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DEPARTMENT OF
ELECTRICAL & ELECTRONICS ENGINEERING

Course Material
for
POWER GENERATION AND DISTRIBUTION

For
B.Tech (EEE) –IV SEMESTER

MODULE - I

THERMAL POWER STATIONS

INTRODUCTION:

- Thermal energy is the major source of power generation in India. More than 60% of electric power is produced by steam plants in India. India has large deposit of coal (about 170 billion tones), 5^{th} largest in world. Indian coals are classified as A-G grade coals.
- In Steam power plants, the heat of combustion of fossil fuels is utilized by the boilers to raise steam at high pressure and temperature. The steam so produced is used in driving the steam turbines or sometimes steam engines couples to generators and thus in generating electrical energy.
- Steam turbines or steam engines used in steam power plants not only act as prime movers but also as drives for auxiliary equipment, such as pumps, stokers fans etc.
- Steam power plants may be installed either to generate electrical energy only or generate electrical energy along with generation of steam for industrial purposes such as in paper mills, textile mills, sugar mills and refineries, chemical works, plastic manufacture, food manufacture etc.
- The steam for process purposes is extracted from a certain section of turbine and the remaining steam is allowed to expand in the turbine. Alternatively the exhaust steam may be used for process purposes.
- Thermal stations can be private industrial plants and central station.

Coal Classification

Coal Type	kJ/kg	kWh/kg	kCal/kg
Peat	8000	28800000	1912
Lignite	20000	72000000	4780
Bituminous	27000	97200000	6453
Anthracite	30000	108000000	7170

Advantages and Disadvantages of a Thermal Power Plant

Advantages: Less initial cost as compared to other generating stations.

- It requires less land as compared to hydro power plant.
- The fuel (i.e. coal) is cheaper.

- The cost of generation is lesser than that of diesel power plants.

Disadvantages:

- It pollutes the atmosphere due to the production of large amount of smoke. This is one of the causes of global warming.
- The overall efficiency of a thermal power station is low (less than 30%).
- Requires long time for erection and put into action.
- Costlier in operating in comparison with that of Hydro and Nuclear power plants.
- Requirement of water in huge quantity.

Selection of site for thermal power plant

- **Nearness to the load centre:** The power plant should be as near as possible to the load centre to the centre of load .So that the transmission cost and losses are minimum. This factor is most important when Dc supply system is adopted. However in the case of AC supply when transformation of energy from lower voltage to higher voltage and vice versa is possible power plants can be erected at places other than that of load provided other conditions are favorable.
- **Water resources:** For the construction and operating of power plant large volumes of water are required for the following reasons
  - To raise the steam in boiler.
  - For cooling purpose such as in condensers
  - As a carrying medium such as disposal of ash.
  - For drinking purposes.
  - This could be supplied from either rivers or underground water resources. Therefore having enough water supplies in defined vicinity can be a factor in the selection of the site.
- **Availability of Coal:** Huge amount of coal is required for raising the steam. Since the government policy is to use the only low grade coal with 30 to 40 % ash content for power generation purposes, the steam power plants should be located near the coal mines to avoid the transport of coal & ash.
- **Land Requirement:** The land is required not only for setting up the plant but for other purposes also such as staff colony, coal storage, ash disposal etc.

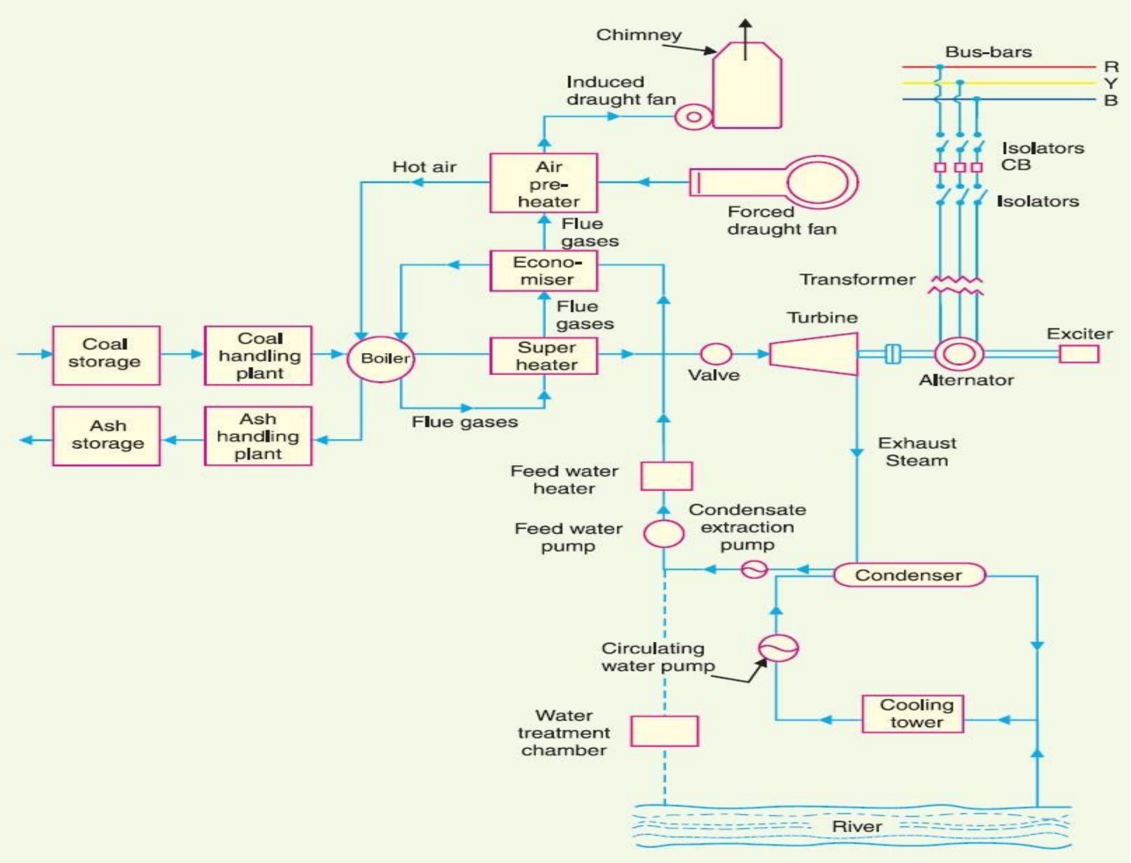
- **Eg:** For 2000MW plant, the land requirement may be of the order of 200-250 acres. As the cost of the land adds up to the final cost of the plant, it should be available at a reasonable price. Land should be available for future extension.

- **Transportation Facilities**: The facilities must be available for transportation of heavy equipment and fuels e.g near railway station.
- **Labour supplies:** Skilled and unskilled laborers should be available at reasonable rates near the site of the plant.
- **Ash Disposal:** Ash is the main waste product of the steam power plant and with low grade coal, it may be 3.5 tones per day , some suitable means for disposal of ash should be though of. It may be purchased by building contractors, or it can be used for brick making near the plant site. If the site is near the coal mine it can be dumped into the disused mines. In case of site located near a river,sea or lake ash can be dumped into it.
- **Distance from populated area:** The continuous burning of coal at the power station Produces smoke, fumes and ash which pollute the surrounding area. Such a pollution due to smoke is dangerous for the people living around the area. Hence, the site of a plant should be at a considerable distance from the populated area.

Major Components of a Thermal Power Plant

- **Coal Handling Plant**
- **Pulverizing Plant**
- **Draft or Draught fan**
- **Boiler**
- **Ash Handling Plant**
- **Turbine and Generator**
- **Condenser**
- **Cooling Tower And Ponds**
- **Feed Water Heater**
- **Economiser**

- **Super heater and Reheater**
- **Air pre heater**
- **Alternator with Exciter**
- **Protection and control equipment**
- **Instrumentation**



Schematic arrangement of Steam Power Station

- A boiler (or steam generator) is a closed vessel in which water, under pressure, is converted into steam. The heat is transferred to the boiler by all three modes of heat transfer i.e. conduction, convection and radiation.
- Major types of boilers are: (i) fire tube boiler and (ii) water tube boiler

❖ Generally water tube boilers are used for electric power stations.

Fire Tube Boiler

❖ The boiler is named so because the products of combustion pass through the tubes which are surrounded by water.

❖ Depending on whether the tube is vertical or horizontal the fire tube boiler is divided into two types

- Vertical tube boiler
- Horizontal tube boiler

❖ A fire tube boiler is simple, compact and rugged in construction. Its initial cost is low.

❖ Water being more and circulation being poor they cannot meet quickly to changes in steam demand.

❖ As water and steam, both are in the same shell, higher pressure of steam are not possible, the maximum pressure which can be had is 17.5 kg/cm^2 with a capacity of 15,000kg of steam per hour.

❖ For the same output the outer shell of a fire tube boiler is much larger than that of a water tube boiler.

❖ In the event of a sudden and major tube failure. Steam explosions may be caused in the furnace due to rush of high pressure water into the hot combustion chamber which may generate large quantities of steam in the furnace.

❖ Fire tube boilers use is therefore limited to low cost small size and low pressure plants.

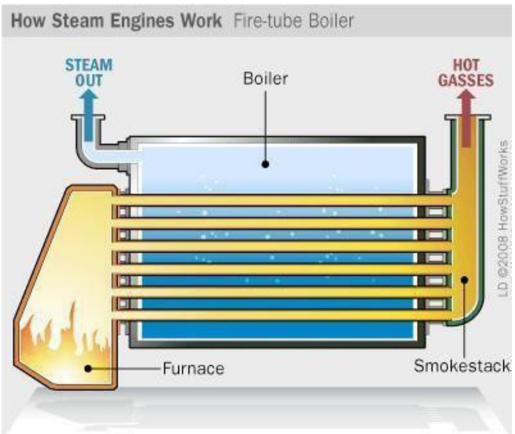


Figure: Fire Tube Boiler

Water Tube Boilers

- In this boiler, the water flows inside the tubes and hot gases flow outside the tube.
- Water tube boiler are classified as
- Vertical tube boiler
- Horizontal tube boiler
- Inclined tube boiler
- The circulation of water in the boiler is may be natural or forced.
- For Central steam power plants large capacity of water tube boilers are used.
- The tubes are always external to the drum they can be built in smaller size and therefore withstand high pressure.
- The boiler drum contains both steam and water, the former being trapped from the top of the drum where the highest concentration of dry steam exists.

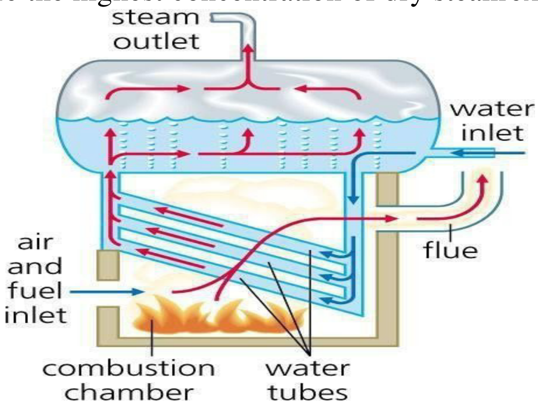


Figure: Water tube boiler

SUPERHEATER AND REHEATERS

- The function of the super heater is to remove the last trash of moisture from the saturated steam leaving the boiler tubes and also increases its temperature above the saturation temperature.
- For this purpose the heat of the combustion gases from the furnace is utilized.
- Super heated steam is that steam which contains more heat than the saturated steam at the same pressure. The additional heat provides more energy to the turbine hence

power output is more.

- Superheated steam causes lesser erosion of the turbine blades and can be transmitted for longer distance with little heat loss
- A super heater may be convention type, radiant type or combination. However, convention super heaters are more commonly used.

Figure: Super heaters

REHEATER

- In addition to super heater modern boiler has reheater also. The function of the reheater is to superheat the partly expanded steam from the turbine, this ensure that the steam remain dry through the last stage of the turbine.
- A reheater may be convention type, radiant type or combination.

Feed Water Heaters: These heaters are used to heat the feed water by means of blend steam before it is supplied to the boiler. Necessity of heating feed water before feeding it back to the boiler arises due to the following reasons.

- Feed Water heating improve overall efficiency.
- The dissolved oxygen which would otherwise cause boiler corrosion are removed in the feed water heater.
- Thermal stresses due to cold water entering the boiler drum are avoided.
- Quantity of steam produced by the boiler is increased.

❖ Some other impurities carried by steam and condensate, due to corrosion in boiler and condenser, are precipitated outside the boiler.

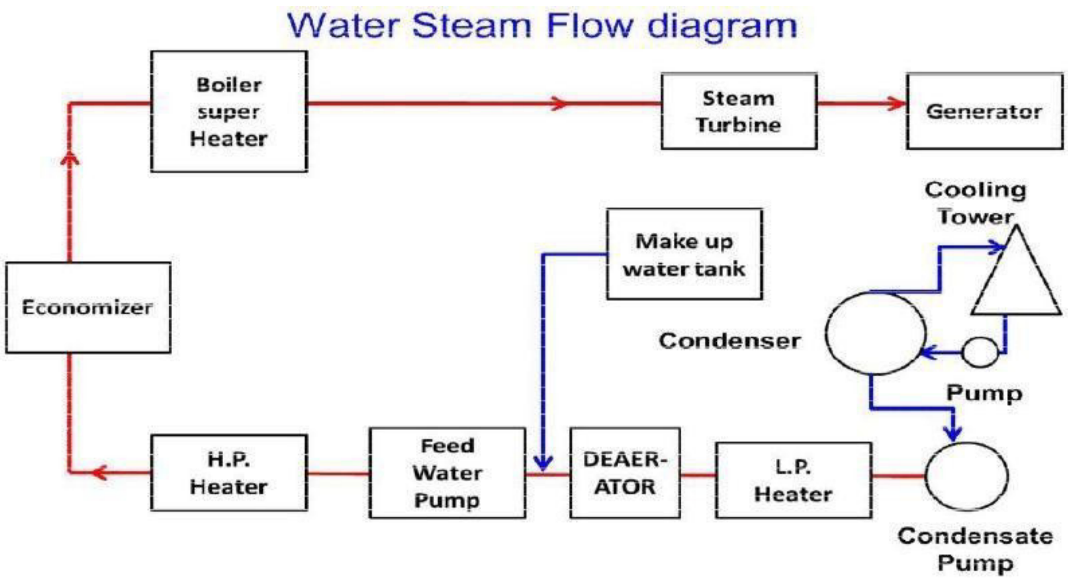


Figure: Water steam flow diagram

ECONOMIZER

❖ Boilers are provided with economizer and air pre-heaters to recover heat from the flue gases. An increase of about 20% in boiler efficiency is achieved by providing both economizer and air pre-heaters.

❖ Economizer alone gives only 10-12% efficiency increase, causes saving in fuel consumption 5-15 %. The feed water from the high pressure heaters enters the economizer and picks up heat from the flue gases after the low temperature super heater.

❖ Economizer can be classified as an inline or staggered arrangement based on the type of tube arrangement.

❖ For pressure of 70 Kg/cm^2 or more economizer becomes a necessity.

❖ The tubes are arranged in parallel continuous loops.

❖ Feed water flows through the tubes and the flue gases outside the tubes across them.

The feed water should be sufficiently pure not to cause forming of scales and cause internal corrosion and under boiler pressure.

- The temperature of the feed water entering the economizer should be high enough so that moister from the flue gases does not condense on the economizer tubes.

AIR PREHEATERS

- After the flue gases leave economizer, some further heat can be extracted from them and is used to heat the incoming air for combustion.
- Air preheaters may be of following types:
  - Plate type
  - Tubular type
  - Regenerative type
- Cooling of flue gases by 20^0 increase the efficiency of the plant by 1%.
- The use of air preheaters is more economical with pulverized fuel boilers because the temperature of flue gases going out is sufficiently large and high air temperatures (250 to 350^0 C) is always desirable for better combustion.
- Air preheaters should have high thermal efficiency, reliability of operation, less maintenance charges, should occupy small space, should be reasonable in initial cost and should be accessible.
- In order to avoid corrosion of the air preheaters, the flue gases should not be cooled below the dew point.

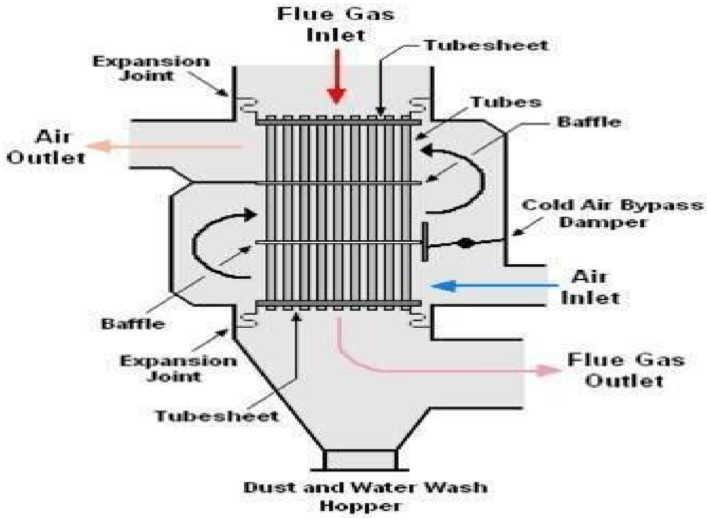


Figure: Air Preheater

STEAM TURBINES

- Steam entering from a small opening attains a very high velocity.
- The velocity attained during expansion depends on the initial and final content of the steam.
- The difference in initial and final heat content represent the heat energy to be converted to kinetic energy.

There are two types of steam turbines:

1) Impluse turbine and 2)Reaction Turbine

Impuse Turbine:

- In this turbine there are alternate rows of moving and fixed blades. The moving blades are mounted on the shaft and fixed blades are fixed to the casing of the turbine.

- A set of fixed nozzle is provided and steam is passed through these nozzles. The in steam due to pressure and internal energy is converted to K.E. The steam comes out of the nozzles with very high velocity and impinges on the rotor blades.

- The direction of steam flow changes without changing its pressure.

- Thus due to the change in momentum the turbine rotor starts rotating.

Reaction Turbine:

- Reaction turbine have no nozzles. These two have alternate rows of moving and fixed blades. The moving blades are mounted on shaft, while fixed blades are fixed in casing of turbine.
- When high pressure steam passes through fixed blades, then steam pressure drops down and velocity of steam increases.
- As steam passes over moving blades, the steam expands and imparts energy,resulting in reduction in pressure and velocity of steam.

Note: Turbines used in thermal power stations are Impuse, Reaction or combined.
Generally multistage turbines are used. H.P steam after doing work in the H.P stage passes over
stage . more workis extracted thereby, with consequent increase in thermal efficiency.

Compounding of steam turbines:

Single stage turbines are of low efficiency.

In compounding, a number of rotors are connected or keyed to the same shaft

Two types of compounding are used: velocity compounding and pressure compounding

Governing of steam turbines:

Governing signifies the process of controlling the volume of steam to meet the load fluctuation.

Figure: Steam Turbines

CONDENSERS

The function of the condenser is to condense the steam exiting the turbine. The condenser helps maintain low pressure at the exhaust.

Two types of condensers are used.

Table: Jet and Surface Condensers

Jet condenser (contact type)	Surface condenser (non-contact type)
Exhaust steam mixes with cooling water.	Steam and water do not mix.
Temperature of the condensate and cooling water is same while leaving the condenser.	Condensate temperature higher than the cooling water temperature at outlet.
Condensate cannot be recovered.	Condensate recovered is fed back to the boiler.
Heat exchanged by direct conduction	Heat transfer through convection.
Low initial cost	High initial cost.
High power required for pumping water.	Condensate is not wasted so pumping power is less.

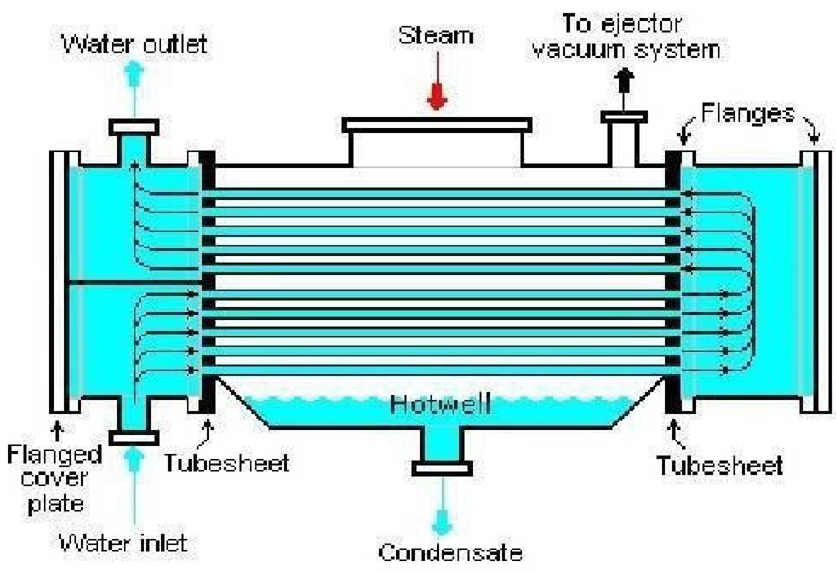
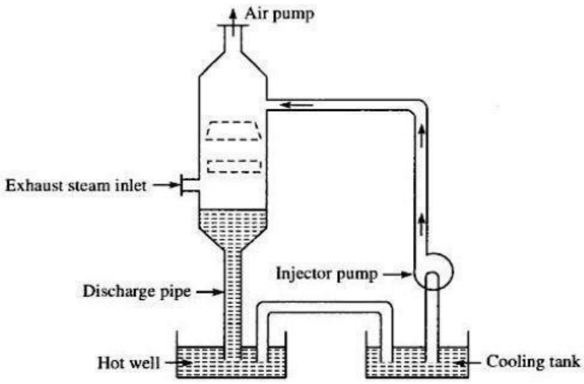


Figure: Surface Condenser



DEAERATORS

- A deaerator is a device that is widely used for the removal of oxygen and other dissolved gases from the feed water to steam-generating boilers.
- In particular, dissolved oxygen in boiler feed waters will cause serious corrosion damage in steam systems by attaching to the walls of metal piping and other metallic equipment and forming oxides (rust).
- There are two basic types of deaerators,
  1. the tray-type an
  2. the spray-type
- The tray-type (also called the cascade-type) includes a vertical domed deaeration section mounted on top of a horizontal cylindrical vessel which serves as the deaerated boiler feedwater storage tank.
- The spray-type consists only of a horizontal (or vertical) cylindrical vessel which serves as both the deaeration section and the boiler feed water storage tank.

COOLING TOWERS AND SPRAY PONDS

- Condensers need huge quantity of water to condense the steam.
- Water is led into the plants by means of circulating water pumps and after passing through the condenser is discharged back into the river.
- If such a source is not available closed cooling water circuit is used where the

warm water coming out of the condenser is cooled and reused.

- In such cases ponds and cooling towers are used where the water loses heat to the atmosphere.

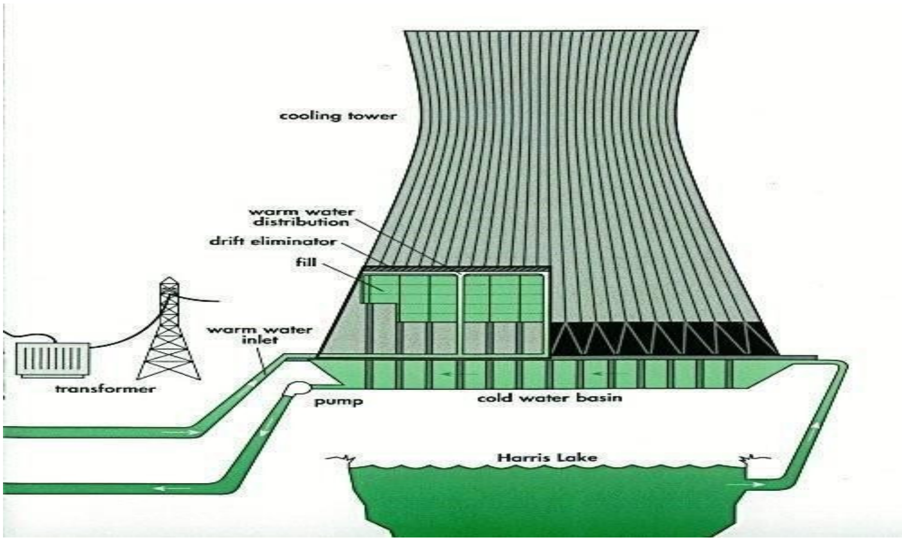
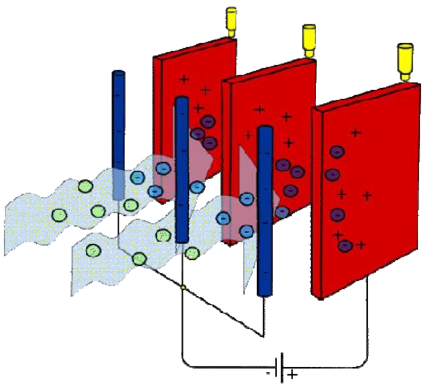


Figure : Cooling Tower

ELECTROSTATIC PRECIPITATORS

- ❖ An electrostatic precipitator (ESP), or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge.



- ❖ the basic idea of an ESP:
- ❖ *Charging*
- ❖ *collecting.*
- ❖ *removing*

- Every particle either has or can be given a charge—positive or negative.
- We impart a negative charge to all the particles in a gas stream in ESP.
- Then a grounded plate having a positive charge is set up.
- The negatively charged particle would migrate to the grounded collection plate and be captured.
- The particles would quickly collect on the plate, creating a dust layer. The dust layer would accumulate until we removed it.
- The structural design and operation of the discharge electrodes (rigid-frame, wires or plate) and collection electrodes.
  - tubular type ESP
  - plate type ESP
- The method of charging
  - single-stage ESP
  - two-stage ESP
- The temperature of operation
  - cold-side ESP
  - hot-side ESP
- The method of particle removal from collection surfaces
  - wet ESP
  - Dry ESP

Ash Handling Plant

In Thermal Power Plant's coal is generally used as fuel and hence the ash is produced as the byproduct of Combustion. Ash generated in power plant is about 30-40% of total coal consumption and hence the system is required to handle Ash for its proper utilization or disposal. The steam power plant produces 5000 of tons ash daily (2000MW)

The ash may be

- ❖ Fly Ash (Around 80% is the value of fly ash generated)
- ❖ Bottom ash (Bottom ash is 20% of the ash generated in coal based power stations.

Fly Ash

Ash generated in the ESP which got carried out with the flue gas is generally called Fly ash. It also consists of Air pre heater ash & Economizer ash (it is about 2 % of the total ash content).

Bottom ash

Ash generated below furnace of the steam generator is called the bottom ash.

The operation of ash handling plants is…….

- ❖ Removal of ash from the furnace ash hoppers
- ❖ Transfer of the ash to a fill or storage
- ❖ and disposal of stored ash

The ash may be disposed in the following way…….

- ❑ Waste land site may be reserved for the disposal of ash.
- ❑ Building contractor may utilize it to fill the lowlying area.
- ❑ Deep ponds may be made and ash can be dumped into these ponds to fill them completely
- ❑ When sea born coal is used, barrage may take the ash to sea for disposal into water grave.

The modern ash handling system usually used in large steam power plants are …….

- Belt conveyor system
- Pneumatic system
- Hydraulic system
- Steam jet system

Belt conveyor system

- In this system the ash is made to flow through a water seal over the belt conveyor in order to cool it down and then carried out to a dumping site over the belt.
- It can deliver 3 tonnes of ash per hour with a speed of 0.3m/minute.

❑ The life of belt is 5 years. it is used in small power plant

Pneumatic system

❑ In this system air is employed as a medium to driving the ash through a pipe over along distance.

❑ This system can handle 5-30 tonnes of ash per hour

❑ This is used for disposal of fly ash

Hydraulic system

❑ In this system a stream of water carries ash along with it in a closed channel and disposed it off to the proper site.

❑ It is of two types high pressure system and low pressure system.

Steam jet system

❑ This system employs jets of high pressure blowing in the direction of ash travel through a conveying pipe in which ash from the boiler ash hopper is fed.

❑ It is employed in small and medium size plant

❑ Steam consumption is 110 kg per tonne of material conveyed.

NUCLEAR POWER STATION

Basics

- Atoms consist of nucleus and electrons.
- The nucleus is composed of protons and neutrons.
- Protons are positively charged whereas neutrons are electrically neutral.
- Atoms with nuclei having same number of protons but difference in their masses are called isotopes. They are identical in terms of their chemical properties but differ with respect to nuclear properties.
- Natural Uranium consists of ${}_{92}U^{238}$ (99.282%), ${}_{92}U^{235}$ (0.712%) and ${}_{92}U^{234}$
- $92U^{235}$ is used as fuel in nuclear power plants.

Energy from Nuclear Reactions

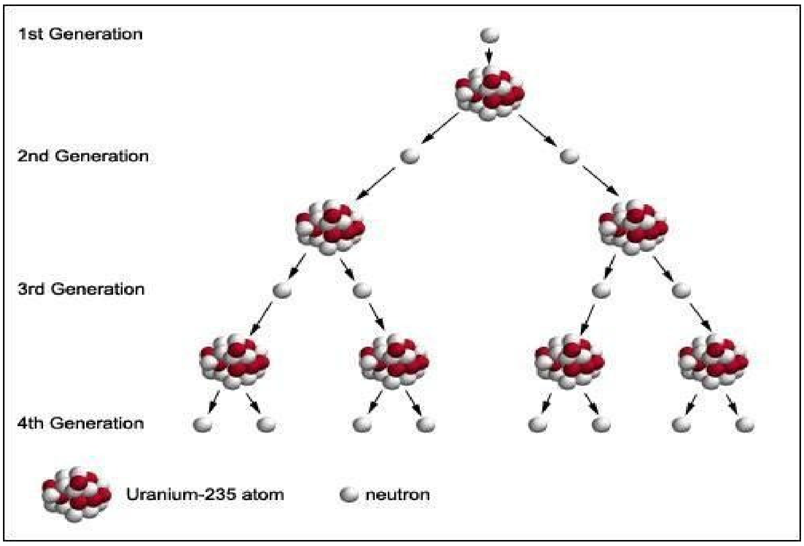
- The sum of masses of protons and neutrons exceeds the mass of the atomic nucleus and this difference is called mass defect Δm.

- In a nuclear reaction the mass defect is converted into energy known as binding energy according to Einstein's equation ($E=\Delta m\, c^2$).
- Fissioning one amu of mass results in release of 931 MeV of energy.
- It has been found that element having higher and lower mass numbers are unstable. Thus the lower mass numbers can be fused or the higher mass numbers can be fissioned to produce more stable elements.
- This results in two types of nuclear reactions known as fusion and fission.
- The total energy per fission reaction of U^{235} is about 200 MeV.
- Fuel burn-up rate is the amount of energy in MW/days produced by each metric ton of fuel.

Nuclear Fission

Nuclear fission is the reaction by which a heavy nucleus (that is one with a high value of Z) is hit with a small particle, as a result of which it splits into two (occasionally more) smaller nuclei.

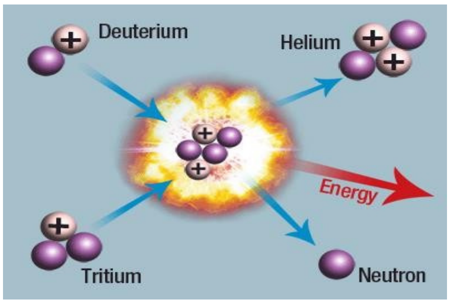
Before the reaction		After the reaction	
${}^{1}_{0}n$	1.008665	${}^{140}_{54}Xe$	139.9216
${}^{235}_{92}U$	235.0439	${}^{94}_{38}Sr$	93.9154
		$2\,{}^{1}_{0}n$	2.0173
Total mass	236.0526	Total mass	235.8543



Nuclear Fusion

Fusion is the opposite of fission, it is the joining together of two light nuclei to form a heavier one (plus a small fragment). For example if two 2H nuclei (two deuterons) can be made to come together they can form He and a neutron.

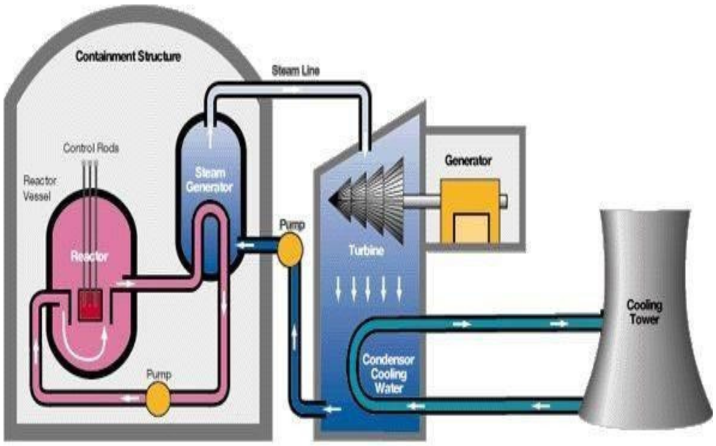
$$^{2}H + {}^{2}H \rightarrow {}^{3}He + n$$



Nuclear Fusion

Nuclear Power Plant

- A nuclear power plant is a thermal power station in which the heat source is one or more nuclear reactors. As in a conventional thermal power station the heat is used to generate steam which drives a steam turbine connected to a generator which produces electricity.



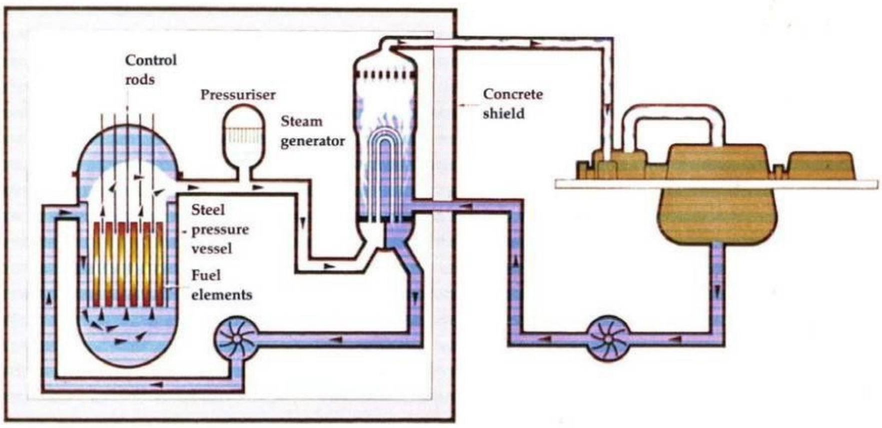
Schematic of a Nuclear Power Plant

Pressurized Water Reactor (PWR)

❑ The most widely used reactor type in the world is the Pressurized Water Reactor (PWR) which uses enriched (about 3.2% U235) uranium dioxide as a fuel in zirconium alloy cans.

❑ The fuel, which is arranged in arrays of fuel "pins" and interspersed with the movable control rods, is held in a steel vessel through which water at high pressure (to suppress boiling) is pumped to act as both a coolant and a moderator.

❑ The high-pressure water is then passed through a steam generator, which raises steam in the usual way.

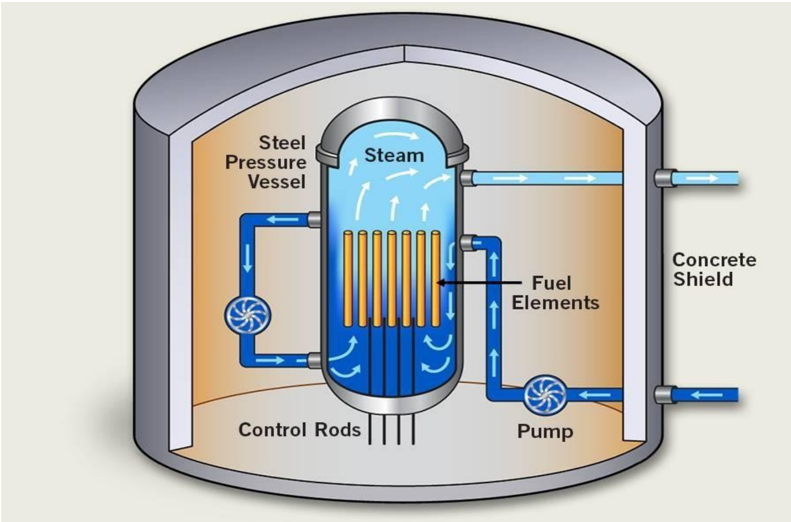


Pressurized Water Reactor

Boiling Water Reactors (BWR)

❑ The second type of water cooled and moderated reactor does away with the steam generator and, by allowing the water within the reactor circuit to boil, it raises steam directly for electrical power generation. Such reactors, known as Boiling Water Reactors (BWRs), throughout the world.

Boiling Water Reactor



❑ This, however, leads to some radioactive contamination of the steam circuit and turbine, which then requires shielding of these components in addition to that surrounding the reactor.

Fast Breeder Reactors

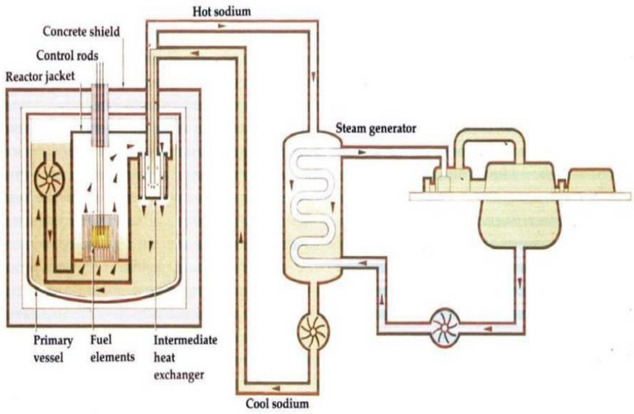
❑ All of today's commercially successful reactor systems are "thermal" reactors, using slow or thermal neutrons to maintain the fission chain reaction in the U^{235} fuel. Even with the enrichment levels used in the fuel for such reactors, however, by far the largest numbers of atoms present are U^{238}, which are not fissile.

❑ Consequently, when these atoms absorb an extra neutron, their nuclei do not split but are converted into another element, Plutonium.

Plutonium is fissile and some of it is consumed in situ, while some remains in the spent fuel together with unused U^{235}. These fissile components can be separated from the fission product wastes and recycled to reduce the consumption of uranium in thermal reactors by up to 40%, although clearly thermal reactors still require a substantial net feed of natural uranium.

It is possible, however, to design a reactor which overall produces more fissile material in the form of Plutonium than it consumes. This is the fast reactor in which the neutrons are unmoderated, hence the term "fast".

- The physics of this type of reactor dictates a core with a high fissile concentration, typically around 20%, and made of Plutonium. In order to make it breed, the active core is surrounded by material (largely U238) left over from the thermal reactor enrichment process. This material is referred to as fertile, because it converts to fissile material when irradiated during operation of the reactor.
- The successful development of fast reactors has considerable appeal in principle. This is because they have the potential to increase the energy available from a given quantity of uranium by a factor of fifty or more, and can utilize the existing stocks of depleted uranium, which would otherwise have no value.



Fast Breeder Reactors

Factors for Site Selection of NPPs

1. Availability of Water: working fluid
2. Distance from Populated Area: danger of radioactivity
3. Nearness to the load centre: reduction in transmission cost
4. Disposal of Waste: radioactive waste

5. Accessibility by Rail and Road: transport of heavy equipment

Advantages of NPPs

1. Reduces demand for fossil fuels
2. Quantity of nuclear fuel is much less: thus reducing transport and resulting costs
3. Area of land required is less: compared to a conventional plant of similar capacity
4. Production of fissile material
5. Location independent of geographical factors: except water requirement

Disadvantages of NPPs

1. Not available for variable loads (load factor-0.8): as the reactors cannot be controlled to respond quickly
2. Economical reason should be substantial
3. Risk of leakage of radioactive material
4. Further investigation on life cycle assessment and reliability needs to be done
5. Perception problems

Comparison of PWR and BWR

PWR	BWR
Advantages	Advantages
• Relatively compact in size • Possibility of breeding plutonium by providing a blanket of U-238 • High power density • Containment of fission products due to heat exchanger • Inexpensive 'light water' can be used as moderator, coolant and reflector • Positive power demand coefficient i.e. the reactor responds to load increase	• Elimination of heat exchanger circuit results in reduction in cost and gain in thermal efficiency (to about 30%) • Pressure inside in the reactor vessel is considerably lower resulting in lighter and less costly design • BWR cycle is more efficient than PWR as the outlet temperature of steam is much higher • Metal surface temperature is lower since boiling of water is inside the reactor • BWR is more stable than PWR and hence is commonly known as a self-controlled reactor

Disadvantages	Disadvantages
• Moderator remains under high pressure and hence a strong pressure vessel is required • Expensive cladding material is required to prevent corrosion • Heat loss occurs due to heat exchanger • Elaborate safety devices are required • Lacks flexibility i.e. the reactor needs to be shut down for recharging and there is difficulty in fuel element	• Possibility of radio-active contamination in the turbine mechanism • Wastage of steam may result in lowering of thermal efficiency on part load operation • Power density of BWR is nearly half that of PWR resulting in large size vessel • Possibility of burn-out of fuel is more as water boiling is on the surface of fuel. • BWR cannot meet a sudden increase in load

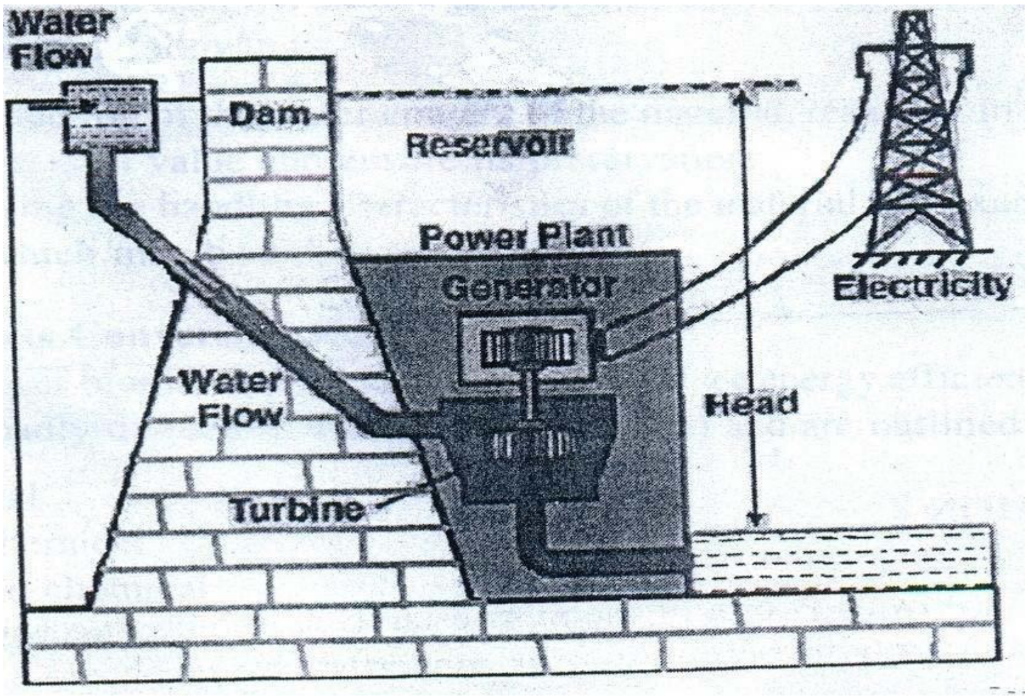
MODULE-II

HYDRO ELECTRIC POWER STSTION & TURBINES

HYDROPOWER

Hydro-energy is known as traditional renewable energy source. It is based on natural circulating water flow and its drop from higher to lower land surface that constitutes the potential. In order to convert this potential to applicable electric energy, water flow should be led to and drive a hydraulic turbine, transforming hydro energy into mechanical energy, the latter again drives a connected generator transforming the mechanical energy into electric energy. As hydro energy exploitation and its utilization are completed at the same time. I.e. the exploitation of first energy source and the conversion of secondary energy source occur simultaneously, unlike the coal power generation which should have two orders; first order is exploitation of fuel, second order is generation, so hydropower has the advantages over thermal power generation.

Mankind has used the energy of falling water for many centuries, at first in mechanical form and since the late 19th century by further conversion to electrical energy. Historically, hydropower was developed on a small scale to serve localities in the vicinity of the plants. With the expansion and increasing load transfer capability of transmission networks, power generation was concentrated in increasingly larger units and to benefit from the economies resulting from development on a larger scale.



General Layout of a dam based hydroelectric plant

Sites selected for development tended to be the most economically attractive; in this regard, higher heads and proximity to load centers were significant factors. For this reason, development was not restricted to large sites, and hydro stations today range from less than 1 MWe capacity to more than 10,000 MWe. The efficiency of hydroelectric generation is more than twice that of competing thermal power stations.

TYPES OF PROJECT

Capacity, unit size and selection of Equipment, their Characteristics and Specifications for design of hydro power station depend upon type of hydroelectric development and classification with respect to head and size. There are three main types of hydropower schemes that can be categorized in terms of how the flow at a given site is controlled or modified. These are:

Run-of-river plants (no active storage); and

Plants with significant storage
Pumped storage

In a run-of-river project, the natural flow of the river is relatively uncontrolled. In a storage project, the filling and emptying of the impounded storage along with the pattern of the natural stream flow controls the flow in the river downstream from the storage impoundment.

Run-of-river plants can be located at the downstream end of a canal fall, open flume, or pipeline diverting the stream's flow around a water supply dam or falls. The available flow governs the capacity of the plant. The plant has little or no ability to operate at flow rates higher than that available at the moment.

In a conventional plant, a dam, which stores water in a reservoir or lake impoundment, controls the river flows. Water is released according to electric, irrigation, water supply, or flood control needs. Constructing a dam and storage reservoir can increase the percentage of time that a project can produce a given level of power. Base load plants-those operated at relatively constant output-may have either a small capacity relative to the river flow or may have a significant storage reservoir. Storage reservoirs can be sized for storing water during wet years or wet seasons. Alternatively, they can be sized to provide water for weekly or daily peak generation. A storage reservoir allows using available energy that might otherwise be wasted as spill.

Plants with storage at both head and tailrace are pumped storage project.

Run of the River Schemes or Diversion Schemes

This type of development aims at utilizing the instantaneous discharge of the stream. So the discharge remains restricted to day to day natural yield from the catchments; characteristics of which will depend on the hydrological features. Diurnal storage is sometime provided for optimum benefits. Development of a river in several steps where tail race discharges from head race inflows for downstream power plants forms an interesting variation of this case and may require sometimes special control measures.

Small scale power generation also generally fall in the category and may have special control requirement especially if the power is fed into a large grid.

Storage Schemes

In such schemes annual yield from the catchment is stored in full or partially and then released according to some plan for utilization of storage. Storage may be for single purpose such as power development or may be for multi purpose use which may include irrigation, flood control, etc. therefore, design of storage works and releases from the reservoir will be governed by the intended uses of the stored water. If the scheme is only for power development, then the best use of the water will be by releasing according to the power demand. Schemes with limited storage may be designed as peaking units. If the water project forms a part of the large grid, then the storage is utilized for meeting the peak demands. Such stations could be usefully assigned with the duty of frequency regulation of the system.

Pump Storage Scheme

Principle

The basic principle of pumped storage is to convert the surplus electrical energy available in a system in off-peak periods, to hydraulic potential energy, in order to generate power in periods when the peak demand on the system exceeds the total available capacity of the generating stations.

By using the surplus scheme electrical energy available in the network during low-demand periods, water is pumped from a lower pond to an upper pond. In periods of peak demand, the power station is operated in the generating mode i.e. water from the upper pond is drawn through the same water conduit system to the turbine for generating power.

There are two main types of pumped storage plants:

Pumped-storage plants and

Mixed pumped-storage plants.

Pump-storage plants: In this type only pumped storage operation is envisaged without any scope for conventional generation of power. These are provided in places where the run-off is poor. Further, they are designed only for operation on a day-to-day basis without room for flexibility in operation.

Mixed pumped-storage plants: In this type, in addition to the pumped storage operation, some amount of extra energy can be generated by utilizing the additional natural run-off during a year. These can be designed for operation on a weekly cycle or other form of a longer period by providing for additional storage and afford some amount of flexibility in operation.

CLASSIFICATION OF HYDROPOWER PLANTS

As such there are no hard and fast rules to classify Hydro power plants. Some of the basis is as follows:

Based on Hydraulic Characteristics

Based on Head

Based on Capacity

Based on Turbine Characteristics

Based on Load Characteristics

Based on Interconnection

Hydropower Project based on Hydraulic Characteristics:

Run off river plant (Diversion plant)

Storage plant (Impoundment plant)
Pumped storage plant
Tidal plant

Run off River Plant (Diversion Plant)

In some areas of the world, the flow rate and elevation drops of the water are consistent enough that hydro electric plants can be built directly in the river.

The water is utilized as it comes in the river.

Practically, water is not stored during flood periods as well as during low electricity demand periods, hence water is wasted.

Run off river plant may be without pondage or with pondage.

The plants with pondage are provided with a barrage to store the water, to take care of daily variation.

During good flow conditions – can supply base load and during low flow conditions - can supply peak load

Seasonal changes in river flow and weather conditions affect the plant's output; hence it is in limited use unless interconnected with grid.

flows that occur in the stream at the intake and flows downstream of the powerhouse are virtually identical to pre-development flows.

Run-of-river facilities use low dams to provide limited storage of water– at most daily pondage.

In a run-off river SHP scheme, through diversion structure water is diverted to water conductor system to the powerhouse.

Water impounded in dam for storage and released in phased manner to generate power and further used for irrigation is shown in (figure 1.5.1).

Site Selection for Hydropower Plants

- **Availability of Water:** Run-off data for many years available
- **Water Storage:** for water availability throughout the year
- **Head of Water:** most economic head, possibility of constructing a dam to get required head
- **Geological Investigations:** strong foundation, earthquake frequency is less
- **Water Pollution:** excessive corrosion and damage to metallic structures
- **Sedimentation:** capacity reduces due to gradual deposition of silt
- **Social and Environmental Effects:** submergence of areas, effect on biodiversity (e.g. western ghat), cultural and historic aspects
- **Access to Site:** for transportation of construction material and heavy machinery new railway lines or roads may be needed
- **Multipurpose:** power generation, irrigation, flood control, navigation, recreation; because initial cost of power plant is high because of civil engineering construction work

Classification of Hydropower Plants

According to water flow regulation:

1. Runoff river plants without pondage
2. Runoff river plants with pondage
3. Hydroelectric plants with storage reservoir

According to Load:

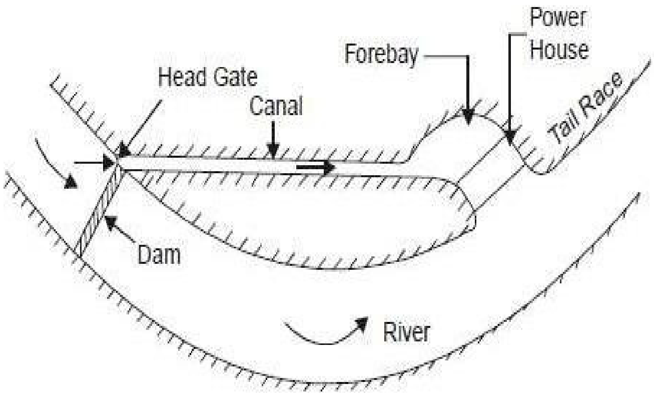
1. Base load plants
2. Peak load plants
3. Pumped storage plants

According to head:

1. High head plants (>100m)
2. Medium head plants (30-100 m)
3. Low head plants (<30 m)

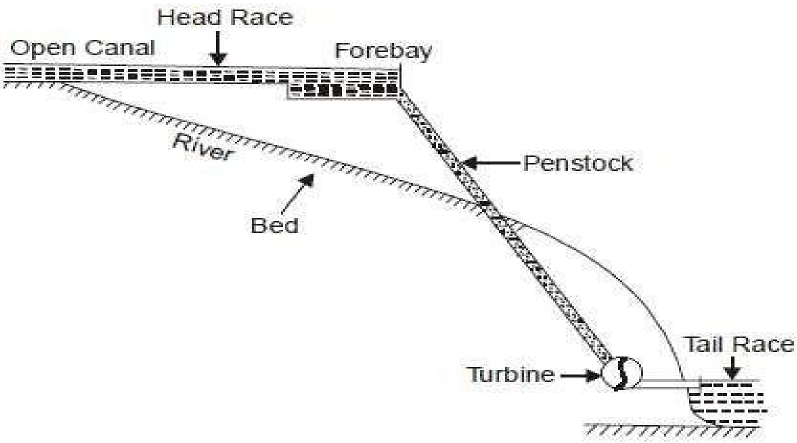
Low head plant

- Operating head is less than 15m.
- Vertical shaft Francis turbine or Kaplan turbine.
- Small dam is required.



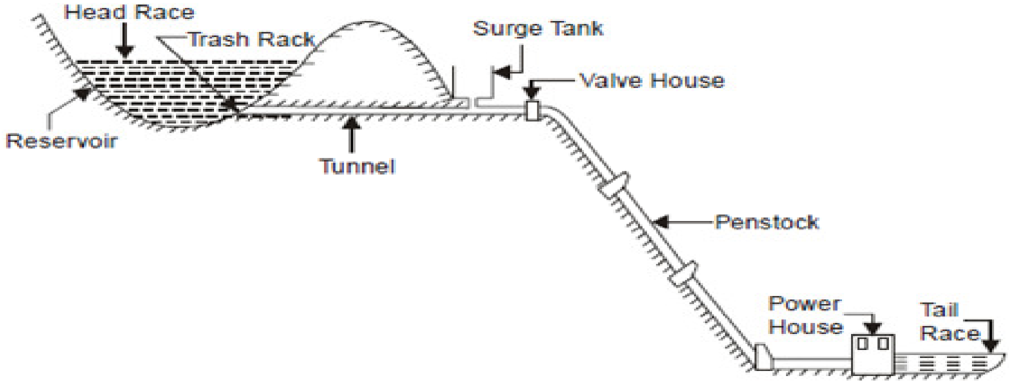
Medium head plant

- Operating head is less than 15 to 50m.
- Francis turbines.
- Forebay is provided at the beginning of the penstock.



High head plant

- Operating head exceed 50m.
- Pelton turbines.
- Surge tank is attached to the penstock to reduce water hammer effect onthe penstock.



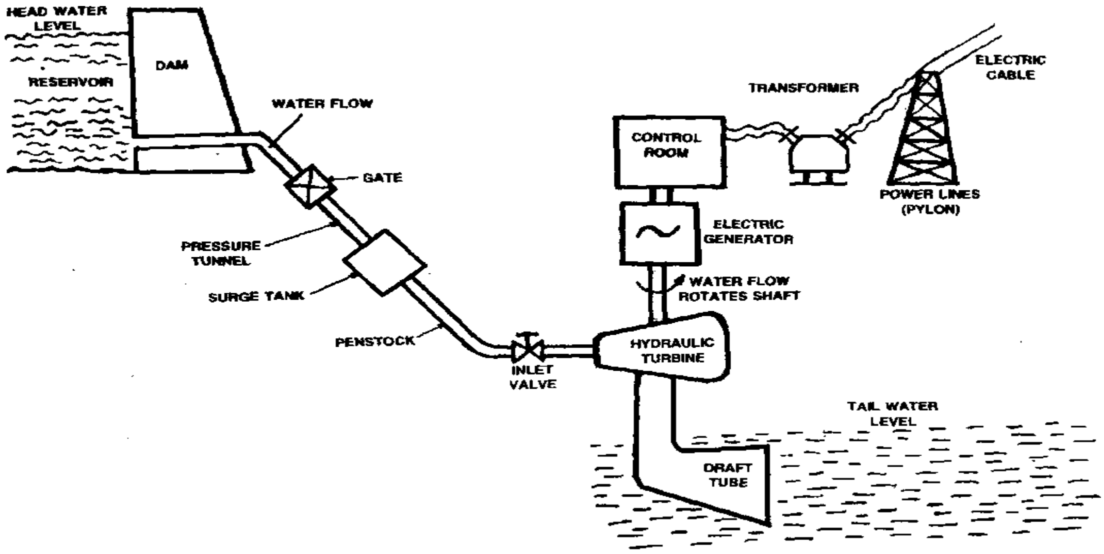


FIG. 3.6: LAYOUT OF HYDRO-ELECTRIC POWER PLANT

Components of a HPP

Schematic of a Hydropower Plant

The various components of HPP are as follows:

1. Catchment area
2. Reservoir
3. Dam
4. Spillways
5. Conduits
6. Surge tanks

7. Draft tubes
8. Power house
9. Switchyard for power evacuation

Dam

- Develops a reservoir to store water
- Builds up head for power generation

Spillway

- To safeguard the dam when water level in the reservoir rises

Intake

- Contains trash racks to filter out debris which may damage the turbine

Forebay

- Enlarged body of water just above the intake

Forebay Conduits

- Headrace is a channel which lead the water to the turbine
- Tailrace is a channel which carries water from the turbine
- A canal is an open waterway excavated in natural ground following its contour.
- A flume is an open channel erected on a surface above ground.
- A tunnel is a closed channel excavated through an obstruction.
- A pipeline is a closed conduit supported on the ground.
- **Penstocks** are closed conduits for supplying water "under pressure" from head pond to the turbines.

Surge Tank

- A surge tank is a small reservoir in which the water level rises or falls to reduce the pressure swings so that they are not transmitted to the penstock.
- Water Hammer
  - Load on the turbine is suddenly reduced
  - Governor closes turbine gates
  - Sudden increase of pressure in the penstock
- Negative Pressure
  - Load on the generator is suddenly increased
  - Governor opens the turbine gates
  - Tends to cause a vacuum in the penstock
- When the gates are closed, water level rises in the surge tank and when the gates are suddenly opened, surge tank provides the initial water supply.

Surge Tank Draft Tubes

The function of the draft tube is to

- To reduce the velocity head losses of the water
- To allow the turbine to be set above the tailrace to facilitate inspection and maintenance

Tailrace:

- A tailrace is required to discharge the water leaving the turbine into the river.
- The design of the tail race should be such that water has a free exit.

Power House

1. Hydraulic turbines
2. Electric generators
3. Governors
4. Gate valves
5. Relief valves
6. Water circulation pumps
7. Air ducts
8. Switch board and instruments
9. Storage batteries
10. Cranes

Switchyard

1. Step up transformers
2. Instrument transformers
3. Transmission lines

Advantages of hydro power plant:

- Water is a renewable energy source.
- Maintenance and operation charges are very low.
- The efficiency of the plant does not change with age.
- In addition to power generation, hydro-electric power plants are also useful for flood control, irrigation purposes, fishery and recreation.
- Have a longer life (100 to 125 years) as they operate at atmospheric temperature.
- Water stored in the hydro-electric power plants can also be used for domestic water supply.
- Since hydro-electric power plants run at low speeds (300 to 400 rpm) there is no requirement of special alloy steel construction materials or specialised mechanical maintenance.

Disadvantages of hydro power plant:

- The initial cost of the plant is very high.
- Since they are located far away from the load centre, cost of transmission lines and transmission losses will be more.
- During drought season the power production may be reduced or even stopped due to insufficient water in the reservoir.
- Water in the reservoir is lost by evaporation.

PUMP STORAGE SCHEME

Principle

The basic principle of pumped storage is to convert the surplus electrical energy available in a system in off-peak periods, to hydraulic potential energy, in order to generate power in periods when the peak demand on the system exceeds the total available capacity of the generating stations.

By using the surplus scheme electrical energy available in the network during low-demand periods, water is pumped from a lower pond to an upper pond. In periods of peak demand, the power station is operated in the generating mode i.e. water from the upper pond is drawn through the same water conduit system to the turbine for generating power.

There are two main types of pumped storage plants:

Pumped-storage plants and

Mixed pumped-storage plants.

Pump-storage plants: In this type only pumped storage operation is envisaged without any scope for conventional generation of power. These are provided in places where the run-off is poor. Further, they are designed only for operation on a day-to-day basis without room for flexibility in operation.

Mixed pumped-storage plants: In this type, in addition to the pumped storage operation, some amount of extra energy can be generated by utilizing the additional natural run-off during a year. These can be designed for operation on a weekly cycle or other form of a longer period by providing for additional storage and afford some amount of flexibility in operation.

Pumped Storage Plant

Water is utilized for generation of power during peak demand, while same water is pumped back in the reservoir during off peak demand period, when excess power is available for this purpose.

If turbine is reversible, it can be used as a pump to supply water back to reservoir, otherwise separate pump can be used.

Based on operating cycle it can be classified as:

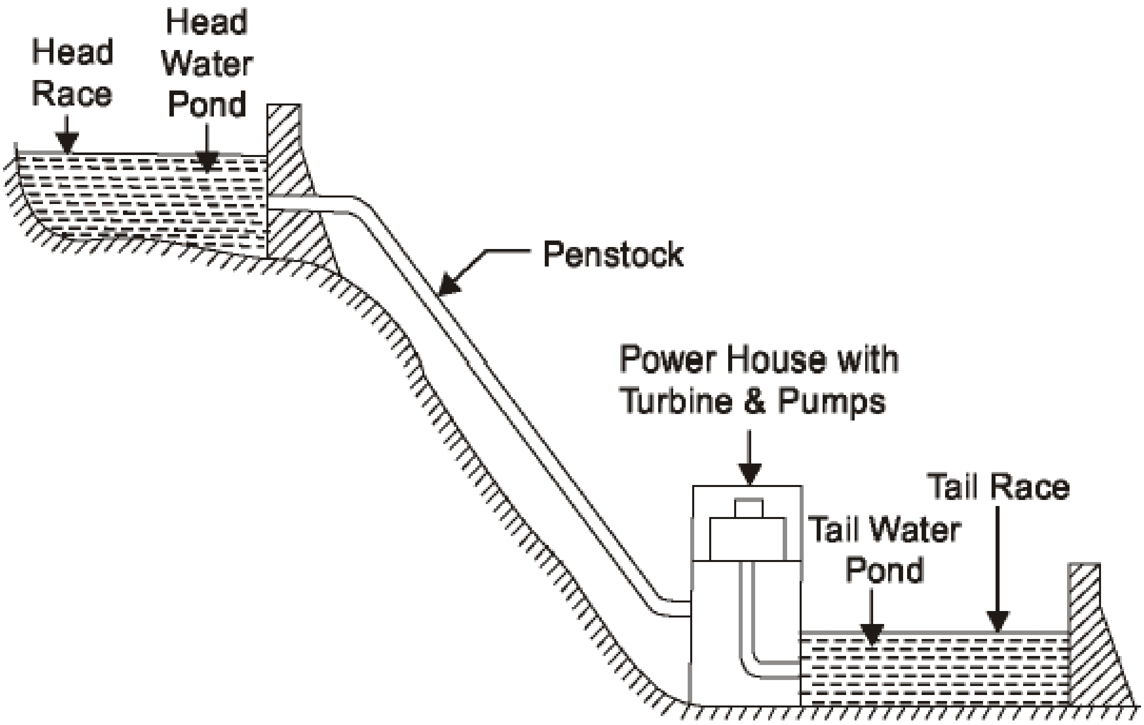
Plant with a daily cycle: water is pumped up from mid night to early morning as well as near lunch time.

Plant with a weekly cycle: water is pumped up during weekend.

Plant with a seasonal cycle: water is pumped up in the winter continuously for several days to be utilized for a continuous power generation in the high demand summer period.

PUMPED STORAGE POWER PLANTS

These plants supply the peak load for the base load power plants and pump all or a portion of their own water supply. The usual construction would be a tail water pond and a head water pond connected through a penstock. The generating pumping plant is at the lower end. During off peak hours, some of the surplus electric energy being generated by the base load plant is utilized to pump the water from tail water pond into the head water pond and this energy will be stored there. During times of peak load, this energy will be released by allowing the water to flow from the head water pond through the water turbine of the pumped storage plant. These plants can be used with hydro, steam and i.e. engine plants. This plant is nothing but a hydraulic accumulator system and is shown. These plants can have either vertical shaft arrangement or horizontal shaft arrangement. In the older plants, there were separate motor driven pumps and turbine driven generators. The improvement was the pump and turbine on the same shaft with the electrical element acting as either generator or motor. The latest design is to use a Francis turbine which is just the reverse of centrifugal pump. When the water flows through it from the head water pond it will act as a turbine and rotate the generator. When rotated in the reverse direction by means of an electric motor, it will act as a pump to shunt the water from the tail water pond to the head water pond



Pumped Storage Plant

Power Estimation

The potential electric power of the water in terms of flow and head can be calculated from the following equation.

$$KW = 9.81 \times Q \times H \times \eta$$

Where,

kW = electric power in kW

Q = quantity of water flowing through the hydraulic turbine in cubic meters per second. Discharge (quantity of water) flowing in a stream and available for power generation has daily and seasonal variation. Optimum discharge for power generation is determined on the basis of energy generation cost.

H = Net available head in meters (gross head – losses)

= overall efficiency of the hydro power plant. For general estimation purposes, η is normally taken as 0.85

Hydrology

- First requirement – Q (discharge)
- Hydrology deals with occurrence and distribution of water over and under earth's surface.
  - Surface Water Hydrology
  - Ground Water Hydrology
- **Watershed, catchment area or drainage area:** length of the river, size and shape of the area it affects, tributaries, lakes, reservoirs etc.
- Investigation of **run-off** for past few years is required for power potential studies of a HPP.

Objectives of Hydrology

- To obtain data regarding the stream flow of water that would be available,
- To predict the yearly possible flow
- To calculate the mean annual rainfall in the area under consideration from a record of the annual rainfall for a number of years, say 25 to 30
- To note the frequency of dry years
- To find maximum rainfall and flood frequency

Various terms related to Hydrology

- Rainfall is also known as precipitation and can be measured by rain gauges.
- Some part of precipitation is lost due to evaporation, interception and transpiration.
- **Transpiration:** Plants absorbing moisture and giving it off to the atmosphere
- Stream flow = precipitation – losses
- Stream flow = surface flow + percolation to ground
- Surface flow is also known as **run-off.**
- **Hydrograph:**
  - Shows the variation of stream flow in m^3/s with time for a particular river site. The time may be hour, week, month or a year.
  - The area under hydrograph gives the total volume of flow

- **Flow duration curve:**
  - Shows the percentage of time during the period when the flow was equal to greater than the given flow.
  - The area under FDC gives the total quantity of run-off during a period

- **Mass curve**
  - Indicates the total volume of run-off in cubic meters up to a certain time.
  - the slope of the curve at any point shows the rate of flow at that time
  - Used for estimating the capacity of storage reservoir
- **Storage:**
  - to ensure water availability during deficient flow and thus increasing the firm capacity

- Storage also results in more energy production

- **Pondage:**
  - Storing water in small ponds near the power plant as the storage reservoir is away from plant
  - To meet the power demand fluctuations over a short period of time e.g. 24 hours

- **Primary Power:** power that will be available 90 % of the time
- **Secondary Power:** power that will be available 75 % of the time
- **Dump Power:** power that will be available 50 % of the time.
- **Maximum flow estimation:** gives estimation of floods and helps in design of dam and spillway.

HYDROGRAPH & FLOW DURATION CURVE:-

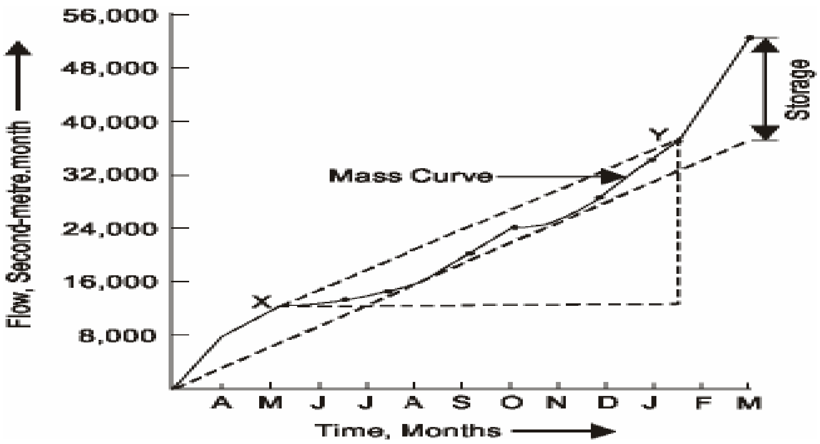
- A hydrograph indicates the variation of discharge or flow with time. It is plotted with flows as ordinates and time intervals as abscissas. The flow is in m^3/sec and the time may be in hours, days, weeks or months.

- A flow duration curve shows the relation between flows and lengths of time during which they are available. The flows are plotted as the ordinates and lengths of time as abscissas. The flow duration curve can be plotted from a hydrograph.

THE MASS CURVE:-

The use of the mass curve is to compute the capacity of the reservoir for a hydro site. The mass curve indicates the total volume of run-off in second meter-months or other convenient units, during a given period. The mass curve is obtained by plotting cumulative volume of flow as ordinate and time (days, weeks by months) as abscissa. Fig. 11.2 shows a mass curve for a typical river for which flow data is given in Table 11.2. The monthly flow is only the mean flow and is correct only at the beginning and end of the months. The variation of flow during each month is not considered. Cumulative daily flows, instead of monthly flows, will give a more accurate mass curve, but this involves an excessive amount of work. The slope of the curve at any point gives the flow rate in second- meter. Let us join two points X and Y on the curve. The slope of this line gives the average rate of flow during the period between X and Y. This will be = (Flow at Y-Flow at X)/Time Span Let the flow demand be, 3000 sec-meter. Then the line X-Y may be called as `demand line' or „Use line". If during a particular period, the slope of the mass Curve is greater than that of the demand line, it means more water is flowing into the reservoir than is being utilized, so the level of water in the reservoir will be increasing during that period and vice versa. Upto point X and beyond point Y the reservoir will be overflowing. Being full at both X and Y.

The capacity of the reservoir is given by the maximum ordinate between the mass curve and the demand line. For the portion of mass curve between point X and Y, the storage capacity is about 4600 sec-meter-month. However, considering the entire mass curve, storage capacity will be about 15,400 sec-meter-months.



MODULE –III

AIR & GAS INSULATED SUBSTATIONS

Sub-Station

The assembly of apparatus used to change some characteristic (e.g. voltage, a.c. to d.c., frequency, p.f. etc.) of electric supply is called a **sub-station.**

Sub-stations are important part of power system. 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.

In a large power system large number of Generating stations, Electrical Power Substations and load centers are interconnected. This large internet-work is controlled from load dispatch center. Digital and voice signals are transmitted over the transmission lines via the Power substations. The substations are interlinked with the load control centers via Power Line Carrier Systems (PLCC). Modern Power System is controlled with the help of several automatic, semi - automatic equipment. Digital Computers and microprocessors are installed in the control rooms of large substations, generating stations and load control centers for data collection, data monitoring, automatic protection and control.

Functions of Electrical Power Substations are:

- Supply electric power to the consumers continuously
- Supply of electric power within specified voltage limits and frequency limits
- Shortest possible fault duration.
- Optimum efficiency of plants and the network
- Supply of electrical energy to the consumers at lowest 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.
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.

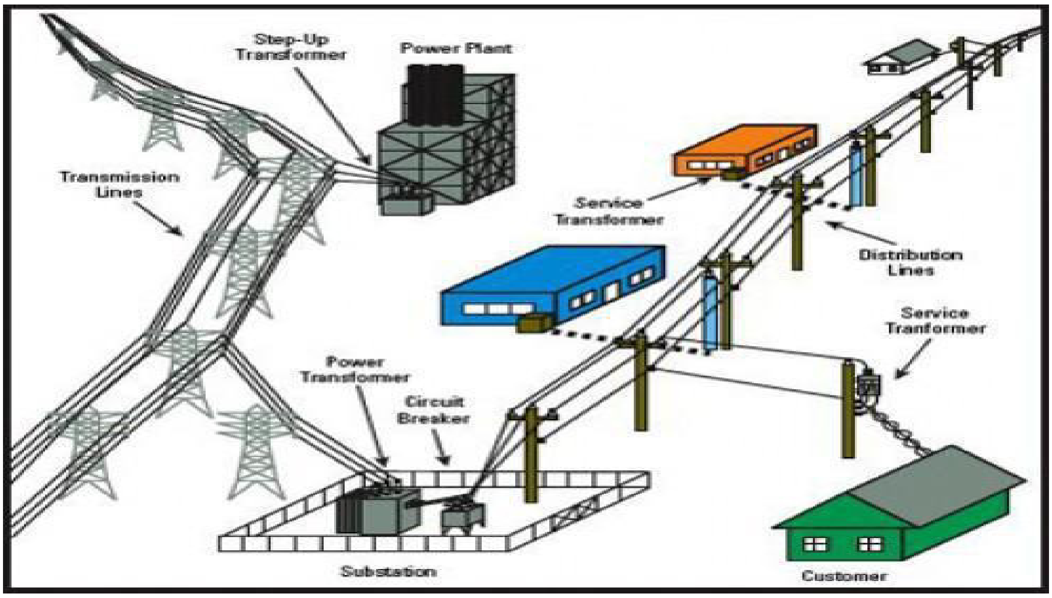
(*iv*) **Frequency changer sub-stations.** Those sub-stations which change the supply frequency are known as frequency changer sub-stations. Such a frequency change may be required for industrial utilisation.

(*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 (*e.g.* ignitron) 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.

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:

- Indoor sub-station
- Outdoor sub-station
- Underground sub-station
- 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 cities, there is scarcity of land as well as the prices of land are very high. This has led to the development of underground sub-station. In such sub-stations, the equipment is placed underground.

The design of underground sub-station requires more careful consideration than other types of sub-stations. While laying out an underground sub-station, the following points must be kept in view:

(***i***) The size of the station should be as minimum as possible.
(***ii***) There should be reasonable access for both equipment and personnel.
(***iii***) There should be provision for emergency lighting and protection against fire.
(***iv***) There should be good ventilation.
(***v***) There should be provision for remote indication of excessive rise in temperature so that H.V. supply can be disconnected.
(***vi***) The transformers, switches and fuses should be air cooled to avoid bringing oil into the premises.

(*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.

Pole-Mounted Sub-Station

It is a distribution sub-station placed overhead on a pole. It is the cheapest form of sub-station as it does not involve any building work. Fig (*i*) shows the layout of pole-mounted sub-station whereas Fig. (*ii*) shows the schematic connections. The transformer and other equipment are mounted on H-type pole (or 4-pole structure).

The 11 kV line is connected to the transformer (11kV / 400 V) through gang isolator and fuses. The lightning arresters are installed on the H.T. side to protect the sub-station from lightning strokes. The transformer steps down the volt-age to 400V, 3-phase, 4-wire supply. The voltage between any two lines is 400V whereas the voltage between any line and neutral is 230 V. The oil circuit breaker (O.C.B.) installed on the L.T. side automatically isolates the transformer from the consumers in the event of any fault.

Comparison between Outdoor and Indoor Sub-Stations

The comparison between outdoor and indoor sub-stations is given below in the tabular form:

S.No.	Particular	Outdoor Sub-station	Indoor Sub-station
1	Space required	More	Less
2	Time required for erection	Less	More
3	Future extension	Easy	Difficult
4	Fault location	Easier because the equipment is in full view	Difficult because the equipment is enclosed
5	Capital cost	Low	High
6	Operation	Difficult	Easier
7	Possibility of fault escalation	Less because greater clearances can be provided	More

From the above comparison, it is clear that each type has its own advantages and disadvantages. However, comparative economics (i.e. annual cost of operation) is the most powerful factor influencing the choice between indoor and outdoor sub-stations. The greater cost of indoor sub-station prohibits its use. But sometimes non-economic factors (e.g. public safety) exert considerable influence in choosing indoor sub-station. In general, most of the sub-stations are of outdoor type and the indoor sub-stations are erected only where outdoor construction is impracticable or prohibited by the local laws.

Transformer Sub-Stations

The majority of the sub-stations in the power system are concerned with the changing of voltage level of electric supply. These are known as transformer sub-stations because transformer is the main component employed to change the voltage level. Depending upon the purpose served, transformer sub-stations may be classified into:

(*i*) Step-up sub-station "(*ii*) Primary grid sub-station

(*iii*) Secondary sub-station *iv*) Distribution sub-station

It may be noted that it is not necessary that all electric supply schemes include all the stages shown in the figure. For example, in a certain supply scheme there may not be secondary sub-stations and in another case, the scheme may be so small that there are only distribution sub-stations.

(*i*) Step-up sub-station. The generation voltage (11 kV in this case) is stepped up to high voltage (220 kV) to affect economy in transmission of electric power. The sub-stations which accomplish this job are called step-up sub-stations. These are generally located in the power houses and are of outdoor type.

(*ii*) Primary grid sub-station. From the step-up sub-station, electric power at 220 kV is trans-mitted by 3-phase, 3-wire overhead system to the outskirts of the city. Here, electric power is re-ceived by the primary grid sub-station which reduces the voltage level to 66 kV for secondary trans-mission. The primary grid sub-station is generally of outdoor type.

(*iii*) Secondary sub-station. From the primary grid sub-station, electric power is transmitted at 66kV by 3-phase, 3-wire system to various secondary sub-stations located at the strategic points in the city. At a secondary sub-station, the voltage is further stepped down to 11 kV. The 11 kV lines run along the important road sides of the city. It may be noted that big consumers (having demand more than 50 kW) are generally supplied power at 11 kV for further handling with their own sub-stations. The secondary sub-stations are also generally of outdoor type.

(*iv*) Distribution sub-station. The electric power from 11 kV lines is delivered to distribution sub-stations. These sub-stations are located near the consumers localities and step down the voltage to 400 V, 3-phase, 4-wire for supplying to the consumers. The voltage between any two phases is 400V and between any phase and neutral it is 230 V. The single phase residential lighting load is connected between any one phase and neutral whereas 3-phase, 400V motor load is connected across 3-phase lines directly. It may be worthwhile to mention here that majority of the distribution sub-stations are of pole-mounted type.

Components of Sub-Stations:

Besides the transformers, the several other equipment include

- busbars
- circuit breakers
- isolators
- surge arresters
- Substation Earthing System
- current transformers
- voltage transformers
- Shunt reactors
- Shunt Capacitors etc.

Each equipment has certain functional requirement.

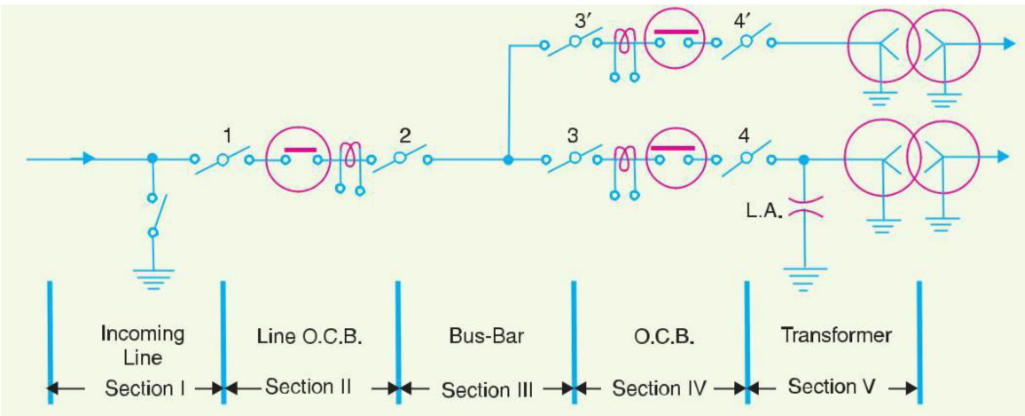
Busbars

Busbars are conducting bars to which number of circuit connections is connected. Bus-bars are copper or aluminium bars (generally of rectangular *x*-section) and operate at constant voltage. The incoming and outgoing lines in a sub-station are connected to the bus-bars. The most commonly used bus-bar arrangements in sub-stations are :

(i) Single bus-bar arrangement
(ii) Single bus-bar system with sectionalisation
(iii) Double bus-bar arrangement

Insulators. The insulators serve two purposes. They support the conductors (or bus-bars) and confine the current to the conductors. The most commonly used material for the manufacture of insulators is porcelain. There are several types of insulators (*e.g.* pin type, suspension type, post insulator etc.) and their use in the sub-station will depend upon the service requirement. For example, post insulator is used for bus-bars. A post insulator consists of a porcelain body, cast iron cap and flanged cast iron base. The hole in the cap is threaded so that bus-bars can be directly bolted to the cap.

Isolating switches. In sub-stations, it is often desired to disconnect a part of the system for general maintenance and repairs. This is accomplished by an isolating switch or isolator. An isolator is essentially a knife switch and is designed to open a circuit under *no load.* In other words, isolator switches are operated only when the lines in which they are connected carry *no current.



The entire sub-station has been divided into V sections. Each section can be disconnected with the help of isolators for repair and maintenance. For instance, if it is desired to repair section No. II, the procedure of disconnecting this section will be as follows. First of all, open the circuit breaker in this section and then open the isolators 1 and 2. This procedure will disconnect section II for repairs. After the repair has been done, close the isolators 1 and 2 first and then the circuit breaker.

Circuit breaker. A circuit breaker is an equipment which can open or close a circuit under normal as well as fault conditions. It is so designed that it can be operated manually (or by remote control) under normal conditions and automatically under fault conditions. For the latter operation, a relay circuit is used with a circuit breaker. Generally, bulk oil circuit breakers are used for voltages upto 66kV while for high (>66 kV) voltages, low oil circuit breakers are used. For still higher voltages, air-blast, vacuum or SF_6 circuit breakers are used.

Power Transformers: A power transformer is used in sub-station to step-up or step-down the voltage. Except at the power station, all the subsequent sub-stations use step-down transformers to gradually reduce the voltage of electric supply and finally deliver it at utilisation voltage. The modern practice is to use 3-phase transformers in sub-stations ; although 3 single phase bank of transformers can also be used. The use of 3-phase transformer (instead of 3 single phase bank of transformers) permits two advantages. Firstly, only one 3-phase load-tap changing mechanism can be used. Secondly, its installation is much simpler than the three single phase transformers.

The power transformer is generally installed upon lengths of rails fixed on concrete slabs having foundations 1 to 1·5 m deep. For ratings upto 10 MVA, naturally cooled, oil immersed transformers are used. For higher ratings, the transformers are generally air blast cooled.

Instrument transformers. The lines in sub-stations operate at high voltages and carry current of thousands of amperes. The measuring instruments and protective devices are designed for low voltages (generally 110 V) and currents (about 5 A). Therefore, they will not work satisfactorily if mounted directly on the power lines. This difficulty is overcome by installing *instrument trans-formers* on the power lines. The function of these instrument transformers is to transfer voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays. There are two types of instrument transformers *viz.*

(***i***) Current transformer (C.T.) (***ii***) Potential transformer (P.T.)

(*i*) Current transformer (C.T.). A current transformer in essentially a step-up transformer which steps down the current to a known ratio. The primary of this transformer consists of one or more turns of thick wire connected in series with the line. The secondary consists of a large number of turns of fine wire and provides for the measuring instruments and relays a current which is a constant fraction of the current in the line. Suppose a current transformer rated at 100/5 A is con-nected in the line to measure current. If the current in the line is 100 A, then current in the secondary will be 5A. Similarly, if current in the line is 50A, then secondary of C.T. will have a current of 2·5 A. Thus the C.T. under consideration will step down the line current by a factor of 20.

(*ii*) Voltage transformer. It is essentially a step down transformer and steps down the voltage to a known ratio. The primary of this transformer consists of a large number of turns of fine wire connected across the line. The secondary winding consists of a few turns and provides for measuring instruments and relays a voltage which is a known fraction of the line voltage. Suppose a potential transformer rated at 66kV/110V is connected to a power line. If line voltage is 66kV, then voltage across the secondary will be 110 V.

Metering and Indicating Instruments. There are several metering and indicating instruments (*e.g.* ammeters, voltmeters, energy meters etc.) installed in a sub-station to maintain watch over the circuit quantities. The instrument transformers are invariably used with them for satisfactory operation.

Miscellaneous equipment. In addition to above, there may be following equipment in a sub-station :

- Fuses
- carrier-current equipment
- sub-station auxiliary supplies

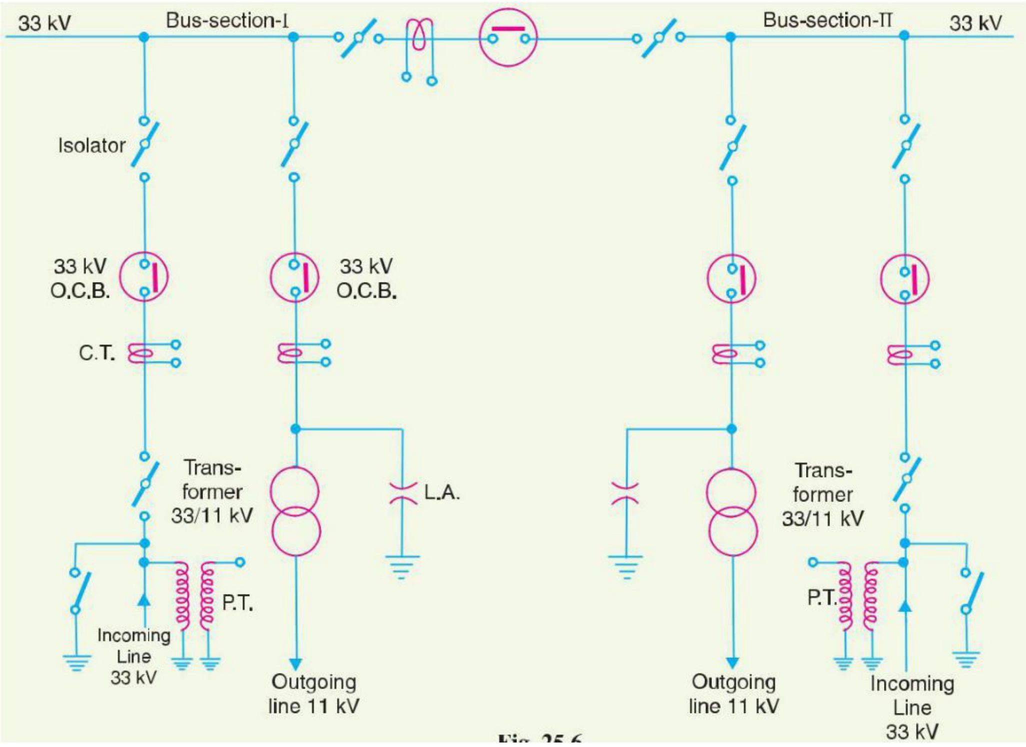
Bus-Bar Arrangements in Sub-Stations

Bus-bars are the important components in a sub-station. There are several bus-bar arrangements that can be used in a sub-station. The choice of a particular arrangement depends upon various factors such as system voltage, position of sub-station, degree of reliability, cost etc. The following are the important bus-bar arrangements used in sub-stations :

(*i*) **Single bus-bar system.** As the name suggests, it consists of a single bus-bar and all the incoming and outgoing lines are connected to it. The chief advantages of this type of arrangement are low initial cost, less maintenance and simple operation. However, the principal disadvantage of single bus-bar system is that if repair is to be done on the bus-bar or a fault occurs on the bus, there is a complete interruption of the supply. This arrangement is not used for voltages exceeding 33kV.

The indoor 11kV sub-stations often use single bus-bar arrangement.

There are two 11 kV incoming lines connected to the bus-bar through circuit breakers and isolators. The two 400V outgoing lines are connected to the bus bars through transformers (11kV/400 V) and circuit breakers.



(*ii*) **Single bus-bar system with sectionalisation.** In this arrangement, the single bus-bar is divided into sections and load is equally distributed on all the sections. Any two sections of the bus-bar are connected by a circuit breaker and isolators. Two principal advantages are claimed for this arrangement. Firstly, if a fault occurs on any section of the bus, that section can be isolated without affecting the supply from other sections. Secondly, repairs and maintenance of any section of the bus-bar can be carried out by de-energising that section only, eliminating the possibility of complete shut down. This arrangement is used for voltages upto 33 kV.

Fig. 25.6 shows bus-bar with sectionalisation where the bus has been divided into two sections. There are two 33 kV incoming lines connected to sections I and II as shown through circuit breaker and isolators. Each 11 kV outgoing line is connected to one section through transformer (33/11 kV) and circuit breaker. It is easy to see that each bus-section behaves as a separate bus-bar.

(iii) Duplicate bus-bar system. This system consists of two bus-bars, a "main" bus-bar and a "spare" bus-bar. Each bus-bar has the capacity to take up the entire sub-station load. The incoming and outgoing lines can be connected to either bus-bar with the help of a bus-bar coupler which con-sists of a circuit breaker and isolators. Ordinarily, the incoming and outgoing lines remain connected to the main bus-bar. However, in case of repair of main bus-bar or fault occuring on it, the continuity of supply to the circuit can be maintained by transferring it to the spare bus-bar. For voltages exceed-ing 33kV, duplicate bus-bar system is frequently used.

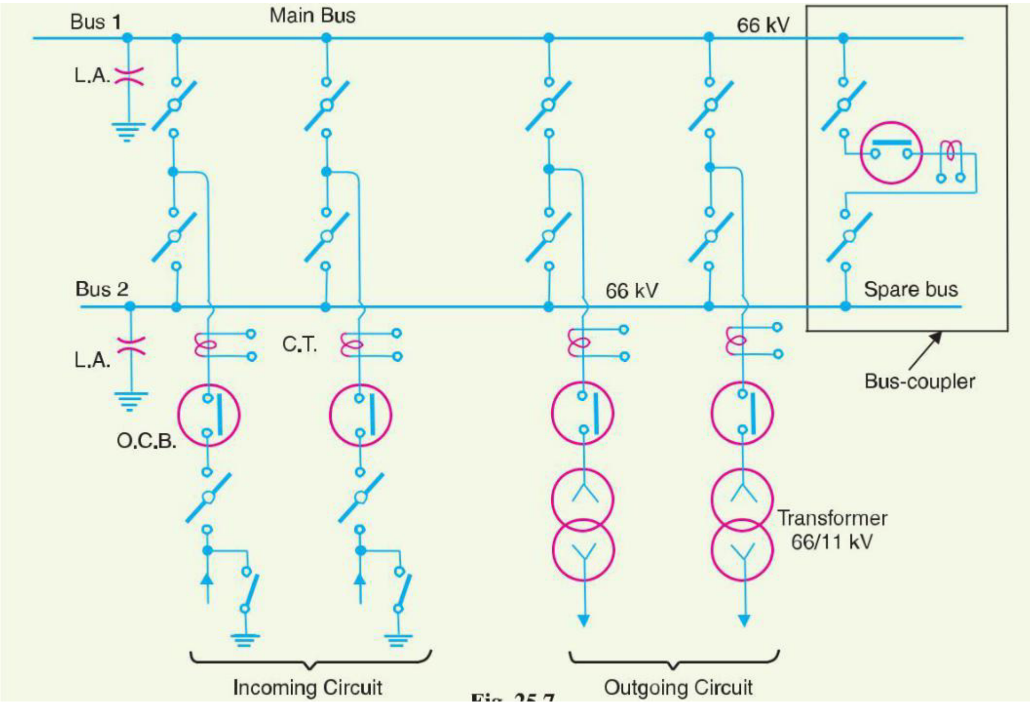


Fig. 25.7

Fig. 7 shows the arrangement of duplicate bus-bar system in a typical sub-station. The two 66kV incoming lines can be connected to either bus-bar by a bus-bar coupler. The two 11 kV outgoing lines are connected to the bus-bars through transformers (66/11 kV) and circuit breakers.

Terminal and Through Sub-Stations

All the transformer sub-stations in the line of power system handle incoming and outgoing lines. Depending upon the manner of incoming lines, the sub-stations are classified as:

(*i*) Terminal sub-station **(*ii*)** Through sub-station

(*i*) Terminal sub-station. A terminal sub-station is one in which the line supplying to the substation terminates or ends. It may be located at the end of the main line or it may be situated at a point away from main line route. In the latter case, a tapping is taken from the main line to supply to the sub-station. Fig. 25.8 shows the schematic connections of a terminal sub-station. It is clear that incoming 11 kV main line terminates at the sub-station. Most of the distribution sub-stations are of this type.

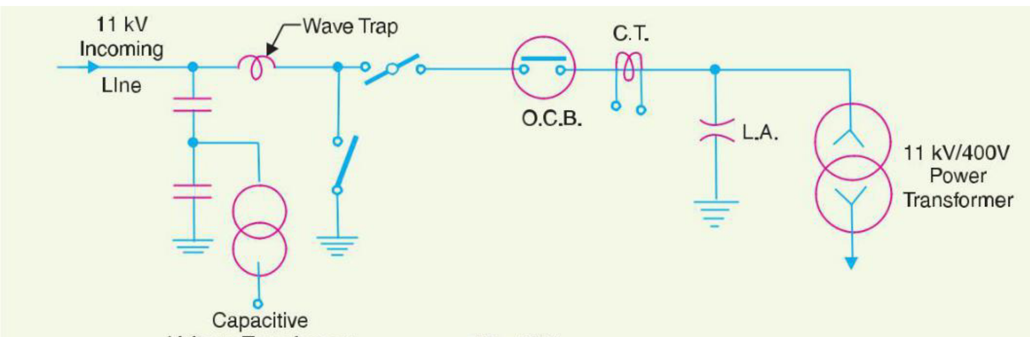


Fig. 25.8

(*ii*) **Through sub-station.** A through sub-station is one in which the incoming line passes 'through' at the same voltage. A tapping is generally taken from the line to feed to the transformer to reduce the voltage to the desired level. Fig. 25.9 shows the schematic connections of a through sub-station. The incoming 66 kV line passes through the sub-station as 66kV outgoing line. At the same time, the incoming line is tapped in the sub-station to reduce the voltage to 11 kV for secondary distribution.

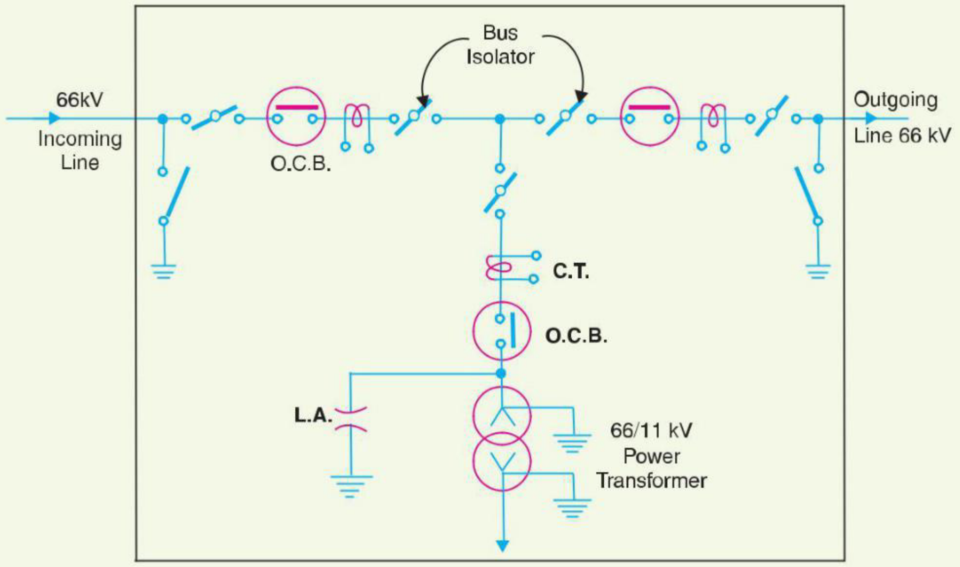


Fig. 25.9

Key Diagram of 66/11 kV Sub-Station

Fig. 25.10 shows the key diagram of a typical 66/11 kV sub-station. The key diagram of this sub-station can be explained as under:

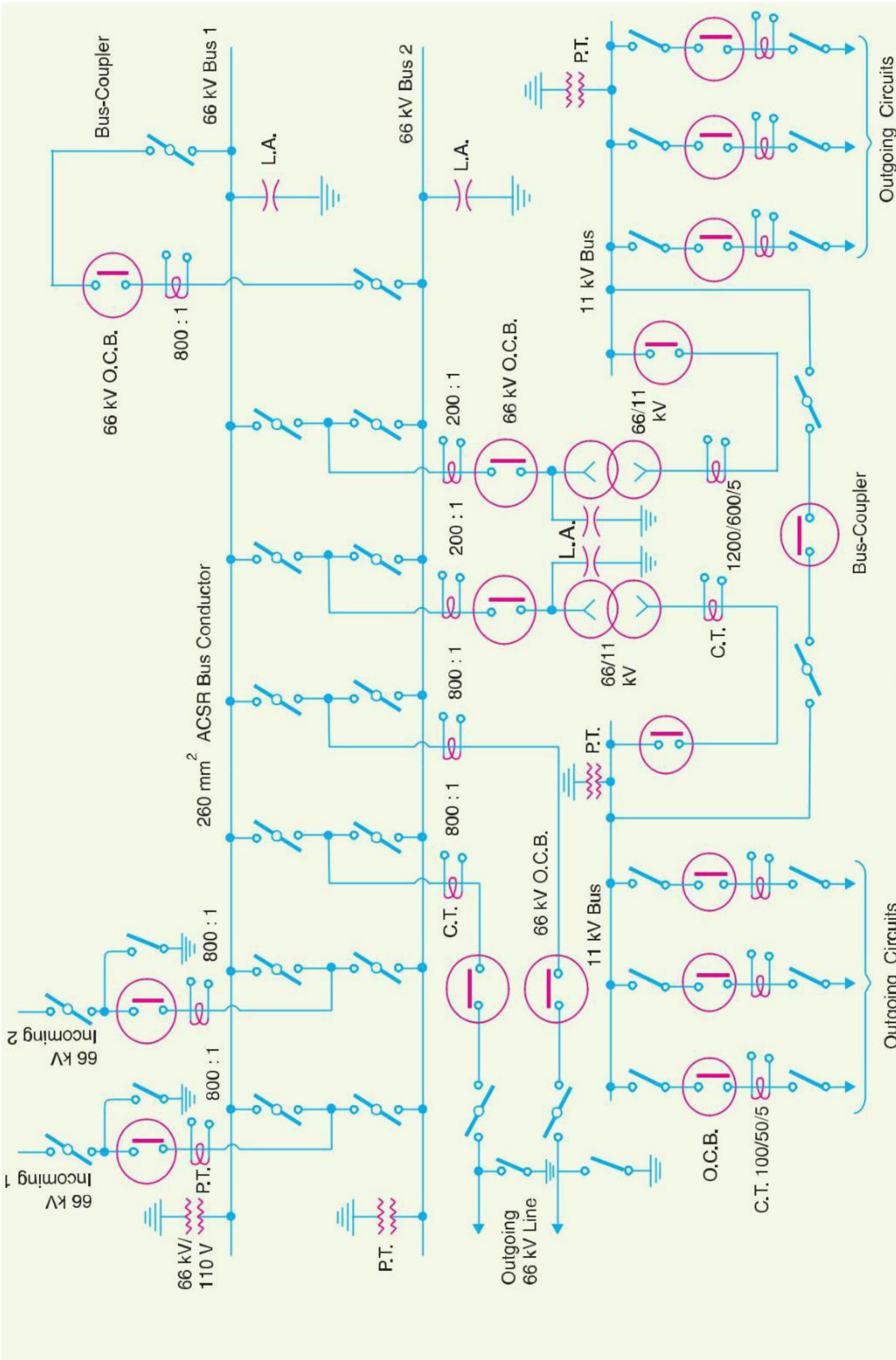


Fig. 25.10

(*i*) There are two 66 kV incoming lines marked ‘incoming 1’ and ‘incoming 2’ connected to the bus-bars. Such an arrangement of two incoming lines is called a double circuit. Each incoming line is capable of supplying the rated sub-station load. Both these lines can be loaded simultaneously to share the sub-station load or any one line can be called upon to meet the entire load. The double circuit arrangement increases the reliability of the system. In case there is a breakdown of one incoming line, the continuity of supply can be maintained by the other line.

(*ii*) The sub-station has duplicate bus-bar system; one ‘main bus-bar’ and the other spare bus-bar. The incoming lines can be connected to either bus-bar with the help of a bus-coupler which consists of a circuit breaker and isolators. The advantage of double bus-bar system is that if repair is to be carried on one bus-bar, the supply need not be interrupted as the entire load can be transferred to the other bus.

(*iii*) There is an arrangement in the sub-station by which the same 66 kV double circuit supply is going out *i.e.* 66 kV double circuit supply is passing through the sub-station. The outgoing 66 kV double circuit line can be made to act as incoming line.

(*iv*) There is also an arrangement to step down the incoming 66 kV supply to 11 kV by two units of 3-phase transformers; each transformer supplying to a separate bus-bar. Generally, one transformer supplies the entire sub-station load while the other transformer acts as a standby unit. If need arises, both the transformers can be called upon to share the sub-station load. The 11 kV outgoing lines feed to the distribution sub-stations located near consumers localities.

(*v*) Both incoming and outgoing lines are connected through circuit breakers having isolators on their either end. Whenever repair is to be carried over the line towers, the line is first switched off and then earthed.

(*vi*) The potential transformers (P.T.) and current transformers (C.T.) and suitably located for supply to metering and indicating instruments and relay circuits (not shown in the figure). The P.T. is connected right on the point where the line is terminated. The CTs are connected at the terminals of each circuit breaker.

(*vii*) The lightning arresters are connected near the transformer terminals (on H.T. side) to protect them from lightning strokes.

(*viii*) There are other auxiliary components in the sub-station such as capacitor bank for power factor improvement, earth connections, local supply connections, d.c. supply connections etc. However, these have been omitted in the key diagram for the sake of simplicity.

Key Diagram of 11 kV/400 V Indoor Sub-Station

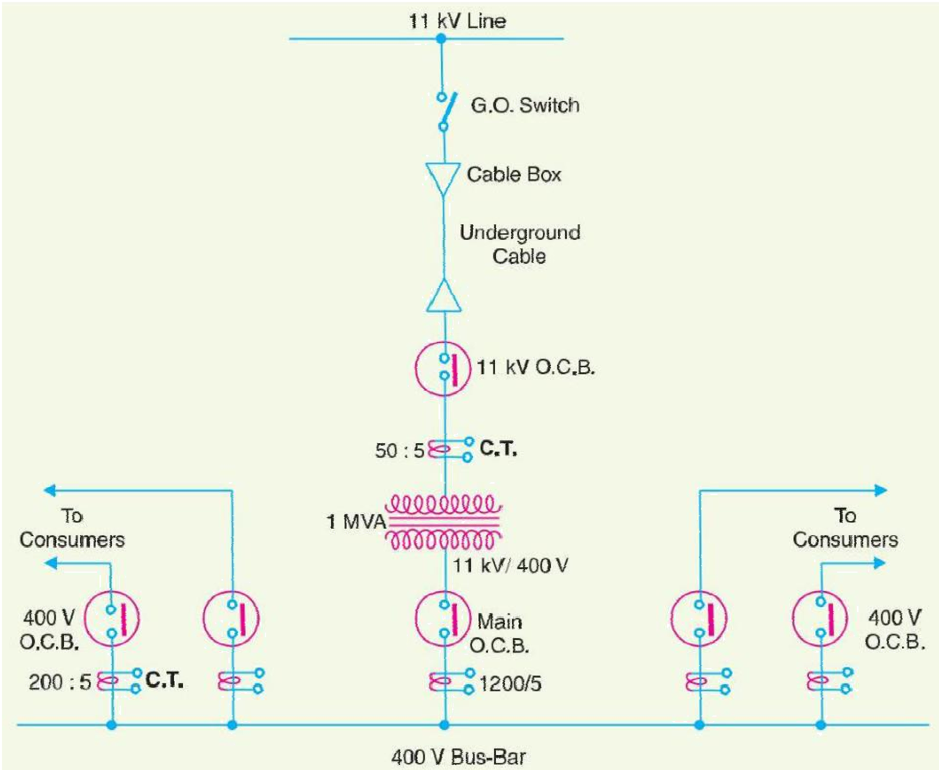
Fig. 25.11 shows the key diagram of a typical 11 kV/400 V indoor sub-station. The key diagram of this sub-station can be explained as under :

(*i*) The 3-phase, 3-wire 11 kV line is tapped and brought to the gang operating switch installed near the sub-station. The G.O. switch consists of isolators connected in each phase of the 3-phase line.

(*ii*) From the G.O. switch, the 11 kV line is brought to the indoor sub-station as underground cable. It is fed to the H.T. side of the transformer (11 kV/400 V) *via* the 11 kV O.C.B. The transformer steps down the voltage to 400 V, 3-phase, 4-wire.

(*iii*) The secondary of transformer supplies to the bus-bars *via* the main O.C.B. From the bus-bars, 400 V, 3-phase, 4-wire supply is given to the various consumers *via* 400 V O.C.B. The voltage between any two phases is 400 V and between any phase and neutral it is 230 V. The single phase residential load is connected between any one phase and neutral whereas 3-phase, 400 V motor load is connected across 3-phase lines directly.

(*iv*) The CTs are located at suitable places in the sub-station circuit and supply for the metering and indicating instruments and relay circuits.


11 kV Line
G.O. Switch
Cable Box
Underground Cable
11 kV O.C.B.
50 : 5
C.T.
1 MVA
11 kV/ 400 V
To Consumers
To Consumers
400 V O.C.B.
Main O.C.B.
400 V O.C.B.
200 : 5
C.T.
1200/5
400 V Bus-Bar

Air Insulated Electrical Power Substation:

In Air Insulated Power Substations busbars and connectors are visibe. In this Power Substations Circuit Breakers and Isolators, Transformers, Current Transformers, Potential Transformers etc are installed in the outdoor. Busbars are supported on the post Insulators or Strain Insulators. Substations have galvanized Steel Structures for Supporting the equipment, insulators and incoming and outgoing lines. Clearances are the primary criteria for these substations and occupy a large area for installation.

Gas Insulated Electrical Power Substation:

In Gas Insulated Substation Various Power Substation equipments like Circuit Breakers, Current Transformers, Voltage Transformers, Busbars, Earth Switches, Surge Arresters, Isolators etc are in the form of metal enclosed SF6 gas modules. The modules are assembled in accordance with the required Configuration. The various Live parts are enclosed in the metal enclosures (modules) containing SF6 gas at high pressure. Thus the size of Power Substation reduces to 8% to 10% of the Air Insulated Power Substation.

Hybrid Electrical Power Substation:

Hybrid Substations are the combination of both Conventional Substation and Gas Insulated Substation. Some bays in a Power Substation are Gas Insulated type and some are Air Insulated Type. The design is based on convenience, Local Conditions available, area available and Cost.

Advantages of GIS Substation:

- It occupies very less space (1/10th) compared to ordinary substations. Hence these Gas Insulated Substations (GIS) are most preferred where area for substation is small (eg: Cities)
- Most reliable compared to Air Insulated Substations, number of outages due to the fault is less
- Maintenance Free
- Can be assembled at the shop and modules can be commissioned in the plant easily

Disadvantages of GIS Substation:

- Cost is higher compared to Ordinary Conventional Substations
- Care should be taken that no dust particles enter into the live compartments which results in flash overs
- When fault occurs internally, diagnosis of the fault and rectifying this takes very long time (outage time is high)

- SF6 gas pressure must be monitored in each compartment, reduction in the pressure of the SF6 gas in any module results in flashovers and fault

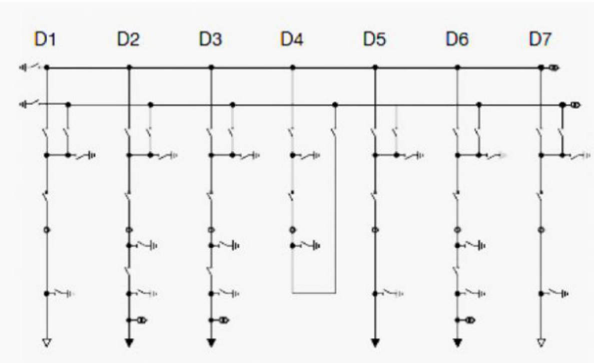


Figure 1 – Single line diagram of double busbar

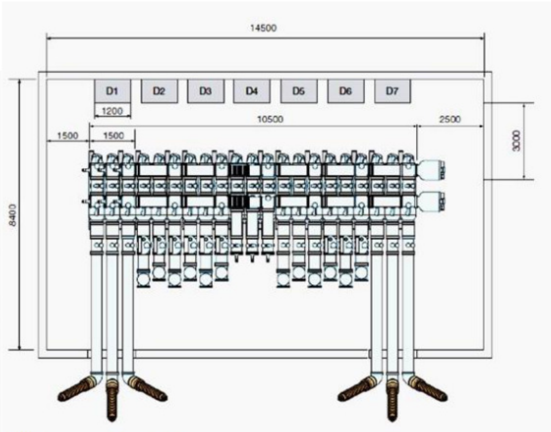


Figure 2 – Layout of double busbar GIS

The Gas insulated substation comprises the following components:
1 Circuit breaker
2 Disconnector switch
3 Earthing switch
4 Current transformer
5 Voltage transformer
6 Bus bar & connectors
7 Power transformer
8 Surge arrester
9 Cable termination
10 SF6 / air or SF6 / oil bushing

Advantages of GIS over the conventional open air substation
The application of GIS during the last fifteen years has been very rapid. The rapid growth in GIS application is due to the following special advantages:

1. Area and volume saving in construction for over or underground applications. Therefore they offer saving in land area and construction costs.
2. Insensitivity to external influences because of grounded metal enclosures.
3. Greatly improved safety and reliability due to earthed metal housing of all high voltage parts and much higher intrinsic strength of SF6 gas as insulation.
4. Short on site erection times, based on large factory assembled and tested shipping units
5. Fulfillment of aesthetic requirements with indoor applications
6. High service reliability due to non-exposure of the use of high voltage parts to atmosphere influences
7. Reduction in radio interference with the use of earthed metal enclosures.
8. Use as mobile substations for transportation to load centers on standard tracks. These substations can be located closer to load centers thereby reducing transmission losses and expenditure in the distribution network.
9. More optimal life cycle costs because of lesser maintenance, down time and repair costs.
10. It is not necessary that high voltage or extra high voltage switchgear has to be installed outdoors.

Disadvantages of GIS

Although GIS has been in operation for several years, a lot of problems encountered in practice need fuller understanding. Some of the problems being studied are:

1. Switching operation generate Very Fast Transients Over Voltages (VFTOS).
2. VFTOS may cause secondary breakdown inside a GIS and Transient Enclosure Voltages (TEV) outside the GIS.
3. Field non-uniformities reduce withstanding levels of a GIS.
4. Prolonged arcing may produce corrosive/toxic by-products.
5. Support spacers can be weak points when arc by-products and metallic particles are present.

MODULE –IV

DC AND AC 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 sub-station fed by the distribution system and the consumers meters. It generally consists of *feeders, distributors* and the *service mains.*

(i) FEEDERS:

A feeder is a conductor which connects the sub-station (or localised 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. 12.1, *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.

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. Each scheme has its own advantages and disadvantages

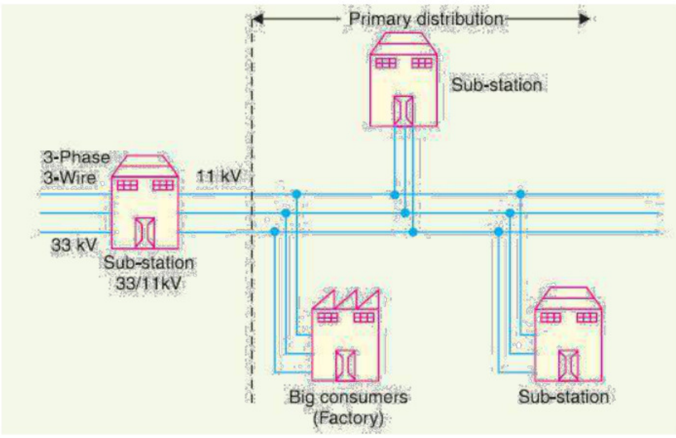
A.C. DISTRIBUTION:

Now-a-days electrical energy is generated, transmitted and distributed in the form of alternating current.

- Alternating current in prefered to direct current is the fact that alternating voltage can be conveniently changed by means of a transformer.
- High distrubution and distribution voltages have greatly reduced the current in the conductors and the resulting line losses.
- The a.c. distribution system is the electrical system between the stepdown substation fed by the distrubution system and the consumers' meters.

(i) primary distribution system and ***(ii)*** secondary distribution system.

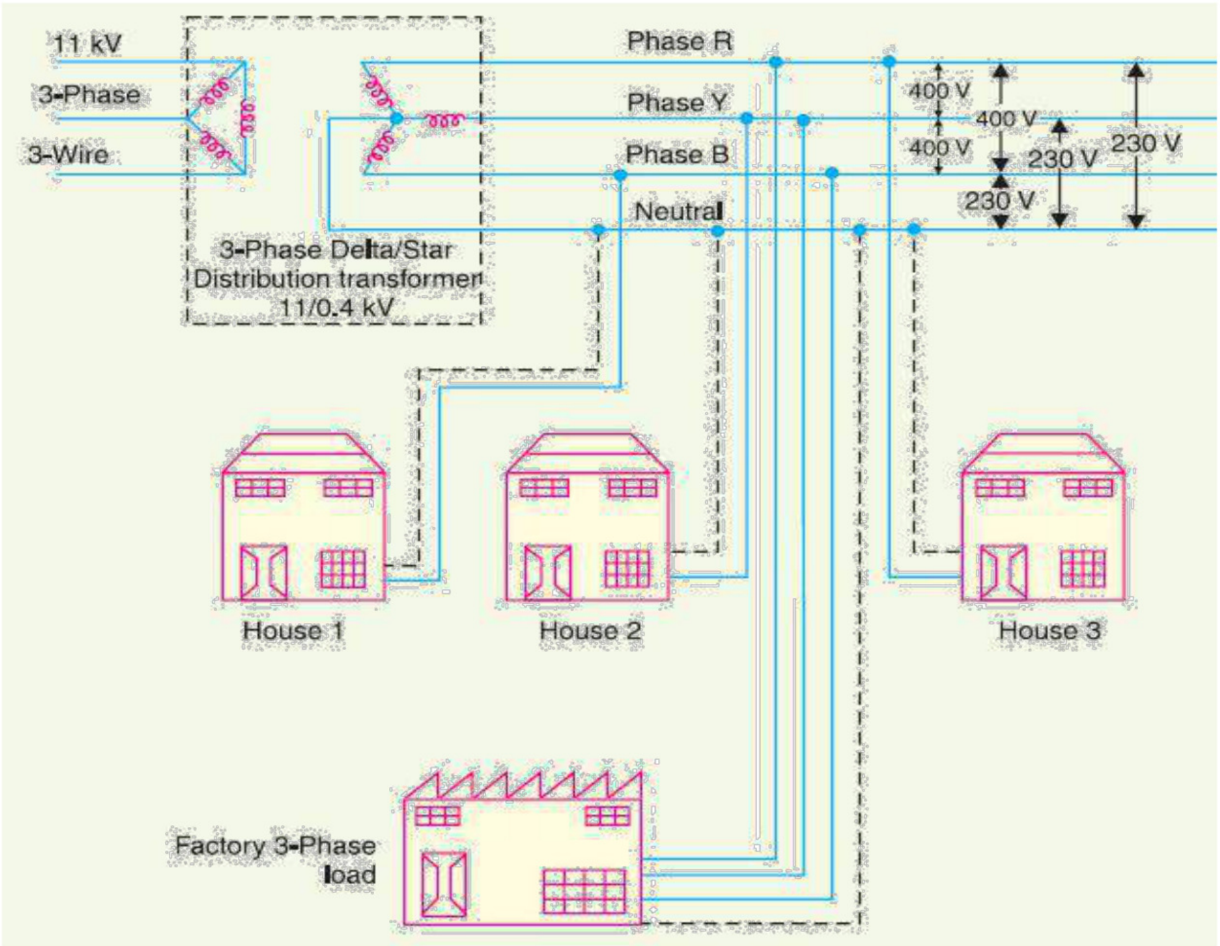
PRIMARY DISTRIBUTION SYSTEM:



It is that part of a.c. distribution system which operates at voltages somewhat higher than general utilisation than the average low- voltage consumer uses the most commonly used primary distribution voltages are 11 kV, 6·6kV and 3·3 kV 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. At this substation, voltage is stepped down to 11 kV with the help of step-down transformer. Power is supplied to various substations for distribution or to big consumers at this voltage. This forms the high voltage distribution or primary distribution.

SECONDARY DISTRIBUTION SYSTEM:



It is that part of a.c. distribution system employs 400/230 V, 3-phase, 4-wire system. shows a typical secondary distribution system.

The primary distribution circuit delivers power to various substations, called distribution substations. The substations are situated near the consumers' localities and contain step down transformers.

At each distribution substation, the voltage is stepped down to 400 V and power is delivered by 3-phase,4-wire a.c. system. The voltage between any two phases is 400 V and between any phase and neutral is 230 V.

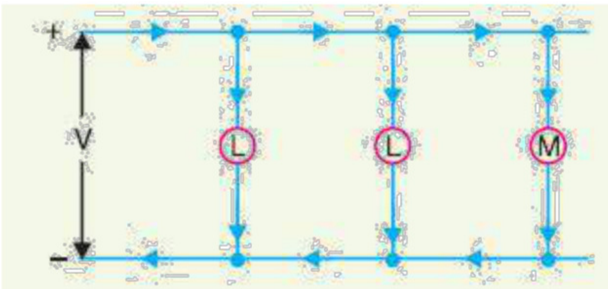
The single phase domestic loads are connected between any one phase and the neutral,. Motor loads are connected across 3-phase lines directly.

D.C. DISTRIBUTION:

- For certain applications, d.c. supply is absolutely necessary. d.c. supply is required for the operation of variable speed machinery (*i.e.*, d.c. motors storage battery.
- For this purpose,a.c. power is converted into d.c. power at the substation by using converting machinery *e.g.,*mercury arc rectifiers, rotary converters and motor-generator sets.
- The d.c. supply obtained in the form of (*i*) 2-wire or (*ii*) 3-wire for distribution.

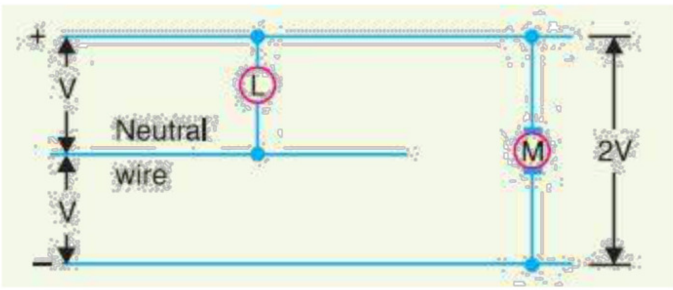
2-WIRE D.C. SYSTEM:

As the name implies, this system of distribution consists of two wires.
One is the outgoing or positive wire and the other is the return or negative wire.
The loads such as lamps, motors etc. are connected in parallel between the two wires as shown in Fig.
This system is never used for distrubution purposes due to low efficiency but may be employed for distribution of d.c. power.



3-WIRE D.C. SYSTEM*:*

- It consists of two outers and a middle or neutral wire which is earthed at the substation.
- The voltage between the outers is twice the voltage between either outer and neutral.
- The principal advantage of this system is that it makes available two voltages at the consumer terminals, *V* between any outer and the neutral and 2V between the outers.
- Loads requiring high voltage (*e.g*., motors) are connected across the outers, whereas lamps and heating circuits requiring less voltage are connected between either outer and the neutral.



COMPARISON OF D.C. AND A.C. DISTRIBUTION:

The electric power can be distributed either by means of d.c. or a.c. Each system has its own merits and demerits

D.C DISTRIBUTION:

ADVANTAGES:

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

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

(*iii*) Due to the absence of inductance, the voltage drop in a d.c. distribution line is less than the a.c. line for the same load and sending end voltage. For this reason, a d.c. distrib ution line has better voltage regulation.

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

(*v*) For the same working voltage, the potential stress on the insulation is less in case of d.c. system than that in a.c. system. Therefore, a d.c. line requires less insulation.

(*vi*) A d.c. line has less corona loss and reduced interference with communication circuits.

(*vii*) The high voltage d.c. distrubution is free from the dielectric losses, particularly in the case of cables.

(*viii*) In d.c. distrubution, there are no stability problems and synchronising difficulties.

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 distrubution of power at high voltages.

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

A.C. DISTRIBUTION:

ADVANTAGES:

(*i*) The power can be generated at high voltages.

(*ii*) The maintenance of a.c. sub-stations is easy and cheaper.

(*iii*) The a.c. voltage can be stepped up or stepped down by transformers with ease and efficiency. This permits to transmit power at high voltages and distribute it at safe potentials.

DISADVANTAGES:

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

(*ii*) The construction of a.c. distrubution line is more complicated than a d.c. distrubution line.

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

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

OVERHEAD VERSUS UNDERGROUND SYSTEM:

- The distribution system can be overhead or underground.
- Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors.
- The underground system uses conduits, cables and manholes under the surface of streets and sidewalks.

The choice between overhead and underground system depends upon a number of widely differing factors.

(i) **Public safety:** The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

(*ii*) **Initial cost:** The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system.

(iii) **Flexibility:** The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles, wires, transformers etc., can be easily shifted to meet the changes in load conditions.

(*iv*) **Faults:** The chances of faults in underground system are very rare as the

cables are laid underground and are generally provided with better insulation.

(*v*) **Appearance:** The general appearance of an underground system is better as all the distribution lines are invisible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.

(*vi*) **Fault location and repairs:** In general, there are little chances of faults in an underground system. However, if a fault does occur, it is difficult to locate and repair on this system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can be easily made.

(*vii*) **Current carrying capacity and voltage drop:** An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, under ground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing ofconductors.

(*viii*) **Useful life:** The useful life of underground system is much longer than that of an over head system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.

(*ix*) **Maintenance cost:** The maintenance cost of underground system is very low as compared with that of overhead system because of less chance of faults and service interruptions from wind, ice, lightning as well as from traffic hazards.

(*x*) **Interference with communication circuits:** An overhead system causes electromagnetic interference with the telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system.

It is clear from the above comparison that each system has its own advantages and disadvantage

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.

REQUIREMENTS OF A DISTRIBUTION SYSTEM

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. High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumer's terminals are within permissible limits. 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.

(*i*i) Availability of powe r on de mand:

Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy ca nnot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

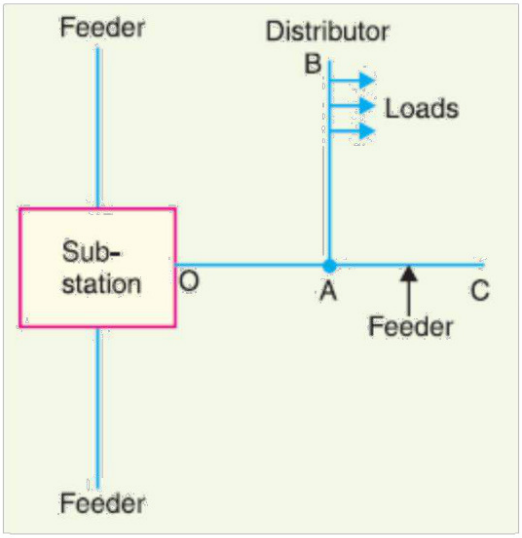
(*ii*i) Reliability:

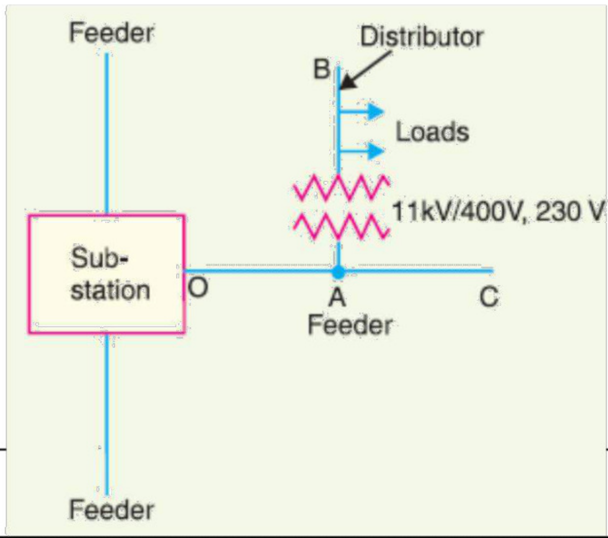
Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man- made, can never be absolutely reliable. However,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

CONNECTION SCHEMES OF DISTRIBUTION SYSTEM

(*i*) Radial System

In this system, separate feeders radiate from a single substation and feed the distributors at one end only.
Fig. (*i*) 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*. 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.





This is the simplest distribution circuit and has the lowest initial cost.

DRAWBACKS :

(***a***) The end of the distributor nearest to the feeding point will be heavily loaded. (***b*** any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault .

(***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.

Fig. 12.9 shows the single line diagram of ring mainsystem for a.c. distribution where substatio n supplies to the closed feeder LMNOPQRS.

The distributors are tapped from different points *M*, *O* and *Q* of the feeder through distribution transformers.

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.

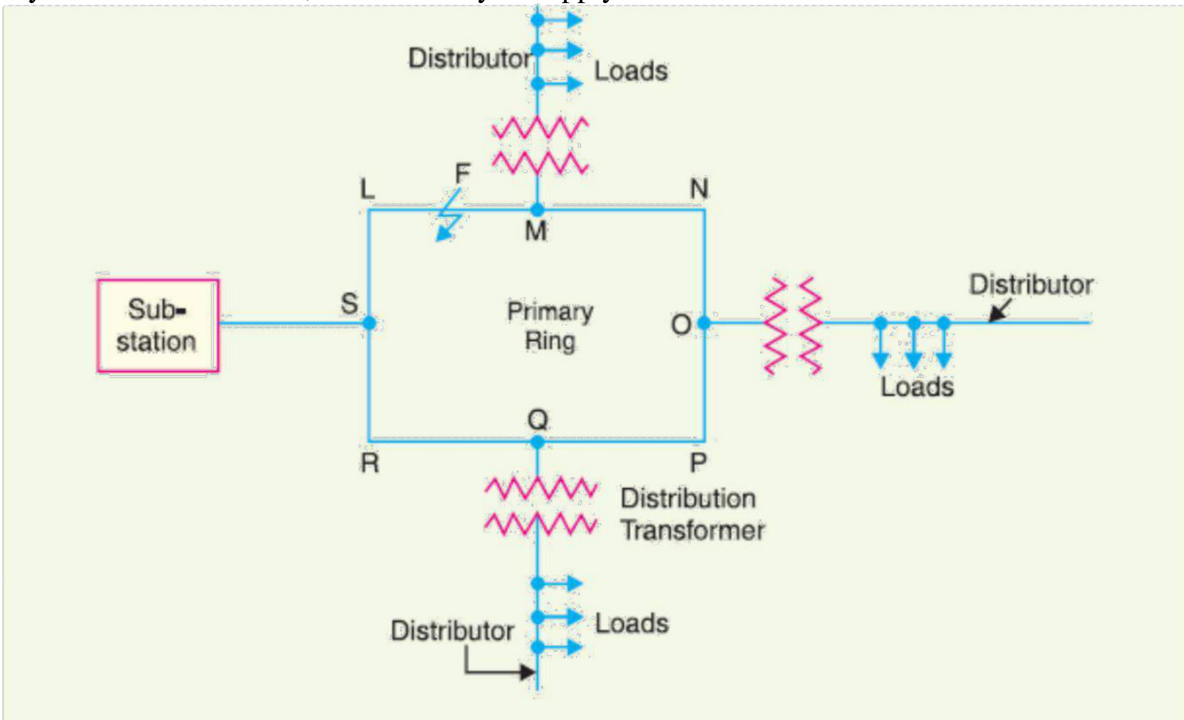
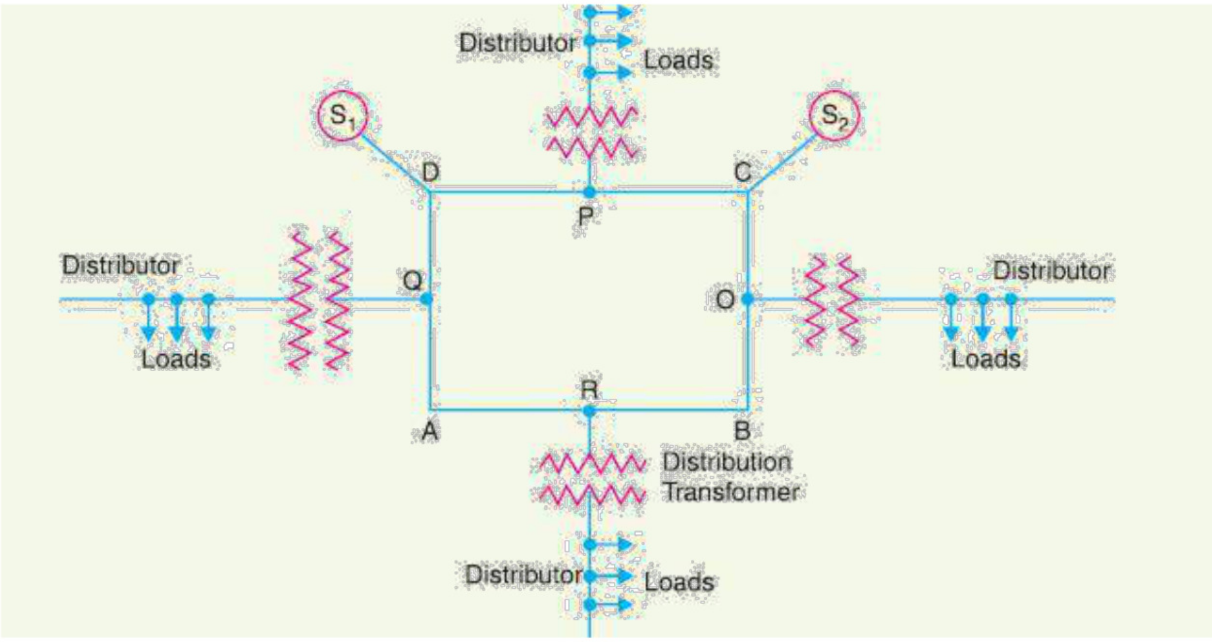


Fig. 12.9

(*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.

Fig. 12.10 shows the single line diagram of interconnected system where the closed feeder ring *ABCD* is supplied bytwo substations *S*1 and *S*2 at points *D* and *C* respectively.



Distributors are connected to points *O*, *P*, *Q* and *R* of the feeder ring through distribution transformers.

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.

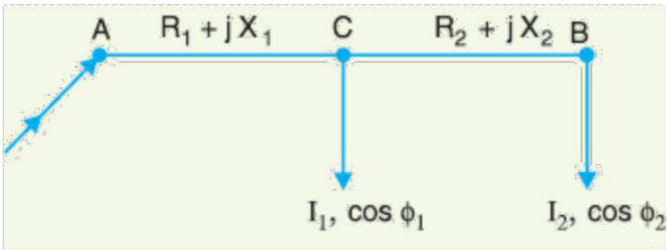
A.C. DISTRIBUTION VOLTAGE CALCULATIONS

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*) Powe r 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 points *C* and *B* as shown in Fig. Taking the receiving end voltage *VB* as the reference vector, let lagging power factors at *C* and *B* be cos Ø1 and cosØ2 *w.r.t. VB*.

Let $R1$, $X1$ and $R2$, $X2$ be the resistance and reactance of sections AC and $C\,B$ of the distributor.



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

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

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

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

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

Current in section AC, $\overrightarrow{I_{AC}} = \vec{I_1} + \vec{I_2}$

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

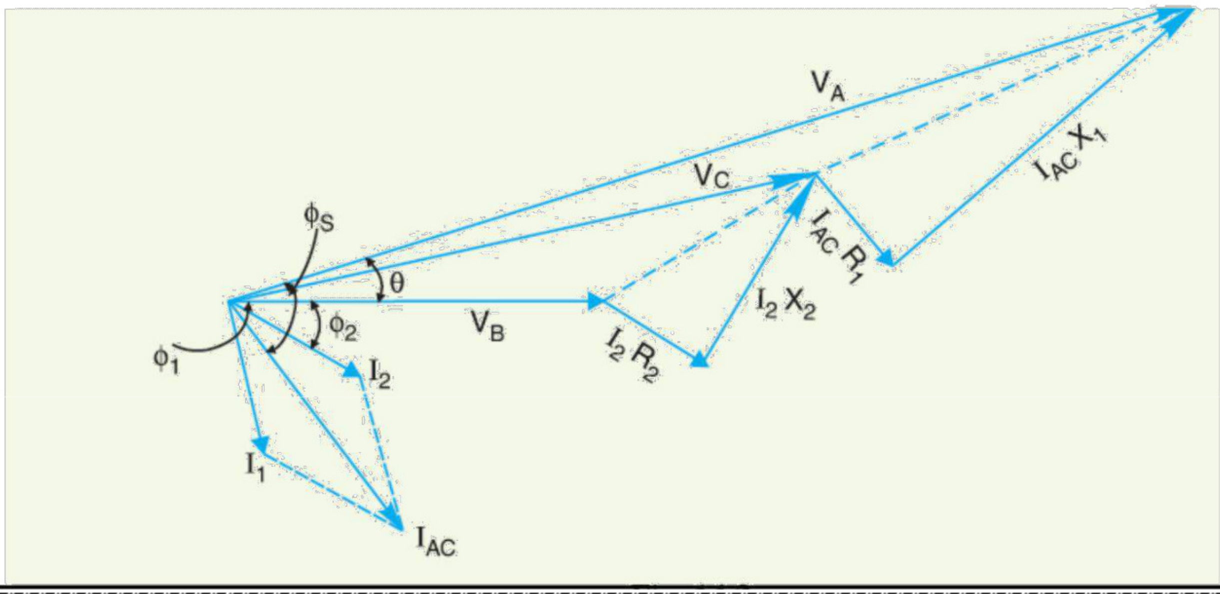
Voltage drop in section CB, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = I_2\,(\cos\phi_2 - j\sin\phi_2)\,(R_2 + jX_2)$

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

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

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

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



(ii) Power factors referred to respective load voltages. Suppose the power factors of loads in the previous Fig. 14.1 are referred to their respective load voltages. Then ϕ_1 is the phase angle between V_C and I_1 and ϕ_2 is the phase angle between V_B and I_2. The vector diagram under these conditions is shown in Fig. 14.3.

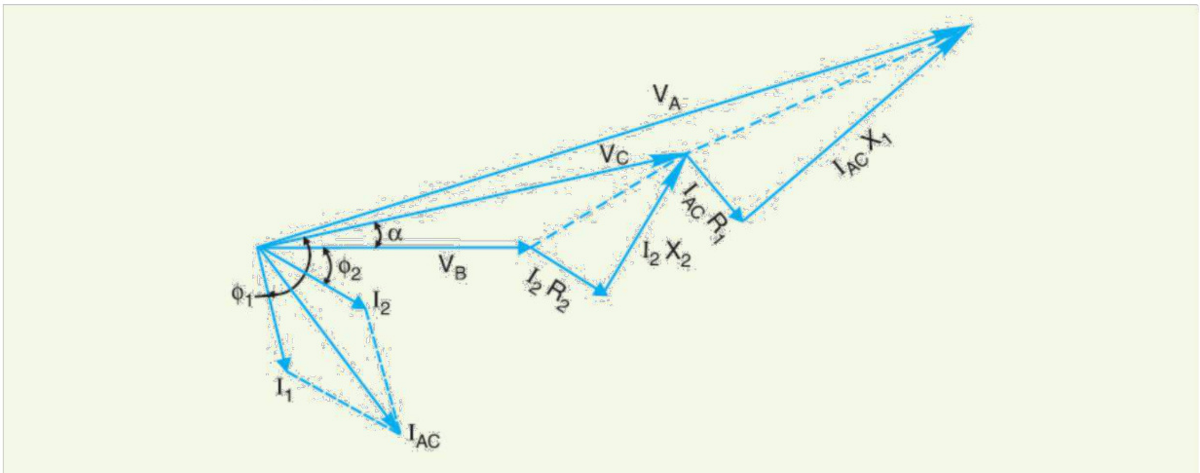


Fig. 14.3

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

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

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

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

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

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

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

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

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

Example 14.1. *A single phase a.c. distributor AB 300 metres long is fed from end A and is loaded as under :*

(*i*) *100 A at 0·707 p.f. lagging 200 m from point A*

(*ii*) *200 A at 0·8 p.f. lagging 300 m from point A*

The load resistance and reactance of the distributor is 0·2 Ω and 0·1 Ω per kilometre. Calculate the total voltage drop in the distributor. The load power factors refer to the voltage at the far end.

Solution. Fig. 14.4 shows the single line diagram of the distributor.

Impedance of distributor/km $= (0 \cdot 2 + j\, 0 \cdot 1)\ \Omega$

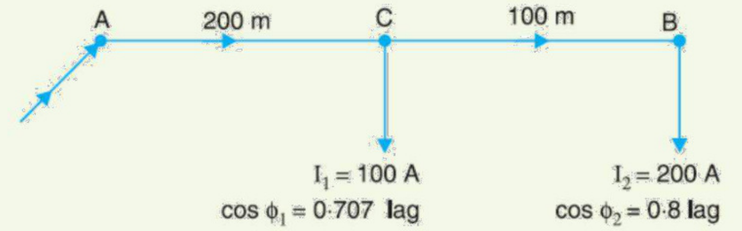


Fig. 14.4

Impedance of section *AC*, $\overrightarrow{Z_{AC}} = (0 \cdot 2 + j\, 0 \cdot 1) \times 200/1000 = (0 \cdot 04 + j\, 0 \cdot 02)\ \Omega$

Impedance of section *CB*, $\overrightarrow{Z_{CB}} = (0 \cdot 2 + j\, 0 \cdot 1) \times 100/1000 = (0 \cdot 02 + j\, 0 \cdot 01)\ \Omega$

Taking voltage at the far end *B* as the reference vector, we have,

Load current at point *B*, $\overrightarrow{I_2} = I_2 (\cos \phi_2 - j \sin \phi_2) = 200\, (0 \cdot 8 - j\, 0 \cdot 6)$
$= (160 - j\, 120)$ A

Load current at point *C*, $\overrightarrow{I_1} = I_1 (\cos \phi_1 - j \sin \phi_1) = 100\, (0 \cdot 707 - j\, 0 \cdot 707)$
$= (70 \cdot 7 - j\, 70 \cdot 7)$ A

Current in section *CB*, $\overrightarrow{I_{CB}} = \overrightarrow{I_2} = (160 - j\, 120)$ A

Current in section *AC*, $\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2} = (70 \cdot 7 - j\, 70 \cdot 7) + (160 - j\, 120)$
$= (230 \cdot 7 - j\, 190 \cdot 7)$ A

Voltage drop in section *CB*, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\ \overrightarrow{Z_{CB}} = (160 - j\, 120)\, (0 \cdot 02 + j\, 0 \cdot 01)$
$= (4 \cdot 4 - j\, 0 \cdot 8)$ volts

Voltage drop in section *AC*, $\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\ \overrightarrow{Z_{AC}} = (230 \cdot 7 - j\, 190 \cdot 7)\, (0 \cdot 04 + j\, 0 \cdot 02)$
$= (13 \cdot 04 - j\, 3 \cdot 01)$ volts

Voltage drop in the distributor $= \overrightarrow{V_{AC}} + \overrightarrow{V_{CB}} = (13 \cdot 04 - j\, 3 \cdot 01) + (4 \cdot 4 - j\, 0 \cdot 8)$

Magnitude of drop $= \sqrt{(17 \cdot 44)^2 + (3 \cdot 81)^2} =$ **17·85 V**

Example 14.2. *A single phase distributor 2 kilometres long supplies a load of 120 A at 0·8 p.f. lagging at its far end and a load of 80 A at 0·9 p.f. lagging at its mid-point. Both power factors are referred to the voltage at the far end. The resistance and reactance per km (go and return) are 0·05 Ω and 0·1 Ω respectively. If the voltage at the far end is maintained at 230 V, calculate :*

(*i*) *voltage at the sending end*

(*ii*) *phase angle between voltages at the two ends.*

Solution. Fig. 14.5 shows the distributor *AB* with *C* as the mid-point

Impedance of distributor/km $= (0{\cdot}05 + j\,0{\cdot}1)\ \Omega$

Impedance of section *AC*, $\vec{Z}_{AC} = (0{\cdot}05 + j\,0{\cdot}1) \times 1000/1000 = (0{\cdot}05 + j\,0{\cdot}1)\ \Omega$

Impedance of section *CB*, $\vec{Z}_{CB} = (0{\cdot}05 + j\,0{\cdot}1) \times 1000/1000 = (0{\cdot}05 + j\,0{\cdot}1)\ \Omega$

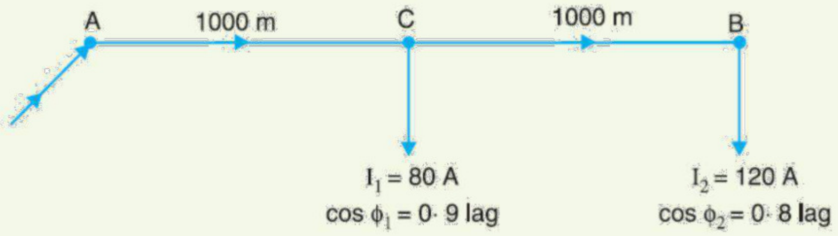


Fig. 14.5

Let the voltage V_B at point *B* be taken as the reference vector.

Then, $\overrightarrow{V_B} = 230 + j\,0$

(*i*) Load current at point *B*, $\vec{I_2} = 120\,(0{\cdot}8 - j\,0{\cdot}6) = 96 - j\,72$

Load current at point *C*, $\vec{I_1} = 80\,(0{\cdot}9 - j\,0{\cdot}436) = 72 - j\,34{\cdot}88$

Current in section *CB*, $\overrightarrow{I_{CB}} = \vec{I_2} = 96 - j\,72$

Current in section *AC*, $\overrightarrow{I_{AC}} = \vec{I_1} + \vec{I_2} = (72 - j\,34{\cdot}88) + (96 - j\,72)$

$= 168 - j\,106{\cdot}88$

Drop in section *CB*, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\ \overrightarrow{Z_{CB}} = (96 - j\,72)\,(0{\cdot}05 + j\,0{\cdot}1)$

$= 12 + j\,6$

Drop in section *AC*, $\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\ \overrightarrow{Z_{AC}} = (168 - j\,106{\cdot}88)\,(0{\cdot}05 + j\,0{\cdot}1)$

$= 19{\cdot}08 + j\,11{\cdot}45$

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

$$= (230 + j\,0) + (12 + j\,6) + (19.08 + j\,11.45)$$

$$= 261.08 + j\,17.45$$

Its magnitude is $= \sqrt{(261 \cdot 08)^2 + (17 \cdot 45)^2} =$ **261·67 V**

(ii) The phase difference θ between V_A and V_B is given by :

$$\tan\theta = \frac{17 \cdot 45}{261 \cdot 08} = 0 \cdot 0668$$

$\therefore$ $\theta = \tan^{-1} 0 \cdot 0668 =$ **$3 \cdot 82^{\circ}$**

MODULE –V

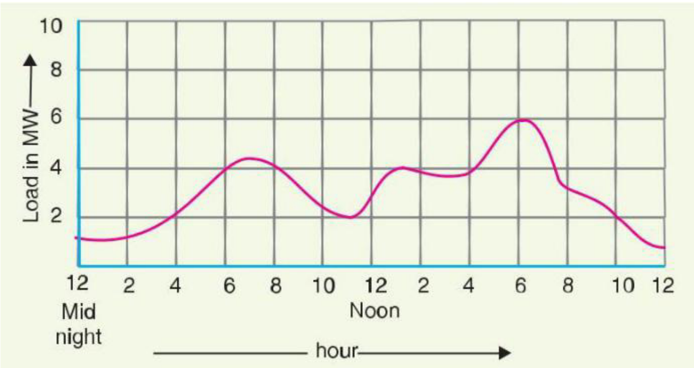
ECONOMIC ASPECTS OF POWER GENERATION & TARIFF METHODS

Load Curves

The curve showing the variation of load on the power station with respect to (wrt) time is known as **load curve.**

The load on a power station is never constant; it varies from time to time. These load variations during the whole day (ie, 24 hours) are recorded half-hourly or hourly and are plotted against time on the graph. The curve thus obtained is known as daily load curve as it shows the variations of load wrt time during the day. Fig. shows a typical daily load curve of a power station. It is clear that load on the power station is varying, being maximum at 6 PM in this case. It may be seen that load curve indicates at a glance the general character of the load that is being imposed on the plant. Such a clear representation cannot be obtained from tabulated figures.

The monthly load curve can be obtained from the daily load curves of that month. For this purpose, average values of power over a month at different times of the day are calculated and then plotted on the graph. **The monthly load curve is generally used to fix the rates of energy.** The yearly load curve is obtained by considering the monthly load curves of that particular year. **The yearly load curve is generally used to determine the annual load factor.**



Importance The daily load curves have attained a great importance in generation as they sup-ply the following information readily:

(i) The daily load curve shows the variations of load on the power station during different hours of the day

(ii) The area under the daily load curve gives the number of units generated in the day

(iii) The highest point on the daily load curve represents the maximum demand on the station on that day

(iv) The area under the daily load curve divided by the total number of hours gives the average load on the station in the day

$$\text{Average load} = \frac{\text{Area (in kWh) under daily load curve}}{\text{24 hours}}$$

(v) The ratio of the area under the load curve to the total area of rectangle in which it is contained gives the load factor

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max demand}} = \frac{\text{Average load} \times 24}{\text{Max demand} \times 24}$$

$$= \frac{\text{Area (in kWh) under daily load curve}}{\text{Total area of rectangle in which the load curve is contained}}$$

(vi) The load curve helps in selecting the size and number of generating units

(vii) The load curve helps in preparing the operation schedule of the station

Important Terms and Factors

The variable load problem has introduced the following terms and factors in power plant engineering:

(i) Connected load It is the sum of continuous ratings of all the equipments connected to supply system

A power station supplies load to thousands of consumers Each consumer has certain equipment installed in his premises The sum of the continuous ratings of all the equipments in the consumer's premises is the "connected load" of the consumer For instance, if a consumer has connections of five 100-watt lamps and a power point of 500 watts, then connected load of the consumer is $5 \times 100 + 500 = 1000$ watts The sum of the connected loads of all the consumers is the connected load to the power station

(ii) Maximum demand: It is the greatest demand of load on the power station during a given period

The load on the power station varies from time to time. The maximum of all the demands that have occurred during a given period (say a day) is the maximum demand. Thus referring back to the load curve of Fig., the maximum demand on the power station during the day is 6 MW and it occurs at 6 PM Maximum demand is generally less than the connected load because all the consumers do not switch on their connected load to the system at a time The knowledge of maximum demand is very important as it helps in determining the installed capacity of the station The station must be capable of meeting the maximum demand

(iii) Demand factor It is the ratio of maximum demand on the power station to its connected load.

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

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

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

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

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

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

(v) Load factor The ratio of average load to the maximum demand during a given period is known as **load factor**,

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

The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year Load factor is always less than 1 because average load is smaller than the maximum demand The load factor plays key role in determining the overall cost per unit generated Higher the load factor of the power station, lesser* will be the cost per unit generated

(vi) Diversity factor The ratio of the sum of individual maximum demands to the maximum demand on power station is known as **diversity factor**

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

A power station supplies load to various types of consumers whose maximum demands generally do not occur at the same time Therefore, the maximum demand on the power station is always less than the sum of individual maximum demands of the consumers Obviously, diversity† factor will always be greater than 1 The greater the diversity factor, the lesser‡ is the cost of generation of power

(vii) Plant capacity factor It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max energy that could have been produced}} = \frac{\text{Average demand*T}}{\text{Plant capacity*T}}$$

Thus if the considered period is one year,

$$\text{Annual plant capacity factor} = \frac{\text{Annual kWh output}}{\text{Plant capacity} \times 8760}$$

The plant capacity factor is an indication of the reserve capacity of the plant A power station is so designed that it has some reserve capacity for meeting the increased load demand in future Therefore, the installed capacity of the plant is always somewhat greater than the maximum demand on the plant.

Reserve capacity = Plant capacity – Max demand

It is interesting to note that difference between load factor and plant capacity factor is an indication of reserve capacity If the maximum demand on the plant is equal to the plant capacity, then load factor and plant capacity factor will have the same value In such a case, the plant will have no reserve capacity.

(viii) Plant use factor It is ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation ie

$$\text{Plant use factor} = \frac{\text{Station output in kWh}}{\text{Plant capacity} \times \text{Hours of use}}$$

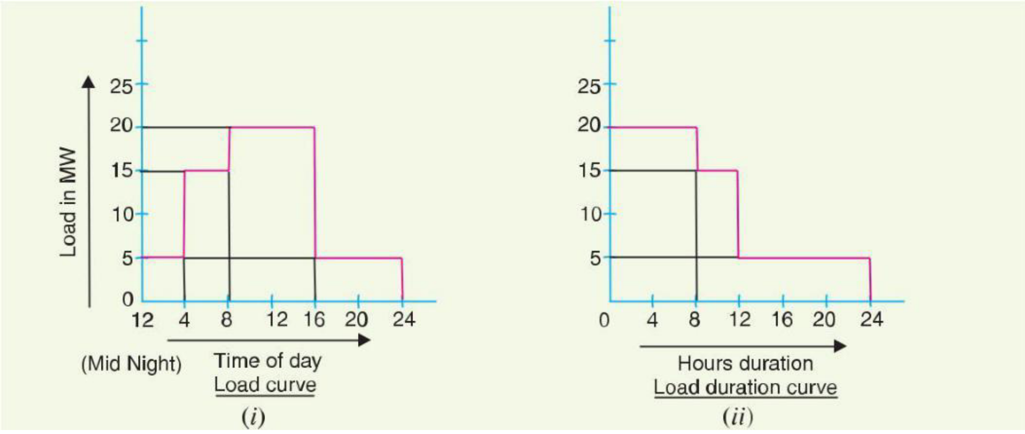
Units Generated per Annum

It is often required to find the kWh generated per annum from maximum demand and load factor The procedure is as follows:

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

Load Duration Curve

When the load elements of a load curve are arranged in the order of descending magnitudes, the curve thus obtained is called a **load duration curve**



The load duration curve is obtained from the same data as the load curve but the ordinates are arranged in the order of descending magnitudes. In other words, the maximum load is represented to the left and decreasing loads are represented to the right in the descending order. Hence the area under the load duration curve and the area under the load curve are equal.
Fig. shows the daily load curve. The daily load duration curve can be readily obtained from it. It is clear from daily load curve, that load elements in order of descending magnitude are: 20 MW for 8 hours; 15 MW for 4 hours and 5 MW for 12 hours.

The following points may be noted about load duration curve:

(i) The load duration curve gives the data in a more presentable form. In other words, it readily shows the number of hours during which the given load has prevailed
(ii) The area under the load duration curve is equal to that of the corresponding load curve Obviously, area under daily load duration curve (in kWh) will give the units generated on that day
(iii) The load duration curve can be extended to include any period of time. By laying out the abscissa from 0 hour to 8760 hours, the variation and distribution of demand for an entire year can be summarised in one curve. The curve thus obtained is called the annual load duration curve

Types of Loads
A device which taps electrical energy from the electric power system is called a load on the system. The load may be resistive (eg, electric lamp), inductive (eg, induction motor), capacitive or some combination of them. The various types of loads on the power system are:

(i) Domestic load Domestic load consists of lights, fans, refrigerators, heaters, television, small motors for pumping water etc. Most of the residential load occurs only for some hours during the day (ie, 24 hours) eg, lighting load occurs during night time and domestic appliance load occurs for only a few hours. For this reason, the load factor is low (10% to 12%)

(ii) Commercial load Commercial load consists of lighting for shops, fans and electric appliances used in restaurants etc. This class of load occurs for more hours during the day as compared to the domestic load. The commercial load has seasonal variations due to the extensive use of air-conditioners and space heaters.

(iii) Industrial load Industrial load consists of load demand by industries. The magnitude of industrial load depends upon the type of industry. Thus small scale industry requires load upto 25 kW, medium scale industry between 25kW and 100 kW and large-scale industry requires load above 500 kW Industrial loads are generally not weather dependent.

(iv) Municipal load Municipal load consists of street lighting, power required for water supply and drainage purposes. Street lighting load is practically constant throughout the hours of the night. For water supply, water is pumped to overhead tanks by pumps driven by electric motors. Pumping is carried out during the off-peak period, usually occurring during the night. This helps to improve the load factor of the power system.

(v) Irrigation load This type of load is the electric power needed for pumps driven by motors to supply water to fields. Generally this type of load is supplied for 12 hours during night.

(vi) Traction load This type of load includes tram cars, trolley buses, railways etc. This class of load has wide variation. During the morning hour, it reaches peak value because people have to go to their work place. After morning hours, the load starts decreasing and again rises during evening since the people start coming to their homes.

Load Curves and Selection of Generating Units

The load on a power station is seldom constant; it varies from time to time Obviously, a single generating unit (ie, alternator) will not be an economical proposition to meet this varying load It is because a single unit will have very poor efficiency during the periods of light loads on the power station Therefore, in actual practice, a number of generating units of different sizes are installed in a power station The selection of the number and sizes of the units is decided from the annual load curve of the station. The number and size of the units are selected in such a way that they correctly fit the station load curve. Once this underlying principle is adhered to, it becomes possible to operate the generating units at or near the point of maximum efficiency.

Important Points in the Selection of Units

While making the selection of number and sizes of the generating units, the following points should be kept in view:

(i) The number and sizes of the units should be so selected that they approximately fit the annual load curve of the station.

(ii) The units should be preferably of different capacities to meet the load requirements. Although use of identical units (i.e., having same capacity) ensures saving* in cost, they often do not meet the load requirement.

(iii) The capacity of the plant should be made 15% to 20% more than the maximum demand to meet the future load requirements.

(iv) There should be a spare generating unit so that repairs and overhauling of the working units

can be carried out.
(v) The tendency to select a large number of units of smaller capacity in order to fit the load curve very accurately should be avoided. It is because the investment cost per kW of capacity increases as the size of the units decreases.

Base Load and Peak Load on Power Station

The changing load on the power station makes its load curve of variable nature Fig. shows the typical load curve of a power station. It is clear that load on the power station varies from time to time. However, a close look at the load curve reveals that load on the power station can be considered in two parts, namely;

(i) Base load
(ii) Peak load
(i) Base load. The unvarying load which occurs almost the whole day on the station is known as base load.

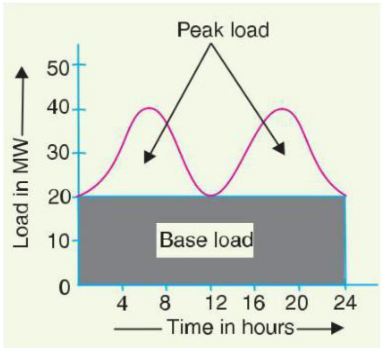


Fig. 3.13

Referring to the load curve of Fig., it is clear that 20 MW of load has to be supplied by the station at all times of day and night ie throughout 24 hours. Therefore, 20 MW is the base load of the station. As base load on the station is almost of constant nature, therefore, it can be suitably supplied (as discussed in the next Article) without facing the problems of variable load.

(ii) Peak load The various peak demands of load over and above the base load of the station is known as **peak load.**

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

Method of Meeting the Load

The total load on a power station consists of two parts viz, base load and peak load. In order to achieve overall economy, the best method to meet load is to interconnect two different power stations. The more efficient plant is used to supply the base load and is known as base load power station. The less efficient plant is used to supply the peak loads and is known as peak load power station. There is no hard and fast rule for selection of base load and peak load stations as it would depend upon the particular situation. For example, both hydro-electric and steam power stations are quite efficient and can be used as base load as well as peak load station to meet a particular load requirement.

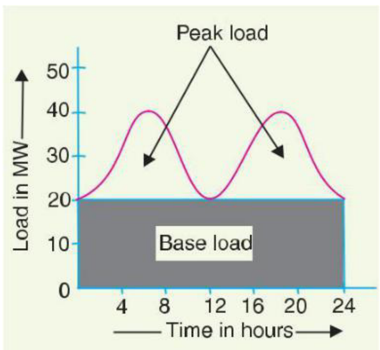
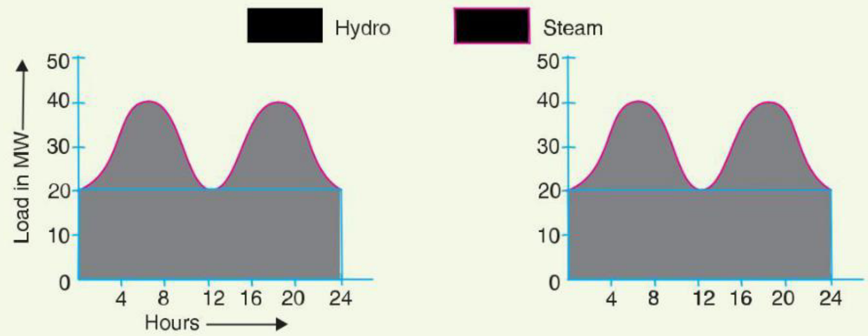


Illustration The interconnection of steam and hydro plants is a beautiful illustration to meet the load. When water is available in sufficient quantity as in summer and rainy season, the hydro-electric plant is used to carry the base load and the steam plant supplies the peak load as shown in Fig. (i).



Load division on Hydro-steam system.

(*i*) High Flow day (*ii*) Low Flow day

However, when the water is not available in sufficient quantity as in winter, the steam plant carries the base load, whereas the hydro-electric plant carries the peak load as shown in Fig. (ii).

Interconnected Grid System

The connection of several generating stations in parallel is known as **interconnected grid system.** The various problems facing the power engineers are considerably reduced by interconnecting different power stations in parallel. Although interconnection of station involves extra cost, yet considering the benefits derived from such an arrrangement, it is gaining much favour these days.
Some of the advantages of interconnected system are listed below:

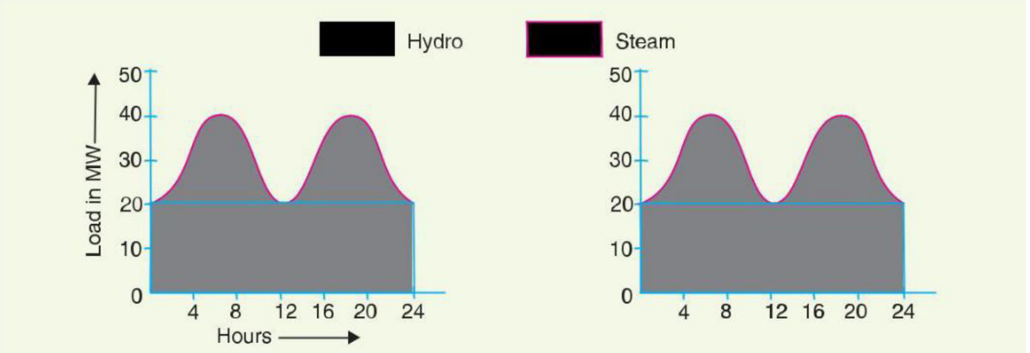
(i) Exchange of peak loads: An important advantage of interconnected system is that the peak load of the power station can be exchanged. If the load curve of a power station shows a peak demand that is greater than the rated capacity of the plant, then the excess load can be shared by other stations interconnected with it.

(ii) Use of older plants: The interconnected system makes it possible to use the older and less efficient plants to carry peak loads of short durations. Although such plants may be inadequate when used alone, yet they have sufficient capacity to carry short peaks of loads when interconnected with other modern plants. Therefore, interconnected system gives a direct key to the use of obsolete plants.

(iii) Ensures economical operation: The interconnected system makes the operation of concerned power stations quite economical. It is because sharing of load among the stations is arranged in such a way that more efficient stations work continuously throughout the year at a high load factor and the less efficient plants work for peak load hours only.

(iv) Increases diversity factor: The load curves of different interconnected stations are generally different. The result is that the maximum demand on the system is much reduced as compared to the sum of individual maximum demands on different stations. In other words, the diversity factor of the system is improved, thereby increasing the effective capacity of the system.

(v) Reduces plant reserve capacity: Every power station is required to have a standby unit for emergencies. However, when several power stations are connected in parallel, the reserve capacity of the system is much reduced. This increases the efficiency of the system.
(iv) Increases reliability of supply: The interconnected system increases the reliability of supply. If a major breakdown occurs in one station, continuity of supply can be maintained by other healthy stations.



Load division on Hydro-steam system.

(*i*) High Flow day (*ii*) Low Flow day

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

Although tariff should include the total cost of producing and supplying electrical energy plus the profit, yet it cannot be the same for all types of consumers. It is because the cost of producing electrical energy depends to a considerable extent upon the magnitude of electrical energy consumed by the user and his load conditions. Therefore, in all fairness, due consideration has to be given to different types of consumers (eg, industrial, domestic and commercial) while fixing the tariff. This makes the problem of suitable rate making highly complicated.

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

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

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

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

(iv) A suitable profit on the capital investment

Desirable Characteristics of a Tariff

A tariff must have the following desirable characteristics:

(i) Proper return: The tariff should be such that it ensures the proper return from each consumer. In other words, the total receipts from the consumers must be equal to the cost of producing and supplying electrical energy plus reasonable profit. This will enable the electric supply company to ensure continuous and reliable service to the consumers.

(ii) Fairness: The tariff must be fair so that different types of consumers are satisfied with the rate of charge of electrical energy. Thus a big consumer should be charged at a lower rate than a small consumer. It is because increased energy consumption spreads the fixed charges over a greater number of units, thus reducing the overall cost of producing electrical energy. Similarly, a consumer whose load conditions do not deviate much from the ideal (ie, non-variable) should be charged at a lower rate than the one whose load conditions change appreciably from the ideal.

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

(iv) Reasonable profit: The profit element in the tariff should be reasonable. An electric supply company is a public utility company and generally enjoys the benefits of monopoly. There-fore, the investment is relatively safe due to non-competition in the market This calls for the profit to be restricted to 8% or so per annum.

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

Types of Tariff

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

Simple tariff When there is a fixed rate per unit of energy consumed, it is called a **simple tariff** or **uniform rate tariff.**

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

Disadvantages

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

Flat rate tariff: When different types of consumers are charged at different uniform per unit rates, it is called a **flat rate tariff.**

In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate. For instance, the flat rate per kWh for lighting load may be 60 paise, whereas it may be slightly less (say 55 paise per kWh) for power load. The different classes of consumers are made taking into account their diversity and load factors. The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculations.

Disadvantages

(i) Since the flat rate tariff varies according to the way the supply is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.

(ii) A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However, a big consumer should be charged at a lower rate as in his case the fixed charges per unit are reduced.

Block rate tariff: When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a **block rate tariff.**

In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy. For example, the first 30 units may be charged at the rate of 60 paise per unit; the next 25 units at the rate of 55 paise per unit and the remaining additional units may be charged at the rate of 30 paise per unit.

The advantage of such a tariff is that the consumer gets an incentive to consume more electrical energy. This increases the load factor of the system and hence the cost of generation is reduced. However, its principal defect is that it lacks a measure of the consumer's demand. This type of tariff is being used for majority of residential and small commercial consumers.

Two-part tariff: When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a **two-part tariff.**

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

Total charges = Rs $(b \times kW + c \times kWh)$

where, b = charge per kW of maximum demand and c = charge per kWh of energy consumed

This type of tariff is mostly applicable to industrial consumers who have appreciable maximum Demand.

Advantages

- It is easily understood by the consumers.
- It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed

Disadvantages

(i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy

(ii) There is always error in assessing the maximum demand of the consumer

Maximum demand tariff: It is similar to two-part tariff with the only difference that the maximum demand is actually measured by installing maximum demand meter in the premises of the consumer. This removes the objection of two-part tariff where the maximum demand is assessed merely on the basis of the rateable value. This type of tariff is mostly applied to big consumers. However, it is not suitable for a small consumer (eg, residential consumer) as a separate maximum demand meter is required.

Power factor tariff: The tariff in which power factor of the consumer's load is taken into consideration is known as **power factor tariff.**

In an ac system, power factor plays an important role. A low power factor increases the rating of station equipment and line losses. Therefore, a consumer having low power factor must be penalized. The following are the important types of power factor tariff:

(i) k VA maximum demand tariff: It is a modified form of two-part tariff In this case, the fixed charges are made on the basis of maximum demand in kVA and not in kW. As kVA is inversely proportional to power factor, therefore, a consumer having low power factor has to contribute more towards the fixed charges. This type of tariff has the advantage that it encourages the consumers to operate their appliances and machinery at improved power factor.

(ii) Sliding scale tariff: This is also know as average power factor tariff. In this case, an average power factor, say 0·8 lagging, is taken as the reference. If the power factor of the consumer falls below this factor, suitable additional charges are made. On the other hand, if the power factor is above the reference, a discount is allowed to the consumer.

(iii) kW and kVAR tariff: In this type, both active power (kW) and reactive power (kVAR) supplied are charged separately. A consumer having low power factor will draw more reactive power and hence shall have to pay more charges.

Three-part tariff: When the total charge to be made from the consumer is split into three parts viz, fixed charge, semi-fixed charge and running charge, it is known as a **three-part tariff**.

Total charge = Rs $(a + b \times kW + c \times kWh)$

Where, a= fixed charge made during each billing period. It includes interest and depreciation on the cost of secondary distribution and labour cost of collecting revenues, b= charge per kW of maximum demand,

c= charge per kWh of energy consumed.

It may be seen that by adding fixed charge or consumer's charge (ie, a) to two-part tariff, it becomes three-part tariff. The principal objection of this type of tariff is that the charges are split into three components. This type of tariff is generally applied to big consumers.