ملخص عن

أساسيات هندسة القوى الكهربائية

Basics of Electrical Power Engineering

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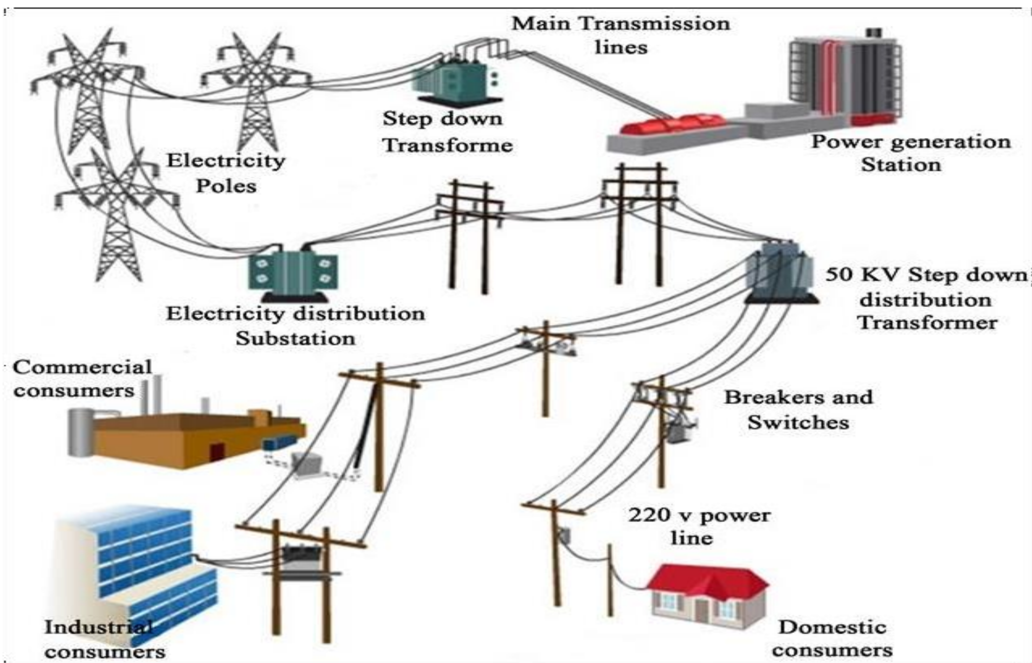
مقدمة عن النظام الطاقة الكهربائية

Introduction to Electric Power System

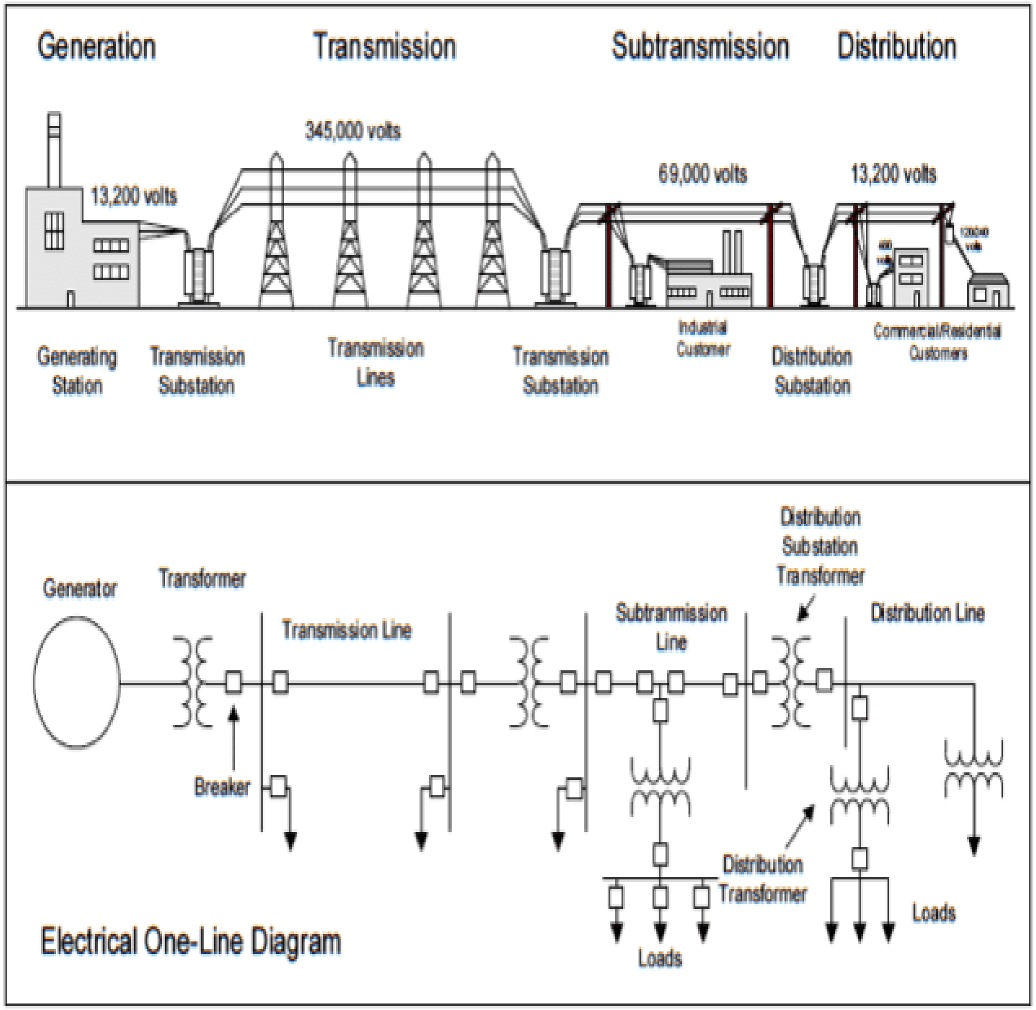
Electric power is the rate at which electric energy is transferred. Electric power is measured by capacity and is commonly expressed in megawatts (MW). A **megawatt** (MW) is one million watts.

Electric power system is comprised of components that produce electrical energy and transmit the energy to consumers. It is the networking of all the equipment with their associated control and auxiliary systems for generation, transmission, distribution and utilization of electrical power.



In general, the **main components** of electric power system are

i. Generation
ii. Transmission
iii. Distribution
iv. Utilization of power (Loads).



These components can be further expanded into **six sub-components**:

a) power plants which generate electric power,

b) transformers which raise or lower the voltages as needed,

c) transmission lines to carry power,

d) substations at which the voltage is stepped down for carrying power over the distribution lines,

e) distribution lines, and

f) distribution transformers which lower the voltage to the level needed for the consumer equipment.

Why we need Single Line Diagrams (SLD)

- In Power Engineering, a **one-line diagram** or **single-line diagram** is a simplified notation for representing a three-phase power system.
- Electrical elements such as circuit breakers, transformers, capacitors, bus bars, and conductors are shown by standardized schematic symbols.
- Instead of representing each of three phases with a separate line or terminal, only one conductor is represented.
- It is a form of block diagram graphically depicting the paths for power flow between entities of the system.
- Elements on the diagram do not represent the physical size or location of the electrical equipment, but it is a common convention to organize the diagram with the same left-to-right, top-to-bottom sequence as the switchgear or other apparatus represented.

- The power systems are so complex that a one complete diagram showing all the connections is not practical. So, we use a simple way to show the basic arrangement of power system components.

طرق توليد الكهرباء

Power Generation methods

Power Generating Stations:

All over the world the electrical power is produced by conventional method and the second one is non-conventional method.

In conventional method, there are three main sources. They are:

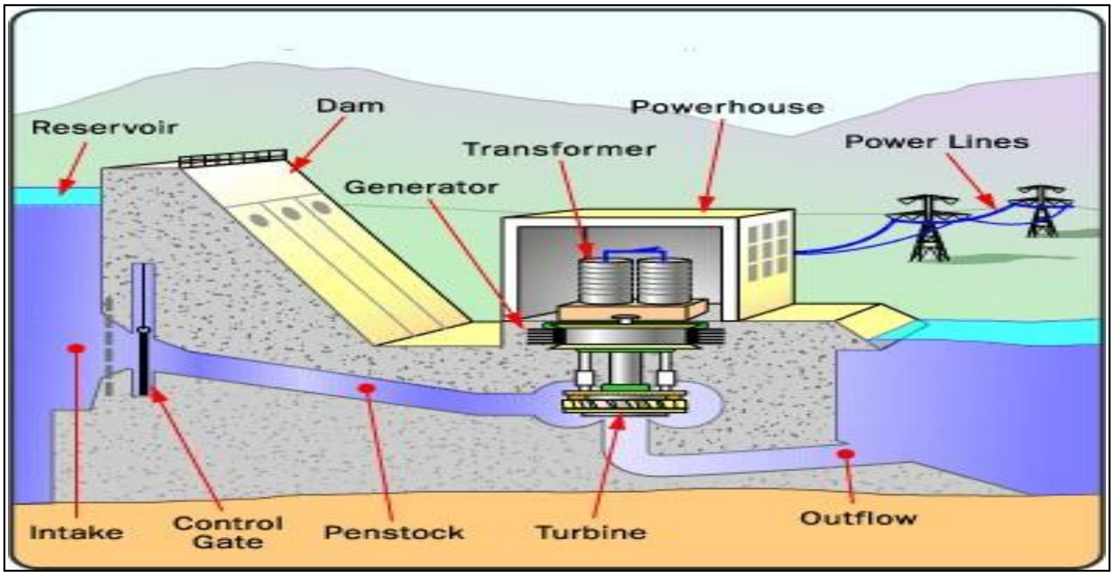
1. Hydroelectric Power Station,
2. Thermal Power Station
3. Nuclear Power Station.

In non-conventional method, there are many sources. They are:

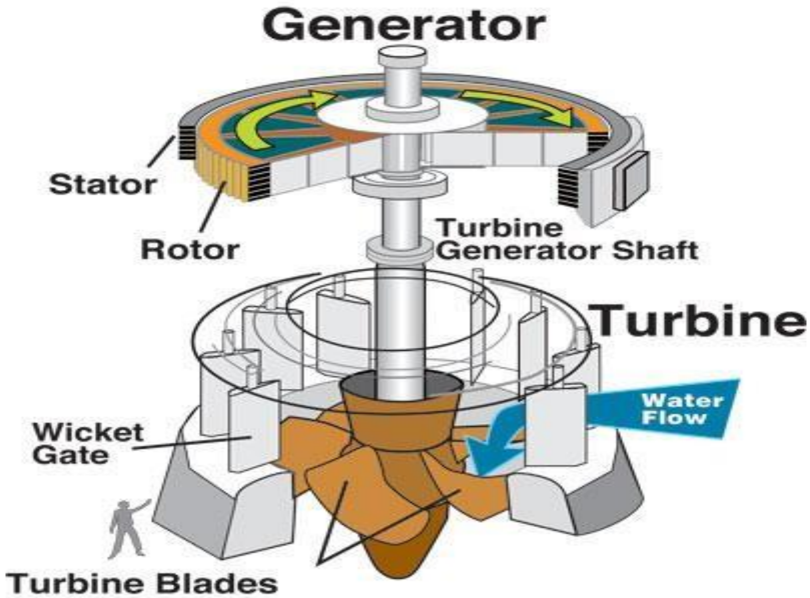
1. Solar Energy
2. Wind Energy
3. Tidal Energy
4. Bio-mass

Conventional Method:

طريقة توليد الطاقة الكهرومائية
Hydro Electric Power generation



- Hydroelectric power (hydropower) systems convert the kinetic energy* in flowing water into electric energy.
- Flowing water is directed at a turbine through penstock pipe. The flowing water causes the turbine to rotate, converting the water's kinetic energy into mechanical energy.



- The mechanical energy produced by the turbine is converted into **electric energy** using a turbine generator. Inside the generator, the shaft of the turbine spins a magnet inside coils of copper wire. It is a fact of nature that moving a magnet near a conductor causes an electric current.

- 25% of electricity generation capacity in world is provided by hydro power plant. So, Because the water cycle is continuous, hydropower is a renewable energy source.

How much electricity can be generated by a hydroelectric power plant?

The amount of electricity that can be generated by a hydropower plant depends on two factors:

- **flow rate** - the quantity of water flowing in a given time; and
- **Head** - the height from which the water falls.

The greater the flow and head, the more electricity produced.

ADVANTAGES OF HYDRO POWER PLANT

- This plant is free from pollution.
- Its operation and maintenance cost is less.
- It has no stand by losses.
- Unit cost of power is less.
- Hydraulic turbines can be started speedily.
- The plant has longer service life.
- No fuel is required.
- No change in efficiency with the age.

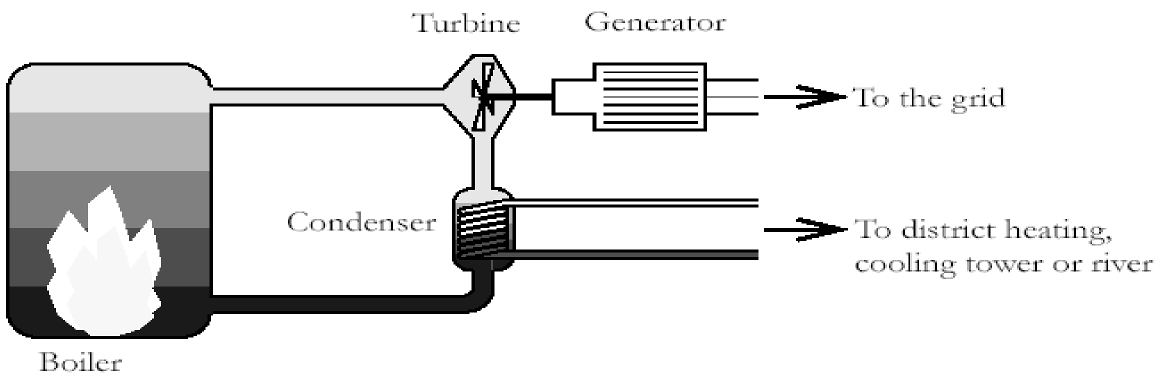
DISADVANTAGES OF HYDRO POWER PLANT

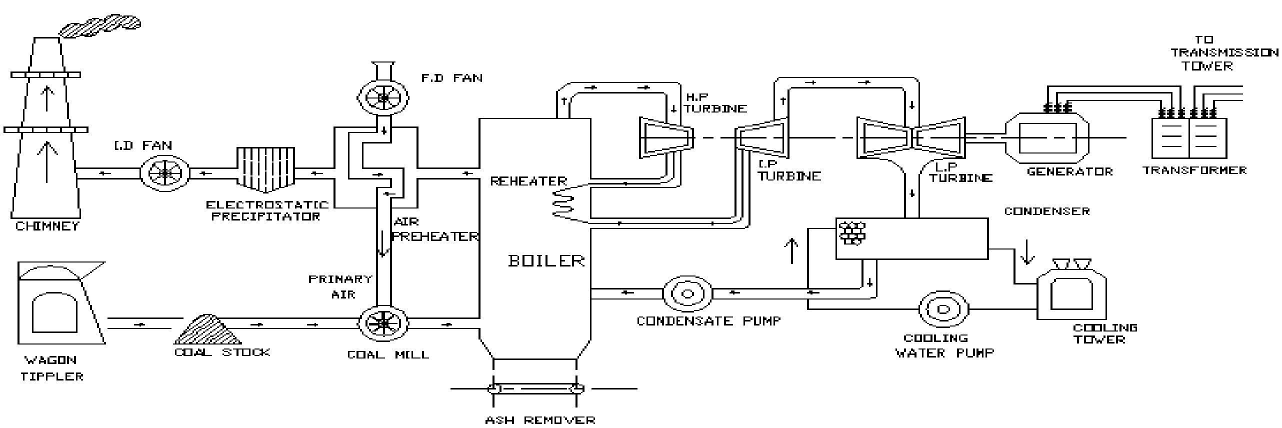
- Initial cost of dam and plant is high.
- The availability of power from it is not much reliable.
- Time required for construction of hydro project is more.

طريقة توليد الطاقة الحرارية

Thermal Power Station

- In thermal power stations, heat energy is converted into electrical energy.
- Most thermal power stations produce steam, and these are sometimes called steam power stations.
- Water is heated inside the boiler using coal as a fuel to produce steam.
- The high pressure and high temperature steam from the boiler is used to turn the blades of the turbine.
- The generator which is coupled with the turbine produces electrical energy.





- It basically works on Rankin cycle.
- cheap and abundant
- but source of greenhouse gases

ADVANTAGES OF THERMAL POWER PLANT

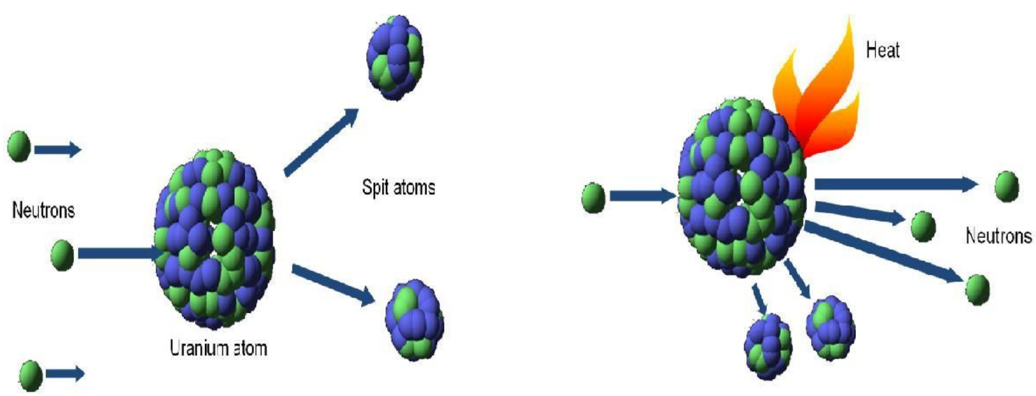
- Cheaper per unit energy than oil or natural gas.
- Will continue to be an important global resource.
- Abundance.
- Coal is the world's most abundant fossil fuel.
- Sufficient reserves for the next 250 years.

DISADVANTAGES OF THERMAL POWER PLANT

- Coal-Fired Power Plants are the largest contributor of hazardous air pollutants.
- Sulfur dioxide (SO_2)
- Nitrogen Oxide (NO_x)
- Carbon Dioxide (CO_2)
- Mercury

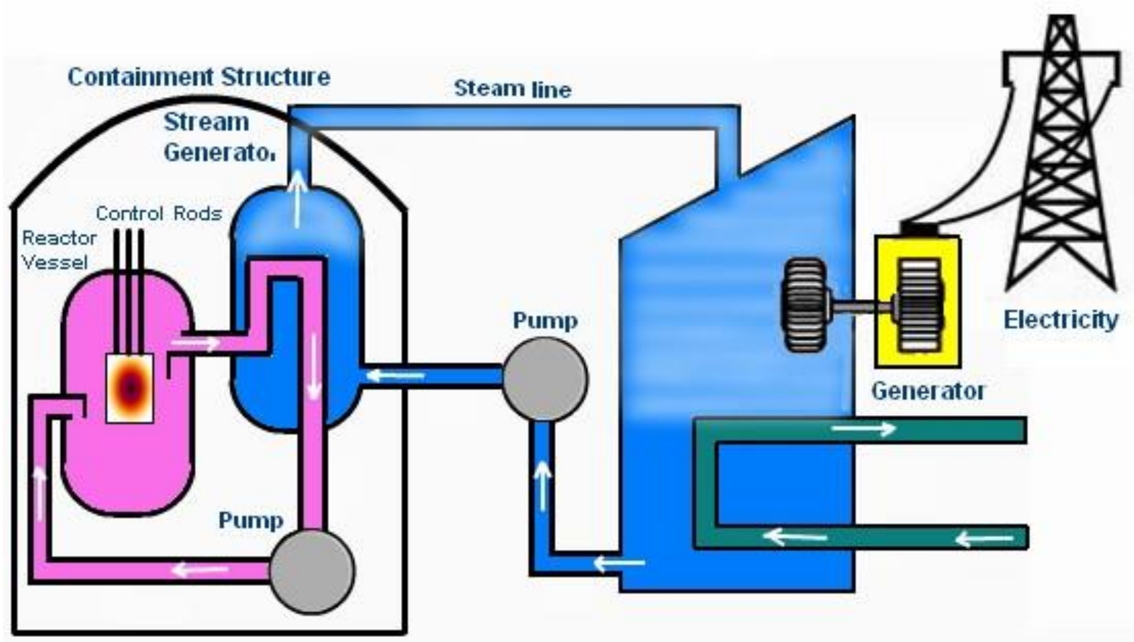
محطة طاقه النووية

Nuclear Power Station



Working of Nuclear power plant

- Heavy elements such as Uranium (U^{235}) or Thorium (Th^{232}) are subjected to nuclear fission in a reactor to produce steam at high temperatures and pressure.
- Steam runs a steam turbine, which converts this energy into energy. The turbine drives the alternator, which converts mechanical energy into electrical energy.
- This Nuclear reactor consists of uranium rods and cooling agent. This cooling agent is otherwise called as moderator. This moderator is Deuterium di oxide which cools the boiling water.



This power station is generally located far from populated areas. This kind of power station can be used to produce large amounts of electrical energy. In most countries these power stations are used as Base load power stations. This is because they can take several days to be warmed up and brought on-line.

Advantages of Nuclear power plant

- Nuclear power generation does emit relatively low amounts of carbon dioxide (CO_2). The emissions of green house gases and therefore the contribution of nuclear power plants to global warming is therefore relatively little.
- This technology is readily available; it does not have to be developed first.
- It is possible to generate a high amount of electrical energy in one single plant.

Disadvantages of Nuclear power plant

- The problem of radioactive waste is still an unsolved one.
- High risks: It is technically impossible to build a plant with 100% security.

مصادر الطاقة غير التقليدية

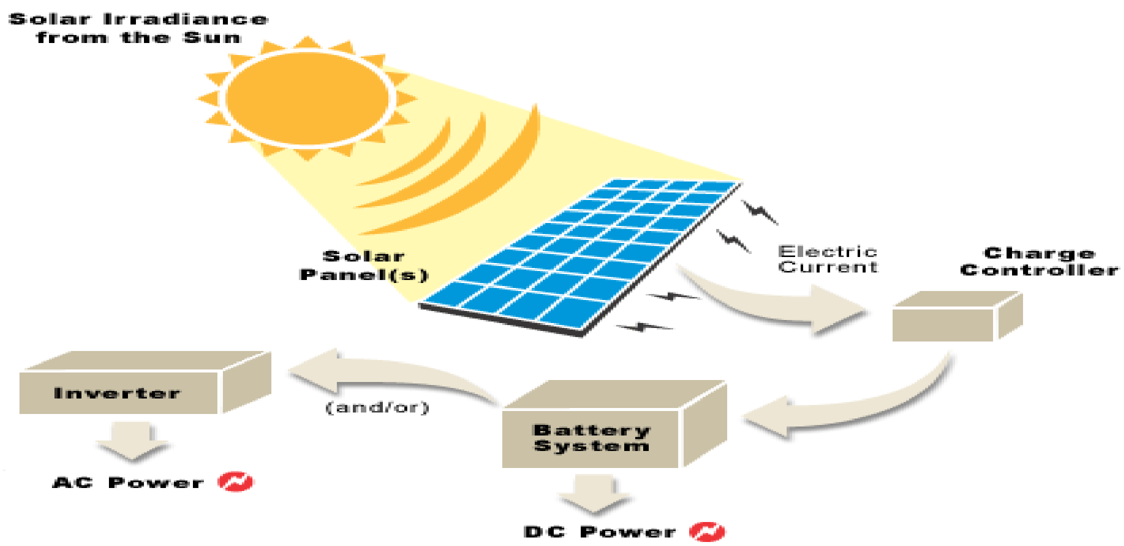
Non-Conventional Energy Sources

These sources are used to generate electricity without pollution.

محطات توليد الطاقة الشمسية

Solar Power generating stations

a. Direct Method (photovoltaic (PV) system)



Working

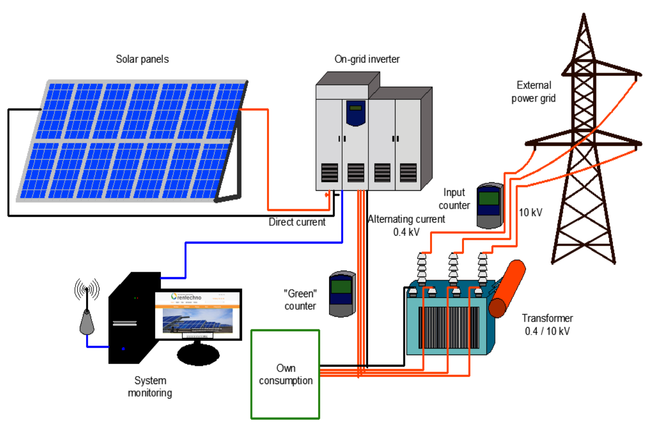
- A solar photovoltaic power plant uses photovoltaic cells to convert sunlight into direct current electricity using the photoelectric effect.
- This type of plant does not use rotating machines for energy conversion.
- From the sun, the sun rays fall on the photo voltaic cell which converts the light energy into the electrical energy.
- There is no turbine used in this mode of generating electrical power.

Advantages of solar power plant

1. Solar energy is free although there is a cost in the building of ‘collectors’ and other equipment required to convert solar energy into electricity or hot water.
2. Solar energy does not cause pollution.
3. Solar energy can be used in remote areas where it is too expensive to extend the electricity power grid.
4. It is estimated that the world’s oil reserves will last for 30 to 40 years. On the other hand, solar energy is infinite (forever).

Disadvantages of solar power plant

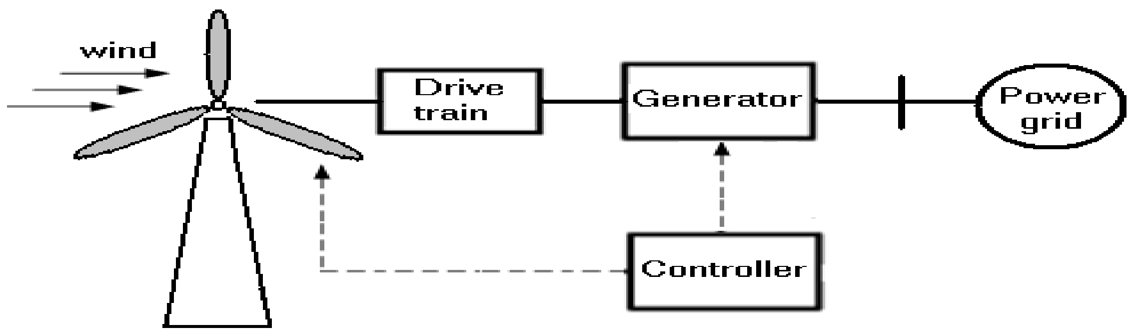
1. Solar energy can only be harnessed when it is daytime and sunny.
2. Solar collectors, panels and cells are relatively expensive
3. Solar power stations can be built but they do not match the power output of similar sized conventional power stations. They are also very expensive.
4. Large areas of land are required to capture the suns energy.
5. Solar power is used to charge batteries so that solar powered devices can be used at night. However, the batteries are large and heavy and need storage space. They also need replacing from time to time.



محطات توليد طاقة الرياح

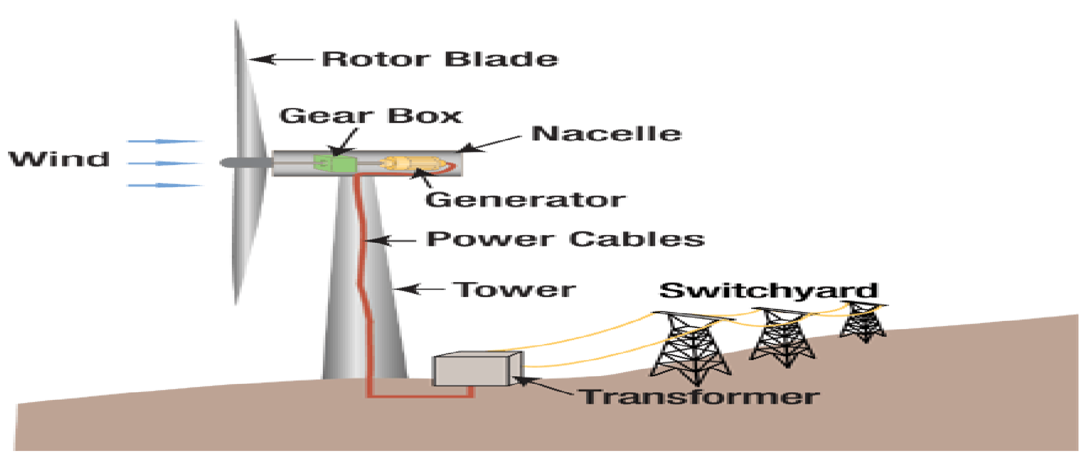
Wind Power generating stations

Wind power is the conversion of wind energy into a useful form, such as electricity, using wind turbines. The main components of this system are the wind turbine, the mechanical drive train, the generator, the power grid, and the controller.



Working Wind Power Station

- The wind turbine converts the kinetic energy of the wind into mechanical energy. The wind with the particular speed limit (2m/sec to 25m/sec) is cut by the blades of this wind mill. So the fan is made to rotate.
- This is connected with wind turbine and AC generator. The generator converts the mechanical energy into electrical energy.
- The controller is the “brain” of the system. It ensures that the whole system works as expected.



Advantages of wind power generation

1. The wind is free and with modern technology it can be captured efficiently.
2. Once the wind turbine is built the energy it produces does not cause green house gases or other pollutants.
3. Although wind turbines can be very tall each takes up only a small plot of land.
4. Many people find wind farms an interesting feature of the landscape.
5. Remote areas that are not connected to the electricity power grid can use wind turbines to produce their own supply.

Disadvantages of wind power generation

1. The strength of the wind is not constant and it varies from zero to storm force. This means that wind turbines do not produce the same amount of electricity all the time. There will be times when they produce no electricity at all.
2. Wind turbines are noisy. Each one can generate the same level of noise as a family car travelling at 70 mph.
3. Many people see large wind turbines as unsightly structures and not pleasant or interesting to look at.
4. When wind turbines are being manufactured some pollution is produced. Therefore wind power does produce some pollution.
5. Large wind farms are needed to provide entire communities with enough electricity.

مقارنة بين محطات توليد الطاقة الكهربائية

Comparison of Electric power generating station

Particulars	Solar power	Wind power	Hydro power	Fuel power	Nuclear power
Initial cost	High	High	High	Lowest	Highest
Running cost	High	High	Low	Highest	Least
Reserves	Day time only	permanent	permanent	limited	abundant
Cleanliness	High	High	Highest	Lowest	Low
Simplicity	complex	complex	simplest	complex	Most complex
Reliability	Low	Low	Highest	Low	High

خطوط النقل الطاقة و الكابلات الارضية

Power Transmission line & Underground Cables

Introduction to Electric power transmission

Electric power transmission is the bulk movement of electrical energy from a generating site, such as a power plant, to an electrical substation.

In electrical power system, there are two types of transmission of electric power, they are

(a). D.C transmission

(b). A.C transmission

Comparison of D.C. and A.C. Transmission

D.C. transmission:

For some years past, the transmission of electric power by d.c. has been receiving the active consideration of engineers due to its numerous advantages.

Advantages.

(i) It requires only **two conductors** as compared to three for a.c. transmission.

(ii) There **is no inductance, capacitance, phase displacement and surge problems**.

(iii) Due to the **absence of inductance**, the voltage drop in a d.c. transmission line is less than the a.c. line for the same load and sending end voltage.

(iv) There is **no skin effect** in a d.c. system. Therefore, entire cross-section of the line conductor is utilised.

(v) For the same working voltage, a d.c. line requires **less insulation**.

Disadvantages

(i) Electric power cannot be generated at high d.c. voltage due to **commutation problems**.

(ii) The d.c. voltage **cannot be stepped up** for transmission of power at high voltages.

(iii) The d.c. switches and circuit breakers have their own limitations.

A.C. transmission:

Now-a-days, electrical energy is almost exclusively generated, transmitted and distributed in the form of a.c.

Advantages of A.C transmission:

(a) The power can be generated at high voltages.
(b) The maintenance of a.c. sub-stations is easy and cheaper.
(c) The a.c. voltage can be stepped up or stepped down by transformers.

Disadvantages

(a) An a.c. line requires more copper than a d.c. line.

(b) The construction of a.c. transmission line is more complicated than a d.c.

(c) Due to skin effect in the a.c. system, the effective resistance of the line is increased.

(d) An a.c. line has capacitance. Therefore, there is a continuous loss of power due to charging current even when the line is open.

Various Systems of Power Transmission

It has already been pointed out that for transmission of electric power, 3-phase, 3-wire a.c. system is universally adopted. However, other systems can also be used for transmission under special circumstances.

The different possible systems of transmission are:

1. D.C. system

(i) D.C. two-wire.

(ii) D.C. two-wire with mid-point earthed.

(iii) D.C. three-wire.

2. Single-phase A.C. system

(i) Single-phase two-wire.

(ii) Single-phase two-wire with mid-point earthed.

(iii) Single-phase three-wire.

3. Two-phase A.C. system

(i) Two-phase four-wire.

(ii) Two-phase three wire.

4. Three-phase A.C. system

(i) Three-phase three-wire.

(ii) Three-phase four-wire.

Elements of a Transmission Line

For reasons associated with economy, transmission of electric power is done at high voltage by **3-phase, 3-wire overhead system**. The principal elements of a HV transmission line are :

(i) ***Conductors,*** usually three for a single-circuit line and six for a double-circuit line. The usual material is aluminum reinforced with steel.

(ii) ***Step-up and step-down transformers,*** at the sending and receiving ends respectively. The use of transformers permits power to be transmitted at high efficiency.

(iii) ***Line insulators,*** which mechanically support the line conductors and isolate them electrically from the ground.

(iv) ***Support,*** which are generally steel towers and provide support to the conductors.

(v) ***Protective devices,*** such as ground wires, lightning arrestors, circuit breakers, relays etc. They ensure the satisfactory service of the transmission line.

Conductor Material

The conductor material used for transmission and distribution of electric power should have the following properties:

(i) high electrical **conductivity**.

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

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

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

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

Line Supports

The supporting structures for overhead line conductors are various types of poles and towers called *line supports*. In general, the line supports should have the following properties :

(i) High mechanical strength to withstand the weight of conductors and wind loads etc.

(ii) Light in weight without the loss of mechanical strength.

(iii) Cheap in cost and economical to maintain.

The line supports used for transmission and distribution of electric power are of various types including *wooden poles, steel poles, R.C.C. poles* and *lattice steel towers*. The choice of supporting structure for a particular case depends upon the life span, X-sectional area, line voltage, cost and local conditions.

Overhead lines:

- Overhead transmission lines are used for the transmission of electric power with the help of conductors in an effective manner.
- Normally the conductors are made up of **aluminum or copper**. Since copper is of high cost, Aluminum is widely used.
- The important things to consider in the design and operation of a transmission line are the a) **determination of voltage drop b) line losses and c) efficiency of transmission.**

Classification of Overhead Transmission Lines

- A transmission line has three constants *R*,*L* and *C* distributed uniformly along the whole length of the line.
- There is resistance and inductance form the series impedance.
- The capacitance existing between conductors for Phase line or from a conductor to neutral for a 3-phase line forms a shunt path through out 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:

Short transmission lines

- When the length of an overhead transmission line is up toabout50 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.

Medium transmission lines

- When the length of an over head transmission line is about 50-150 km and the line voltage is moderately high (>20kV<100kV), 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.

Long transmission lines

- When the length of an overhead transmission line is more than 150 km and line voltage is very high (>100kV),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.

#	Type of transmission Line	Length of the line	Voltage level of the line
1	Short transmission lines	Up to 50KM	Less than 20KV
2	Medium transmission lines	50-150KM	More than 20KV and less than 100KV
3	Long transmission lines.	More than 150 KM	More than 150 KV

Table 1. Comparison of types of Transmission lines

Important terms

1. Voltage Regulation

The difference in the voltage between sending end and receiving end in the transmission line with respect to the receiving end voltage is called as Voltage Regulation of the transmission line.

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

Where V_S = Sending end Voltage

V_R = Receiving end Voltage

Usually the regulation is expressed in percentage.

$V_S \approx V_R + I_R (R \cos \Phi_R + X \sin \Phi_R)$

So, voltage drop = $V_S - V_R = I_R (R \cos \Phi_R + X \sin \Phi_R)$

2. Transmission Efficiency

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

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

Usually the efficiency is expressed in percentage.

Performance of Short transmission lines:

In the case of short transmission line, the capacitance effect is neglected.

Let, I= load current or receiving-end current per phase

R = Resistance of transmission line per phase in ohm

X_L= Reactance of transmission line per phase in ohm = $\omega L=2\pi fL$
V_R= Receiving end voltage per phase
cos φ_R= Receiving end power factor
V_S= Sending end voltage per phase
cosφ_S= Sending end power factor

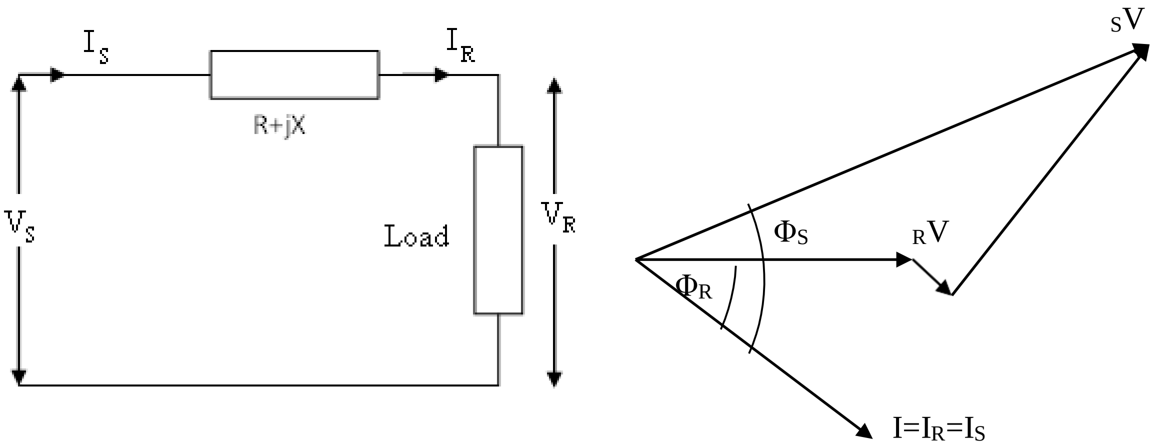


Fig 2.1 Small transmission line equivalent circuit & Phasor diagram

Performance of Medium Transmission line:

The performance of medium transmission line can be done by three methods:

a) **End Condenser method,**
b) **Nominal T method,**
c) **Nominal ∏ method**

In the short transmission line the effect of capacitor is neglected. But when the length and the voltage level are increased the effect of capacitance is included.

In the **end condenser method** the capacitance is considered as **lumped or concentrated**.

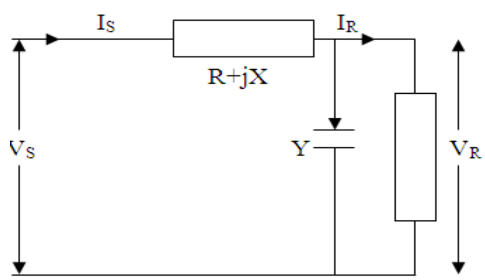


Fig 2.2 End Condenser Method

In the **nominal T method**, the whole capacitance is considered at the **center point** of the line.

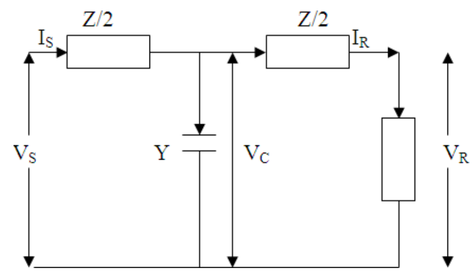


Fig 2.3 Nominal T-Method [12]

In the **nominal ∏ method**, the capacitance is divided in two. **One half** is in the **sending end** and the **other half** is in the **receiving end.**

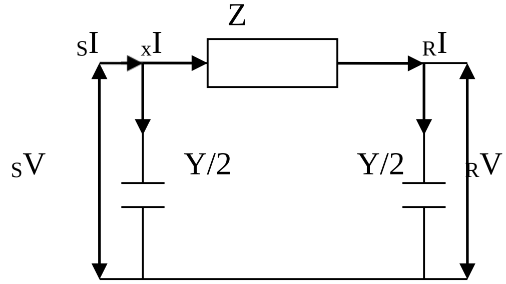


Fig 2.4 Nominal ∏-Method

Performance of long transmission lines

Here the line constants are **uniformly transmitted** throughout the whole line.

Skin Effect and Ferranti effect

- When a conductor is carrying steady direct current (d.c.), this current is uniformly distributed over the whole cross-section of the conductor. However, an alternating current flowing through the conductor does not distribute uniformly, rather it has the tendency to concentrate near the surface of the conductor. This is known as skin effect.
  - *The tendency of alternating current to concentrate near the surface of a conductor is known as* **skin effect.**
- Due to skin effect, the effective area of cross-section of the conductor through which current flows is reduced. Consequently, the resistance of the conductor is slightly increased when carrying an alternating current.

The skin effect depends upon the following factors:

(i) Nature of material

(ii) Diameter of wire − increases with the diameter of wire.

(iii) Frequency − increases with the increase in frequency.

(iv) Shape of wire − less for stranded conductor than the solid conductor.

Ferranti effect:

- The effect in which the voltage at the receiving end of the transmission line is more than the sending voltage is known as the Ferranti effect. Such type of effect mainly occurs because of light load or open circuit at the receiving end.
- Ferranti effect can be controlled by placing the shunt reactors at the receiving end of the lines. Ferranti effect is more occurs in short transmission cables because their capacitance is high.

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.**

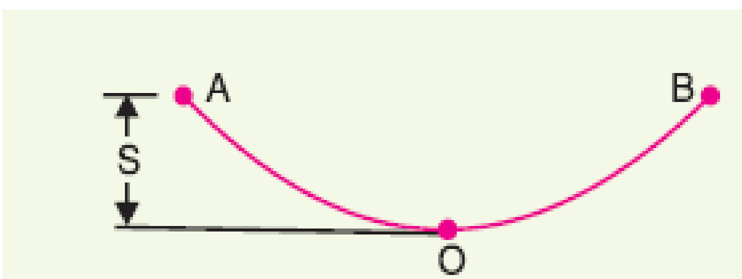


Fig. 2.5 Sag in Overhead lines

Fig. 2.5. shows a conductor suspended between two equi-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*.

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.

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.3.7. 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 *wx* of conductor acting at a distance *x/*2 from *O*.

(b) The tension *T* acting at *O*.

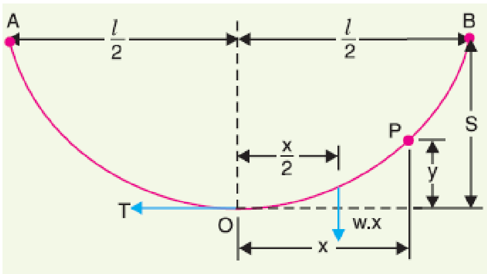


Fig. 2.6 When supports are at equal levels

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

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

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

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*

Sag, $$S = w \times \frac{\left(\frac{l}{2}\right)^2}{2T} = \frac{wl^2}{8\,T}$$

Underground Cables

The other way of transmitting electrical power is through **Underground Cable**. There are some disadvantages in overhead transmission line like the factors which affect the size the conductor due to moisture and environmental conditions. So it's better to go for other technology i.e. Underground cables**.**

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

The desirable requirements for an underground cable are:

1. The conductor should be made up of copper or aluminum of high conductivity.
2. The size of the conductor should be designed to carry the desirable load current.

Construction of the Underground Cable:

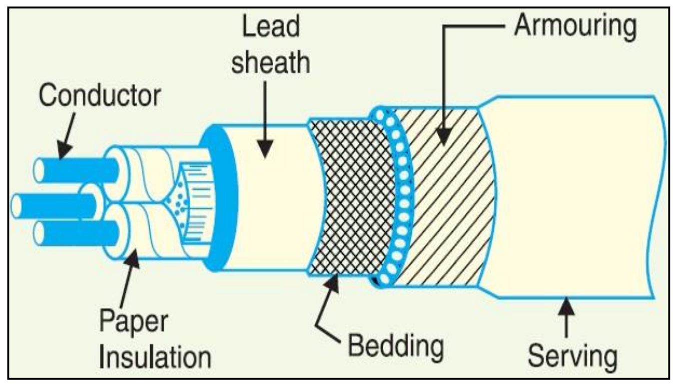


Fig 2.6 Cross sectional view of UG Cables

1. Core or Conductor:

A cable may have one or more than one core or conductor depending upon the type of service. Usually they are made up of either copper or aluminum.

2. Insulation:

Each core is provided with proper thickness of insulation to withstand the voltage to be carried by it. The commonly used insulating materials are Impregnated paper, Varnished cambric and rubber mineral.

2 Metallic Sheath:

In order to protect the cable form moisture, gases and acids, a metallic sheath of aluminum or lead is provided.

3 Bedding

Over the metallic sheath, a fibrous material like jute or hessian tape is layered. The purpose of bedding is protecting the metallic sheath against corrosion and avoids mechanical injury while armouring.

4 Armouring

Over bedding, armouring is done with galvanized steel. Its purpose is to avoid the mechanical injury of the cable while it.

5 Serving

In order to protect armouring from atmospheric conditions, a layer of fibrous material like jute is provided over armouring.

Required properties of insulating material:

1. High insulation resistance to avoid leakage resistance.
2. High dielectric strength to avoid the electrical breakdown.
3. Non-inflammable.
4. Unaffected by acids and alkalis to avoid chemical reaction.

Types of Underground cables:

Cables are classified into five types according to their voltage level.

#	Type of Cable	Voltage level
1	Low Tension(LT) Cable	Up to 1000V
2	High Tension(HT) Cable	Up to 11000 V
3	Super Tension(ST) Cable	From 22KV to 33KV
4	Extra High Tension(EHT) Cable	From 33KV to 66KV
5	Extra Super Voltage Cable	Beyond 132 KV

Table 2: Types of Cables

Types of Cable faults:

Open Circuit fault, Short Circuit fault, Earth fault.

#	Overhead line	Underground cable
1	Fault can be located easily	Fault cannot be located easily since it’s laid in the underground.
2	Unprotected	Highly protected.

Table 3. Comparison of Overhead line and Underground Cable

عوازل خطوط النقل

Overhead line insulators

Introduction to Overhead line insulators:

- Overhead line insulators are used for insulation of line from the transmission/distribution tower.

- They are classified into different types based on their make, structure etc.
- The insulator supports the transmission line which is a steel reinforced conductor called as an A.C.S.R (Aluminum Conductor Steel Reinforced/Aluminum Cored Steel Reinforced).
- Desirable Properties of insulators are shown below.
  1. High mechanical strength in order to withstand conductor load, wind load etc.
  2. High electrical resistance of insulator material in order to avoid leakage currents to earth.
  3. High relative permittivity of insulator material in order that dielectric strength is high.
  4. The insulator material should be non-porous, free from impurities and cracks otherwise the permittivity will be lowered.
  5. High ratio of puncture strength to flashover.

- The successful operation of an overhead line depends to a considerable extent upon the proper selection of insulators. **There are several types of insulator** but the most commonly used are
    a. Pin type.
    b. Suspension type.
    c. Strain Insulator and
    d. Shackle Insulator.

Pin type:

- This type of insulator is secured to the cross-arm on the pole is shown in fig 3.1
- Pin type of insulators is used for transmission and distribution of electric power at voltages upto 33kV.

- Beyond operating voltage of 33kV, the pin type insulators become too bulky and hence uneconomical.

Fig3.1 A two layer pin insulator

Suspension type:

-This type is also the disc type of insulator is shown in fig 3.2.

- They consist of a number of porcelain discs connected in series by metal links in the form of a string which is suspended.

- Each disc is designed for low voltage, say 11kV.

- The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66kV, then six discs in series will be provided on the string.

Fig 3.2 Suspension insulator

Advantages of suspension insulators:

1. This type of insulators is cheaper than pin type insulators for voltages beyond 33kV.
2. If any one disc is damaged, the whole string does not become useless, because the damaged disc can be replaced by the sound one.
3. The suspension arrangement provides greater flexibility to the line.
4. They are generally used with steel tower.

Strain Insulator

-When there is a dead end of the line.

-There is a corner or sharp curve, the line is subjected to greater tension.

-In order to relieve the line of excessive tension.

Shackle Insulator

- They are used for low voltage distribution lines.
- They 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.

Calculation of grading of strain, shackle and post insulators:

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

$$String\ Efficiency = \frac{Voltage\ across\ the\ string}{n \times Voltage\ across\ disc\ nearest\ to\ conductor}$$

Where n = number of discs in the string.

- String efficiency decides the potential distribution along the string.
- Greater the string efficiency, more uniform is the voltage distribution.

$$\text{String Efficiency} = \frac{\text{Voltage across the string}}{\text{n} \times \text{Voltage across disc nearest to conductor}}$$

$$= \frac{V}{3V_3} \times 100$$

3.8. Methods of Improving String Efficiency

(i) By using longer cross-arms.

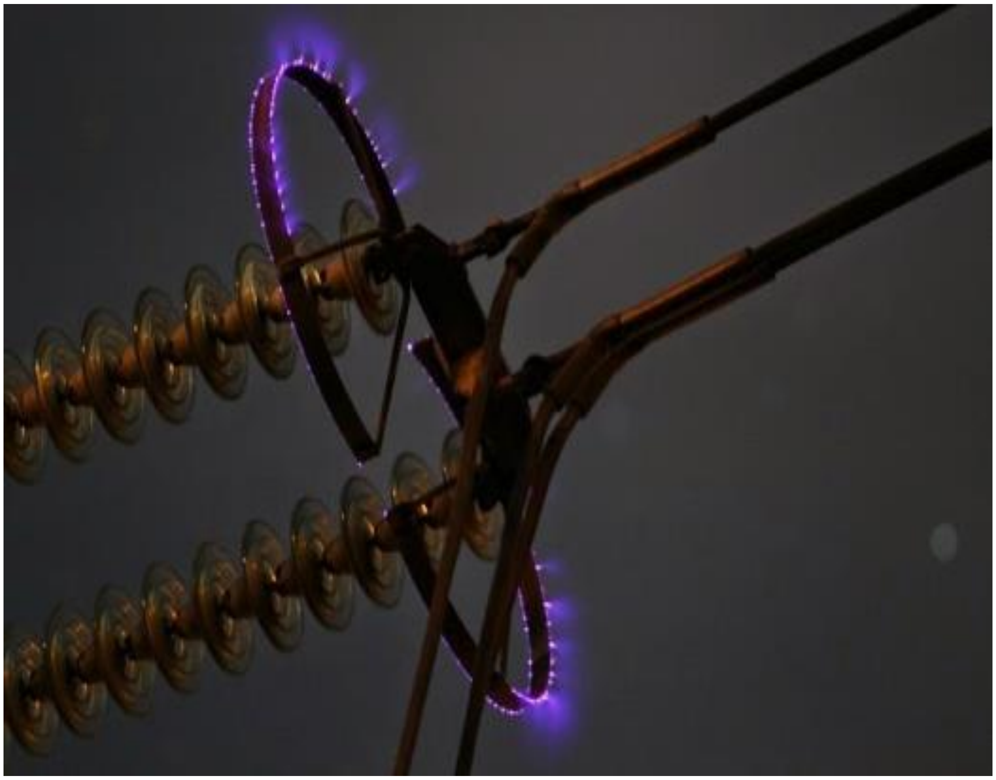
(ii) By grading the insulators.

Corona (ظاهرة كورونا)

Definition of Corona:

- When an alternating potential difference is applied across two conductors.
- Whose spacing is large as compared to their diameters.
- 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 violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona”.



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

Factors affecting corona:

Atmosphere:

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

Conductor size:

- Corona effect depends upon the shape and conditions of the conductors.
- Rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage.

Spacing between conductors:

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

Line voltage:

- Higher line voltage more chances of corona.
- However, if the line voltage has such a value that electrostatic stresses developed at the conductor surfaces make the air around the conductor conducting, the corona is formed.

Advantages and Disadvantages of corona:

Advantages

1. Due to corona formation, the air surrounding the conductor becomes conducting and hence virtual diameter of the conductor is increased.
2. The increased diameter reduces the electro-static stresses between the conductors.

Disadvantages

1. Corona is accompanied by a loss of energy.
2. This loss of energy affects the transmission efficiency of the line.
3. Ozone is produced by corona and may cause corrosion of the conductor due to chemical action.
4. Current drawn by the line due to corona is non-sinusoidal.
5. Hence, inducing interference in the neighbouring communication lines.

Methods of reducing corona effect

1. By increasing conductor size, the voltage at which corona occurs is raised and hence the effects of corona are considerably reduced.
2. By increasing the spacing between conductors.

Power Line Carrier

- Power line carrier (PLC) systems operate by superimposing a high-frequency radio signal onto an existing low-frequency power line.
- These systems are point to point (i.e., substation to substation). They offer slow data rates compared to fiber or microwave systems.
- PLC systems like that shown in Figure 3.2 have been in operation for many decades and several systems are still in service today.

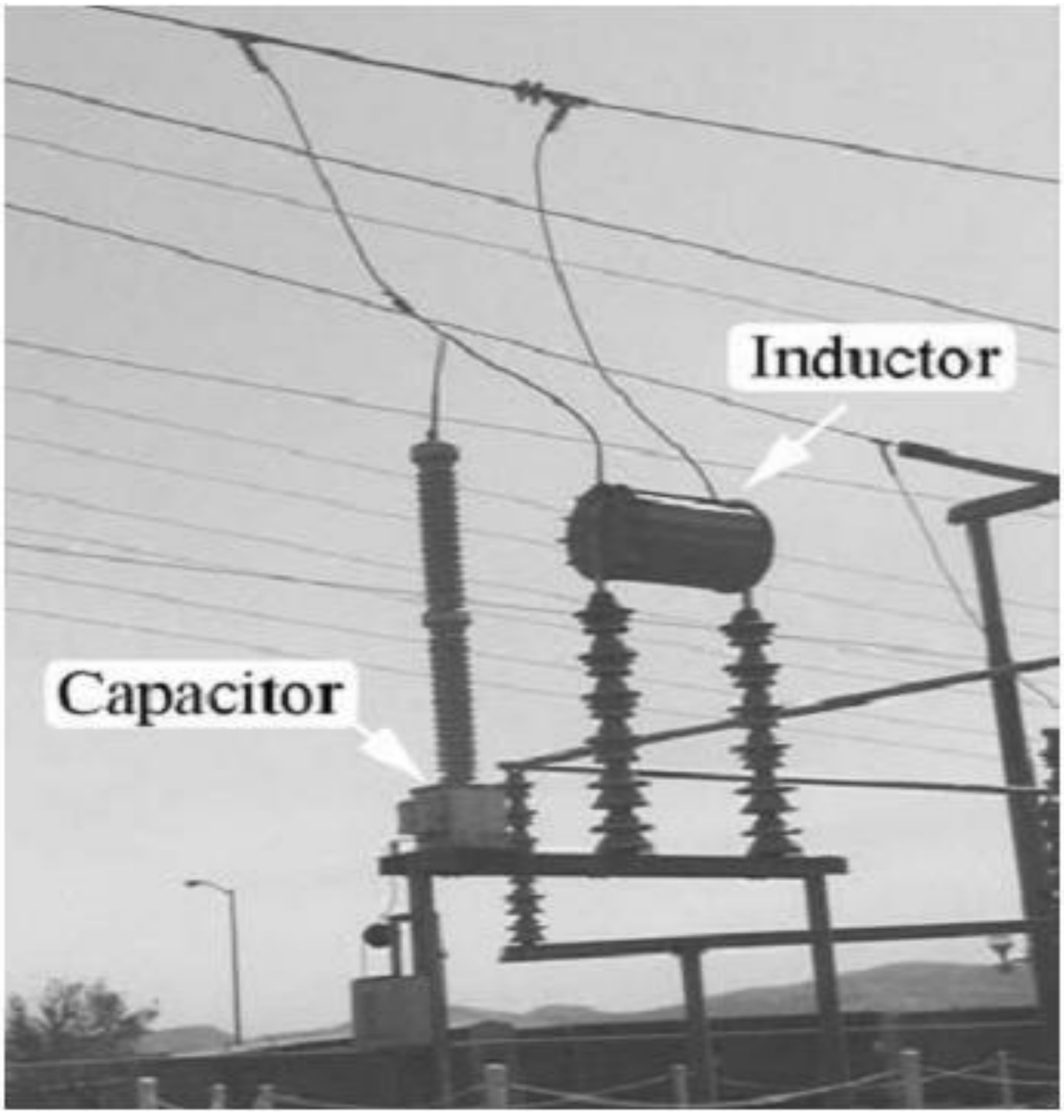


Fig.3.4 Power line carrier communication

Referring to Figure 3.4, the theory of operation takes into account the fact that high-frequency radio signals pass easily through capacitors yet are blocked or severely attenuated by inductors or coils, there as low-frequency signals are just the opposite—they pass through inductors easily yet are blocked by capacitors. The drawing below shows how the equipment is located on a power line inside a substation.

The inductors are sometimes called line traps or wave traps, and the capacitors are called coupling capacitors. Notice that the radio communications occur between the coils and the circuit breakers. Therefore, a line fault that trips the circuit breakers will not disrupt communications (unless the line is cut).

There are a few drawbacks to this older PLC technology, such as transformers that severely attenuate PLC signals, snow and rain weather conditions that can cause high noise levels, and high noise that causes data errors.

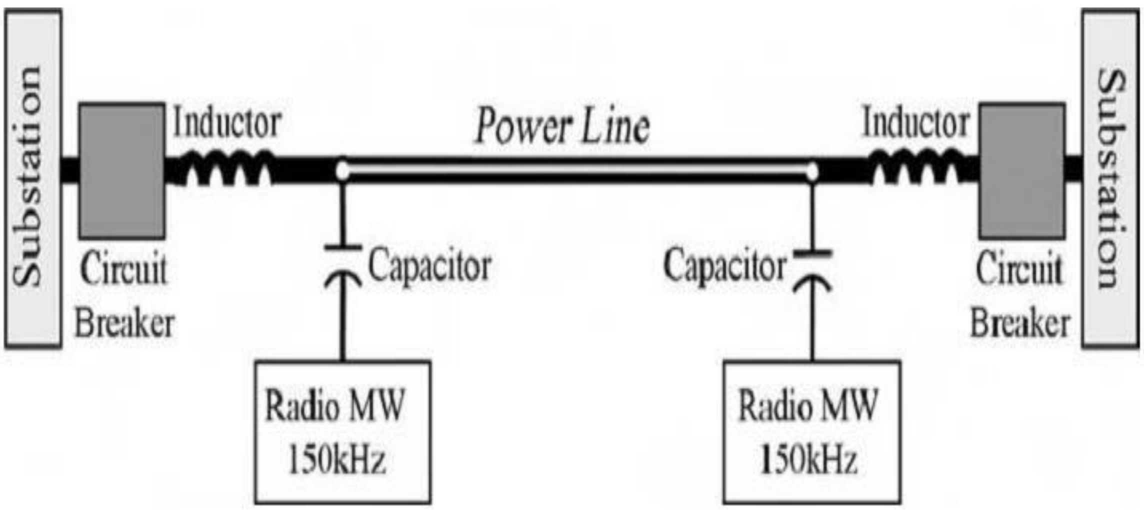


Fig.3.5 PLC system

نظام توزيع الطاقة
Power Distribution Systems

Introduction:

The electrical energy produced at the generating station is supplied to the customers through transmission and distribution. In general, the distribution system is one which distributes power for consumers.

<u>What is a distribution system?</u>

The part of power system which distributes power for local use is called distribution system.

In general the distribution system consists of three main parts.

Feeders, Distributor, Service Mains

1. Feeders:

A feeder is a conductor which connects the substation to the area where the power has to be distributed. The main consideration in the design of the feeder is its current carrying capacity.

2. Distributor:

A distributor is a conductor from which tapings are taken from the supply to the consumers. The main consideration in designing is the distributor is the voltage drop along the line.

3. Service Mains:

A service is a small cable which connects the distributors to the consumer terminals.

Fig.4.1 shows the structure of distribution system, S is the Substation. A, B, C, D are the distributors.

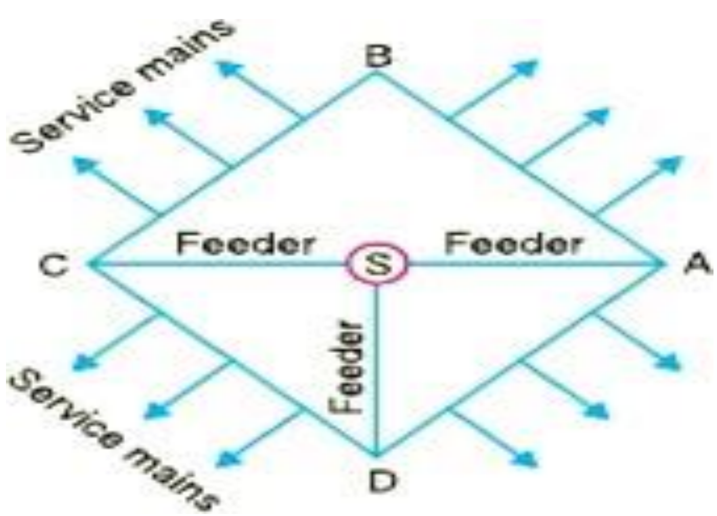


Fig 4.1 structure of distribution system

Classification of Distribution System:

According to the nature of current, Distribution system is classified into two types:

- AC Distribution
- DC Distribution

According to construction, it is classified in to two types:

- Overhead
- Underground

According to scheme of connection, it is classified into three types:

- Radial
- Ring
- Interconnected

AC Distribution:

Nowadays the electric power is transmitted through alternating current only. In the case of AC distribution system, it has two parts.

1. Primary Distribution system
2. Secondary Distribution system

-Primary Distribution System

It is the part of the AC distribution system which operates at voltages higher than general utilisation. Normally the voltages to be distributed are 33KV, 11KV or 6.6KV. The primary distribution is carried out by 3 phase, 3 wire system is shown in fig 4.2 (Delta Connected System) considering the economical conditions.

Here Line Current = √3 × Phase Current i.e. $I_L = \sqrt{3} \times I_P$

Here Line Voltage, V_L = Phase Voltage, V_P

Here Line Voltage ($V_L = V_P$) is the voltage between the lines = 11kV (or 33kV)

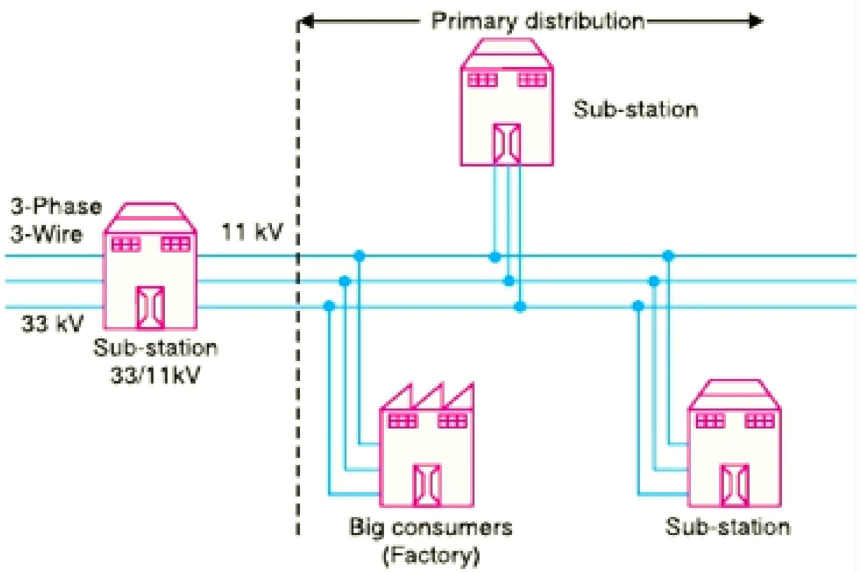


Fig 4.2 Primary distribution system

Secondary Distribution System

It is the part of the AC distribution system which includes the voltages at which the consumers utilise the electrical energy. This system employs 415/240V, 3 phase-4 wire system is shown in fig 4.3 (Star Connected System).

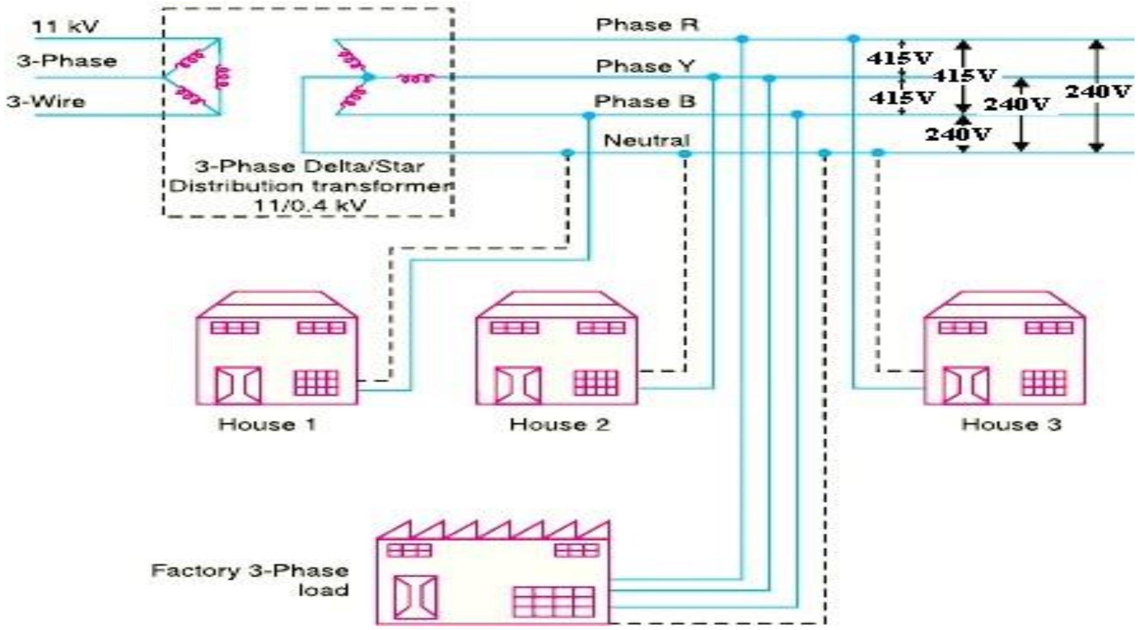


Fig4.3 Secondary distribution system

Here Line Voltage (V_L) is the voltage between the lines = 415V

Here Phase Voltage (V_P) is the voltage between any line to neutral = 240V

Here Line Voltage = √3 × Phase Voltage i.e. $V_L = \sqrt{3} \times V_P$

Here Line Current, I_L = Phase Current, I_P

Here power consumed by the 3 phase load will be expressed as follows

Apparent Power, $S = \sqrt{3}\, V_L \times I_L = 3\, V_P \times I_P$ in VA or kVA or MVA

Real Power, $P = \sqrt{3}\, V_L \times I_L \cos\Phi = 3\, V_P \times I_P \cos\Phi$ in W or kW or MW

Reactive Power, $Q = \sqrt{3}\, V_L \times I_L \sin\Phi = 3\, V_P \times I_P \sin\Phi$ in Var or kVar or MVar

Here $\cos\Phi$ is called the power factor of the load

DC Distribution:

Although AC distribution used widely, for certain applications DC voltage is necessary. AC can be converted into DC by using the devices like Mercury Arc rectifiers, Rotary converters, Motor-Generator Sets.

Types of DC distribution:

a. 2 Wire DC Distribution Systems
b. 3 Wire DC Distribution Systems

Distribution Systems

a. 2 Wire DC Distribution Systems

Here there are two wires, one is outgoing or positive wire and the other is the return or negative wire is shown in fig.4.4. This type of system is never used for transmission since its very low efficiency but used for distribution purpose. Between these two wires the loads like lamp, motor can be connected.

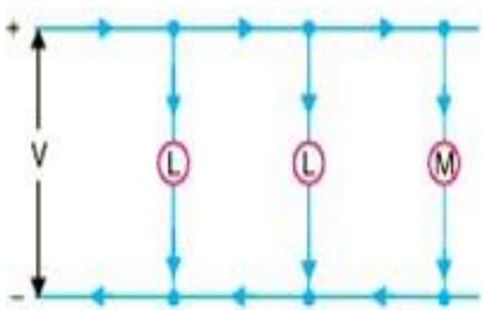


Fig 4.4: 2 Wire DC

a) 3 Wire DC Distribution Systems:

It consists of two outer and one neutral or middle wire which are grounded at the substation is shown in fig 4.5. The advantage of this system is it has two voltages V between the outer and the neutral and 2V between the outers.

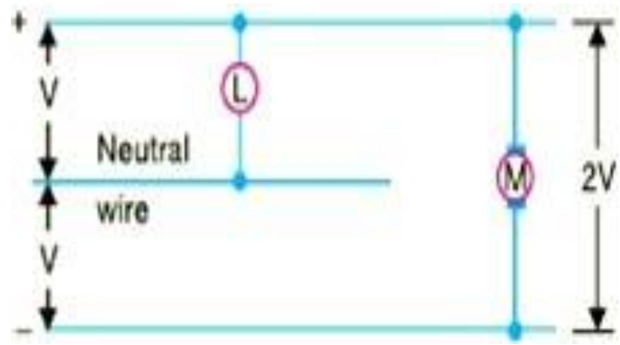


Fig 4.5: 3 Wire DC Distribution Systems

Types of Distribution according to its connection:

a) Radial Distribution System

In this system, separate feeders from one substation will feed the distributors at one end only is shown in fig 4.6.

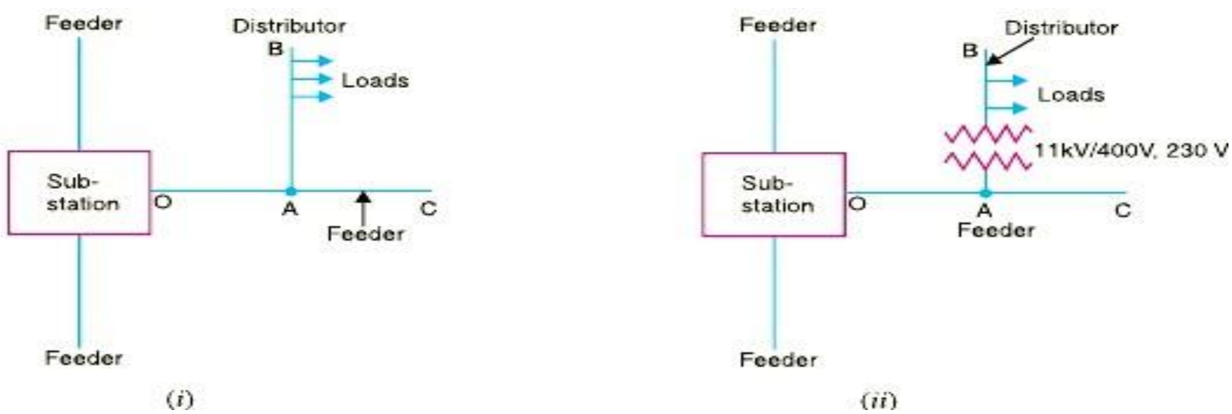


Fig 4.6 Radial Distribution Systems

Here from the substation O there are separate feeders. But the feeder OC has one distributor and it is connected with loads. So the distributor is fed at one end only. This system is useful when the substation is located at the load centre.

b) ***Ring Distribution System**: The* primaries of the distribution transformer form a loop is shown in fig 4.7. It starts at the substation and makes a loop through the area to be served and return to the substation.

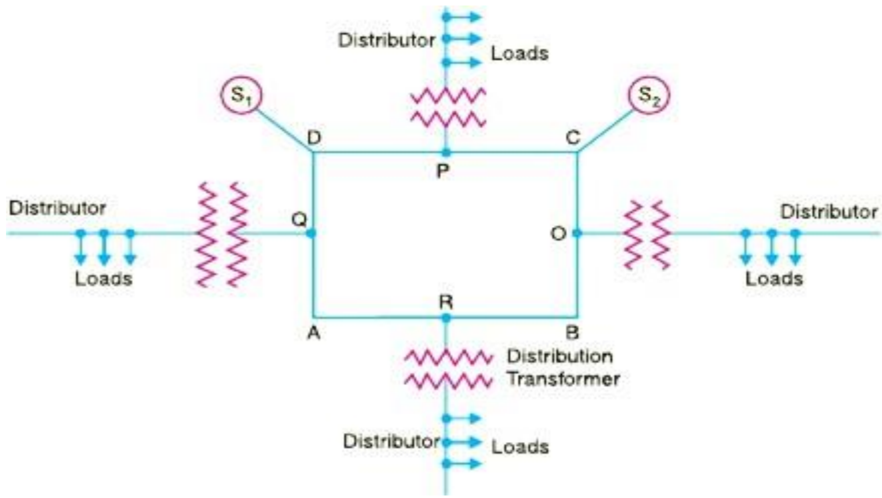


Fig 4.7 Ring Distribution Systems

Here from the substation S, the loop starts from L and go through the path LMNOPQRSL. The distributors are tapped from different points and fed with supply. The advantages of this system:

- ✓ The voltage fluctuation is very less.
- ✓ The distributor is fed with two feeders. So the system is highly reliable.

c) *Interconnected System*

When the feeder is energised by one or more generating stations or substations, then it is said to be interconnected system is shown in fig4.8.

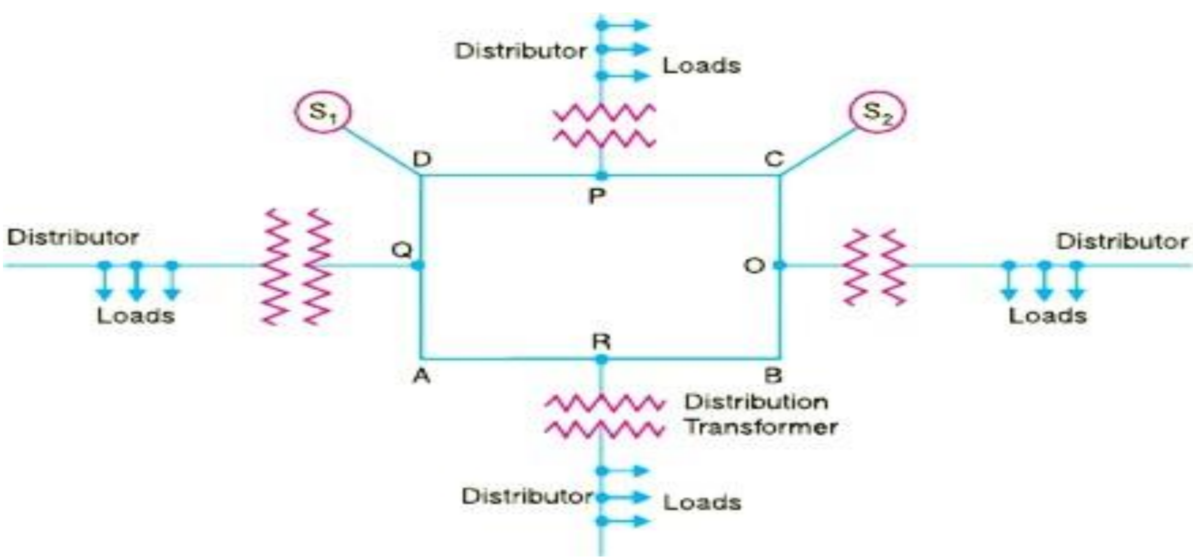


Fig 4.8 Interconnected Distribution Systems

Here two sub stations S1 and S2 are giving supply to the feeders C and D. Distributors are connected to the feeders O, P, Q, and R.

Advantages:

- ✓ It increases the service reliability.
- ✓ Any area fed from one generating station during peak load hours can be fed from another generating station. Thus the efficiency increased.

Power factor (cos Φ) definition

It is the cosine of the phase angle between voltage and current phasors in ac circuits.

From the phasor diagram(fig.4.9) we see that the current has two components. One (I cos Φ) in phase with V and another (I sin Φ) in 90^0 to V.

I = total current in the line

I_P = I cos Φ = active current in the line

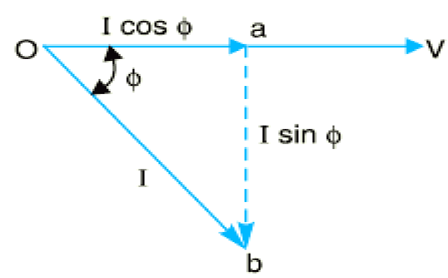


Fig 4.9 Phasor diagram between voltage and current

I_Q= I sin Φ = reactive current in the line

- ➢ *Other definitions of power factor*

Power factor,

- ✓ *cos Φ = (Resistance R of the load) / (Impedance Z of the load).*
- ✓ *cos Φ = (Active power, P taken by the load) / (Apparent power |S| taken by the load) = (VI cos Φ/VI)*

➢ *Range of power factor*

Minimum value of cos Φ is 0 and maximum value is 1.

➢ ***Problems in distribution systems with low power factor***

- The feeder will carry large current.
- It increases the size of feeder conductor.
- It also causes more power (copper) loss and more voltage drop in feeders.
- The equipment in the system will be of more ratings.

➢ *Methods of power factor improvement*

Normally, the power factor of the whole load on a large generating center is in the range of 0.8 to 0.9. Sometimes, this value becomes less, so we need to improve by following methods.

- ➢ Static Capacitors(fig 4.10)
- ➢ Synchronous Condensers(fig 4.11)

Static Capacitors

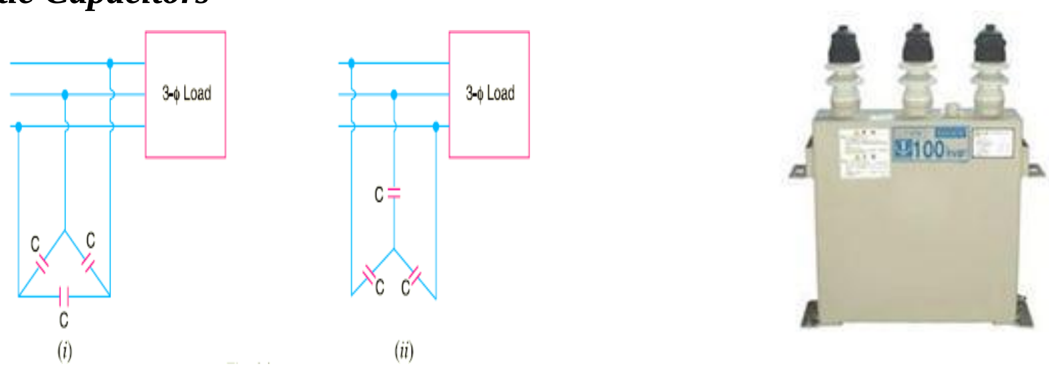


Fig 4.10 Static Capacitors in star and delta connection

Here the capacitors are connected across the lagging loads and they draw leading currents and help the system to improve power factor.

Synchronous Condensers

A synchronous motor takes leading current when overexcited and can behave like a capacitor. An overexcited synchronous motor under no load is known as synchronous condenser.

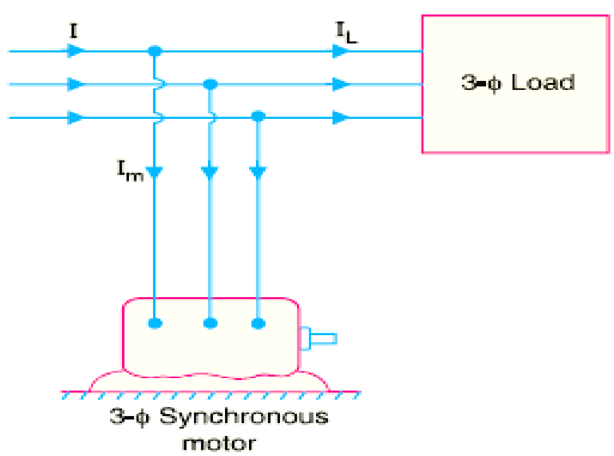


Fig 4.11 ***Synchronous Condensers***

4.2 Economics aspects of Power Systems

[Load Curves, Load Factor, Diversity Factor, Tariff Systems]

Load Curve:

Loads on power are constantly changing every time.

The curve showing the variation of loads on a power station with respect to time is called a **load curve** is shown in fig 4.12

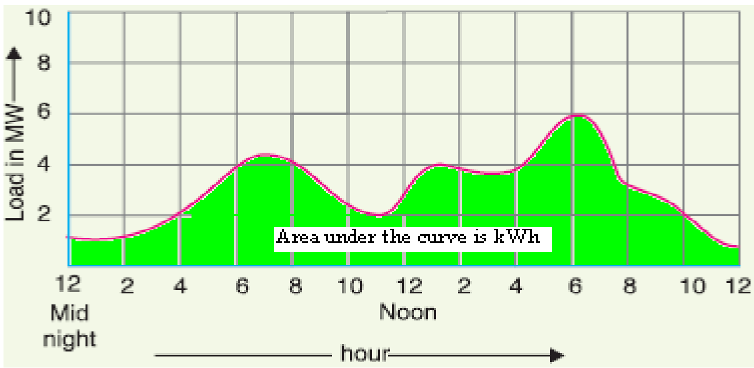


Fig 4.12 load curve of generating station [2]

There are three types of load curves required by power engineers for following purposes.

Daily Load Curve: It helps to understand the variation of load on a power station every day to manage the operation of the system. Area under this curve represents the daily energy of kWh production.

Monthly Load Curve: It helps to fix the energy rates.

Yearly Load Curve: It helps to obtain the annual load factor of the system.

Load Factor:

Average Load = (Area (kWh) under the daily load curve) / (24 hours).

Maximum Demand = It is the greatest of the demand of the load on the power station on a given day.

Load factor = Average Load / Maximum Demand of the day

Its value is always less or equal to 1.

Diversity Factor:

The power station supplies power to various types of consumers such as domestic consumers, commercial consumers and industrial consumers. All these consumers are grouped together and diversity factor is determined.

Diversity Factor = (Sum of individual maximum demand) / (Maximum demand on power station).

نظام الحماية في القوى الكهربائية

Power System Protection

Protective relay

- Protective relay is an electromechanical apparatus, often with more than one coil, designed to calculate operating conditions on an electrical circuit and trip circuit breakers when a fault is detected.
- Protective relaying senses the abnormal condition in a part of power system and gives an alarm or isolates (removes) that part from healthy system. Protective relaying is a teamwork of CT, PT, protective relays, time delay relays, trip circuits, circuit breakers etc.
- In an electric power system, a **fault** is any abnormal electric current. For example, a short circuit is a fault in which current bypasses the normal load.
- An open-circuit fault occurs if a circuit is interrupted by some failure. In three-phase systems, a fault may involve one or more phases and ground, or may occur only between phases.
- In a "ground fault" or "earth fault", charge flows into the earth. The prospective short circuit current of a fault can be calculated for power systems.
- Protective relaying plays an important role in minimizing the faults and also in minimizing the damage in the event of faults.

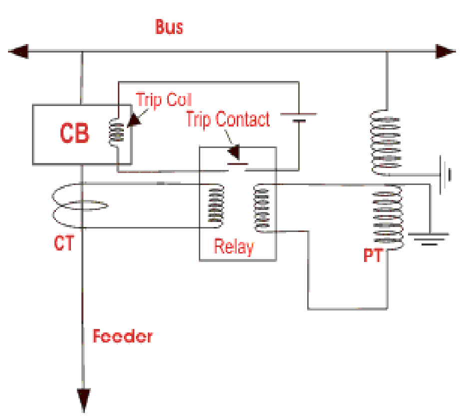


Fig.1.16 Basic Connection Diagram of protection relay

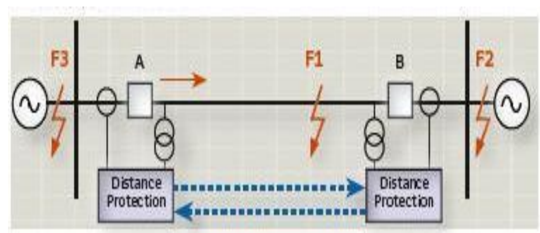


Fig.1.17 Distance protection method of a transmission line using relays

Instrumentation Transformers

- A **current transformer** (**CT**) is used for measurement of alternating electric currents. Current transformers, together with voltage transformers (VT) (potential transformers (**PT**)), are known as **instrument transformers**.
- When current in a circuit is too high to directly apply to measuring instruments, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments.
- A current transformer also isolates the measuring instruments from what may be very high voltage in the monitored circuit.
- Current transformers are commonly used in metering and protective relays in the electrical power systems.

Protection Relays Codes:

Description	ANSI	IEC 60617	Description	ANSI	IEC 60617
Overspeed relay	12	$\omega >$	Inverse time earth fault overcurrent relay	51G	$I \perp >$
Underspeed relay	14	$\omega <$	Definite time earth fault overcurrent relay	51N	$I \perp >$
Distance relay	21	$Z <$	Voltage restrained/controlled overcurrent relay	51V	$U \nearrow I >$
Overtemperature relay	26	$\theta >$	Power factor relay	55	$\cos\varphi >$
Undervoltage relay	27	$U<$	Overvoltage relay	59	$U>$
Directional overpower relay	32	$\rightarrow P >$	Neutral point displacement relay	59N	$U_{rsd} >$
Underpower relay	37	$P <$	Earth-fault relay	64	$I \perp >$
Undercurrent relay	37	$I <$	Directional overcurrent relay	67	$\rightarrow I >$
Negative sequence relay	46	$I_2 >$	Directional earth fault relay	67N	$\rightarrow I \perp >$
Negative sequence voltage relay	47	$U_2 >$	Phase angle relay	78	$\varphi >$
Thermal relay	49		Autoreclose relay	79	$O \rightarrow I$
Instantaneous overcurrent relay	50	$I >>$	Underfrequency relay	81U	$f <$
Inverse time overcurrent relay	51	$I >$	Overfrequency relay	81O	$f >$
			Differential relay	87	$I_d>$

Circuit breakers (القواطع الكهربائية)

- A circuit breaker is an equipment which **can open or close a circuit** under all conditions viz. **no load, full load and fault conditions**.
- It is designed that it can be operated manually (or by remote control) under normal conditions and automatically under fault conditions.
- The arc produced during the opening operation. The circuit breaker are classified based on the arc quenching technique used.

Accordingly, circuit breakers may be classified into :

(i) Oil circuit breakers which employ some insulating oil (e.g., transformer oil) for arc extinction.

(ii) Air Blast Circuit Breaker

(iii) Sulphur hexafluroide circuit breakers in which sulphur hexafluoride (SF6) gas is used for arc extinction.

(iv) Vacuum circuit breakers in which vacuum is used for arc extinction.

Oil Circuit Breakers

In such circuit breakers, some **insulating oil** (e.g., transformer oil) is used as an arc quenching medium. The contacts are opened under oil and an arc is struck between them.

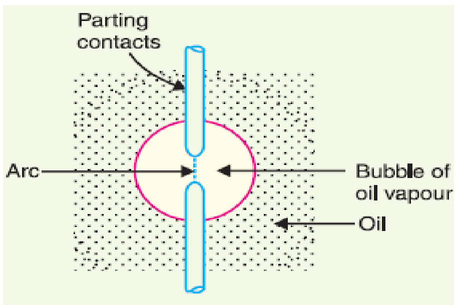


Fig.1.18. Oil circuit Breaker [2]

Sulphur Hexaflouride (SF_6) Circuit Breakers

In such circuit breakers, sulphur hexaflouride (SF_6) gas is used as the arc quenching medium. The SF6 is an electro-negative gas and has a strong tendency to absorb free electrons. The contacts of the breaker are opened in a high pressure flow of SF6 gas and an arc is struck between them.

The SF_6 circuit breakers have been found to be very effective for high power and high voltage service.

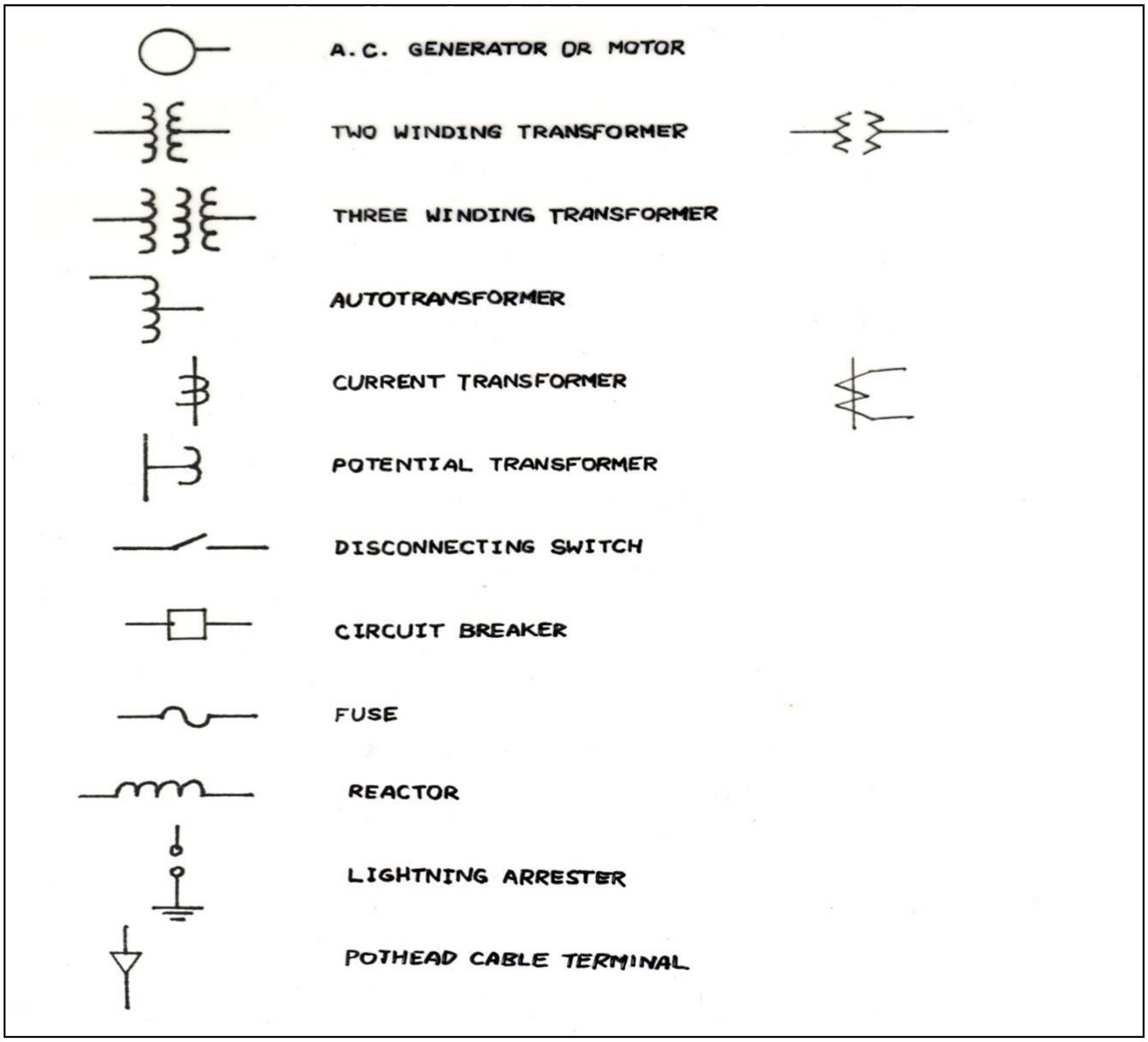


Fig.1.19 Graphical symbols used in Single Line Diagrams

أختبر نفسك

Test Your Self

Review Questions:

1. What are the power generation techniques?
2. Draw the structure of any one power station?
3. Draw the structure of any one sub-station using Single line diagram.
4. Explain different types of insulators used in electrical power system.
5. What is corona? How corona affects the atmosphere?
6. How to reduce the corona effects in power system?
7. What is string efficiency? What is its significance in power system?
8. What is power factor?
9. Define the following terms a) load curve b) diversity factor c) load factor.
10. Draw the cable layout with names?
11. A single phase overhead transmission line delivers 4000KW at 11Kv at 0.8 Power factor lagging. If the resistance and reactance per conductor are 0.15 ohms and 0.02 ohms respectively. Calculate: i. percentage voltage regulation ii. Line loses iii. Power input and efficiency.
12. What are the advantages and disadvantages of overhead transmission line?

13. Explain the classification of transmission lines based on length and voltage level?

14. How the electric underground cable is classified based on voltage level?

15. What are the advantages and disadvantages of underground cable and overhead transmission lines?

16. What are the advantages and disadvantages of hydropower plant?

17. What are the advantages and disadvantages of thermal station?

18. Explain the classification of circuit breaker?

19. Mention names of protection relay codes 27,87,50,37&59?

20. What is sag in overhead line? Write the equation?

21. What are the problems of low power factor?

22. Explain skin effect & Ferranti effect?

23. What are the different between delta and star connection? Write equation for each?

24. Explain apparent power, active power & reactive power with equation? Draw power triangle?

25. Explain which circuit breaker is mostly used in power plants.

26. When and why receiving end voltage is more than the sending end voltage? Name the effect.

27. Why alternating current is flowing on the surface of conductor? Name the effect and what are the factors that it depends on?

28. Why paper insulation and bedding are used in electric cables?

29. A three phase, 50 Hz, 20000 m long overhead line supplies 1.5 MW at 12000 V, 0.81pf lagging. The line resistance is 700 mΩ per phase per km and line inductance is 0.9 mH per phase per km. Calculate the transmission efficiency and voltage regulation.

30. Draw the block diagram of a power station which does not use turbine for generating electrical power.

31. Explain Ring Distribution System with diagram?

32. Explain working principle of protection relay and distance relay with drawing?

33. Explain working principle of power transformer with drawing?

34. Write any three types of protection in transformer?

35. Compere between hydropower plant and solar power station in terms of running cost and reliability?

36. What are the method for improvement power factor? Explain one of them?

37. With short note explain how the power transfer from starting point to the end point?

38. Why we need single line diagram?

بالتوفيق