 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. This is one of the reasons that 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. However, spacing cannot be increased too much otherwise the cost of supporting structure (e.g., bigger cross arms and supports) may increase to a considerable extent.

OVERHEAD LINE

CONDUCTORS

Commonly used conductor materials:

The most commonly used conductor materials for over head lines are copper, aluminium, steel cored aluminium, galvanised steel and cadmium copper. The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions. All conductors used for overhead lines are preferably stranded in order to increase the flexibility. In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24 ...... wires. Thus, if there are n layers, the total number of

individual wires is 3n(n + 1) + 1. In the manufacture of stranded conductors, the consecutive layers of wires are twisted or spiralled in opposite directions so that layers are bound together.

TYPES OF CONDUCTOR

1.Copper

Copper is an ideal material for overhead lines owing to its high electrical conductivity and greater tensile strength.

Copper has high current density *i.e.*, the current carrying capacity of copper per unit of X-sectional area is quite large. This leads to two advantages. Firstly, smaller X-sectional area of conductor is required and secondly, the area offered by the conductor to wind loads is reduced. However, due to its higher cost and non-availability, it is rarely used for these purposes. Nowadays the trend is to use aluminium 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:

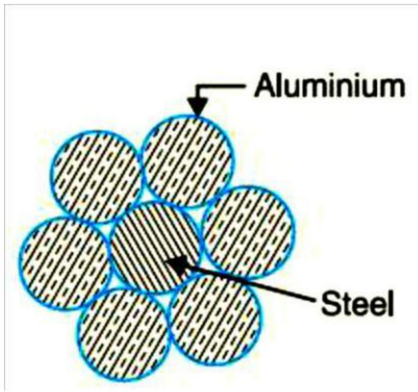
(*i*) The conductivity of aluminium is 60% that of copper. The smaller conductivity of aluminium means that for any particular transmission efficiency, the X-sectional area of conductor must be larger in aluminium than in copper. For the same resistance, the diameter of aluminium conductor is about 1·26 times the diameter of copper conductor. The increased X-section of aluminium exposes a greater surface to wind pressure and, therefore, supporting towers must be designed for greater transverse strength. This often requires the use of higher towers with consequence of greater sag.

(*ii*) The specific gravity of aluminium (2·71 gm/cc) is lower than that of copper (8·9 gm/cc).Therefore, an aluminium conductor has almost one-half the weight of equivalent copper conductor. For this reason, the supporting structures for aluminium need not be made so strong as that of copper conductor.

(*iii*) Aluminium conductor being light, is liable to greater swings and hence larger cross-arms are required.

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 galvanised 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. Usually, diameter of both steel and aluminium wires is the same.

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. **Galvanised steel**

Steel has very high tensile strength. Therefore, galvanised 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. However, they can be used to advantage for transmitting a small power over a small distance where the size of the copper conductor desirable from economic considerations would be too small and thus unsuitable for use because of poor mechanical strength.

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. Therefore, 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 i.e., where the cost of conductor material is comparatively small compared with the cost of supports.

INSULATOR

Insulating Materials

The main cause of failure of overhead line insulator, is flash over, occurs in between line and earth during abnormal over voltage in the system. During this flash over, the huge heat produced by arcing, causes puncher in insulator body. Viewing this phenomenon the materials used for electrical insulator, has to posses some specific properties.

Properties of insulating material

1. The materials generally used for insulating purpose is called **insulating material**. For successful utilization, this material should have some specific properties as listed below-1.It must be mechanically strong enough to carry tension and weight of conductors.

2. It must have very high dielectric strength to withstand the voltage stresses in High Voltage system.

3. It must possess high Insulation Resistance to prevent leakage current to the earth.

4. There physical as well as electrical properties must be less affected by changing temperature

TYPES OF INSULATOR

There are mainly three types of insulator likewise

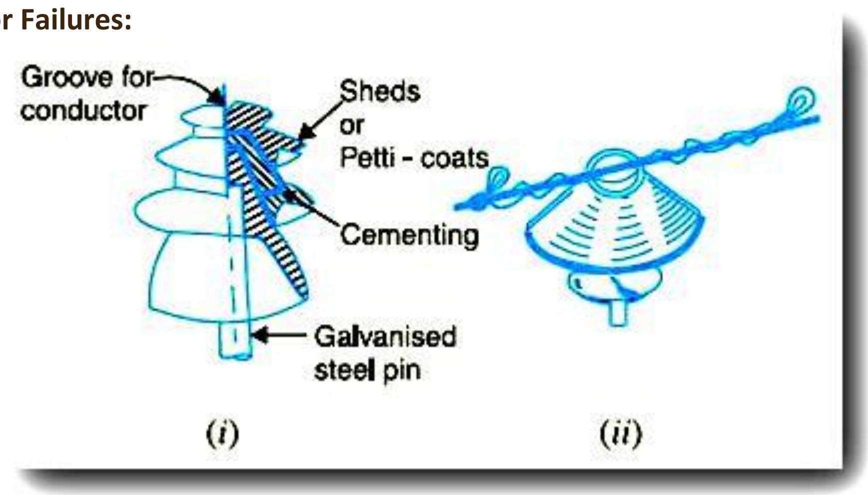
1. Pin Insulator
2. Suspension Insulator
3. Strain insulator
4. Shackle insulator
5. Stay Insulator

In addition to that there are other two types of electrical insulator available mainly for low voltage application, e.i. stay insulator and shackle insulator.

1. Pin Type Insulators

As the name suggests, 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 electric power at voltages up to 33 kV. Beyond operating voltage of 33 kV, the pin type insulators become too bulky and hence uneconomical.

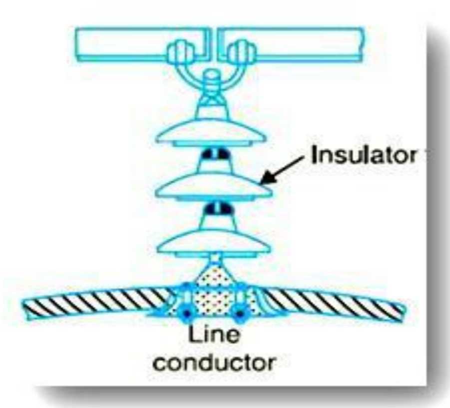
Causes of Insulator Failures:



Insulators are required to withstand both mechanical and electrical stresses. The latter type is primarily due to line voltage and may cause the breakdown of the insulator. The electrical breakdown of the insulator can occur either by flash-over or puncture. In flashover, an arc occurs between the line conductor and insulator pin (i.e., earth) and the discharge jumps across the air gaps, following shortest distance.

In case of flash-over, the insulator will continue to act in its proper capacity unless extreme heat produced by the arc destroys the insulator. In case of puncture, the discharge occurs from conductor to pin through the body of the insulator. When such breakdown is involved, the insulator is permanently destroyed due to excessive heat. In practice, sufficient thickness of porcelain is provided in the insulator to avoid puncture by the line voltage. The ratio of puncture strength to flashover voltage is known as **safety factor**.

2. Suspension Type

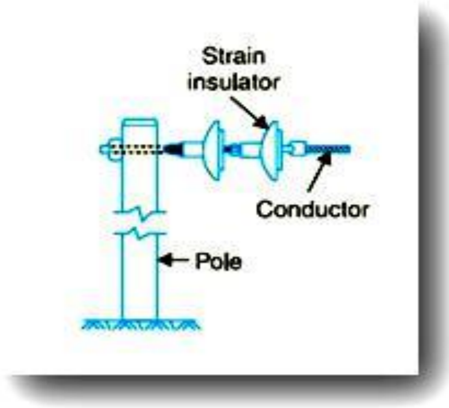


For high voltages (>33 kV), it is a usual practice to use suspension type insulators shown in Figure. Consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower. Each unit or disc is designed for low voltage, say 11 kV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66 kV, then six discs in series will be provided on the string.

Advantages of suspension type:

- Suspension type insulators are cheaper than pin type insulators for voltages beyond 33 kV.
- Each unit or disc of suspension type insulator is designed for low voltage, usually 11 kV. Depending upon the working voltage, the desired number of discs can be connected in series.
- If anyone disc is damaged, the whole string does not become useless because the damaged disc can be replaced.
- The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.
- In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.
- 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.

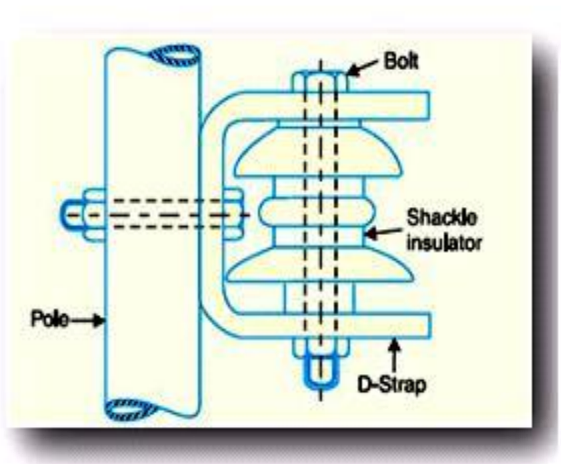
3. Strain Insulators

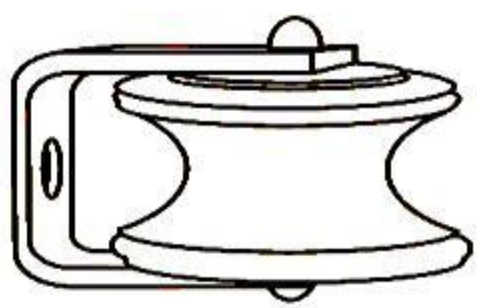


When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, strain insulators are used. For low voltage lines (< 11 kV), shackle insulators are used as strain insulators. However, for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators as shown in Figure. The discs of strain insulators are used in the vertical plane. When the tension in lines is exceedingly high, at long river spans, two or more strings are used in parallel.

4. Shackle Insulators

In early days, the shackle insulators were used as strain insulators. But now a day, they are frequently used for low voltage distribution lines. Such insulators can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or to the cross arm.





5. Stay Insulator

For low voltage_lines, the stays are to be insulated from ground at a height. The insulator used in the stay wire is called as the **stay insulator** and is usually of porcelain and is so designed that in case of breakage of the insulator the guy-wire will not fall to the ground. There are several methods of increasing the string efficiency or improving voltage distribution across different units of a string.

Mechanical design of transmission line – sag and tension calculations for different weather conditions, Tower spotting, Types of towers, Substation Layout (AIS, GIS), Methods of grounding.

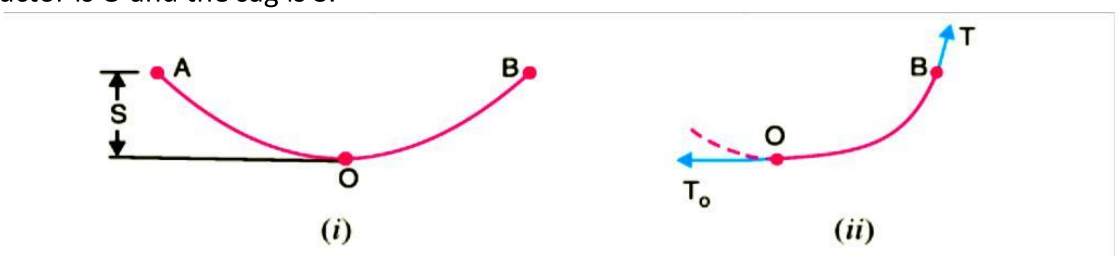
MECHANICAL DESIGN OF TRANSMISSION LINE

SAG IN OVERHEAD LINES

While erecting an overhead line, it is very important that conductors are under safe tension. If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension.

In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag. The difference in level between points of supports and the lowest point on the conductor is called **sag**.

Following Fig. shows a conductor suspended between two equal level supports A and B. The conductor is not fully stretched but is allowed to have a dip. The lowest point on the conductor is O and the sag is S.



The following points may be noted

(i) When the conductor is suspended between two supports at the same level, it takes the shape of catenary. However, if the sag is very small compared with the span, then sag-span curve is like a parabola.

(ii) The tension at any point on the conductor acts tangentially. Thus tension T_O at the lowest Point O acts horizontally as shown in Fig. (ii).

(iii) The horizontal component of tension is constant throughout the length of the wire.

(iv) The tension at supports is approximately equal to the horizontal tension acting at any point on the wire. Thus if T is the tension at the support B, then $T = T_O$

Conductor Sag and Tension

This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level. It is also desirable that tension in the conductor should be low to avoid the mechanical failure of conductor and to permit the use of less strong supports.

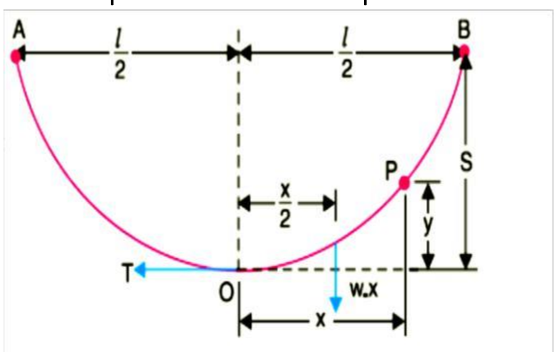
CALCULATION OF SAG

In an overhead line, the sag should be so adjusted that tension in the conductors is within safe limits. The tension is governed by conductor weight, effects of wind, ice loading and temperature variations. It is a standard practice to keep conductor tension less than 50% of its ultimate tensile strength i.e., minimum factor of safety in respect of conductor tension should be 2.

We shall now calculate sag and tension of a conductor when (i) supports are at equal levels and (ii) supports are at unequal levels.

(i) **When supports are at equal levels**

Consider a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig.8.2. It can be proved that lowest point will be at the mid-span.



It can be proved that 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 that the curvature is so small that curved length is equal to its horizontal projection (i.e., OP = x), the two forces acting on the portion OP of the conductor are :

(a) The weight w_x 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,

$$Ty = w x \times \frac{x}{2}$$

or $$y = \frac{w x^2}{2T}$$

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

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

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

(ii) **When supports are at unequal levels**

In hilly areas, we generally come across conductors suspended between supports at unequal levels. Fig.3 shows a conductor suspended between two supports A and B which are at different levels. The lowest point on the conductor is O.

Let,

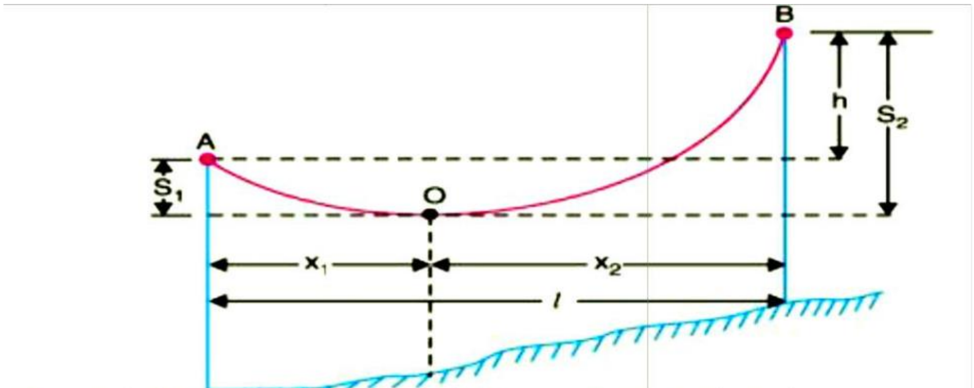
l = Span length

h = Difference in levels between two supports

x 1 = Distance of support at lower level (A to O)

x 2 = Distance of support at higher level (O to B)

T = Tension in the conductor



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

$$\text{Sag } S_1 = \frac{w x_1^2}{2T}$$

and

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

Also $x_1 + x_2 = l$

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

$\therefore$ $S_2 - S_1 = \frac{w\,l}{2T}(x_2 - x_1)$ $[\because x_1 + x_2 = l]$

But $S_2 - S_1 = h$

$\therefore$ $h = \frac{w\,l}{2T}(x_2 - x_1)$

or $x_2 - x_1 = \frac{2\,Th}{w\,l}$ ...(*ii*)

Solving exps. (*i*) and (*ii*), we get,

$$x_1 = \frac{l}{2} - \frac{T\,h}{w\,l}$$

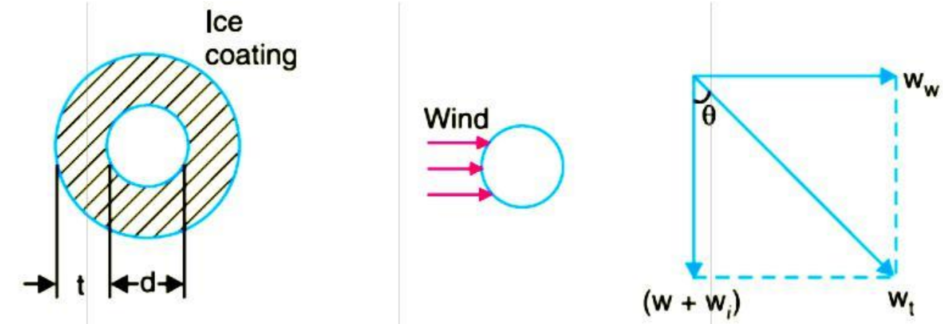
$$x_2 = \frac{l}{2} + \frac{T\,h}{w\,l}$$

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

EFFECT OF WIND AND ICE LOADING

The above formulae for sag are true only in still air and at normal temperature when the conductor is acted by its weight only. However, in actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure. The weight of ice acts vertically downwards i.e., in the same direction as the weight of conductor. The force due to the wind is assumed to act horizontally i.e., at right angle to the projected surface of the conductor.

Hence, the total force on the conductor is the vector sum of horizontal and vertical forces as shown in below.



(i) (ii) (iii)

Total weight of conductor per unit length is

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

Where W = weight of conductor per unit length

= conductor material density · volume per unit length

Wi = weight of ice per unit length

= density of ice * volume of ice per unit length

$$= \text{density of ice} \times \frac{\pi}{4}\,[(d+2t)^2 - d^2] \times 1$$
$$= \text{density of ice} \times \pi\, t\,(d+t)^*$$

w_W = wind force per unit length

= wind pressure per unit area projected area per unit length

$$= \text{wind pressure} \times [(d+2t) \times 1]$$

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 to the vertical where

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

ii)The sag in the conductor is given by

$$S = \frac{w_t\, l^2}{2T}$$

Hence S represents the slant sag in a direction making an angle to the vertical. If no specific mention is made in the problem, then slant slag is calculated by using the above formula.

iii)The vertical sag = $S\cos\theta$

MODELLING AND PERFORMANCE OF TRANSMISSION LINES

Classification of lines - short line, medium line and long line - equivalent circuits, phasor diagram, attenuation constant, phase constant, surge impedance; transmission efficiency and voltage regulation, real and reactive power flow in lines, Power - circle diagrams, surge impedance loading, methods of voltage control; Ferranti effect.

CLASSIFICATION OF LINES - INTRODUCTION

The important considerations in the design and operation of a transmission line are the determination of voltage drop, line losses and efficiency of transmission. These values are greatly influenced by the line constants *R*, *L* and *C* of the transmission line.

In this chapter, we shall develop formulas by which we can calculate voltage regulation, line losses and efficiency of transmission lines.

Firstly, they provide an opportunity to understand the effects of the parameters of the line on bus voltages and the flow of power. Secondly, they help in developing an overall understanding of what is occurring on electric power system.

CLASSIFICATION OF OVERHEAD TRANSMISSION LINES

A transmission line has three constants *R*, *L* and *C* distributed uniformly along the whole length of the line. The resistance and inductance form the series impedance. The capacitance existing between conductors for 1-phase line or from a conductor to neutral for a 3-phase line forms a shunt path throughout the length of the line. Therefore, capacitance effects introduce complications in transmission line calculations.

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), it is usually considered as a short transmission line. Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected. Therefore, while studying the performance of a short transmission line, 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 moderately 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. For purposes of calculations, the distributed capacitance of the line is divided and lumped in the form of condensers shunted across the line at one or more points.

(iii) Long transmission lines. When the length of an overhead transmission line is more than 150 km 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.

It may be emphasised here that exact solution of any transmission line must consider the fact that the constants of the line are not lumped but are distributed uniformly throughout the length of the line.

However, reasonable accuracy can be obtained by considering these constants as lumped for short and medium transmission lines.

Important Terms

While studying the performance of a transmission line, it is desirable to determine its voltage regulation and transmission efficiency. We shall explain these two terms in turn.

(i) Voltage regulation. When a transmission line is carrying current, there is a voltage drop in the line due to resistance and inductance of the line. The result is that receiving end voltage (V_R) of the line is generally less than the sending end voltage (V_S). This voltage drop ($V_S - V_R$) in the line is expressed as a percentage of receiving end voltage V and is called 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.

(ii) Transmission efficiency. The power obtained at the receiving end of a transmission line is generally less than the sending end power due to losses in the line resistance.

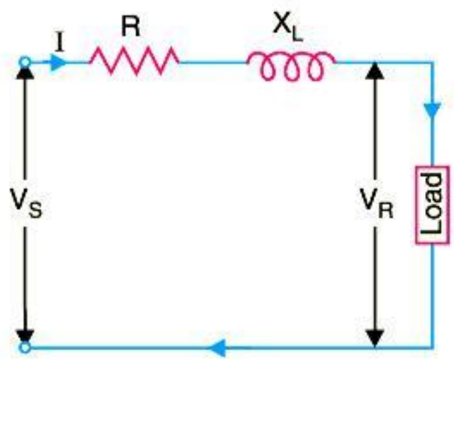
The ratio of receiving end power to the sending end power of a transmission line is known as the **transmission efficiency** of the line

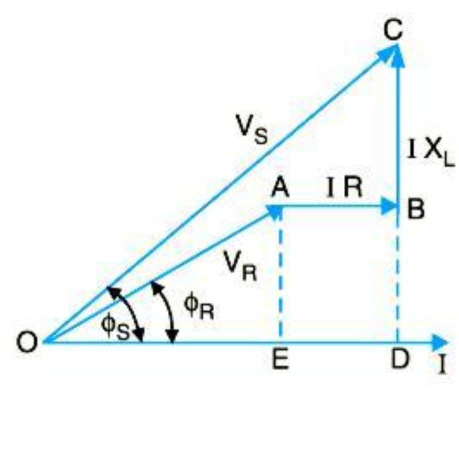
PERFORMANCE OF SINGLE PHASE SHORT TRANSMISSION LINES

As stated earlier, the effects of line capacitance are neglected for a short transmission line. Therefore, while studying the performance of such a line, only resistance and inductance of the line are taken into account. The equivalent circuit of a single phase short transmission line is shown in Fig.

Here, the total line resistance and inductance are shown as concentrated or lumped instead of being distributed. The circuit is a simple a.c. series circuit.

Let,
I = load current
R = loop resistance i.e., resistance of both conductors
X_L= loop reactance
V_R = receiving end voltage
cos ϕ_R = receiving end power factor (lagging)
V_S= sending end voltage
cos ϕ_S= sending end power factor





The phasor diagram of the line for lagging load power factor is shown in Fig. From the right angled triangle ODC, we get,

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

or

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

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

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

(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 $= \dfrac{\text{Power delivered}}{\text{Power sent out}} \times 100$

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

An approximate expression for the sending end voltage Vs can be obtained as follows. Draw S perpendicular from B and C on OA produced as shown in Fig. Then OC is nearly equal to OF

OC=OF=OA+AF=OA+AG+GF

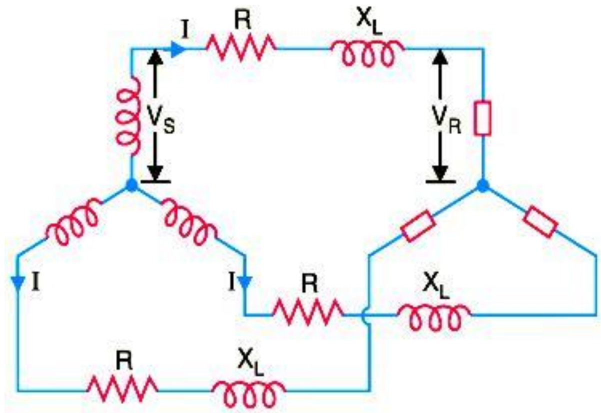
=OA+AG+BH

$V_S = V_R + IR \cos \phi_R + I X_L \sin \phi_R$

THREE-PHASE SHORT TRANSMISSION LINES

For reasons associated with economy, transmission of electric power is done by 3-phase system. This system may be regarded as consisting of three single phase units, each wire transmitting one-third of the total power. As a matter of convenience, we generally analyse 3-phase system by considering one phase only. Therefore, expression for regulation, efficiency etc. derived for a single phase line can also be applied to a 3-phase system.

Thus, Vs and V_R are the phase voltages, whereas R and X_L are the resistance S and inductive reactance per phase respectively.



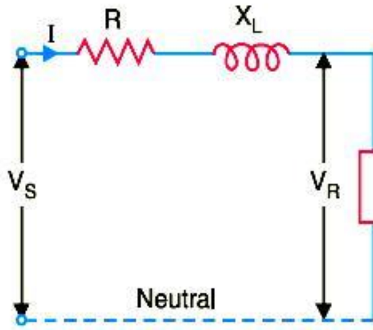


Fig (*i*) shows a *Y*-connected generator supplying a balanced *Y*-connected load through a transmission line. Each conductor has a resistance of *R* Ω and inductive reactance of *X* Ω.

Fig. (ii) shows one phase separately. The calculations can now be made in the same way as for a single phase line.

Effect of Load PF on Regulation and Efficiency

The regulation and efficiency of a transmission line depend to a considerable extent upon the power factor of the load.

1. Effect on regulation.

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 $I\,X_L \sin \phi_R > I \cos \phi_R$, 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.

2. Effect on transmission efficiency.

The power delivered to the load depends upon the power factor.

$$P = V_R * I \cos \phi_R \quad \text{(For 1-phase line)}$$

$$I = \frac{P}{V_R \cos \phi_R}$$

$$P = 3\, V_R\, I \cos \phi_R \quad \text{(For 3-phase line)}$$

$$I = \frac{P}{3 V_R \cos \phi_R}$$

It is clear that in each case, for a given amount of power to be transmitted (P) and receiving end voltage Power Factor Meter (V_R), the load current I is inversely proportional to the load p.f..

Consequently, with the decrease in load p.f., the load current and hence the line losses are increased. This leads to the conclusion that transmission efficiency of a line decreases with the decrease in load Power Factor Regulator p.f. and vice-versa.

MEDIUM TRANSMISSION LINES

In short transmission line calculations, the effects of the line capacitance are neglected because such lines have smaller lengths and transmit power at relatively low voltages (< 20 kV). However, as the length and voltage of the line increase, the capacitance gradually becomes of greater importance.

Since medium transmission lines have sufficient length (50-150 km) and usually operate at voltages greater than 20 kV, the effects of capacitance cannot be neglected. Therefore, in order to obtain reasonable accuracy in medium transmission line calculations, the line capacitance must be taken into consideration.

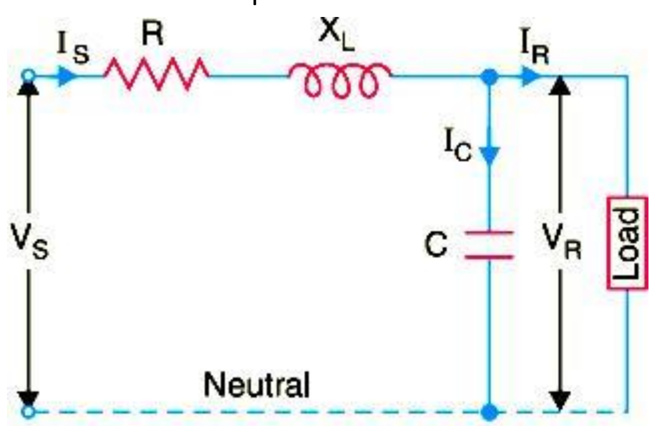
The capacitance is uniformly distributed over the entire length of the line. However, in order to make the calculations simple, the line capacitance is assumed to be lumped or concentrated in the form of capacitors shunted across the line at one or more points. Such a treatment of localising the line capacitance gives reasonably accurate results. The most commonly used methods (known as localised capacitance methods) for the solution of medium transmissions lines are :

(i) End condenser method
(ii) Nominal T method
(iii) Nominal π method.

Although the above methods are used for obtaining the performance calculations of medium lines, they can also be used for short lines if their line capacitance is given in a particular problem.

i)End Condenser Method

In this method, the capacitance of the line is lumped or concentrated at the receiving or load end as shown in Fig.This method of localising the line capacitance at the load end overestimates the effects of capacitance. In Fig, one phase of the 3-phase transmission line is shown as it is more convenient to work in phase instead of line-to-line values.



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 Taking the receiving end voltage VR as the reference phasor,

$$\text{we have, } \vec{V_R} = V_R + j\,0$$

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

$$\text{Capacitive current, } \vec{I_C} = j\,\vec{V_R}\,\omega C = j\,2\pi f C\,\vec{V_R}$$

The sending end current I_S is the phasor sum of load current I_R and capacitive current I_C i.e. ,

$$\begin{aligned} \vec{I_S} &= \vec{I_R} + \vec{I_C} \\ &= I_R\,(\cos\phi_R - j\sin\phi_R) + j\,2\pi f C\,V_R \\ &= I_R\cos\phi_R + j\,(-I_R\sin\phi_R + 2\pi f C V_R) \\ &= \vec{I_S}\,\vec{Z} = \vec{I_S}\,(R + jX_L) \end{aligned}$$

$$\vec{V_S} = \vec{V_R} + \vec{I_S}\,\vec{Z} = \vec{V_R} + \vec{I_S}\,(R + j\,X_L)$$

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

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

$$\begin{aligned} \%\text{ Voltage transmission efficiency} &= \frac{\text{Power delivered / phase}}{\text{Power delivered / phase} + \text{losses / phase}} \times 100 \\ &= \frac{V_R\,I_R\cos\phi_R}{V_R\,I_R\cos\phi_R + I_S^2\,R} \times 100 \end{aligned}$$

Limitations

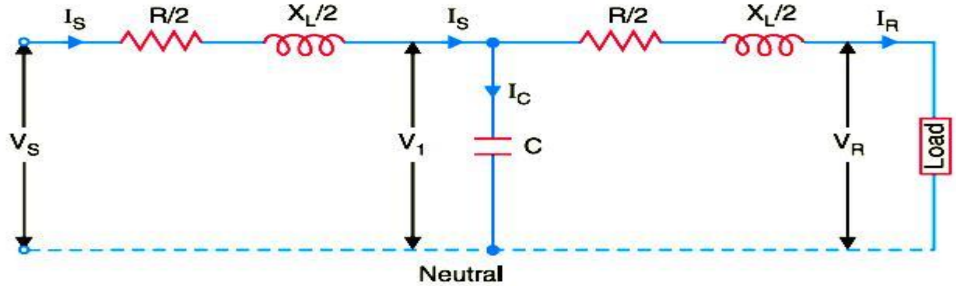
Although end condenser method for the solution of medium lines is simple to work out calculations, yet it has the following drawbacks :

(i) There is a considerable error (about 10%) in calculations because the distributed capacitance has been assumed to be lumped or concentrated.

(ii) This method overestimates the effects of line capacitance.

ii)Nominal T Method

In this method, the whole line capacitance is assumed to be concentrated at the middle point of the line and half the line resistance and reactance are lumped on its either side as shown in Fig.Therefore, in this arrangement, full charging current flows over half the line. In Fig. one phase of 3-phase transmission line is shown as it is advantageous to work in phase instead of line-to-line values.



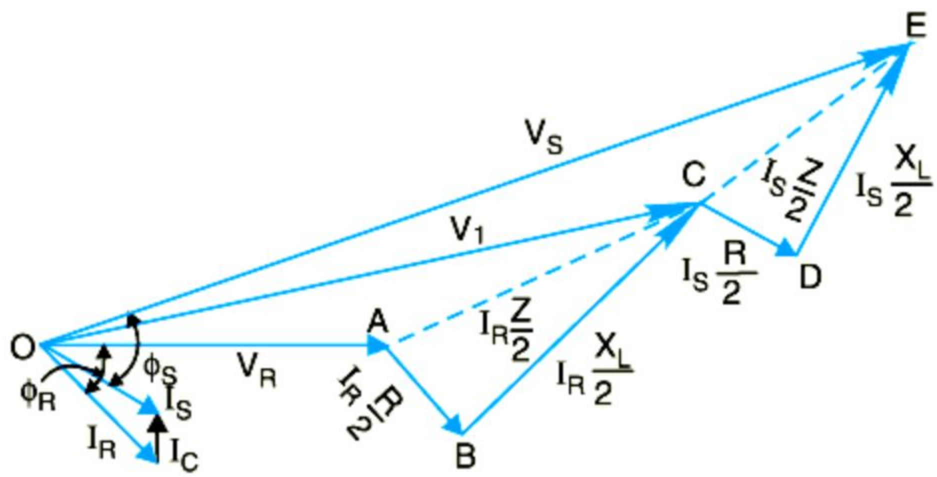
Let

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

Receiving end voltage, $\vec{V_R} = V_R + j\,0$

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



Voltage across C, $\vec{V_1} = \vec{V_R} + \vec{I_R}\vec{Z}/2$

$$= V_R + I_R(\cos\phi_R - j\sin\phi_R)\left(\frac{R}{2} + j\frac{X_L}{2}\right)$$

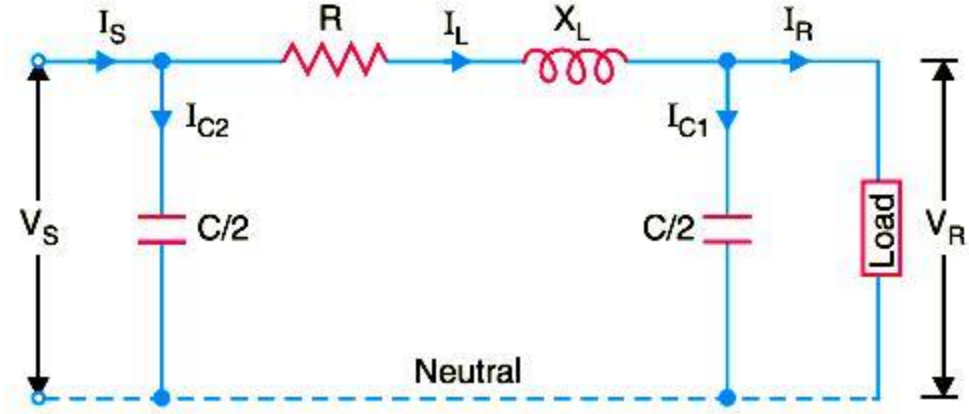
Capacitive current, $\vec{I_C} = j\,\omega\,C\,\vec{V_1} = j\,2\pi f\,C\,\vec{V_1}$

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

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

iii) Nominal π Method

In this method, capacitance of each conductor (i.e., line to neutral) is divided into two halves; one half being lumped at the sending end and the other half at the receiving end as shown in Fig. It is obvious that capacitance at the sending end has no effect on the line drop. However, its charging current must be added to line current in order to obtain the total sending end current.



Let

I_R = load current per phase

R = resistance per phase

X_L = inductive reactance per phase

C = capacitance per phase

cos ϕ_R = receiving end power factor (lagging)

V_S= sending end voltage per phase

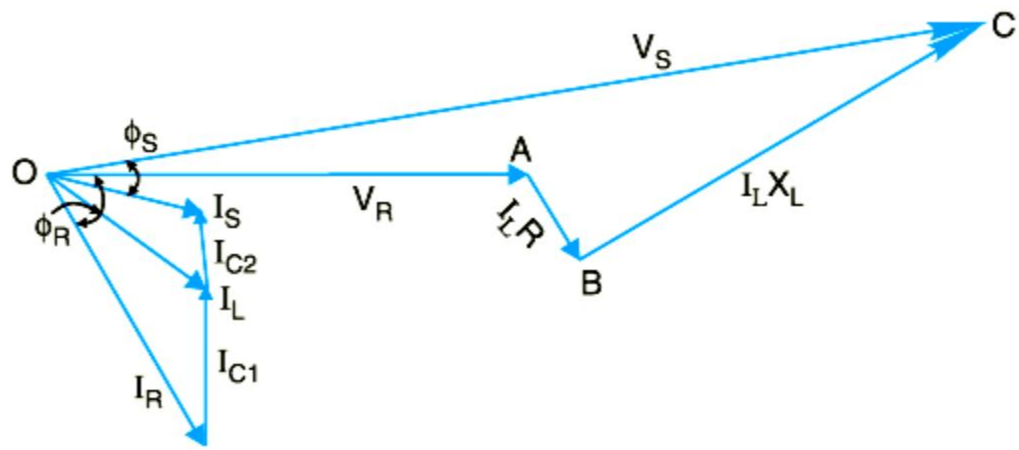
The phasor diagram for the circuit is shown in Fig. Taking the receiving end voltage as the reference phasor, we have,

$$\overrightarrow{V_R} = V_R + j\,0$$

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

Charging current at load end is

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



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

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

Charging current at the sending end is

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

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

LONG TRANSMISSION LINES

It is well known that line constants of the transmission line are uniformly distributed over the entire length of the line. However, reasonable accuracy can be obtained in line calculations for short and medium lines by considering these constants as lumped. If such an assumption of lumped constants is applied to long transmission lines (having length excess of about 150 km), it is found that serious errors are introduced in the performance calculations. Therefore, in order to obtain fair degree of accuracy in the performance calculations of long lines, the line constants are considered as uniformly distributed throughout the length of the line. Rigorous mathematical treatment is required for the solution of such lines. Fig shows the equivalent circuit of a 3-phase long transmission line on a phase-neutral basis. The whole line length is divided into n sections, each section having line constants 1 /n th of those for the whole line. The following points may by noted :

(i) The line constants are uniformly distributed over the entire length of line as is actually the case.

(ii) The resistance and inductive reactance are the series elements.

(iii) The leakage suptance (B) and leakage conductance (G) are shunt elements. The leakage suptance is due to the fact that capacitance exists between line and neutral. The leakage conductance takes into account the energy losses occurring through leakage over the insulators or due to corona effect between conductors.

Admittance $= \sqrt{G^2 + B^2}$.

(iv) The leakage current through shunt admittance is maximum at the sending end of the line and decreases continuously as the receiving end of the circuit is approached at which point its value is zero.

DISTRIBUTION SYSTEMS

DISTRIBUTION SYSTEM

That part of power system which distributes electric power for local use is known as distribution system. In general, the distribution system is the electrical system between the substation fed by the Transmission system and the consumer's meters. It generally consists of feeders, distributors, and service mains.

(i) Feeders

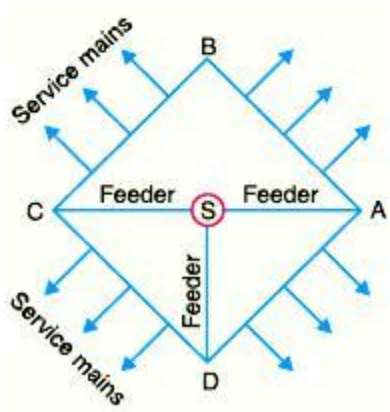
A feeder is a conductor which connects the sub-station (or localized generating station) to the area where power is to be distributed. Generally, no tappings are taken from the feeder so that current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying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

(ii)Distributor

A distributor is a conductor from which tappings are taken for supply to the consumers. In 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. While designing a distributor, voltage drop along its length is the main consideration since the statutory 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.



REQUIREMENTS OF A DISTRIBUTION SYSTEM

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are : proper voltage, availability of power on demand and reliability.

(i) Proper voltage.

One important requirement of a distribution system is that voltage variations at consumer's terminals should be as low as possible. The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors.

The statutory limit of voltage variations is ± 6% of the rated value at the consumer's terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

(ii) Availability of power on demand.

Power must be available to the consumers in any amount that they may require from time to time. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

(iii) Reliability.

Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by (a) interconnected system (b) reliable automatic control system (c) providing additional reserve facilities.

DESIGN CONSIDERATIONS IN DISTRIBUTION SYSTEM

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration.

(i) Feeders.

A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation.

(ii) Distributors.

A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer's terminals (± 6% of rated value). The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

CLASSIFICATION OF DISTRIBUTION SYSTEMS

A distribution system may be classified according to ;

i)Nature of current

According to nature of current, distribution system may be classified as

(a) d.c. Distribution system
(b) a.c. Distribution system

Now-a-days, a.c. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method

ii) Type of construction

According to type of construction distribution system may be classified as

(a) Overhead system
(b) Underground system.

The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general, the underground system is used at places where overhead construction is impracticable or prohibited by the local laws

(iii) Scheme of connection

According to scheme of connection, the distribution system may be classified as

(a) Radial system

(b) Ring main system

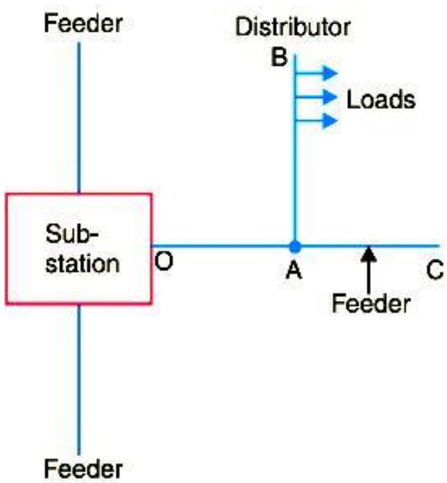
(c) Inter-connected system

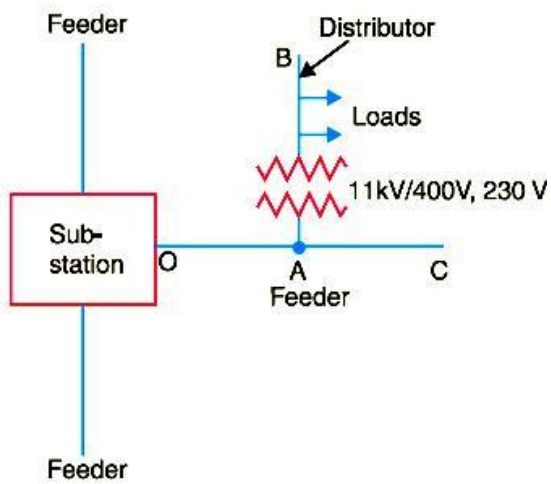
CONNECTION SCHEMES OF DISTRIBUTION SYSTEM

All distribution of electrical energy is done by constant voltage system. In practice, 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. Fig. shows a single line diagram of a radial system for d.c. distribution where a feeder OC supplies a distributor A B at point A . Obviously, the distributor is fed at one end only i.e., point A is this case. Fig (ii) shows a single line diagram of radial system for a.c. distribution. 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. However, it suffers from the following drawbacks :

(a) The end of the distributor nearest to the feeding point will be heavily loaded.

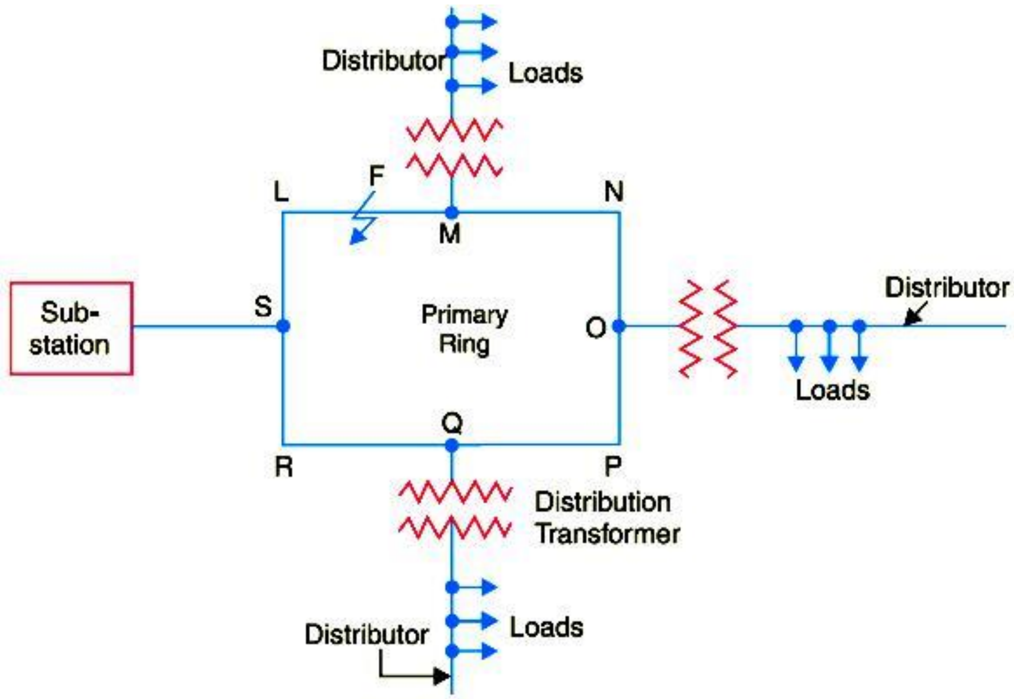
(b) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

(c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes.

Due to these limitations, this system is used for short distances only.

(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. Figure below shows the single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS.



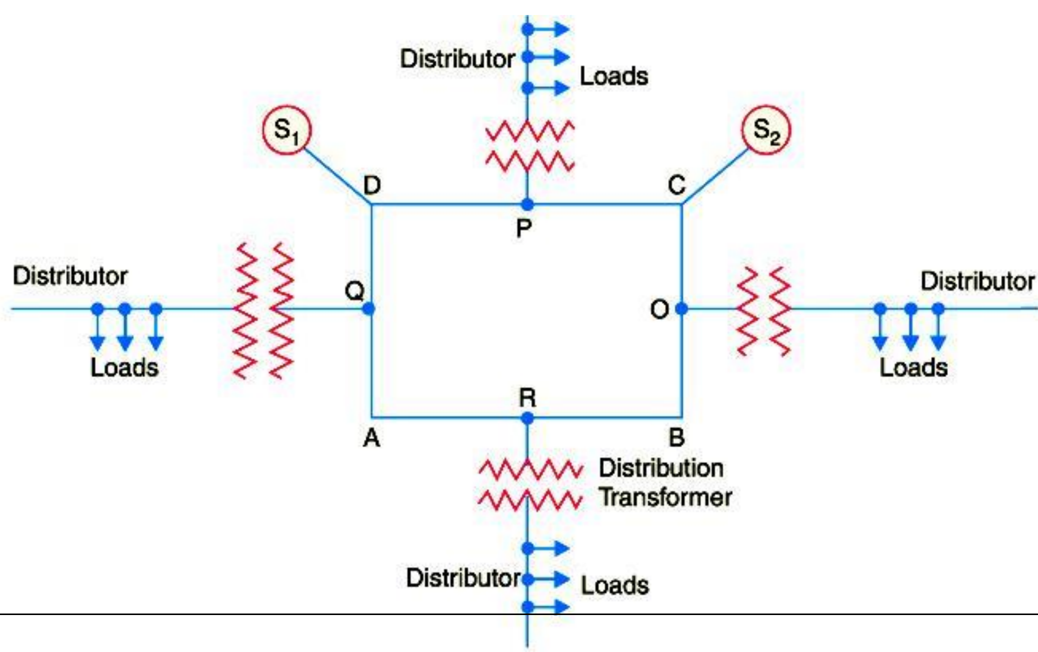
The distributors are tapped from different points M, O and Q of the feeder through distribution transformers. The ring main system has the following advantages :

(a) There are less voltage fluctuations at consumer's terminals.

(b) The system is very reliable as each distributor is fed via *two feeders. In the event of fault on any section of the feeder, the continuity of supply is maintained. For example, suppose that fault occurs at any point F of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers via the feeder SRQPONM.

(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. Figure below shows the single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two substations S and S at points D and C respectively.



Distributors are connected to points O, P, Q and R of the feeder ring through distribution transformers. The interconnected system has the following advantages :

(a) It increases the service reliability.

(b) Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.

TYPES OF D.C. DISTRIBUTORS

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.

(i) 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 point along the length of the distributor.

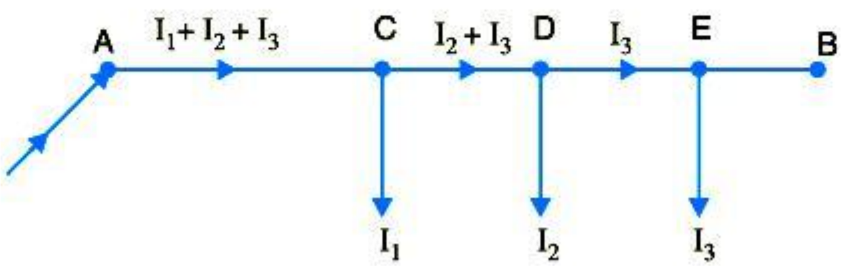


Fig. shows the single line diagram of a d.c. distributor A B fed at the end A (also known as singly fed distributor) and loads I_1 , I_2 and I_3 tapped off at points C, D and E respectively.

The following points are worth noting in a singly fed distributor:

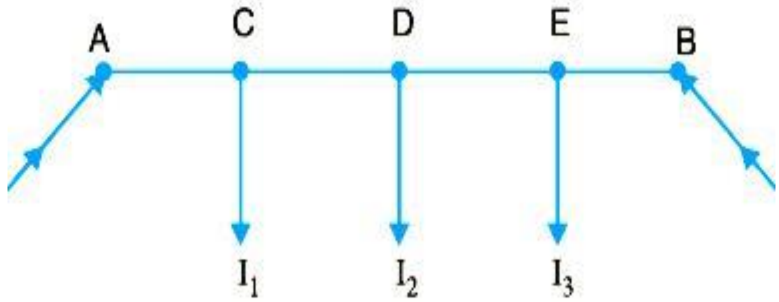
(a) The current in the various sections of the distributor away from feeding point goes on decreasing. Thus current in section AC is more than the current in section CD and current in section CD is more than the current in section DE.

(b) The voltage across the loads away from the feeding point goes on decreasing. Thus in Fig. the minimum voltage occurs at the load point E.

(c) In case a fault occurs on any section of the distributor, the whole distributor will have to be disconnected from the supply mains. Therefore, continuity of supply is interrupted.

(ii) Distributor fed at both ends.

In this type of feeding, the distributor is connected to the supply mains at both ends and loads are tapped off at different points along the length of the distributor. The voltage at the feeding points may or may not be equal. Fig. shows a distributor A B 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.



Here, the load voltage goes on decreasing as we move away from one feeding point say A , reaches minimum value and then again starts rising and reaches maximum value when we reach the other feeding point B. The minimum voltage occurs at some load point and is never fixed. It is shifted with the variation of load on different sections of the distributor.

Advantages

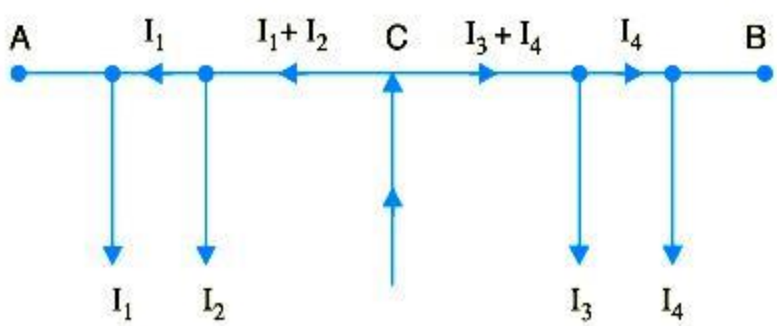
(a) If a fault occurs on any feeding point of the distributor, the continuity of supply is maintained from the other feeding point.

(b) In case of fault on any section of the distributor, the continuity of supply is maintained from the other feeding point.

(c) The area of X-section required for a doubly fed distributor is much less than that of a singly fed distributor.

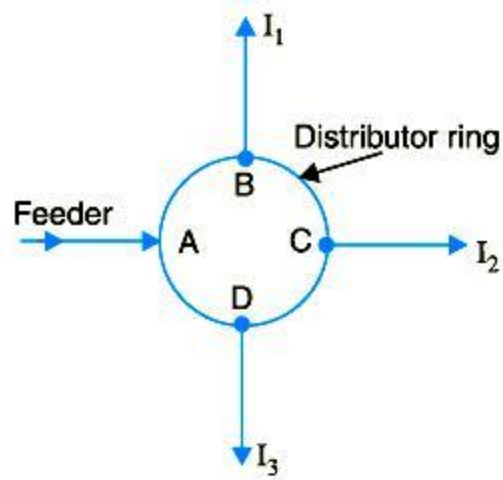
(iii) Distributor fed at the centre.

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



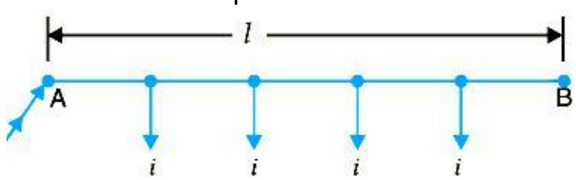
(iv)Ring mains.

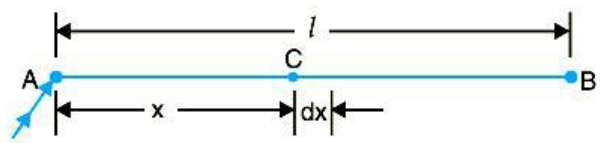
In this type, the distributor is in the form of a closed ring as shown in Figure below. It is equivalent to a straight distributor fed at both ends with equal voltages, the two ends being brought together to form a closed ring. The distributor ring may be fed at one or more than one point.



UNIFORMLY LOADED DISTRIBUTOR FED AT ONE END

Fig shows the single line diagram of a 2-wire d.c. distributor *A B* fed at one end *A* and loaded uniformly with *i* amperes per metre length. It means that at every 1 m length of the distributor, the load tapped is *i* amperes. Let *l* metres be the length of the distributor and *r* ohm be the resistance per metre run.





Consider a point *C* on the distributor at a distance *x* metres from the feeding point *A* as shown in Fig. Then current at point *C* is

$= i\,l - i\,x$ amperes $= i\,(l - x)$ amperes

Now, consider a small length dx near point C. Its resistance is r dx and the voltage drop over length dx is $dv = i\,(l - x)\,r\,dx = i\,r\,(l - x)\,dx$ Total voltage drop in the distributor upto point C is

$$v = \int_0^x i\,r\,(l - x)\,dx = i\,r\left(l\,x - \frac{x^2}{2}\right)$$

The voltage drop upto point B (i.e. over the whole distributor) can be obtained by putting $x = l$ in the above expression.

∴ Voltage drop over the distributor AB

$$= i\,r\left(l \times l - \frac{l^2}{2}\right)$$

$$= \tfrac{1}{2}\,i\,r\,l^2 = \tfrac{1}{2}\,(i\,l)\,(r\,l)$$

$$= \tfrac{1}{2}\,I\,R$$

where

$i\,l = I$, the total current entering at point A

$r\,l = R$, the total resistance of the distributor

Thus, in a uniformly loaded distributor fed at one end, the total voltage drop is equal to that produced by the whole of the load assumed to be concentrated at the middle point.

AC DISTRIBUTION

Now-a-days electrical energy is generated, transmitted and distributed in the form of alternating current. One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer. Transformer has made it possible to transmit a.c. power at high voltage and utilise it at a safe potential. High transmission and distribution voltages have greatly reduced the current in the conductors and the resulting line losses.

The a.c. distribution system is classified into

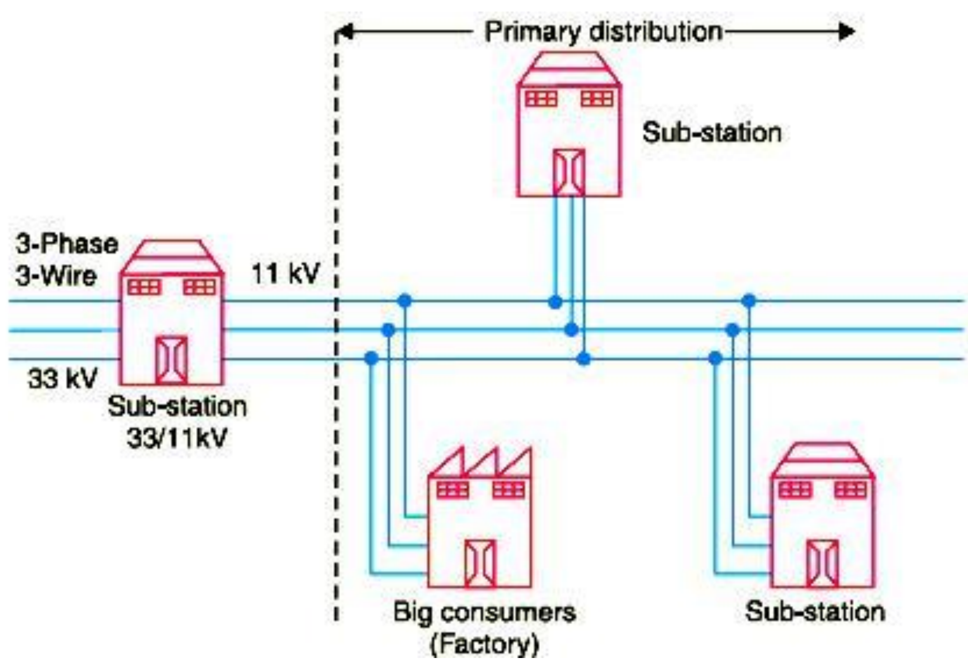
i. primary distribution system and

ii. Secondary distribution system.

i) Primary distribution system.

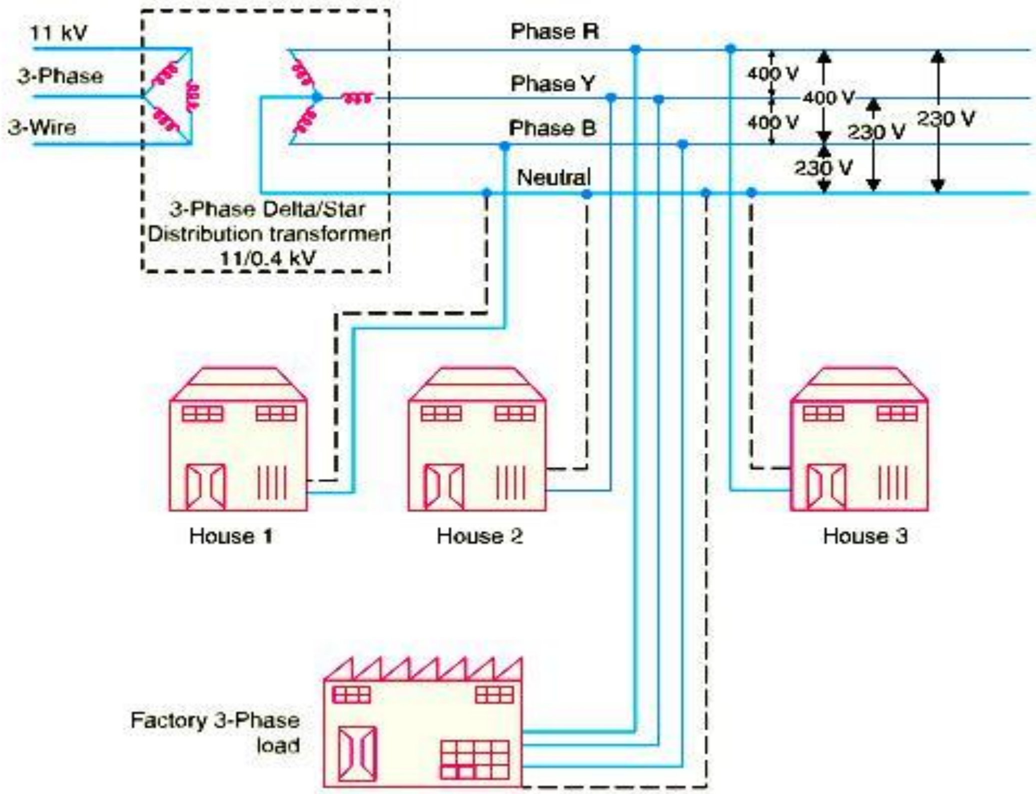
It is that part of a.c. distribution system which operates at voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low-voltage consumer uses. The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed. The most commonly used primary distribution voltages are 11 kV, 6·6 kV and 3·3 kV.

Due to economic considerations, primary distribution is carried out by 3- phase, 3-wire system Fig. shows a typical primary distribution system Electric power from the generating station is transmitted at high voltage to the substation located in or near the city.



ii) Secondary distribution system

It is that part of a.c. distribution system. The secondary distribution employs 400/230V, 3-phase, 4wire system. Figure shows a typical secondary distribution system. The primary distribution circuit delivers power to various substations, called distribution sub-stations. The substations are situated near the consumers' localities and contain step-down transformers. At each distribution substation, the voltage is stepped down to 400V and power is delivered by 3-phase, 4-wire a.c. system. The voltage between any two phases is 400V and between any phase and neutralize 230V. The single phase domestic loads are connected between any one phase and the neutral, whereas 3-phase 400V motor loads are connected across 3-phase lines directly.



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 vectorially.

(iii) In an a.c. system, power factor (p.f.) has to be taken into account. Loads tapped off form the distributor are generally at different power factors. There are two ways of referring power factor viz

(a) It may be referred to supply or receiving end voltage which is regarded as the reference vector.

(b) It may be referred to the voltage at the load point itself.

There are several ways of solving a.c. distribution problems. However, symbolic notation method has been found to be most convenient for this purpose. In this method, voltages, currents and impedances are expressed in complex notation and the calculations are made exactly as in d.c. distribution.

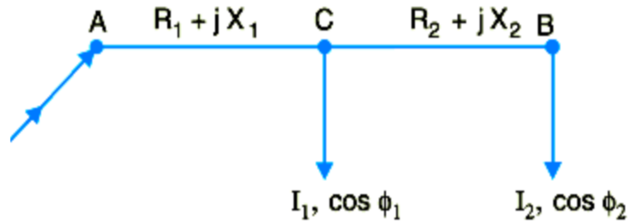
METHODS OF SOLVING A.C. DISTRIBUTION PROBLEMS

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. Each case shall be discussed separately.

(*i*) Power factors referred to receiving end voltage.

Consider an a.c. distributor *A B* with concentrated loads of I_1 and I_2 tapped off at *C* and B as shown in Fig. Taking the receiving end voltage V_B points as the reference vector, let points as the reference vector, let lagging power factors at *C* and *B* be cos ϕ_1 and cos ϕ_2 *w.r.t.* V_B . Let R_1 , X_1 and R_2 , X_2 be the resistance and reactance of sections *A C* and *CB* of the distributor.



Impedance of section *A C*, $\overrightarrow{Z_{AC}} = R_1 + j X_1$

Impedance of section *CB*, $\overrightarrow{Z_{CB}} = R_2 + j X_2$

Load current at point *C*, $\overrightarrow{I_1} = I_1 (\cos \phi_1 - j \sin \phi_1)$

Load current at point *B*, $\overrightarrow{I_2} = I_2 (\cos \phi_2 - j \sin \phi_2)$

Current in section *CB*, $\overrightarrow{I_{CB}} = \overrightarrow{I_2} = I_2 (\cos \phi_2 - j \sin \phi_2)$

Current in section *A C*, $\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2}$

$$= I_1 (\cos \phi_1 - j \sin \phi_1) + I_2 (\cos \phi_2 - j \sin \phi_2)$$

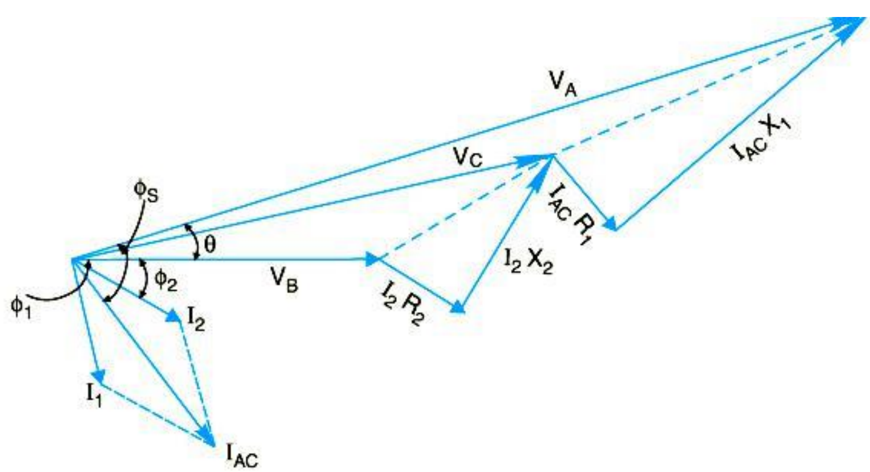
Voltage drop in section *CB*, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = I_2 (\cos \phi_2 - j \sin \phi_2)(R_2 + j X_2)$

Voltage drop in section *A C*, $\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}} = \left(\overrightarrow{I_1} + \overrightarrow{I_2}\right) Z_{AC}$

$$= [I_1(\cos \phi_1 - j \sin \phi_1) + I_2 (\cos \phi_2 - j \sin \phi_2)] [R_1 + jX_1]$$

Sending end voltage, $\overrightarrow{V_A} = \overrightarrow{V_B} + \overrightarrow{V_{CB}} + \overrightarrow{V_{AC}}$

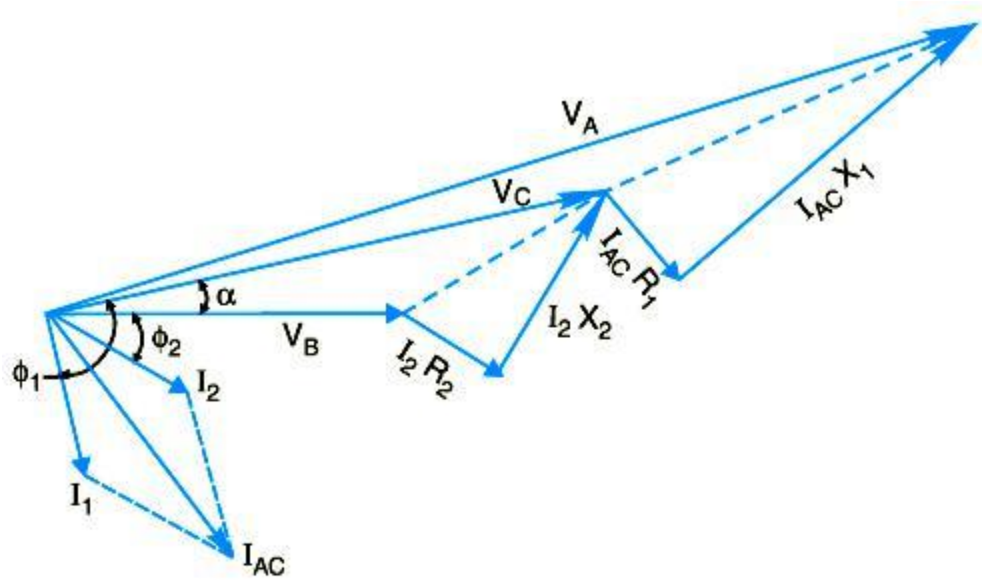
Sending end current, $\overrightarrow{I_A} = \overrightarrow{I_1} + \overrightarrow{I_2}$



The vector diagram of the a.c. distributor under these conditions is shown in Fig. Here, the receiving end voltage V_B is taken as the reference vector. As power factors of loads are given *w.r.t.* V_B , therefore, I_1 and I_2 lag behind V_B by ϕ_1 and ϕ_2 respectively.

(ii) Power factors referred to respective load voltages.

Suppose the power factors of loads in the previous Fig. are referred to their respective load voltages. Then ϕ1 is the phase angle between Vc and I1 and ϕ2 is the phase angle between VB and I2 . The vector diagram under these conditions is shown in Fig



$$\text{Voltage drop in section } CB = \vec{I_2}\,\overrightarrow{Z_{CB}} = I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2)$$

$$\text{Voltage at point } C = \vec{V_B} + \text{Drop in section } CB = V_C\angle\alpha \text{ (say)}$$

Now $\vec{I_1} = I_1\angle-\phi_1$ *w.r.t.* voltage V_C

$\therefore$ $\vec{I_1} = I_1\angle-(\phi_1-\alpha)$ *w.r.t.* voltage V_B

i.e. $\vec{I_1} = I_1[\cos(\phi_1-\alpha) - j\sin(\phi_1-\alpha)]$

Now $\overrightarrow{I_{AC}} = \vec{I_1} + \vec{I_2}$

$$= I_1[\cos(\phi_1-\alpha) - j\sin(\phi_1-\alpha)] + I_2(\cos\phi_2 - j\sin\phi_2)$$

$$\text{Voltage drop in section } AC = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}}$$

$$\therefore \quad \text{Voltage at point } A = V_B + \text{Drop in } CB + \text{Drop in } AC$$

EHVAC and HVDC TRANSMISSION SYSTEM

EHVAC (Extra High Voltage Alternating Current)

This decrease in load current results in following advantages:

- As current gets reduced, size and volume of conductor required also reduces for transmitting the same amount of power.
- Voltage drop in line (3IR) reduces and hence voltage regulation of the line is improved.
- Line losses ($3I^2R$) gets reduced which results in the increase in transmission line efficiency.

Some other *advantages of extra high voltage transmission* are as under:

- Power handling capacity of the line increases as we increase the transmission voltage. It is proportional to the square of operating voltage. The cost related to tower, insulators and different types of equipment are proportional to voltage rather than the square of voltage. Thus the net capital cost of transmission line decreases as voltage increases.

Therefore, a large power can be transmitted with high voltage transmission lines economically.

- The total line cost of per MW per km decreases considerably.
- The operation of EHV AC system is simple, reliable and can be adopted easily.
- The lines can be easily tapped and extended.

Disadvantages of High Voltage Transmission

The major problems in this system are as under.

- Corona loss is a big problem at higher voltages. This may further increase in bad weather conditions.
- It increases radio interference.
- The height of towers and insulation increases with increase in transmission voltage.
- The cost of different types of equipment and switchgear required for transmission increases with increase in transmission voltage.
- The high voltage lines produce electrostatic effects which are injurious to human beings and animals.

HVDC

Merits of HVDC

- Undersea cables, where high capacitance causes additional AC losses. (e.g., 250 km Baltic Cable between Sweden and Germany),
- Endpoint-to-endpoint long-haul bulk power transmission without intermediate.
- Increasing the capacity of an existing power grid in situations where additional wires are difficult or expensive to install
- Power transmission and stabilization between unsynchronized AC distribution systems.
- Connecting a remote generating plant to the distribution grid, for example Nelson River Bipoler.

- Stabilizing a predominantly AC power-grid, without increasing prospective short circuit current.
- Reducing line cost. HVDC needs fewer conductors as there is no need to support multiple phases. Also, thinner conductors can be used since HVDC does not suffer from the skin effect.
- Facilitate power transmission between different countries that use AC at differing voltages and/or frequencies.
- Synchronize AC produced by renewable energy sources.

Demerits

- Circuit breaking Is difficult in D.C circuits, therefore the coast of dc circuit is high.
- D.C system does not have step up or step down transformers to change the voltage level.
- The coast of converter station is very high.
- Both ac and dc harmonics are generated.
- System control stability is quite difficult.

UNDERGROUND CABLE

Electric power can be transmitted or distributed either by overhead system or by underground cables. The underground cables have several advantages such as less liable to damage through storms or lightning, low maintenance cost, less chance of faults, smaller voltage drop and better general appearance. However, their major drawback is that they have greater installation cost and introduce insulation problems at high voltages compared with the equivalent overhead system. For this reason, underground cables are employed where it is impracticable to use overhead lines.

UNDERGROUND CABLES

An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover. Although several types of cables are available, the type of cable to be used will depend upon the working voltage and service requirements. In general, a cable must fulfil the following necessary requirements:

(i) The conductor used in cables should be tinned stranded copper or aluminium of high conductivity. Stranding is done so that conductor may become flexible and carry more current.

(ii) The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.

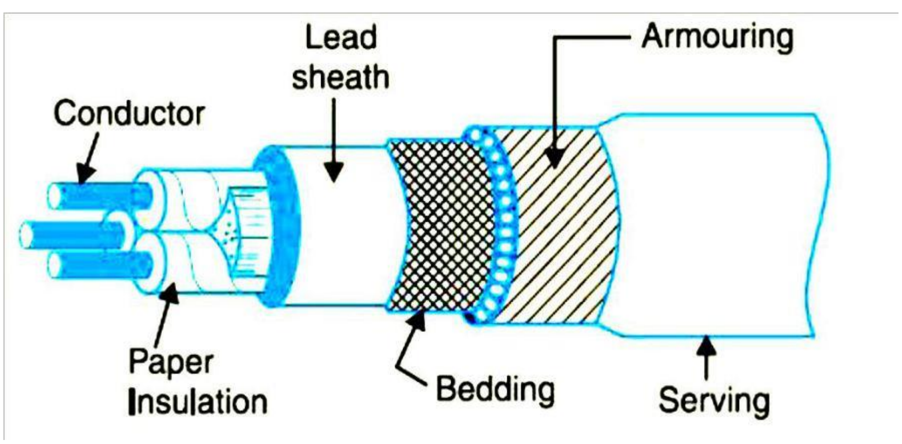
(iii) The cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed.

(iv) The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.

(v) The materials used in the manufacture of cables should be such that there is complete chemical and physical stability throughout.

CONSTRUCTION OF CABLES

Fig shows the general construction of a 3-conductor cable. The various parts are



a)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. For instance, the 3- conductor cable shown in Fig. is used for 3-phase service. The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable.

b) Insulation

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.

c)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 aluminum is provided over the insulation as shown in Fig.

d) 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.

e) Armouring.

Over the bedding, armouring is provided which consists of one or two layers of galvanized 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.

f) Serving.

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

It may not be out of place to mention here that bedding, armouring and serving are only applied to the cables for the protection of conductor insulation and to protect the metallic sheath from Mechanical injury.

INSULATING MATERIALS FOR CABLES

The satisfactory operation of a cable depends to a great extent upon the characteristics of insulation used. Therefore, the proper choice of insulating material for cables is of considerable importance. 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. The moisture tends to decrease the insulation resistance and hastens the breakdown of the cable. In case the insulating material is hygroscopic, it must be enclosed in a waterproof covering like lead sheath.

(v) Non-inflammable.

(vi) Low cost so as to make the underground system a viable proposition.

(vii) Unaffected by acids and alkalis to avoid any chemical action. No one insulating material possesses all the above mentioned properties. Therefore, the type of insulating material to be used depends upon the purpose for which the cable is required and the quality of insulation to be aimed at..

Rubber

Rubber may be obtained from milky sap of tropical trees or it may be produced from oil products. It has relative permittivity varying between 2 and 3, dielectric strength is about 30 kV/mm and resistivity of insulation is 1017 cm. Although pure rubber has reasonably high insulating properties, it suffers form some major drawbacks viz., readily absorbs moisture, maximum safe temperature is low (about 38ºC), soft and liable to damage due to rough handling and ages when exposed to light. Therefore, pure rubber cannot be used as an insulating material.

Vulcanised India Rubber (V.I.R.)

It is prepared by mixing pure rubber with mineral matter such as zinc oxide, red lead etc., and 3 to 5% of sulphur. The compound so formed is rolled into thin sheets and cut into strips. The rubber compound is then applied to the conductor and is heated to a temperature of about 150ºC. The whole process is called vulcanisation and the product obtained is known as vulcanised India rubber. Vulcanised India rubber has greater mechanical strength, durability and wear resistant property than pure rubber. Its main drawback is that sulphur reacts very quickly with copper and for this reason, cables using VIR insulation have tinned copper conductor. The VIR insulation is generally used for low and moderate voltage cables.

Impregnated paper

It consists of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinic or naphthenic material. This type of insulation has almost superseded the rubber insulation. It is because it has the advantages of low cost, low capacitance, high dielectric strength and high insulation resistance. The only disadvantage is that paper is hygroscopic and even if it is impregnated with suitable compound, it absorbs moisture and thus lowers the insulation resistance of the cable. For this reason, paper insulated cables are always provided with some protective covering and are never left unsealed. If it is required to be left unused on the site during laying, its ends are temporarily covered with wax or tar. Since the paper insulated cables have the tendency to absorb moisture, they are used where the cable route has a few joints. For instance, they can be profitably used for distribution at low voltages in congested areas where the joints are generally provided only at the terminal apparatus. However, for smaller installations, where the lengths are small and joints are required at a number of places, VIR cables will be cheaper and durable than paper insulated cables.

Varnished cambric

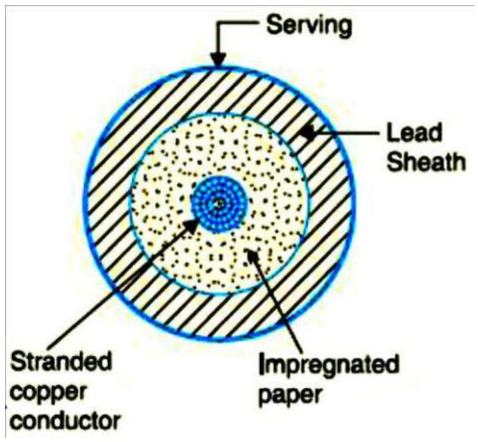
It is a cotton cloth impregnated and coated with varnish. This type of insulation is also known as empire tape. The cambric is lapped on to the conductor in the form of a tape and its surfaces are coated with petroleum jelly compound to allow for the sliding of one turn over another as the cable is bent. As the varnished cambric is hygroscopic, therefore, such cables are always provided with metallic sheath. Its dielectric strength is about 4 kV/mm and permittivity is 2.5 to 3.8.

Polyvinyl chloride (PVC)

This insulating material is a synthetic compound. It is obtained from the polymerization of acetylene and is in the form of white powder. For obtaining this material as a cable insulation, it is compounded with certain materials known as plasticizers which are liquids with high boiling point. The plasticizer forms a gell and renders the material plastic over the desired range of temperature. Polyvinyl chloride has high insulation resistance, good dielectric strength and mechanical toughness over a wide range of temperatures. It is inert to oxygen and almost inert to many alkalies and acids. Therefore, this type of insulation is preferred over VIR in extreme environmental conditions such as in cement factory or chemical factory. As the mechanical properties (i.e., elasticity etc.) of PVC are not so good as those of rubber, therefore, PVC insulated cables are generally used for low and medium domestic lights and power installations.

CLASSIFICATION OF CABLES

Cables for underground service may be classified in two ways according to
(i) the type of insulating material used in their manufacture
(ii) the voltage for which they are manufactured. However, the latter method of classification is generally preferred, according to which cables can be divided into the following groups:



- Low-tension (L.T.) cables — upto 1000 V
- High-tension (H.T.) cables — upto 11,000 V
- Super-tension (S.T.) cables — from 22 kV to 33 kV
- Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
- 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) (ii) two-core
(iii) (iii) three-core
(iv) (iv) four-core etc.

For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand. Fig. shows the constructional details of a single-core low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (up to 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) insulated by layers of impregnated paper. The insulation is surrounded by a lead sheath which prevents the entry of moisture into the inner parts. In order to protect the lead sheath from corrosion, an overall serving of compounded fibrous material (jute etc.) is provided. Single-core cables are not usually armoured in order to avoid excessive sheath losses. The principal advantages of single-core cables are simple construction and availability of larger copper section.

Cable For 3-Phase

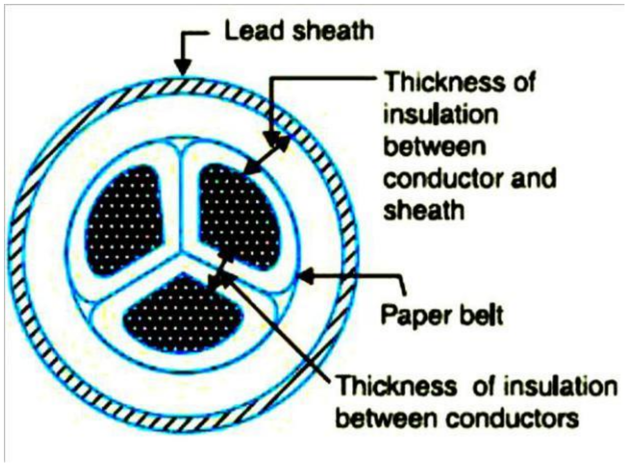
In practice, underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cable or three single core cables may be used. For voltages upto 66 kV, 3-core cable (i.e., multi-core construction) is preferred due to economic reasons. However, for voltages beyond 66 kV, 3-core-cables become too large and unwieldy and, therefore, single-core cables areused. The following types of cables are generally used for 3-phase service :

1. Belted cables — upto 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 upto 11kV but in extraordinary cases, their use may be extended upto 22kV. Fig.3 shows the constructional details of a 3-core belted cable. The cores are insulated from each other by layers of impregnated paper.



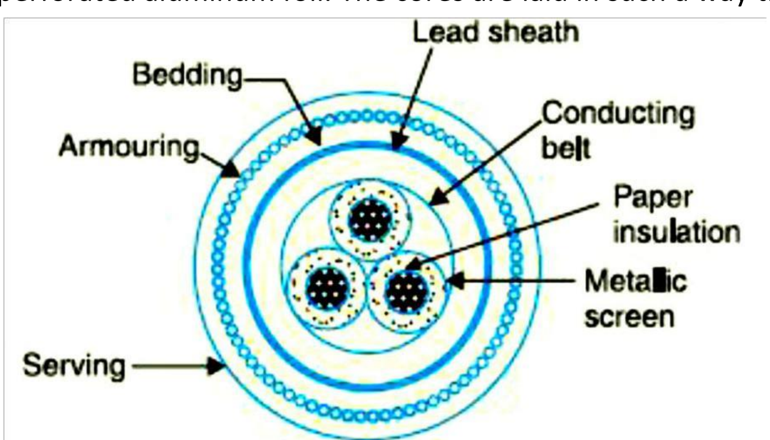
Another layer of impregnated paper tape, called paper belt is wound round the grouped insulated cores. The gap between the insulated cores is filled with fibrous insulating material (jute etc.) so as to give circular cross-section to the cable. The cores are generally stranded and may be of non circular shape to make better use of available space. The belt is covered with lead sheath to protect the cable against ingress of moisture and mechanical injury. The lead sheath is covered with one or more layers of armouring with an outer serving (not shown in the figure).The belted type construction is suitable only for low and medium voltages as the electro static stresses developed in the cables for these voltages are more or less radial i.e., across the insulation.

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. Hochstetler and hence the name. Fig. shows the constructional details of a typical 3-core, H-type cable. 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 aluminum foil. The cores are laid in such a way that metallic screens



Make contact with one another. An additional conducting belt (copper woven fabric tape) is Wrapped round the three cores. The cable has no insulating belt but lead sheath, bedding, armouring and serving follow as usual. It is easy to see that each core screen is in electrical contact with the conducting belt and the lead sheath. As all the four screens (3 core screens and one conducting belt) and the lead sheath are at earth potential, therefore, the electrical stresses are purely radial and consequently dielectric losses are reduced. Two principal advantages are claimed for *H*-type cables. Firstly, the perforations in the metallic screens assist in the complete impregnation of the cable with the compound and thus the possibility of air pockets or voids (vacuous spaces) in the dielectric is eliminated. The voids if present tend to reduce the breakdown strength of the cable and may cause considerable damage to the paper insulation. Secondly, the metallic screens increase the heat dissipating power of the cable.

(Ii) S.L. Type cables

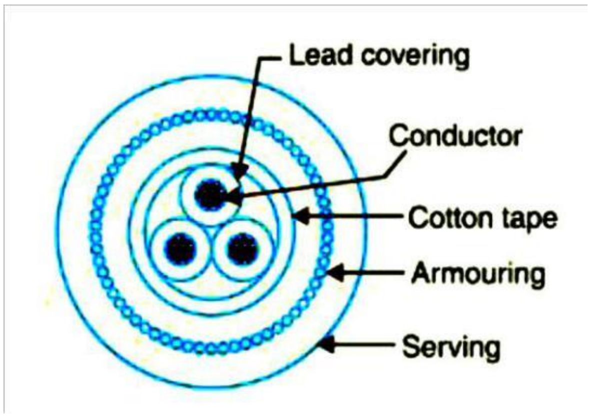


Fig. shows the constructional details of a 3-core S.L. (separate lead) type cable. It is basically H-type cable but the screen round each core insulation is covered by its own lead sheath. There is no overall lead sheath but only armouring and serving are provided. The S.L. type cables have two main advantages over H-type cables. Firstly, the separate sheaths minimize the possibility of core-to-core breakdown. Secondly, bending of cables becomes easy due to the elimination of overall lead sheath. However, the disadvantage is that the three lead sheaths of S.L. cable are much thinner than the single sheath of H-cable and, therefore, call for greater care in manufacture

3. Pressure cables

For voltages beyond 66 kV, solid type cables are unreliable because there is a danger of breakdown of insulation due to the presence of voids. 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 viz oil-filled cables and gas pressure cables are commonly used.

(i)Oil-filled cables.

In such types of cables, channels or ducts are provided in the cable for oil circulation. The oil under pressure (it is the same oil used for impregnation) 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 in to 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 up to 230 kV. Oilfilled cables are of three types viz., single-core conductor channel, single-core sheath channel and three-core filler-space channels.

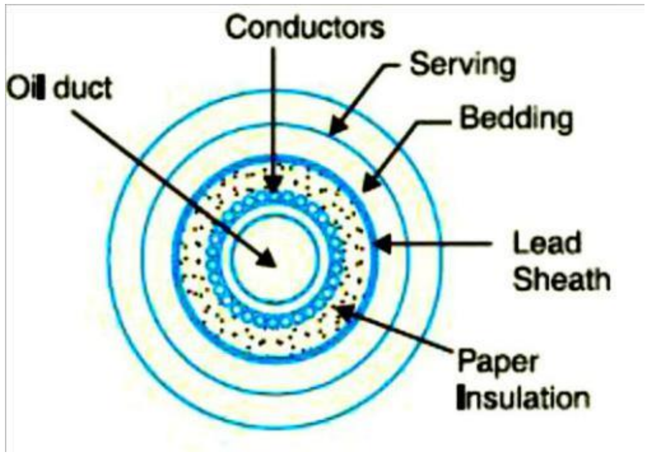
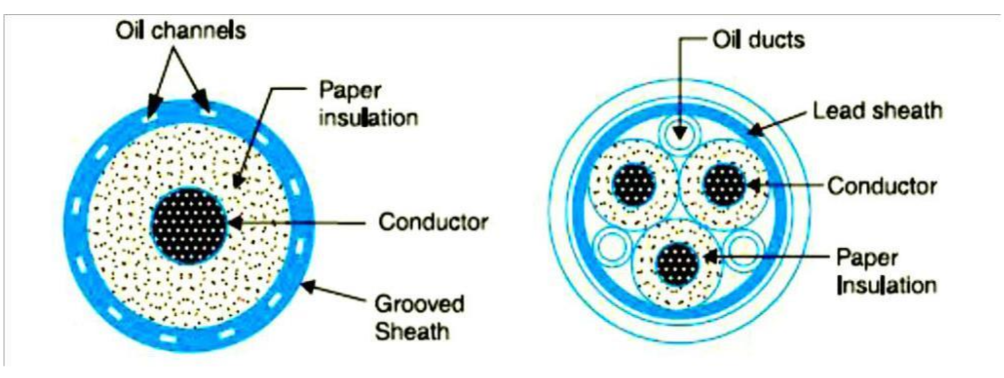


Fig. shows the constructional details of a single-core conductor channel, oil filled cable. The oil channel is formed at the center by stranding the conductor wire around a hollow cylindrical steel spiral tape. The oil under pressure is supplied to the channel by means of external reservoir. As the channel is made of spiral steel tape, it allows the oil to percolate between copper strands to the wrapped insulation. The oil pressure compresses the layers of paper insulation and prevents the possibility of void formation. The system is so designed that when the oil gets expanded due to increase in cable temperature, the extra oil collects in the reservoir. However, when the cable temperature falls during light load conditions, the oil from the reservoir flows to the channel. The disadvantage of this type of cable is that the channel is at the middle of the cable and is at full voltage *w.r.t.* earth, so that a very complicated system of joints is necessary. Fig. shows the constructional details of a single core sheath channel oil-filled cable. In this type of cable, the conductor is solid similar to that of solid cable and is paper insulated. However, oil ducts are provided in them etallic sheath as shown. In the 3-core oil-filler cable shown in Fig. the oil ducts are located in the filler spaces. These channels are composed of perforated metalribbon tubing and are at earth potential.



(ii)Gas Pressure Cable

The voltage required to set up ionization inside a void increases as the pressure is increased. Therefore, if ordinary cable is subjected to a sufficiently high pressure, the ionization can be altogether eliminated. At the same time, the increased pressure produces radial compression which tends to close any voids. This is the underlying principle of gas pressure cables.

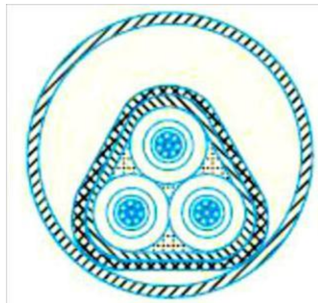
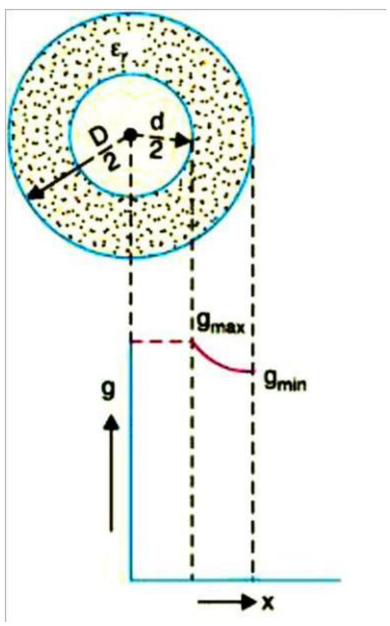


Fig Shows the section of external pressure cable designed by Hochstetler, Vogal and Bowden. The construction of the cable is similar to that of an ordinary solid type except that it is of triangular shape and thickness of lead sheath is 75% that of solid cable. The triangular section reduces the weight 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. The gas pressure produces radial compression and closes the voids that may have formed between the layers of paper insulation. Such cables can carry more load current and operate at higher voltages than a normal cable. Moreover, maintenance cost is small and the nitrogen gas helps in quenching any flame. However, it has the disadvantage that the overall cost is very high.

Dielectric Stress In Cable



Under operating conditions, the insulation of a cable is subjected to electrostatic forces. This is known as dielectric stress. The dielectric stress at any point in a cable is in fact the potential gradient (or electric intensity) at that point. Consider a single core cable with core diameter d and a internal sheath diameter D. As proved in Art 8, the electric intensity at a point x metres from the centre of the cable is

$$E_x = \frac{Q}{2\pi \varepsilon_o \varepsilon_r x} \text{ volts/m}$$

By definition, electric intensity is equal to potential gradient. Therefore, potential gradient g at a point x meters from the Centre of cable is

$$g = E_x$$

or $$g = \frac{Q}{2\pi\varepsilon_0\varepsilon_r x} \text{ volts/m} \qquad ...(i)$$

As proved, potential difference V between conductor and sheath is

$$V = \frac{Q}{2\pi\varepsilon_o\varepsilon_r}\log_e\frac{D}{d} \text{ volts}$$

or $$Q = \frac{2\pi\,\varepsilon_o\varepsilon_r V}{\log_e \frac{D}{d}} \qquad ...(ii)$$

Substituting the value of Q from exp. (ii) in exp. (i), we get,

$$g = \frac{\dfrac{2\pi\varepsilon_o\varepsilon_r V}{\log_e D/d}}{2\pi\varepsilon_o\varepsilon_r x} = \frac{V}{x\log_e\frac{D}{d}} \text{ volts/m} \qquad ...(iii)$$

It is clear from exp. (iii) that potential gradient varies inversely as the distance x. Therefore, potential gradient will be maximum when x is minimum i.e., when x = d/2 or at the surface of the conductor. On the other hand, potential gradient will be minimum at x = D/2 or at sheath surface. Maximum potential gradient is

$$g_{max} = \frac{2V}{d\log_e\frac{D}{d}} \text{ volts/m} \qquad [\text{Putting } x = d/2 \text{ in exp. } (iii)]$$

Minimum potential gradient is

$$g_{min} = \frac{2V}{D\log_e\frac{D}{d}} \text{ volts/m} \qquad [\text{Putting } x = D/2 \text{ in exp. } (iii)]$$

$$\therefore \quad \frac{g_{max}}{g_{min}} = \frac{\dfrac{2V}{d\log_e D/d}}{\dfrac{2V}{D\log_e D/d}} = \frac{D}{d}$$

The variation of stress in the dielectric is shown in Fig.14. It is clear that dielectric stress is maximum at the conductor surface and its value goes on decreasing as we move away from the conductor. It may be noted that maximum stress is an important consideration in the design of a cable. For instance, if a cable is to be operated at such a voltage that maximum stress is 5 kV/mm, then the insulation used must have a dielectric strength of at least 5 kV/mm, otherwise breakdown of the cable will become inevitable.

ECONOMIC ASPECT

Power Factor

Power factor is a measurement defined as the ratio of real power to total power. In other words, power factor measures the percentage of power that is being used for useful work.

Causes of Low Power Factor

Low power factor usually is caused by inductive loads, such as:

- Electric motors
- Transformers
- Arc welders
- HVAC systems
- Molding equipment
- Presses
- High-intensity discharge lighting

Unlike resistive loads (i.e., incandescent lights, electric heaters, cooking ovens), which involve a more direct conversion to useful work in the form of heat energy, inductive loads operate off of the magnetic field that is created by reactive power.

Benefits of Improving Power Factor

There are many benefits to improving a low power factor, including:

- A smaller utility bill.
- An increase in electrical system capacity.
- Fewer voltage fluctuations.

Correction of power factor

While low power factor can cause a significant increase in your plant expenses and a decrease in your system's efficiency, you can take several steps to help correct your power factor, including:

- Minimizing the operation of idling or lightly loaded inductive equipment, particularly motors
- Replacing defunct motors with energy-efficient ones, and operating these near their rated capacity
- Avoiding operating your equipment above its rated voltage
- Installing capacitors to decrease the amount of reactive power used

Demand factor

The ratio of the maximum coincident demand of a system, or part of a system, to the total connected load of the system

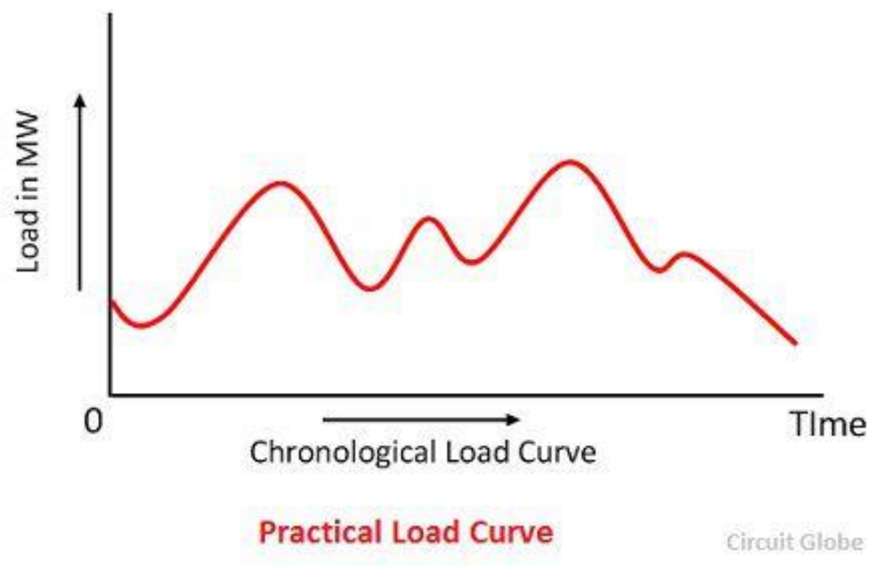
Load factor

Load factor is defined as the ratio of the average load over a given period to the maximum demand (peak load) occurring in that period. In other words, the load factor is the ratio of energy consumed in a given period of the times of hours to the peak load which has occurred during that particular period.

$$Load\ factor = \frac{average\ load}{peak\ load}$$

Load Curve

Load curve or chronological curve is the graphical representation of load (in kW or MW) in proper time sequence and the time in hours. It shows the variation of load on the power station. When the load curve is plotted for 24 hours a day, then it is called daily load curve. If the one year is considered then, it is called annual load curve.



Diversity Factor

Diversity factor is defined as the ratio of the sum of the maximum demands of the various part of a system to the coincident maximum demand of the whole system. The maximum demands of the individual consumers of a group do not occur simultaneously. Thus, there is a diversity in the occurrence of the load.

$$Diversity\ factor = \frac{(sum\ of\ individual\ maximum\ demands)}{(coincident\ maximum\ demand\ of\ the\ whole\ system)}$$

Capacity Factor

The capacity factor is defined as the ratio of the total actual energy produced or supply over a definite period, to the energy that would have been produced if the plant (generating unit) had operated continuously at the maximum rating. The capacity factor mainly depends on the type of the fuel used in the circuit.

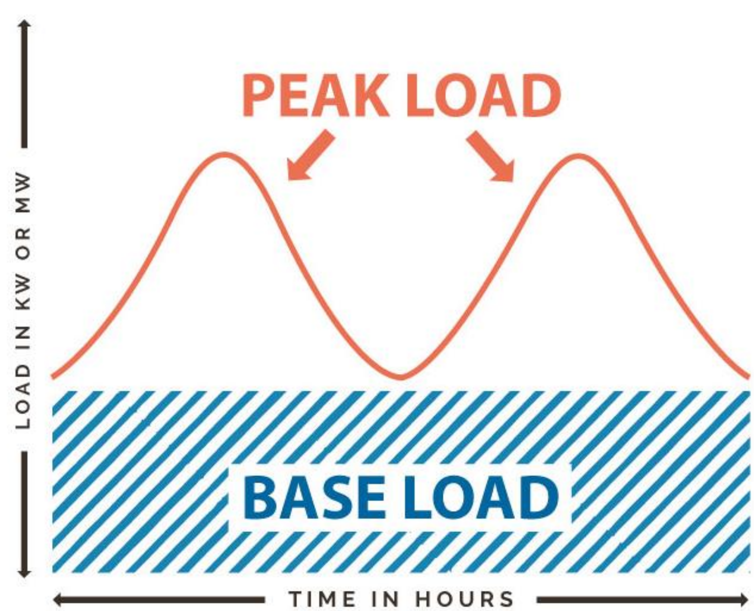
$$Capacity\ factor = \frac{(actual\ energy\ produced\ or\ supplied\ in\ time\ T)}{maximum\ plant\ rating \times T}$$

$$Capacity\ factor = \frac{peak\ load}{plant\ capacity} \times load\ factor$$

BASE LOAD AND PEAK LOAD

Base load is the minimum level of electricity demand required over a period of 24 hours. It is needed to provide power to components that keep running at all times (also referred as continuous load).

Peak load is the time of high demand. These peaking demands are often for only shorter durations. In mathematical terms, peak demand could be understood as the difference between the base demand and the highest demand.



Base Load Power plants

Plants that are running continuously over extended periods of time are said to be base load power plant.

Examples of base load power plants are:

1. Nuclear power plant
2. Coal power plant
3. Hydroelectric plant
4. Geothermal plant
5. Biogas plant
6. Biomass plant
7. Solar thermal with storage
8. Ocean thermal energy conversion

Peak Load Power plants

To cater the demand peaks, peak load power plants are used. They are started up whenever there is a spike in demand and stopped when the demand recedes.

Examples of gas load power plants are:

1. Gas plant
2. Solar power plants
3. Wind turbines
4. Diesel generators

ELECTRICITY TARIFF

Electricity Tariffs

The amount of money frame by the supplier for the supply of electrical energy to various types of consumers in known as an electricity tariff. In other words, the tariff is the methods of charging a consumer for consuming electric power. The tariff covers the total cost of producing and supplying electric energy plus a reasonable cost.

The electricity tariffs depends on the following factors

- Type of load
- Time at which load is required.
- The power factor of the load.
- The amount of energy used.

Objectives of an Electricity Tariff

1. Recovery of cost of producing electrical energy at the power station.
2. Recovery of cost on the capital investment in transmission and distribution systems.
3. Recovery of cost of operation and maintenance of the supply of electrical energy. For example, metering equipment, billing, etc.
4. A suitable profit on the capital investment.

Electricity Tariff Characteristics

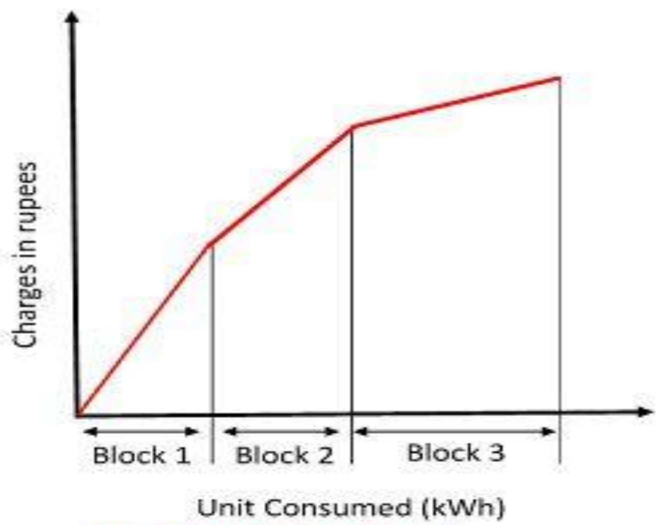
1. **Proper return.** The tariff should be structured in such a way that it guarantees the proper return from each consumer. The total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus the reasonable profit.
2. **Fairness.** The tariff must be fair so that each and every consumer is satisfied with the cost of electrical energy. Thus, a consumer who consumes more electrical energy should be charged at a lower rate than a consumer who consumes little energy..
3. **Simplicity.** The tariff should be simple and consumer-friendly so that an ordinary consumer can easily understand.
4. **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 a monopoly.
5. **Attractive.** The tariff should be attractive so that it can attract a large number of consumers to use electricity

Types of tariffs:

1. Flat demand rate tariff – The flat demand rate tariff is expressed by the equation C = Ax. In this type of tariff, the bill of the power consumption depends only on the maximum demand of the load. The generation of the bill is independent of the normal energy consumption.

This type of tariff is used on the street light, sign lighting, irrigation, etc., where the working hours of the equipment are unknown. The metering system is not used for calculating such type of tariffs.

3. Block meter rate tariff – In this type of tariff, the energy consumption is distinguished into blocks. The per unit tariff of the individual block is fixed. The price of the block is arranged in the decreasing order. The first block has the highest cost, and it goes on decreasing accordingly.



Block Meter Rate Tariff

The price and the energy consumption are divided into three blocks. The first few units of energy at a certain rate, the next at a slightly lower rate and the remaining unit at a very lower rate.

3. Two-part tariff – In such type of tariff, the total bill is divided into two parts. The first one is the fixed charge and the second is the running charge. The fixed charge is because of the maximum demand and the second charge depends on the energy consumption by the load.

$$C = Ax + By$$

$$C = A(kW) + B(kWh)$$

The factor A and B may be constant and vary according to some sliding.

4. Maximum demand tariff – This is also a two-part tariff.

$Total\ charges = A(kVA) + B(kWh)$ The low power factor increases the KVA rating of the load.

The peak load and seasonal tariffs both are used for reducing the idle or standby capacity of the load.

SUBSTATION

Introduction

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 continuity of supply depends to a considerable extent upon the successful operation of sub-stations. It is, therefore, essential to exercise utmost care while designing and building 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. As far as possible, it should be located at the centre of gravity of load.

(ii) It should provide safe and reliable arrangement. For safety, consideration must be given to the maintenance of regulation clearances, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion or fire etc. For reliability, consideration must be given for good design and construction, the provision of suitable protective gear etc.

(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

A sub-station may be called upon to change voltage level or improve power factor or convert a.c. power into d.c. power etc. 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. These sub-stations receive power at some voltage and deliver it at some other voltage. Obviously, transformer will be the main component in such sub- stations. Most of the sub-stations in the power system are of this type.

(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. Such sub-stations are generally located at the receiving end of transmission lines. These sub-stations generally use synchronous condensers as the power factor improvement equipment.

(iv) Frequency changer sub-stations

Those sub-stations which change the supply frequency are known as frequency changer sub-stations. Such a frequency change may be required for industrial utilisation.

(v) Converting sub-stations

Those sub-stations which change a.c. power into d.c. power are called converting sub-stations. These sub-stations receive a.c. power and convert it into d.c power with suitable apparatus to supply for such purposes as traction, electroplating, electric welding etc.

(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

A sub-station has many components (e.g. circuit breakers, switches, fuses, instruments etc.) which must be housed properly to ensure continuous and reliable service.

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 because of economic considerations. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages upto 66 kV.

(ii) Outdoor sub-stations

For voltages beyond 66 kV, equipment is invariably installed out- door. It is because for such voltages, the clearances between conductors and the space required for switches, circuit breakers and other equipment becomes so great that it is not economical to install the equipment indoor.

(iii) Underground sub-stations

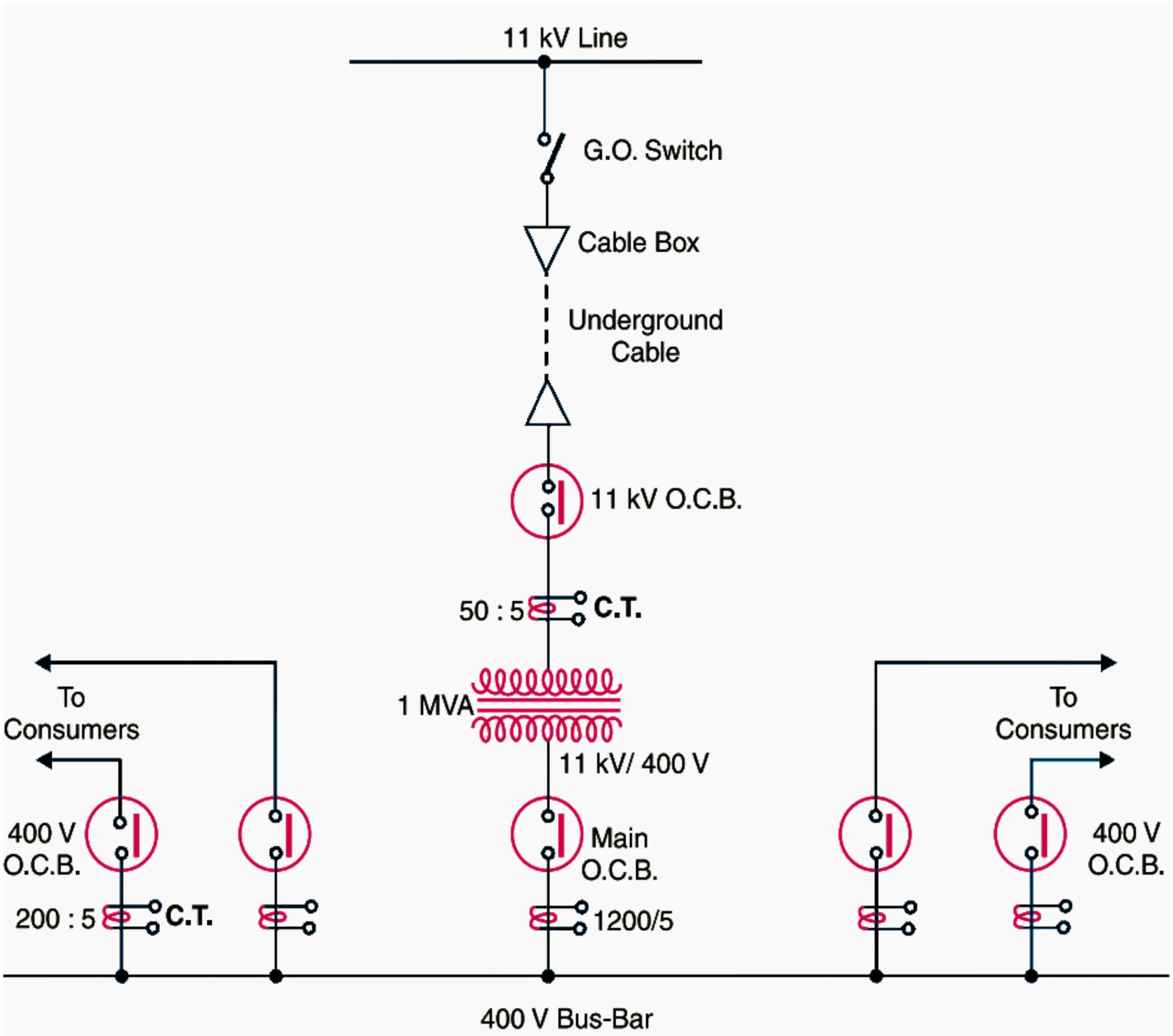
In thickly populated areas, the space available for equipment and building is limited and the cost of land is high. Under such situations, the sub-station is created underground.

(iv) Pole-mounted sub-stations

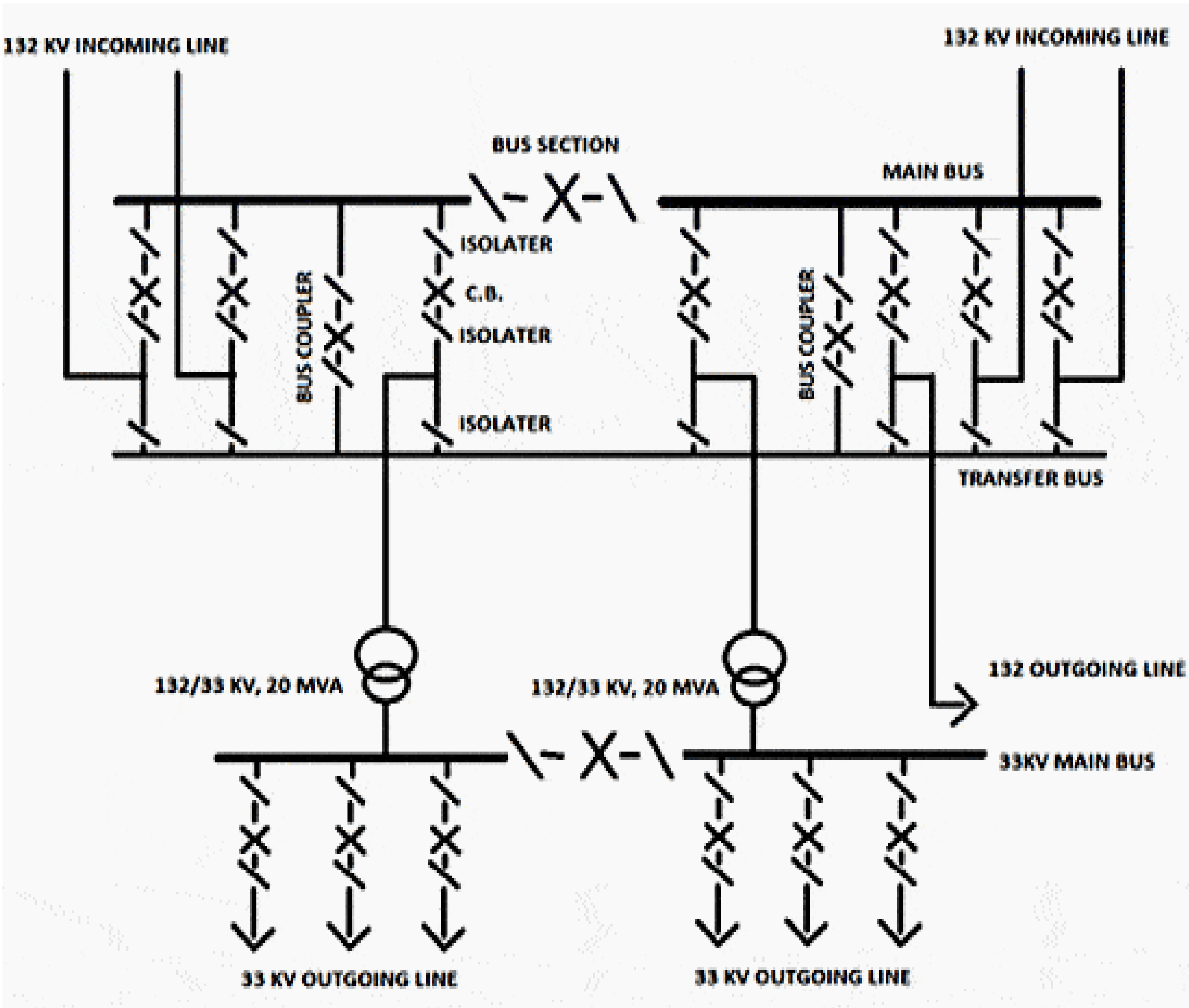
This is an outdoor sub-station with equipment installed over- head on H-pole or 4-pole structure. It is the cheapest form of sub-station for voltages not exceeding 11kV (or 33 kV in some cases). Electric power is almost distributed in localities through such sub- stations. For complete discussion on pole-mounted sub-station,

Substation Layout

1. **LT substation**



2. HT substation



3. EHV substation