GUDLAVALLERU ENGINEERING COLLEGE

(An Autonomous Institute with Permanent Affiliation to JNTUK, Kakinada)

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Department of Electrical and Electronics Engineering

POWER SYSTEMS-I

Unit-I

Unit-I

Learning Objectives:

- To familiarize the operation of a thermal power station.
- To introduce various components of a thermal power station.
- To represent the layout diagram of thermal power station.
- To emphasize on calculating the efficiency of a thermal power station.

Syllabus:

Thermal PowerStations

Introduction to power systems and its components, classification of energy sources, conventional non-conventional methods, single line diagram of Thermal Power Stations showing paths of coal, steam, water, air, ash and flue gasses, advantages and disadvantages of thermal power stations, selection of site location for thermal power stations-Brief descriptionofThermal Power Stationcomponents: economizers, boilers, super heaters, turbines, condensers, chimney and cooling towers, efficiency of thermal power station.

Learning outcomes:

Students will be able to

- ✓ Define power system and its components
- ✓ List out the advantages &disadvantages of thermal power station.
- ✓ Select an appropriate location for thermal power station.
- ✓ Explain the single line diagram of thermal power station.
- ✓ Describe the functions of various components of thermal power station.
- ✓ Define efficiency of thermal power station & suggest the methods to improve it.

1.1 INTRODUCTION TO POWER SYSTEMS

An **Electric Power System** is a network of electrical components used to generate, transmit and use electric power.

A Power system can be broadly classified as Generation, Transmission, Distribution, and Utilization of electrical power.

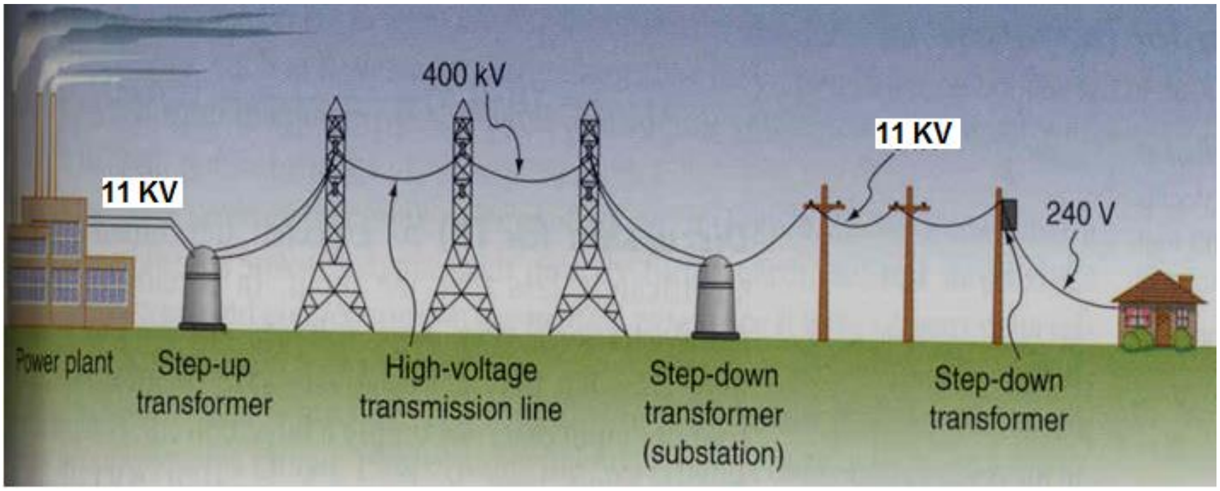


Fig 1.1: Different stages of a Power System

- Power Systems is the subject which deals with Generation, Transmission, Distribution, Utilization and Protection of Electrical energy.
- In the subject power system-I
  - Firstly we deal with different methods of generation of electrical energy
  - Secondly we deal withdistributionsystems & substations.
  - We conclude this course by dealing with economical aspects in Power stations &TariffMethods

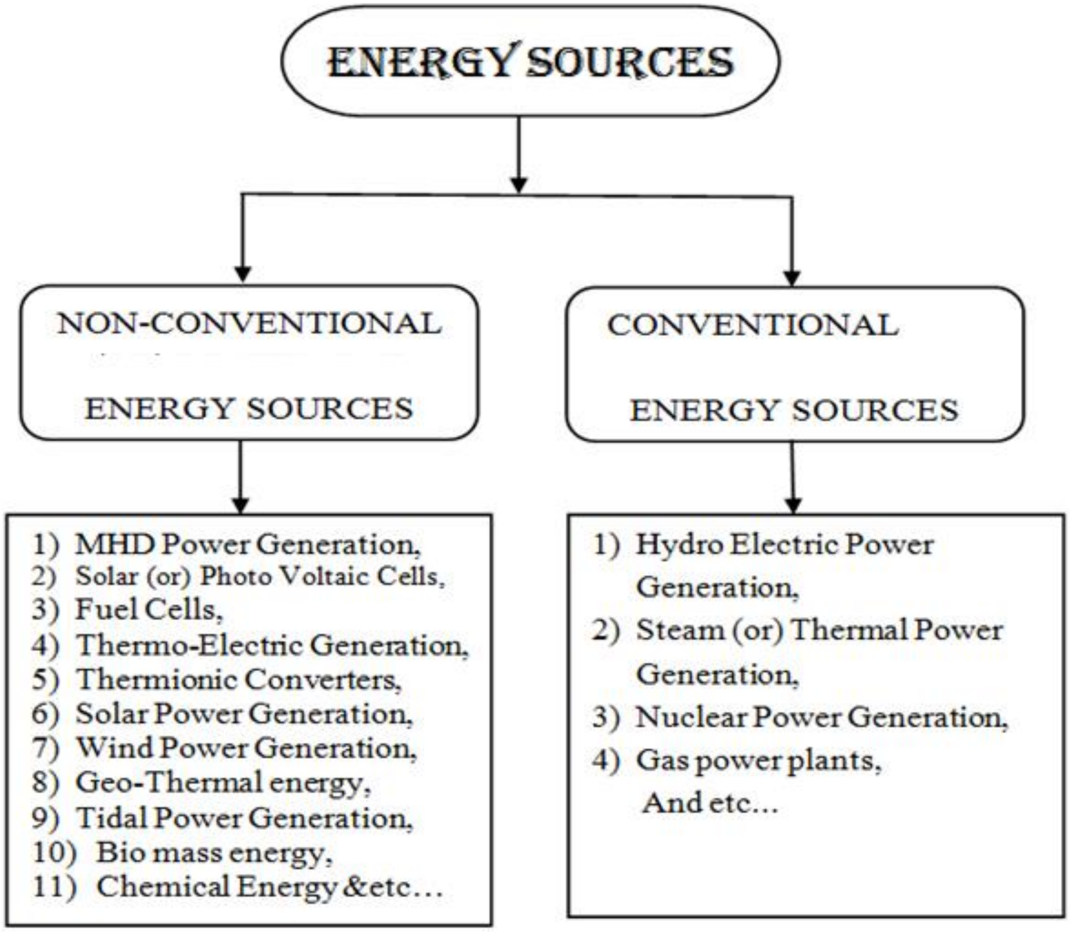
GENERATION OF ELECTRICAL ENERGY

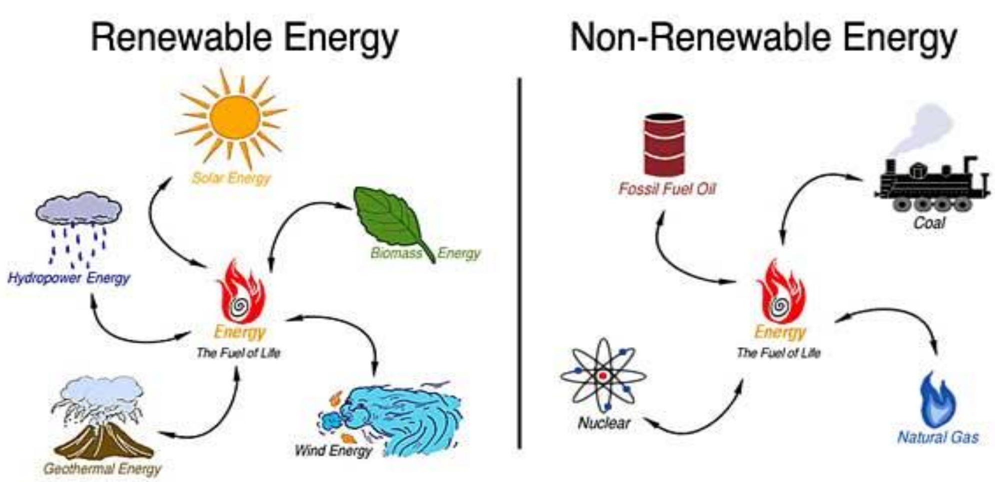
Electrical energy is generated by conversion of energy available in different forms from different natural sources such as kinetic energy of blowing wind, pressure head of water, chemical energy of fuels(either in solid, liquid or gaseous form) and nuclear energy of radio -active substance into electrical energy.

CLASSIFICATION OF ENERGY SOURCES

The energy sources are majorly classified into two types. They are conventional energy sources like coal, petroleum, natural gas etc.

And non-conventional energy sources like solar cells, fuel cells, thermo-electric generator, thermionic converter, solar power generation, wind power generation, geo-thermal energy generation, tidal power generation etc.





Now in this course we will be dealing with thermal, hydro and nuclear power plants.

A Power station (also referred to as a generating station or power plant) is an industrial facility for the generation of electric power,where electricity, is generated from another source of energy such as burning coal, nuclear reactions, flowing water, chemical or wind and etc.

Unit-1

THERMAL POWER STATIONS

1.2 Steam Power Station (Thermal Station)

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

Principle of Operation

A steam power station basically works on the Rankine cycle principle. Steam is produced in the boiler by utilizing the heat of coal combustion. The steam is then expanded in the prime mover (i.e., steam turbine) and is condensed in a condenser to be fed in to the boiler again. The steam turbine drives the alternator which converts mechanical energy of the turbine into electrical energy. This type of power station is suitable where coal and water are available in abundance and a large amount of electric power is to be generated.

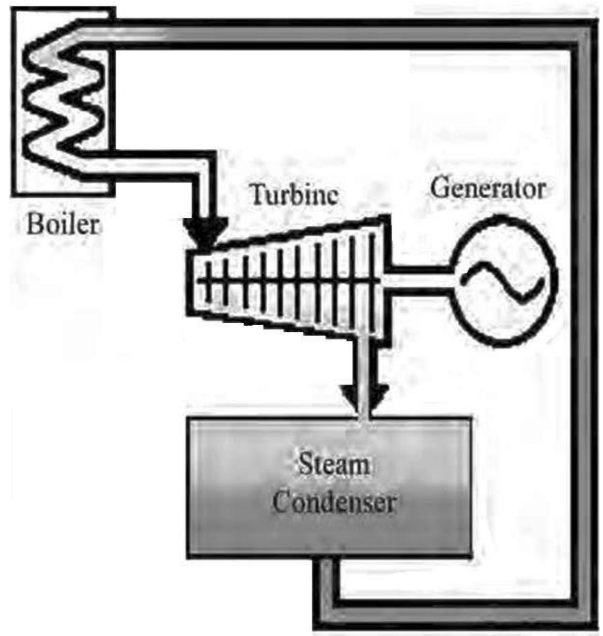


Fig 1.2: Principle of Operation

1.3 Advantages & Disadvantages

Advantages

(*i*) The fuel (*i.e.*,coal) used is quite cheap.

(*ii*) Less initial cost as compared to other generating stations.

(*iii*) It can be installed at any place irrespective of the existence of coal. The coal can be trans-ported to the site of the plant by rail or road.

(*iv*) It requires less space as compared to the hydroelectric power station.

(*v*) The cost of generation is lesser than that of the diesel power station.

Disadvantages

(*i*) It pollutes the atmosphere due to the production of large amount of smoke and fumes.

(*ii*) It is costlier in running cost as compared to hydroelectric plant.

1.4 Selection of site for a thermal power plant

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

(1) Supply of fuel

The steam power station should be located near the coal mines so that transportation cost of fuel is low. However, if such a plant is to be installed at a place where coal is not available, then care should be taken that adequate facilities exist for the transportation of coal.

(2) Availability of water

Availability of water is required for the condenser, boiler… Therefore, such a plant should be located at the bank of a river or near a canal to ensure the continuous supply of water.

(3) Transportation facilities

A modern steam power station often requires the transportation of material and machinery. Therefore, adequate transportation facilities must exist to carry material and as well as for the workers, employees, who are working in the plant. i.e., the plant should be well connected to other parts of the country by rail, road, etc..,

(4) Cost and type of land

The steam power station should be located at a place where land is cheap and further extension, if necessary, is possible. Moreover, the bearing capacity of the ground should be adequate so that heavy equipment could be installed.

(5) Nearness to load centers

In order to reduce the transmission cost and transmission line losses, the plant should be located near the center of the load.

(6) Distance from the populated area

As huge amount of coal is burnt in a steam power station, therefore, smoke and fumes pollute the surrounding area. This necessitates that the plant should be located at a considerable distance from the polluted area.

(7) Labour supplies

Skilled and unskilled labourers should be available at reasonable rates near the site of the plant.

(8) Ash disposal

Ash is the main waste product of the steam power plant, which may pollute the surrounding areas. Hence some suitable means should be provided for the disposal of ash.

1.5 Single Line Diagram of Thermal Power Station

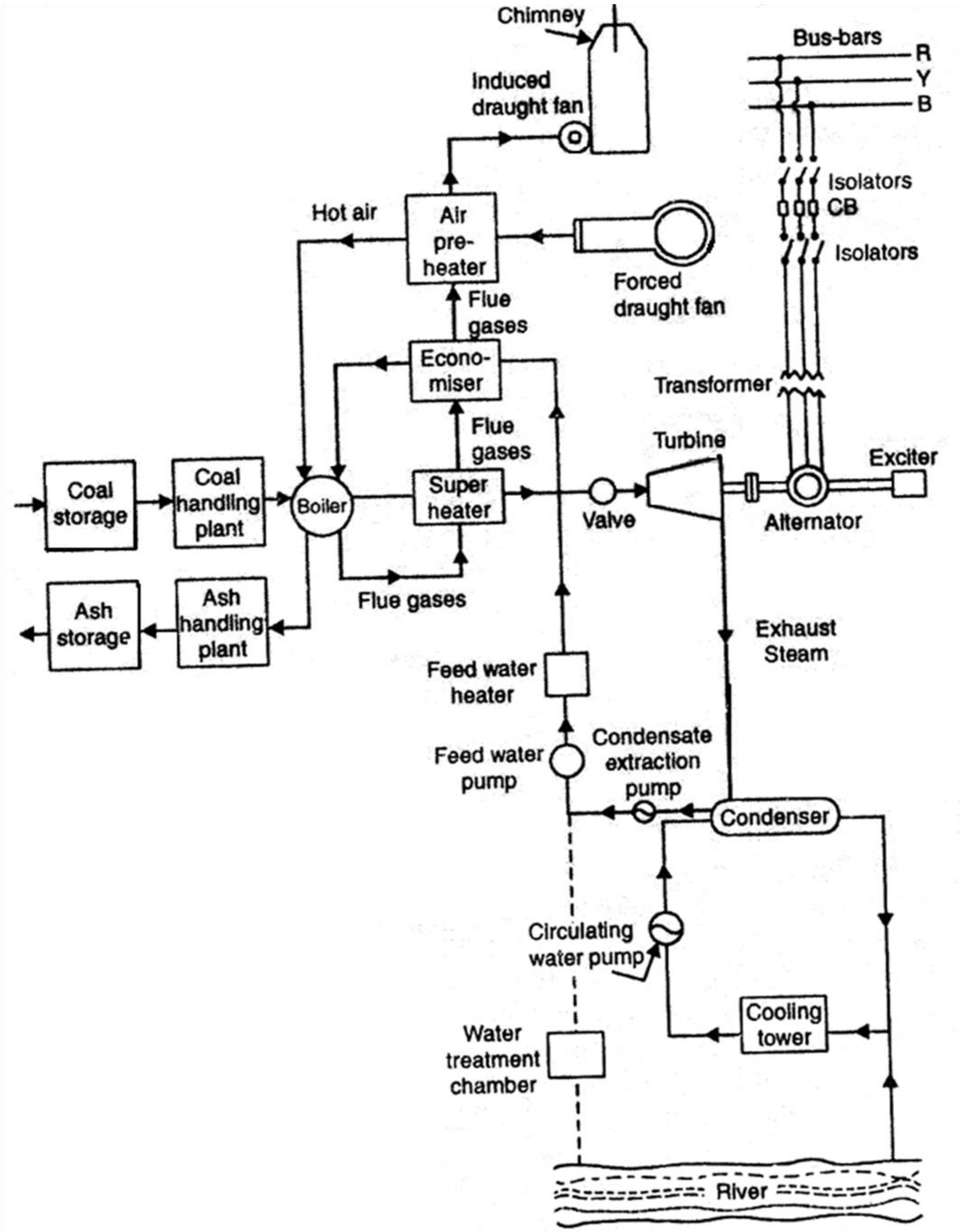


Fig 1.3: Single Line Diagram of Thermal Power Station

1.6 Brief description of Thermal power station

Although steam power station simply involves the conversion of heat of coal combustion in to electrical energy, yet it includes many arrangements for proper working and efficiency. The schematic arrangement of a modern steam power station is shown in the above figure. The whole arrangement can be divided into the following stages.

1. Coal and ash handling plant.
2. Steam generating plant.
3. Steam turbine.
4. Feed water.
5. Cooling arrangement.

1. **Coal and ash handling plant:**The coal is transported to the power station by road or rail andis stored in the coal storage plant. Storage of coal is primarily a matter of protection against coal strikes, failure of transportation system and general coal shortages. From the coal storage plant, coal is delivered to the coal handling plant where it is pulverized (*i.e.*, crushed into small pieces) in order to increase its surface exposure, thus promoting rapid combustion without using large quantity excess air. The pulverized coal is fed to the boiler by belt conveyors. The coal is burnt in the boiler and the ash produced after the complete combustion of coal is removed to the ash handling plant and then delivered to the ash storage plant for disposal. The removal of the ash from the boiler furnace is necessary for proper burning of coal.

Fuel handling system:

In general, majority of the thermal plants are all over the world uses coal as fuel. In a thermal power station half of the total station's operating cost is on account of coal, and therefore problems of coal handling for a thermal station requires careful considerations.

Function:-

The function of coal handling system is, to move coal from a receiving point (coal available areas) to the firing equipment.

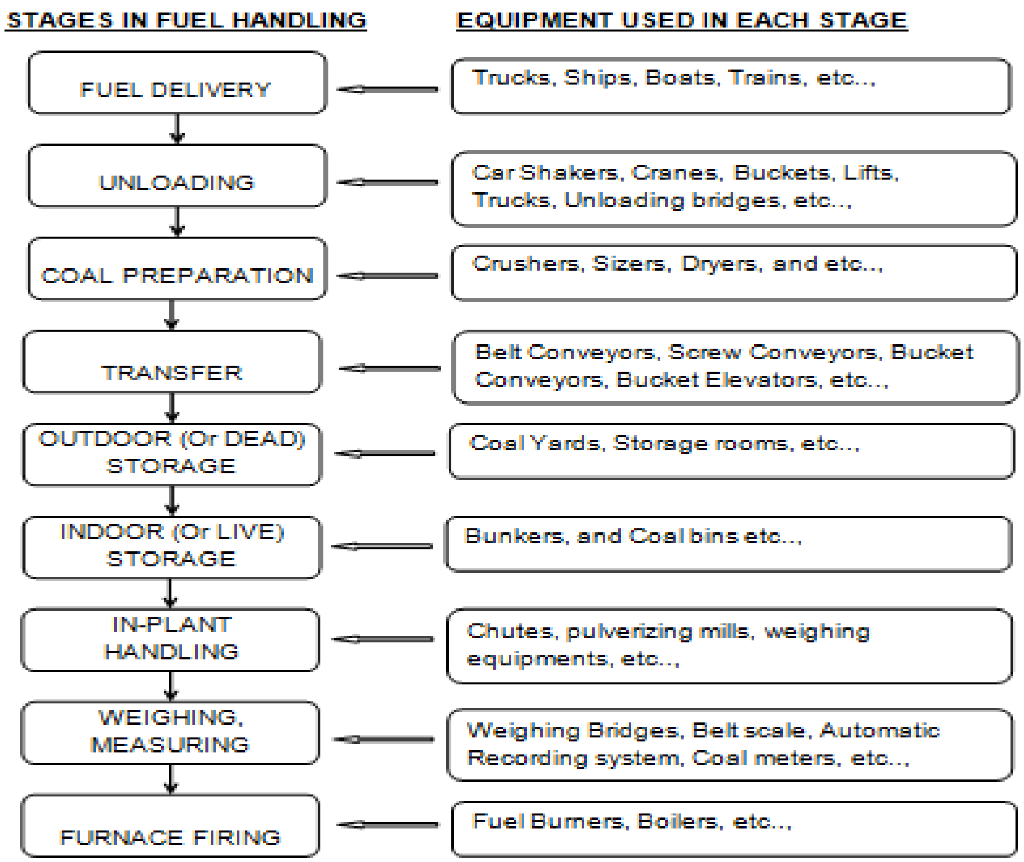
Requirements:-

i) It should be reliable, simple, and requiring a minimum of operatives and minimum of maintenance.

ii) The plant should be able to deliver the required quantity of coal at destination during peak periods.

The coal handling plant consists of various stages are shown follows. All of these steps may or may not follow in all the plants. It depends on the type of plant, load factor and the plant capacity.

FUEL HANDLING SYSTEM:



- **Delivery of Coal:-**

Coal may be delivered by sea or river, rail or road. Selecting of proper method of coal supply from coal mines to the power station depends upon system capacity, and plant location with respect to the facility available nearer to the plant.

- **Un Loading:-**

In Un-loading, the choice of equipment will depend on how the coal is received. Equipments used for unloading are Car Shakers, Cranes, Buckets, Lifts,Unloading bridges, Trucks, etc..,

- **Coal Preparation:-**

Preparation of coal before feeding to the combustion chamber becomes necessary only if the un-sized coal is brought to the site and sizing is desirable for the purpose of storage or firing. It has the equipments like Crushers, Sizers, Dryers, and etc..,

- **Transfer:-**

This means carrying coal from unloading point to the storage site, from where it is discharged to the firing equipment. Equipments used for this purpose are Belt Conveyors, Screw Conveyors, Bucket Conveyors, Bucket Elevators, etc..,

- **Outdoor (or Dead) Storage:-**

Storage of coal is essentially for two reasons,

1) In order to supply coal continuously to the plant operation even in emergency situations like strikes in coal mines, failure of transportation system, general coal shortages, etc..,
2) In order to take the advantage of seasonal market conditions, i.e.,when prices are low coal can be purchased and stored for future use.

In outdoor storage, coal can be stored to meet the coal requirements up to 15 days to One month of the plant operation, with respect to the distance between the plant and coal mines.

Anyway storage of coal for long periods is not advantageous because it may cause damage to the quality of the coal.

- **Indoor (or Live) Storage:-**

This storage constitutes coal requirements of the plant for a single day. The live storage can be provided with Bunkers and coal bins.

- **In-Plant handling:-**

This refers to handling of coal between storage to the firing equipment. Pulverization of fuel is done in this section. This requires various equipments like Chutes, Pulverizing mills, Weighing equipments, etc..,

- **Weighing, measuring:-**

A correct measurement of coal enables one to have an idea of total quantity of coal delivered at the site and whether or not proper quantity has been burned as per load on the plant.

This uses equipment like Weighing Bridges, Belt scale, automatic recording system, Coal meters, etc..,

- **Furnace Firing:-**

Fuel is burnt in a confined space called the furnace. Coal combustion takes place in this stage. The general equipment used is Fuel burner for this operation.

Pulverization of coal:

Pulverization is the process of crushing the coal in to a fine powder. Especially all the Indian coals contain 20-40% of ash content and the coal demand varies according to the plant capacity. For example a 400MW capacity plant requires about 5000-6000 tons of coal every day. High ash content of coal reduces the boiler thermal efficiency. Hence the pulverization is needed in order to utilize the coal effectively and by that to improve overall plant efficiency.

Advantages:-

1) Surface exposure is increased, resulting in rapid combustion without requiring large amount of excess air.
2) Wide varieties of coal, even low grade of coal can be used, since it is used in powdered form.
3) The rate of feed of the fuel can be regulated properly and easily, resulting in fuel economy.
4) Higher boiler efficiency is achieved due to almost complete combustion of the fuel.
5) Ash removing problems are reduced.
6) The firing process in boiler can be started rapidly.
7) Fluctuations of load can be easily met. (Fast response to load changes).
8) Pulverized fuel increases over all plant efficiency, so we can construct larger capacity plants to meet peak loads.

Dis-Advantages:-

1) Coal preparation plant is required which makes the installation expensive in initial cost.
2) There is risk of explosion as coal is burnt like gas. Hence, skilled personnel are required.

However, the pulverized fuel firing has some disadvantages, the advantages of using pulverized fuel outweigh the disadvantages, and hence all modern plants use pulverized fuel.

2. **Steam generating plant:**The steam generating plant consists of a boiler for the production ofsteam and other auxiliary equipment for the utilization of flue gases.

(i) **Boiler:**The heat of combustion of coal in the boiler is utilized to convert water into steam at high temperature and pressure. The flue gasses from the boiler make their journey through super heater, economizer, and air pre-heater and are finally exhausted to atmosphere through the chimney.The boilers are classified into 2 types(*a*) Water tube boilers(***b***) Fire tube boilers

a) **Water tube boilers:**In a water tube boiler water flows through the tubes and the hot gases of combustion flows out to these tubes. For central steam power plants of large capacity water tube boilers are used, since water tube boilers have number of advantages over fire tube boilers as mentioned below.

b) **Fire tube boilers:**In a fire tube boiler, the hot products of combustion pass through the tubes surrounded by water. Fire tube boilers are limited to low cost, small size and low pressure plants, since it's operation is uneconomical for huge plants.

(ii) **Super-heater:**The steam produced in the boiler is wet and is passed through a super heater where it is dried and super heated by the flue gases on their way to chimney. By using this super heating process, we can improve the overall efficiency of the plant by keeping the steam at high pressure and temperature before expanded in the turbine. The super heated steam from the super heater is fed to the steam turbine through the main valve as shown in the figure.

Super heaters are mainly classified into two types

(a) Radiant super heater ***(b)*** Convection super heater

- The radiant super heater is placed in the furnace between the water walls and receives heat from the burning fuel through radiation process.
- The convection super heater is placed in the boiler tube bank and receives heat from flue gases entirely through the convection process. It has the advantage that temperature of super heater increases with the increase in steam output

(iii) **Economizer:**An economizer is essentially a feed water heater and drives heat from the flue gases for this purpose. The feed water is fed to the economizer before supplying to the boiler. The economizer extracts a part of heat of flue gasses to increase the feed water temperature.

Advantages:

i) Economizer raises boiler efficiency by 10-12%.
ii) Causes saving in fuel consumption about 5-15%.
iii) Reduces temperature stresses in boiler as a result of higher feed water temperature.

Dis-advantages:-

i) Increases the installation cost of the plant.
ii) Maintenance and regular cleaning is required, also additional requirement of space.

Air preheater: An air preheater increases the temperature of the air supplied for coal burning by deriving heat from flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through air preheater before supplying to the boiler furnace. The air preheater extracts heat from flue gases and increases the temperature of air used for coal combustion. The principal benefits of preheating the air are increased thermal efficiency and increased steam capacity per square meter of boiler surface.

These are classified into two types

a) Recuperative type***(b)*** Regenerative type

- The recuperative type air-heater consists of a group of steel tubes. The flue gases are passed through the tubes while the air flows externally to the tubes. Thus heat of flue gases is transferred to air.

- The regenerative type air pre-heater consists of slowly moving drum made of corrugated metal plates. The flue gases flow continuously on one side of the drum and air on the other side. This action permits the transference of heat of flue gases to the air being supplied to the furnace for coal combustion.

3. **Steam turbine:**The dry and super heated steam from the super heater is fed to the steam turbine through main valve. The heat energy of steam when passing over the blades of the turbine is converted in to mechanical energy.

   Steam turbines are classified into two types**(*i*)** Impulse turbines
   (*ii*) Reactions turbines
   - In an impulse turbine, the steam expands completely in the stationary nozzles (or fixed blades), the pressure over the moving blades remaining constant. In doing so, the steam attains a high velocity and impinges against the moving blades. This results in the impulsive force on the moving blades which sets the rotor rotating.
   - In a reaction turbine, the steam is partially expanded in the stationary nozzles, the remaining expansion n takes place during its flow over the moving blades.
4. **Alternator:**The steam turbine is coupled to an alternator. The alternator converts mechanicalenergy of turbine into electrical energy. The electrical output from the alternator is delivered to the bus bars through transformer, circuit breakers and isolators
5. **Feed water:**The steam after utilized by turbine is exhausted to the condenser which condenses the exhausted steam by means of cold water circulation. The condensate from the condenser is used to feed water to the boiler. This feed water on its way to the boiler is heated by feed water heaters and economizer. After heated by feed water heater, the feed water is passed to economizer through de-aerator. The function of de-aerator is to reduce dissolved oxygen content in the feed water. This helps in raising the overall efficiency of the plant.

6. **Cooling arrangement:**In order to improve the efficiency of the plant, the steam exhaustedfrom the turbine is condensed by means of a condenser

Condenser : A Condenser is a device which condenses the steam at the exhaust of turbine. Condensation is the processof converting steam in to water. It will improve the overall plant efficiency.

i) It creates a very low pressure at the exhaust of turbine, thus permitting expansion of the steam in the prime mover to a very low pressure. This helps in converting heat energy of steam into mechanical energy in the prime mover.

ii) To convert steam in to condensate, thus Condensed steam can be used as feed water to the boiler.

There are two types of Condensers, namely a) Jet Condenser. b) Surface condenser.

a) **Jet condenser:** In a Jet condenser, Cooling water and exhausted steam are mixed together. Therefore, the temperature of cooling water condensate is the same when leaving the condenser. i.e., heat transfer is by direct conduction.

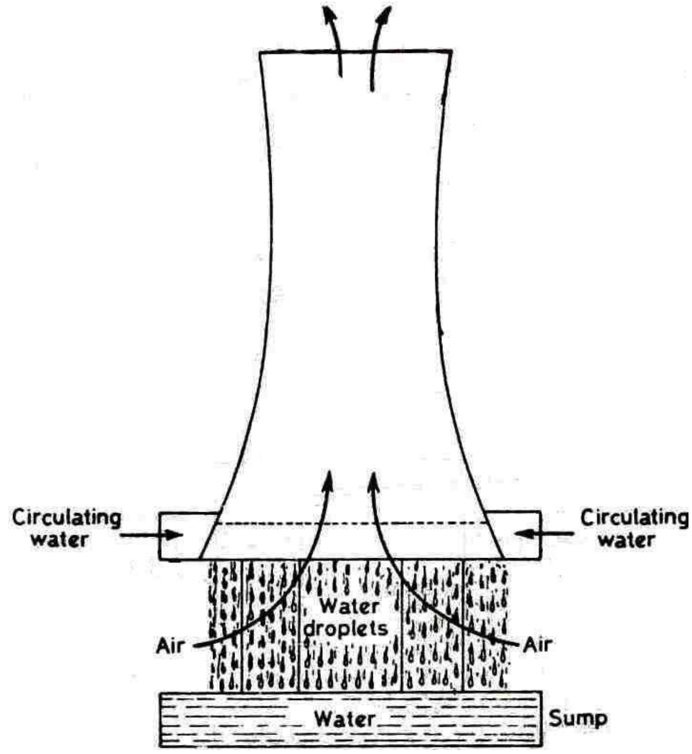
b) **Surface condenser:** In a surface condenser, there is no direct contact between cooling water and exhausted steam. If consists a group of horizontal tubes enclosed in a cast iron shell .Jet type condensers are not used, as steam mixes with cooling water and the condensate cannot be used as feed water, and hence, Surface condensers are most commonly used in all modern power plants.

7. **Cooling tower:** The water used for cooling the exhaust steam (i.e., converting in to condensate) in the condenser, is circulated from natural sources like a lake or a river, by means of circulating water tubes and is returned back to the source.

Need for a Cooling Tower:

If sufficient quantity of water is not available, i.e., the natural resources like river, lake are far away from the power plant, then the circulating water should be cooled and used again.

In such cases, water is taken from the natural sources to a tank by pumps and stored. It is then pumped in to the condenser, where it absorbs latent heat from the exhaust steam and becomes hot, and then the hot water is passed to a cooling tower to make this hot circulating water cool to use again.



Operation: A cooling tower is a structure usually made of concrete. The hot water from the condenser is fed to the tower and is allowed to fall as droplets in to a sump and air passes through these droplets as shown in the figure. The air flows from bottom of the tower and exhaust to the atmosphere after effective cooling.

8. **Water Treatment Plant:** Boilers require clean and soft water for longer life and better efficiency.However, the source of boiler feed water is generally a river or lake which may containsuspended and dissolved impurities, dissolved gases etc. Therefore, it is very important that water is first purified and softened by chemical treatment and then delivered to the boiler.The water from the source of supply is stored in storage tanks.

9. **Electrical equipment**

A modern power station contains various electrical equipments.

(*i*) Alternators:Each alternator is coupled to a steam turbine and converts mechanical energyof the turbine into electrical energy. The alternator may be hydrogen or air cooled. Thenecessary excitation is provided by means of main and pilot exciters directly coupled to thealternator shaft.

(*ii*) Transformer:A generating station has different types of transformers, *viz.*,

(*a*) Main step-up transformers which step-up the generation voltage for transmission ofpower.

(*b*) Station transformers which are used for general service (*e.g.*, lighting) in the powerstation.

(*c*) Auxiliary transformers which supply to individual unit-auxiliaries.fault

(*iii*) Switchgear: It houses such equipment which locates the on the system and isolate thefaulty part from the healthy section. It contains circuit breakers, relays, switches and othercontrol devices.

1.7 EFFICIENCY OF A THERMAL PLANT:

The generation of electrical power in thermal power plants includes basically two states.

Stage-I:- Conversion of heat energy of coal combustion into mechanical energy of turbine.

Stage-II:-Conversion of mechanical energy of turbine into electrical energy by using a Generator or an Alternator.

By using this concept the efficiency of a thermal power plant can be defined as follows.

1) Thermal efficiency. 2) Electrical efficiency. 3) The overall Plant efficiency.

1) Thermal efficiency:-

The ratio of heat equivalent of mechanical energy transmitted to the turbine shaft to the heat of combustion of coal is known as "Thermal Efficiency" of steam power station.

$$\text{Thermal efficiency } (\eta_{\text{Thermal}}) = \frac{\text{Heat equivalent of mechanical energy transmitted to turbine shaft}}{\text{Heat of coal combustion}}$$

2) Electrical Efficiency(or) Efficiency of generation:-

The ratio of heat equivalent of electrical output to the heat equivalent of mechanical energy transmitted to turbine shaft is known as "Electrical Efficiency" of steam power plant.

$$\text{Electrical efficiency } (\eta_{Electrical}) = \frac{\text{Heat equivalent of electrical output}}{\text{Heat equivalent of mechanical energy transmitted to turbine shaft}}$$

3) Ov

The ratio of heat equivalent of electrical output to the heat of combustion of coal is known as "Overall Efficiency" of steam power station.

$$\text{Overall efficiency } (\eta_{Overall}) = \frac{\text{Heat equivalent of electrical output}}{\text{Heat of combustion of coal}}$$

Hence,**Overall Plant efficiency=Thermalefficiency × Electricalefficiency.**

NOTE:In general, the overall thermal efficiency of thermal power plant is 18 to 24%.

1.8 Methods of improving Thermal Efficiency of Thermal Power Plant

The overall efficiency of a steam power station is quite low(about 20%).As can be seen the main loss is due to heat rejected to the condenser ,which is unavoidable due for thermodynamic reason ,viz. that heat cannot be converted into mechanical energy without a drop in temperature and the steam in the condenser is at lowest temperature.Some of the methods are as follows:

- Pulverizing the fuel especially when the fuel is of low calorific value. This helps in complete combustion of fuel.
- Reheating the steam between the various stages of turbine.
- Breeding of steam turbines, this means taking out a small quantity of steam from turbine at certain points and circulating it around the feed water pipe to raise the temperature of the feed water.
- Proper deaeration of condensate and raw make-up water to avoid formation of scale on the inner walls of the boiler tubes.(scales interferes the heat transfer)
- Cooling water passing through condenser tubes should be properly treated (by addition of chlorine) to avoid growth of scale formation.(The growth of scale sticking to the walls of tubes is harmful because it interferes heat transfer)
- Initial and final steam conditions supplied to the turbine are important. Stations employing higher pressure and higher temperatures are more efficient.

Assignment-Cum-Tutorial Questions

SECTION – A:-

1. Pulverized coal is

(A) Coal free from ash (B) non-smoking coal

(C) Coal which burns for long time **(D) coal broken into fine particles**

2. Power plants using coal work closely on known which of the following cycle ?

(A) Otto cycle (B) Binary vapor cycle (C) Brayton cycle **(D) Rankine cycle**.

3. Out of the following which one is conventional source of energy?

(A) Tidal power (B) Geothermal energy

(C) Nuclear energy (D) Wind power.

4. Overall thermal efficiency of a steam power station is in the range

(A) 18-24% **(B) 30-40%** (C) 44-62% (D) 68-79%.

5. Standard frequency usually for electric supply is

(A) 50 Hz (B) 60 Hz (C) 50 to 60 Hz (D) 50 to 55 Hz.

6. In a super heater

(A) Pressure rises and temperature drops

(B) Temperaturerises and Pressure drops

(C) Temperature rises and Pressure remains unchanged

(D) Pressure rises and temperature remains the same

7. The coal that has highest ash content is

(A) Lignite (C)Coking coal

(B) Bituminous coal (D) Steam coal

8. Equipment used for pulverizing the coal is

(A) Hopper (B) Stoker **(C) Ball mill** (D) Burner

9. Which of the following enters the super heater of a boiler?

(A) Cold water (B) Hot water **(C) Wet steam** (D) Super-heated steam.

10. Most of the generators in thermal power plants run at

(A) 3000 rpm (B) 1500 rpm (C) 1000 rpm (D) 750 rpm.

11. Most of the steam turbo-alternators are wound for

(a) 2 poles (b)10 poles (c)20poles (d)6 poles

12. Large size steam plants are suitable for

(a) Peak load (b) Intermediate load **(c) Base load** (d) Both a & c

13. Forced draught fans are used to

(a) Cool the steam let out by the turbine in thermal station
(b) Cool the hot gases coming out of the boiler
(c) Force the air inside the coal furnace
(d) Control the heat generated in a nuclear reactor

14. The average ash content inIndian coals is around

(a) 5% (b) 10% **(c) 20%** (d) 30%

15. In a steam power plant water is used for cooling purposes in

(a)Economizer **(b) Condenser** (c)Super heater (d)none

16. Steam pressure used in steam power plants in india is in the range of

(a)110-170 kg/cm^2 (b)40-80 kg/cm^2 (c)20-40kg/cm^2 (d)250 kg/cm^2

17. The following is the correct order of energy conversion in thermal power plants

(A) Chemical energy – Mechanical energy – Electrical energy
(B) Mechanical energy – Chemical energy – Electrical energy
(C) Wind energy – Mechanical energy – Electrical energy
(D) Heat energy – Electrical energy – Mechanical energy

18. As steam expands in turbine

(A) its pressure increases **(B) its specific volume increases**
(C) its boiling point increases (D) its temperature increases.

19. A 100 MW thermal power-plant will consume nearly how many tonnes of coal in one hour ?

(A) 50 tonnes (B) 150 tonnes (C) 1500 tonnes (D) 15,000 tonnes.

20. A coal fired steam power station working at a plant load factor of 80% has one 500MW generating unit. If the heat content of coal is 2 kWh/kg, the overall plant efficiency is 40% and a train load of coal is 2000 metric tons, then the number of trains required daily for the plant is

(a) 1 (b) 6 **(c) 10** (d) 24

SECTION – B:-

1. How does air preheater save fuel in TPS?
2. Why thermal plants are always located by the side of a river or lake?
3. What is running speed of a turbo-alternator in a central thermal power station?
4. What is the function of condenser in steam power plant?

5. Give the expression for overall efficiency in TPS?
6. List out the advantages & disadvantages of thermal power station?
7. What factors are taken into account while selecting the site for a thermal power station?
8. Explain the single line diagram of thermal power station?
9. Describe the functions of various components of thermal power station?
10. Define thermal efficiency and what are the methods to improve the thermal efficiency?
11. Distinguish between super-heater and economizer?
12. Why pulverized coal is preferred?
13. What is feed water? What are the problems due to impurities in feed water?
14. What is water tube boiler? What are its merits as well as demerits of water tube boilers?

15. What arethe steps in involved in coal handling plant?

16. A steam power station has an overall efficiency of 20% and 0•6kg of coal is burnt per kWh of electrical energy generated. Calculate the calorific value of fuel. [**Ans :7166.67 kcal/kg]**

17. A thermal station has an overall efficiency of 21% and 0.5kg of coal is burnt per kWh of generated energy. Determine the calorific value of coal. **[Ans :8190.47 kcal/kg]**

18. A steam power station spends Rs.30 lakhs per annum for coal used in the station. The coal has a calorific value of 5000 kcal/kg and costs Rs. 300 per ton. If the station has thermal efficiency of 33% and electrical efficiency of 90%, find the average load on the station. **[Ans : 1971 KW]**

19. A 75 MW steam power station uses coal of calorific value of 6400 kcal/kg. Thermal efficiency of the station is 30% while electrical efficiency is 80%. Calculate the coal consumption per hour when the station is delivering its full output. [**Ans : 48687 kg]**

20. A thermal station has the following data

Max.demand	=	20,000kW ;	Load factor = 40%
Boilerefficiency	=	85% ;	Turbine efficiency = 90%
Coalconsumption	=	0•9kg/kWh ;	Cost of 1 ton of coal= Rs.300

Determine (i) thermal efficiency and (ii) coal bill per annum. **[Ans :Rs 1,89,21,600]**

21. A 60 MW steam power station has a thermal efficiency of 30%. If the coal burnt has a calorific value of 6950 kcal/kg, calculate : (i) the coal consumption per kWh, (ii)the coal consumption per day. **[Ans: i. 0.413 kg ii. 238 tonnes]**

SECTION – C:-

GATE/IES QUESTIONS

1. In a Rankine cycle, regeneration results in higher efficiency because [GATE-2003]

(a) Pressure inside the boiler increases

(b) Heat is added before steam enters the low pressure turbine

(c) Average temperature of heat addition in the boiler increases

(d) Total work delivered by the turbine increases

2. The efficiency of superheat Rankine cycle is higher than that of simple Rankine cycle because [GATE-2002]

(a) The enthalpy of main steam is higher for superheat cycle

(b) The mean temperature of heat addition is higher for superheat cycle

(c) The temperature of steam in the condenser is high

(d) The quality of stem in the condenser is low

3. Boiler rating is usually defined in terms of [GATE-1992]

(a) Maximum temperature of steam in Kelvin

(b) Heat transfer rate in KJ/hr

(c) Heat transfer area in metre2

(d) Steam output in kg/hr

4. Air pollution due to smoke around a thermal power station can be re duced by installing

(A)Induced draft fan [IES-2016]

(B) Super heater

(C) Economizer

(D)Electrostatic precipitator

5. The thermal and electrical efficiencies of a 100 MW steam station are respectively 30% and 92%. The coal used has a calorific value of 6400 kcal/kg. For the supply of full-load rated capacity the coal consumption in kg/hour would be approximately [IES-2014]

(a) 24340

(b) 32450

(c) 48690

(d) 64910

6. In a thermal power station, a typical heat balance sheet, for a large turbine and surface condenser taken together, is the percentage distribution of heat energy in : [IES-2011]

1 Work done or thermal efficiency

2 Friction and windage loss

3. Heat to circulating water

4. Heat in condensate to be retained to the boiler.

The percentage amount of heat in the heads Stated above in the descending order is .

(a) 3, 4, I and 2
(b) 2, 1.4 and 3
(c) 3, 1, 4 and 2
(d) 2, 4, l and 3

7. A thermal electric power plant produces 1000 MW of power. If the coal releases 900 x 107 kJ/h of energy, then what is the rate at which heat is rejected from the power plant?

[IES-2009]

(a) 500 MW (b) 1000 MW **(c) 1500 MW** (d) 2000 MW

8. A thermoelectric engine which consists of two dissimilar electric conductors connected at two junctions maintained at different temperatures, converts [IES-2006]

(a) Electric energy into heat energy **(b) Heat energy into electric energy**
(c) Mechanical work into electric energy (d) Electric energy into mechanical work

9. In a surface condenser used in a steam power station, under cooling of condensate is undesirable at this would

[IES-1996]

(a) Not absorb the gases in steam.
(b) Reduce efficiency of the plant.
(c) Increase the cooling water requirements.
(d) Increase thermal stresses in the condenser.

10. In thermal power plants, coal is transferred from bunker to the other places by [IES-1992]

(a) Hoists **(b) conveyors** (c) cranes (d) lifts

UNIT-II

Nuclear Power Stations

Learning Objectives:

- To understand the working principle of nuclear power plant.
- To impart the knowledge of Nuclear fuels.
- To familiarize the students with the various components of a nuclear reactor and its classification
- To understand the working of PWR, BWR and FBR
- To gain the knowledge on radiation hazards

Syllabus:

Nuclear Power Stations

Working principle, Nuclear fuels. Nuclear reactor Components: Moderators, Control roads, Reflectors and Coolants. Types of Nuclear reactors and brief description of PWR, BWR and FBR. Radiation: Radiation hazards and Shielding.

Learning outcomes:

Students will be able to

- ✓ Explain the working principle of nuclear power plant.
- ✓ Explain the different materials used in a Nuclear power station
- ✓ Describe the functions of various components of Nuclear reactor
- ✓ Classify the nuclear reactors
- ✓ Describe the construction and working of PWR, BWR and FBR.
- ✓ Discuss various radiations that are emitted from a nuclear fission process

2.1 Nuclear Power Station

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

In nuclear power station, heavy elements such as Uranium(U-235) or Thorium (Th-232) are subjected to nuclear fission in a special apparatus known as a reactor. The heat energy thus released is utilized in raising steam at high temperature and pressure. The steam runs the steam turbine which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

Importance of a nuclear power plant:

The need of nuclear power plant lies in the fact that the hunger for electricity is virtually unending and after each decade the world demand for electricity is doubled owing to booming increase in the population and industrial growth. Moreover, the reserves of fossil fuels i.e., coal, oil and gas are fast depleting. Thus there is a tendency to seek alternative source of energy and the nuclear power is the only alternative source, which can meet the future energy demands of the world.

1) One of it's main attraction is the huge amount of energy that can be released from a small quantity of active material. The energy obtainable by completely burning of 1kg uranium would give energy equivalent to 3000-4000 tons of high grade coal.
2) The cost of fuel in conventional thermal power plant comes about 40-50% of the total cost per kWh of generated power, while in nuclear power plants it varies from 4-20% depending upon the enrichment of Uranium-235.

2.2 Advantages & disadvantages of nuclear power plants:

1) The amount of fuel required is quite small, & hence there is no problem of transportation, storage and etc..,

2) These plants need less area as compared to any other type of plants of same capacity. For example, for a 2000MW capacity, nuclear power plant requires 80acres of land where as coal fired steam plant requires 250 acres of the land.
3) The plant can be located near to the load centers, so, the cost of transmission and distribution is reduced.These plants are most economical in large capacity.
4) Nuclear power plant reduces the demand for coal, oil, & gas etc.., fossil fuels.The operation cost (for fuel) is quite low.
5) The plant can be always operated as a base load plant, for which it ensures reliable operation.

Disadvantages:

The demerits of nuclear power plants over other conventional power plants are,

1) Initial cost is very high.
2) The fission by-products are generally radio-active and may cause a dangerous amount of radio-active pollution.
3) This plant is not well suited for varying loads.
4) The fuel used is very expensive.
5) Salaries of maintaining staff is very high, since nuclear power plant requires very high skilled and highly qualified engineers to maintain the plant.
6) The disposal of the products, which are radioactive, is a big problem. They have either to be disposed off in a deep trench (deep ditches in ground), or in a sea away from sea-shore or in to a river, which causes water contamination.
7) The chief disadvantage of a nuclear power plant is that, in case of an accident, the disaster is almost like explosion of an atom bomb causing extensive damage to the mankind, animals and environment.
8) The cooling water requirements of a nuclear power plant are very heavy (more than twice the water required for the same size coal-fired steam power plant), hence cooling towers required for nuclear power plants are larger and costlier than those for conventional steam power plants.

2.3 SELECTION OF SITE FOR A NUCLEAR POWER PLANT

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

1) Availability of water supply:-

As sufficient water is required for cooling etc.., therefore, the site selected for the plant should be neara river or lake or by seaside.

2) Distance from populated area:-

In view of danger of radio-activity in the vicinity of the plant, a nuclear station should be as far as possible away from thickly populated areas.

3) Nearness to load centers:-

The plant should be located near to load centers to reduce transmission cost and transmission line losses.

4) Disposal of waste:-

The site selected for these power plants should have adequate space and arrangement for the disposal of radio-active waste. i.e., it may be nearer to a sea or river or there should be a provision to dispose waste into deep ditches.

5) Transportation facilities:-

As nuclear power plant needs very little fuel, hence it does not require direct rail facilities for fuel transport.However, transportation facilities are required during the construction stage and as well as for the workers, employees working in the plant.

6) Type of land:-

The land must be strong to support the heavy weighted reactors and it should be cheap in cost.

Hence from the factors mentioned above it is obvious that ideal choice for a nuclear plant would be nearer to a sea, river or lake and away from thickly populated areas.

2.4 ATOMIC FUELS:

Natural Uranium (U-235), Enriched Uranium (U-238),Thorium (Th-232) and Plutonium (Pu-239) are the main atomic fuels. It has been estimated that uranium alone contains far more energy than all the world's resources of coal and petroleum put together.

The splitting of 1kg of Uranium (U-235) atoms yields 25×10^6 kWh in heat form, which when converted into electrical energy by conveying it to steam turbine through molten metal and heat exchanger results in about 6.5×10^6 kWh of electrical energy.

2.5 ATOMIC NUMBER & MASS NUMBER:

The number of protons (positive charges) inside the nucleus or the number of electrons (negative charges) outside the nucleus of an atom is known as atomic number. It is represented by symbol'Z'.

The total number of protons and neutrons in an atomic nucleus is called mass number and is denoted by symbol 'A'.

The number of neutrons in a given atomic nucleus = A-Z.

So, an element is identified as, ${}^{A}_{Z}X$.

Where, A = Mass number (or) Atomic weight.

Z = Atomic number.

X = chemical symbol of the element.

Ex: - ${}^{235}_{92}U$, ${}^{139}_{56}Ba$,etc..,

2.6 NUCLEAR REACTIONS:

Nuclear reactions are of two types, namely

i) Nuclear fusion reaction.

ii) Nuclear fission reaction.

Which, releases high amount of heat energy.

NUCLEAR FUSION REACTION:-

Nuclear fusion is the reaction in which two or more small nuclei combine together to form a new element with heavy nuclei.

$$ {}^{2}_{1}Duterium + {}^{3}_{1}Tritium = {}^{4}_{2}He + {}^{1}_{0}n + Energy $$

<u>Example:</u>

→ Hydrogen bomb is developed by using the concept of nuclear fusion.

NUCLEAR FISSION REACTION:-

The splitting of a heavy nucleus into two or more smaller nuclei when bombarded by certain particles is termed as nuclear fission.

In nuclear plants fission is done by bombarding uranium nuclei with slow moving neutron. This process of fission gives two or more smaller nuclei and is always accompanied by the ejection of two or more neutrons and liberation of vast energy.

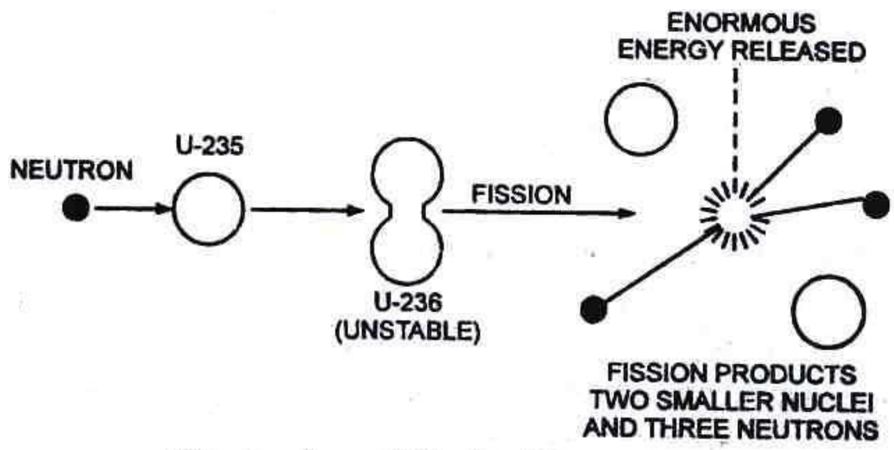


Illustration of Fission Process

A, given large nucleus can fission in many ways forming a variety of products. Thus the fission of U-235 occurs about 35 ways.

Example: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{56}Ba + ^{94}_{36}Kr + 3^{1}_{0}n + Energy$

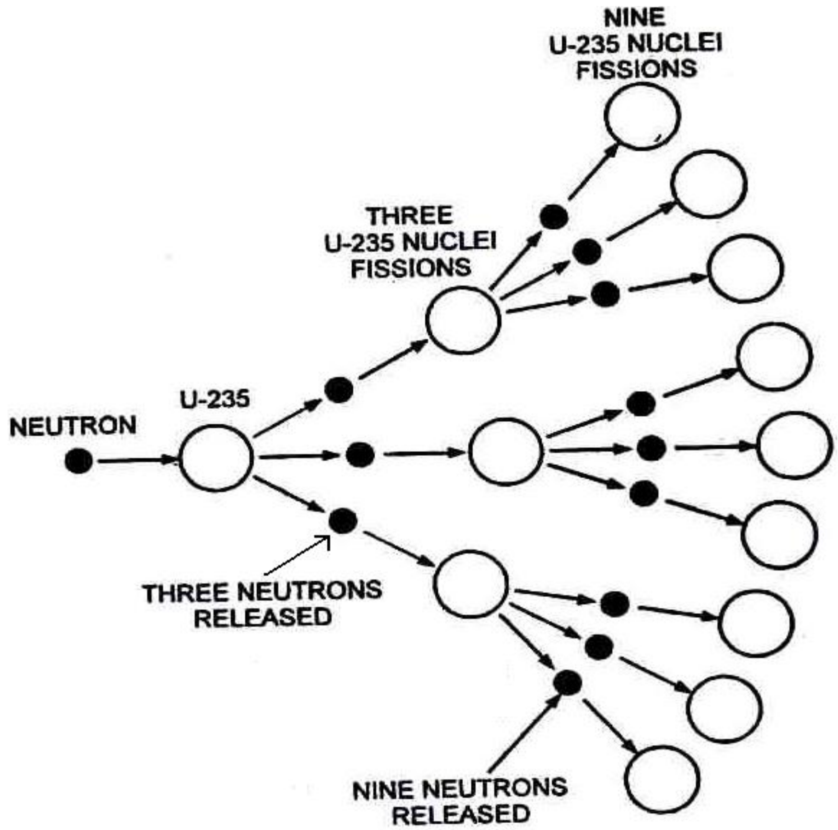
⟶ Atom bomb is developed by using the concept of nuclear fission.

2.7 NUCLEAR CHAIN REACTION:

Nuclear chain reaction may be defined as a fission reaction where the neutrons from a previous step continue to propagate and repeat the reaction.In nuclear plants nuclear fission is done by bombarding uranium nuclei with slow moving neutrons.

This splits uranium nuclei with the release of huge amount of energy and emission of neutrons (called fission neutrons) and these fission neutrons causes further fission.

If this process continues, then in a very short time, huge amount of energy will be released. This is known as chain reaction. This chain reaction is controlled by using control rods in the reactor.



Explanation:-

We know that U-235 nucleus when hit by a neutron undergoes the reaction

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{56}Ba + ^{94}_{36}Kr + 3^{1}_{0}n + Energy$$

Each of the three neutrons produced in the reaction strikes another U-235 nucleus, thus causing nine subsequent reactions. These nine reactions, in turn further give rise to twenty seven reactions. This process of propagation of the reaction by multiplication in threes at each fission is called as chain reaction.

2.8 SCHEMATIC ARRANGEMENT OF A NUCLEAR POWER PLANT

The concept of nuclear power generation is much similar to that of conventional steam power generation. The difference lies only in the steam generation part i.e., coal or oil burning furnace and the boiler are replaced by nuclear reactor and heat exchanger. The schematic arrangement of a nuclear power plant is shown in the following figure.

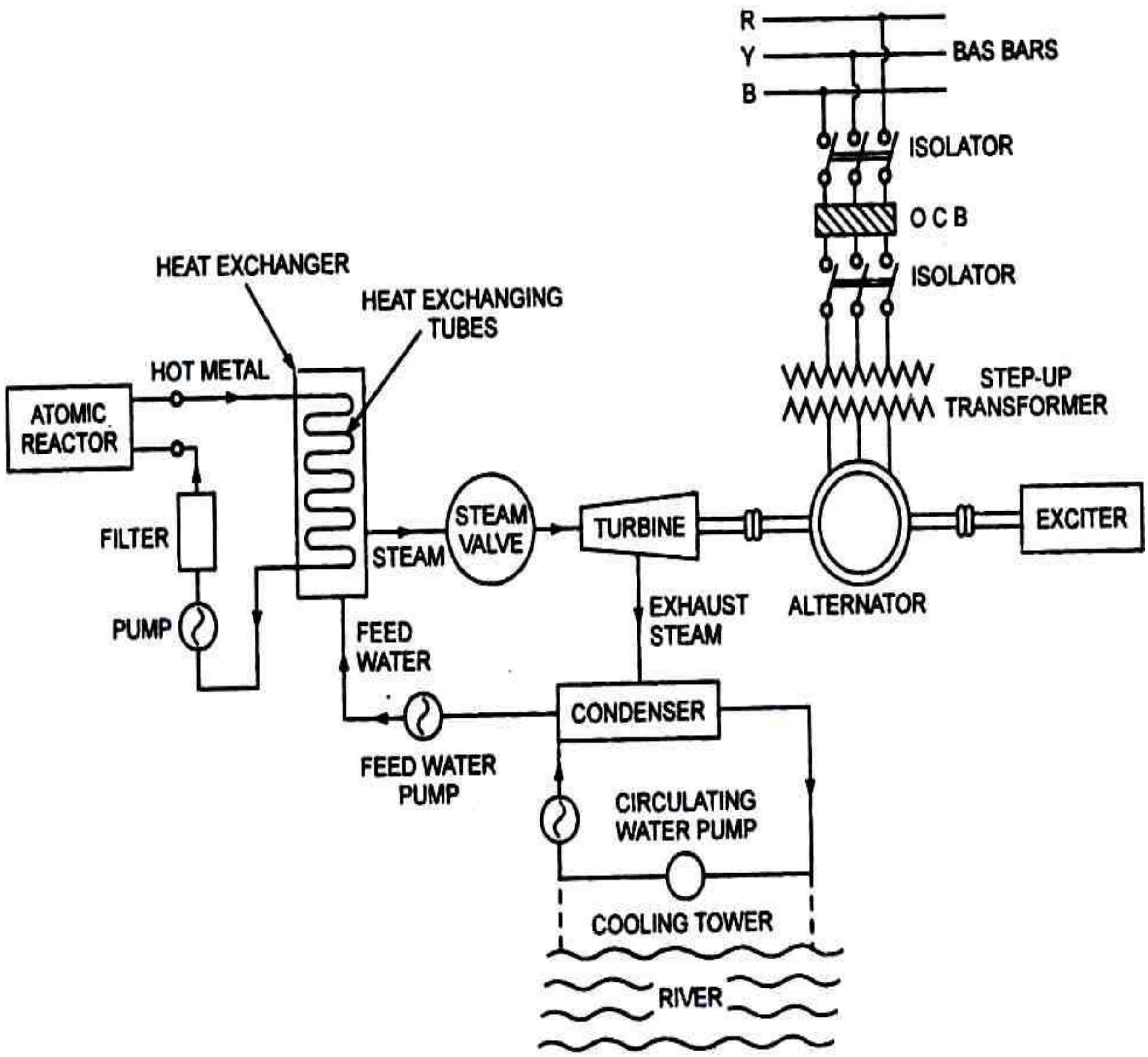
Elements In A Nuclear Power Plant:

A nuclear power plant mainly consists of the following elements,

1) Nuclear Reactor (for heat generation)
2) Heat Exchanger (for converting water in to steam using heat energy)
3) Steam Turbine.
4) Alternator.
5) Condenser.

Operation Of The Plant:-

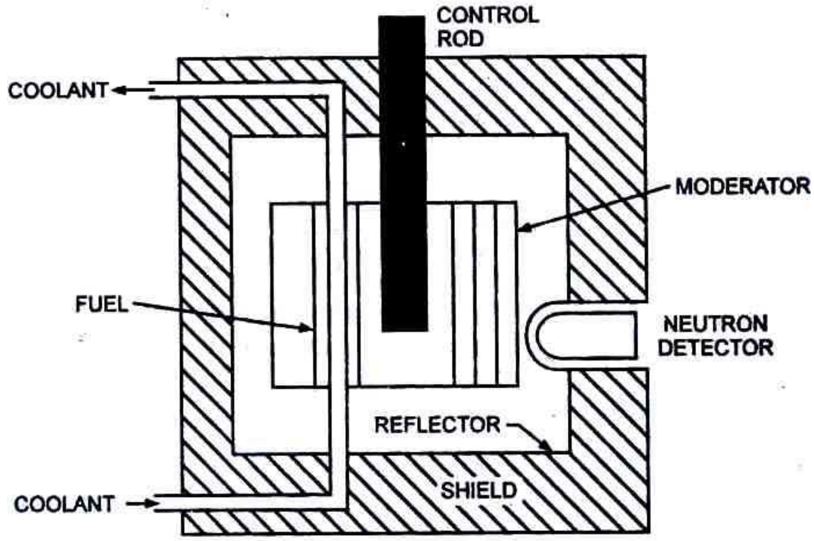
1) In the atomic reactor by the fission process tremendous amount of heat energy is produced. The splitting of a heavy nucleus into two or more smaller nuclei when bombarded by certain particles is termed as nuclear fission.In nuclear plants fission is done by bombarding uranium nuclei with slow moving neutron.
2) This heat energy is extracted by pumping fluid or molten metal, like liquid sodium or gas through pile.
3) The heated metal is then allowed to exchange its heat with the water in the heat exchanger by water circulation.
4) In heat exchanger steam is generated which is utilised to drive steam turbine coupled to an alternator there by generating electrical energy.
5) Steam valves are arranged between the heat exchanger and the turbine units to improve the steam pressure.
6) The exhaust steam from turbine is given to condenser and circulated to exchanger through feed water pump as shown in the figure.



Nuclear Reactor - Main Parts & Their Functions:

Reactor is that part of nuclear power plant where nuclear fuel is subjected to nuclear fission reaction and the heat energy released in this process is utilised to heat the coolant which may in turn, generate steam in heat exchanger.

A nuclear reactor is a device in which heat energy is produced by nuclear chain reaction. The main function of the reactor is to control the emission and absorption of neutrons.



Basic Components of a Nuclear Reactor

A nuclear reactor consists of the following basic components.

1) Reactor core.
2) Moderator.
3) Control rods.
4) Coolant.
5) Reflector.
6) Shielding.
7) Reactor vessel.
8) Neutron detector.

1) Reactor core:-

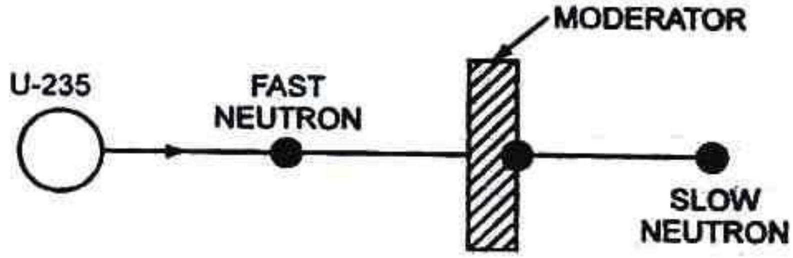
The core consists of number of fuel rods made up of materials like **Uranium (Natural, Enriched), Thorium, Plutonium** etc., the core has a series of parallel fuel elements in the form of thin plates or small rods, with coolant flowing axially into the reactor core assembly, moderator is surrounded by reflector as shown in the figure. The fuel rods should be clad with aluminium, stainless steel, or zirconium.

The reactors are supposed to maintain the Critical size of the core. The size of the core just sufficient to maintain a chain reaction is the “critical size”. The critical size depends on the type of fuel used. For enriched uranium fuel, the critical size of core is less compared to other fuels.

2) Moderator:-

The moderator is used to slow down the fast moving neutrons by absorbing some kinetic energy of neutron by direct collision, and thereby increasing the chain reaction.

Neutrons produced by the fission process are ejected from the nucleus at a very high velocity about, 1.5×10^7 m/s and therefore, have a very high kinetic energy, and are termed as **fast neutrons**.



Moderator Slows Down a Fast Neutron

For more effective use in nuclear reactor, it is desirable to slow down the fast neutrons to speeds corresponding to the speed of molecules in a gas at NTP (i.e., to a speed of about, 2.2×10^3 m/s). Such neutrons are called as **slow or thermal neutrons**. Thus, if the fuel is bombarded by thermal or slow neutrons, the chain reaction can be maintained effectively.

Hence, the fast neutrons collide with the nuclei of moderator material, lose their energy and get slowed down. The materials used for moderators are **Ordinary water, Heavy water, Graphite, Beryllium** etc.

3) Control rods:-

Control rods are meant for controlling the rate of fission of the fuel. These are made of **Boron-10, Cadmium, and Hafnium** etc., which absorbs some of the slowed neutrons and controls the chain reaction.

- **Purpose:-**

In a reactor, nuclear chain reaction has to be initiated when started from cold (initial state), and the chain reaction is to be maintained at a steady value during the operation of reactor. Also the reactor must be able to shut-down automatically under emergency conditions. All this requires a control of reactor so as to prevent the melting of fuel rods, disintegration of coolant, and destruction of reactor as the amount of energy released is enormous.

- **Operation:-**

The control rods are inserted into the reactor core from the top of the reactor vessel. These rods regulate the fissioning in the reactor by absorbing the excess neutrons. These rods can be moved in and out of the holes in the reactor core assembly. If the fissioning rate of the chain reaction is to be increased, the control rods are moved out slightly so that they absorb less number of neutrons and vice-versa.

4) Coolant:-

It is a medium through which the heat generated in the reactor is transferred to the heat exchanger for further utilisation in power generation. Coolant flows through and around the reactor core. It performs the additional function of keeping the interior of reactor at the desired temperature (cooling the reactor core).

A good coolant should not absorb neutrons, should be non-corrosive, and have good heat transfer capability.

- **Materials used:-**

The materials used as coolants are as follows.

- ✓ Air, Helium, Hydrogen and CO_2 amongst the gases,
- ✓ Light and Heavy water amongst the liquids,
- ✓ Molten metal like liquid sodium and Lithium amongst the metals,

5) Reflector:-

It is used to reflect escaping neutrons. A neutron reflector is placed around the core and used to avoid the leakage of neutrons from the core. If a neutron tries to escape from the core, it is reflected back to the core by reflector, thereby improving the efficiency of the reactor.

The main function of the reflector is to reflect as many leakage neutrons as possible back to core.The material normally used is high grade graphite, or most of the times same material is used for both moderator and reflector.

6) Shielding:-

Shielding is provided around a reactor to minimise the effect of radioactive contamination to the surroundings or the personnel living nearby the reactor.

The materials used for shielding are Lead, **Concrete**, Steel, and Cadmium. Concrete is found to be the most commonly used shielding material among the other materials.

7) Reactor vessel:-

The reactor core, reflector, and shielding are all enclosed in the main body of the reactor and is called the reactor vessel or reactor tank.

8) Neutron detector:-

A neutron detector is used to detect the neutrons. It gives the information about the existence of neutrons inside the core for continuing the nuclear chain reaction.

2.9 Classification Of Nuclear Reactors:

Nuclear reactors may be classified in several ways i.e. on basis of their applications, type of fission, fuel used, state of fuel, arrangement of fissile and fertile material, arrangement of fuel and moderator, moderator material, cooling system employed, coolant used etc.

I. ACCORDING TO THE APPLICATIONS THE REACTORS ARE CLASSIFIED AS

(a) Research and Development Reactors:

These reactors are used for testing new reactor designs and research.

(b) Production Reactors:

These reactors are used for converting fertile materials into fissile materials.

(c) Power Reactors: These reactors are used for generation of electrical energy.

II. ACCORDING TO THE TYPE OF FISSION THE REACTORS ARE CLASSIFIED AS

a) Fast reactors.

b) Slow reactors (or) Thermal reactors.

In fast reactors the fission is caused by fast neutrons whereas in thermal reactors it is caused by slow or thermal neutron. Initially all the neutrons are fast when emitted in a reactor and in thermal reactor their speed is reduced with the help of moderator. For natural uranium, graphite moderated reactor, the ratio of moderator to fuel volume is between 50 and 80; for heavy water moderated reactor this ratio lies between 20 and 40 while for enriched uranium light water moderated reactor this ratio is between 1.5 and 2.5. Thus the **reactor core of a thermal reactor is very much larger than that of a fast reactor** which has no moderator.

Obviously heat generated per unit volume of the reactor core in a thermal reactor is very much less than that in a fast reactor with the result that the cooling problems are much simpler in a thermal reactor.

The advantages and disadvantages of fast reactors:-

Advantages:

1. Fast reactors can convert more fertile material to fissile material with the result that the net fuel consumption for such reactors is much less. As a matter of fact more fissile material could be produced in fast reactor than would be consumed by it.
2. These reactors are small and compact and so easier to shield.
3. Since absorption cross-sections are small, any structural material can be used for reactor core.

Disadvantages:

1. Heat transfer and cooling problems in the core are complicated due to high power density.
2. High fuel loading requirement.
3. The core of a fast reactor requires high enrichment.
4. Radiation damage of the structural materials in the core due to fast or high energy neutrons.
5. The fast neutrons having much shorter “neutron lifetimes” than thermal neutrons cause some control problems under certain conditions.

The advantages and disadvantages of thermal reactors:-

Advantages:

1. Ease of control because of relatively low power densities.

2. Longer neutron life time.
3. Greater inherent safety.
4. Low fuel loading.

Disadvantages:

1. Very much restricted choice of fuel when uranium is used as fuel.
2. Higher size and weight of reactor per unit power due to low power density.
3. More fissile material consumption.
4. Requirements of small absorption cross-section structural materials.

III. <u>CLASSIFICATION ACCORDING TO THE TYPE OF FUEL USED</u>

(a) Natural uranium (b) Enriched uranium (c) Plutonium.

IV. <u>CLASSIFICATION ACCORDING TO THE STATE OF FUEL</u>

(a) Solid (b) liquid.

V. <u>AS PER THE ARRANGEMENT OF FISSILE AND FERTILE MATERIAL</u>

The reactors may be classified as:

(a) One region (fissile and fertile material mixed).

(b) Two region (fissile and fertile material separate).

VI. <u>ACCORDING TO THE ARRANGEMENT OF FUEL AND MODERATOR</u>

The reactors may be classified as:

(a) Homogeneous Reactors. (b) Heterogeneous Reactors.

In homogeneous reactors, the nuclear fuel and the moderator represent a uniform mixture in the fluid form, including gases, liquids and slurries whereas in heterogeneous reactors, separate fuel slugs or rods are inserted in the moderator in some sort of regular arrangement forming a so called lattice. In a homogeneous reactor, the mixture of nuclear fuel and moderator is circulated from the reactor to an external heat exchanger, then to a pump and back to the reactor.

The major drawback of homogeneous reactor is that the fuel solution also contains the highly radio-active fission products. Any leakage or component failure in the primary-reactor coolant system is extremely difficult to repair because of the presence of these fission products. Otherwise, a homogeneous reactor has some significant advantages such as excellent in core heat transfer because of generation of the fission energy in the fuel-coolant solution itself. Also, the reactor fuel can be added, removed and reprocessed during reactor operation without shutting it down. **Most of the present reactors are heterogeneous type**.

VII. ON THE BASIS OF MODERATOR MATERIAL USED

The reactors may be classified as:

(a) Heavy water (b) Graphite (c) Ordinary water (d) Beryllium (e) Organic reactors.

The most commonly used moderator materials are graphite, ordinary or natural water and heavy water. Graphite has got higher atomic weight than water and, therefore, the reactors employing graphite as moderator will be very bulky. Natural water gives a small and compact reactor, but the reactor would have to be pressurized and use enriched fuel. With heavy water, ordinary natural fuel can be used but it is very expensive.

VIII. ON THE BASIS OF COOLANT USED

The reactors may be classified as:

(a) Gas (Air, helium, hydrogen, carbon) cooled reactors.

(b) Water (ordinary or heavy) cooled reactors.

(c) Liquid metal (liquid sodium, lithium) reactors.

IX. ON THE BASIS OF COOLING SYSTEM EMPLOYED

The reactors may be classified as:(a)Direct and (b) Indirect reactors.

In direct system of cooling, the fuel is in the liquid form and it acts as a coolant. It is circulated through the reactor core and a heat exchanger in which its heat is transferred to the circulating water to produce steam.

In indirect system of cooling, the coolant may be a gas, water (light or heavy), a liquid metal or an organic coolant.

2.10 Power Reactors

Power reactors commonly employed in nuclear power plants are briefly described as follows.

1) Boiling Water Reactor (BWR).
2) Pressurized Water Reactor (PWR).
3) Heavy Water Cooled and Moderated (CANDU type) Reactor.

4) Gas Cooled Reactor.
5) Liquid Metal Cooled Reactor.
6) Fast Breeder Reactor.

1) BOILING WATER REACTOR (BWR):

This is the simplest type of water reactor. It has a steel pressure vessel surrounded by a concrete shield.

Fuel: Fuel used is Enriched Uranium.

Moderator & Coolant: Ordinary water is used both as moderator and coolant.

Operation:

The steam is generated in the reactor itself. Feed water enters the reactor vessel at the bottom and takes the heat produced due to fission of fuel and gets converted in to steam.

This steam leaves the reactor at the top and after passing through turbine and condenser returns to the reactor. Uranium fuel elements are arranged in a particular lattice form inside the pressure vessel containing water.

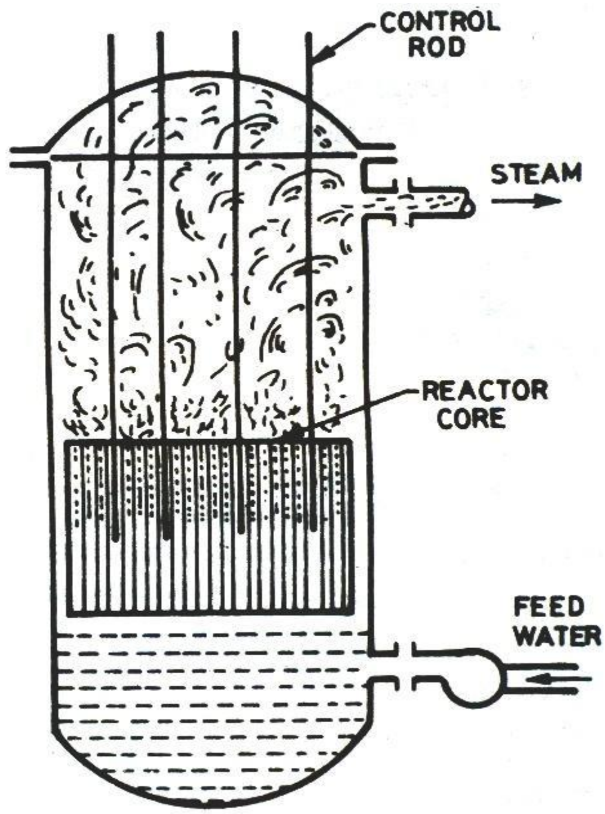


Fig. A boiling water reactor (BWR).

Example:

The reactors installed at Tarapur nuclear power station are of this type.

Advantages:

1) Small size pressure vessel.
2) High steam pressure.
3) Simple construction. Elimination of heat exchanger circuit resulting in reduction in cost and gain in thermal efficiency.
4) Overall efficiency is about 33%.

Disadvantages:

1) In view of direct cycle there is a danger of radio-active contamination of steam, therefore, more elaborate safety measures are to be provided. These add to cost.
2) It cannot meet a sudden increase in load.
3) Because of the danger of small amounts of fissile materials passing through along with the coolant, more biological protection is required.

Limitation:

It is applicable only for small power plants where cost is a major constraint.

2) PRESSURIZED WATER REACTOR (PWR):

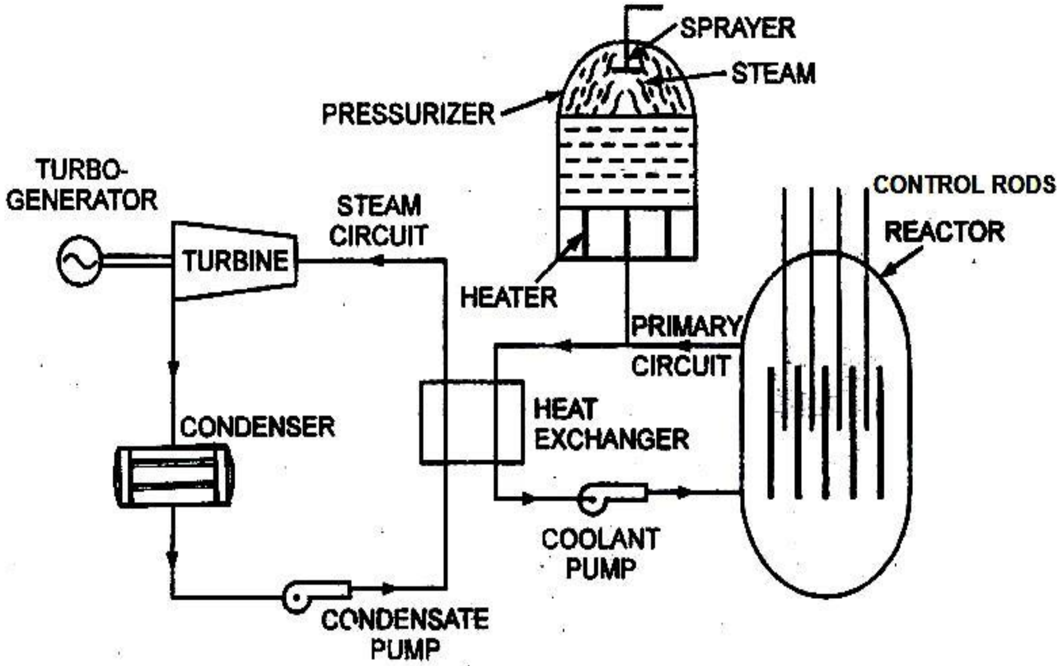
It is a thermal reactor having a pressure vessel is of steel. The pressure vessel and the heat exchanger are surrounded by a concrete shield.

Fuel Used:

The fuel used is Enriched uranium clad with stainless steel or zirconium alloy.

Moderator & Coolant:

Water under pressure is used both as moderator and coolant.



Line Arrangement of a PWR With Heat Exchanger in Circuit

Operation:

This type of reactor is designed to prevent the boiling of water coolant in the Uranium core. A pump circulates water at high pressure (as high as 140kg/cm^2) round the core so that water in liquid state absorbs heat from the uranium core and transfers it to the secondary loop(heat exchanger) to generate steam.

A pressuriser tapped in to the pipe loop maintains constant pressure in the water system throughout the load range. Pressuriser consists of an electric heating element at bottom and water and steam at top. Electric heating coil in the pressuriser boils the water to form steam; this steam pressurizes the entire coolant circuit. Water spray is used to condense the steam when pressure is desired to be reduced.

Since water in passing through the reactor becomes radio-active the entire primary circuit including heat exchanger has to be shielded.

Advantages:

1. Relatively compact in size compared with other types.
2. An inexpensive substance (light water) can be used as Moderator-cum-Coolant-cum-Reflector.
3. Isolation of radio-active materials from the main steam system.
4. High power density.

Disadvantages:

1. Heat loss in heat exchanger.
2. Strong pressure vessel is required.
3. The thermal efficiency of PWR is as low as 20%.
4. Pressuriser equipment increases the cost.
5. Use of expensive cladding material for prevention of corrosion.
6. In comparison to other types, requirement of more elaborate safety devices.

3) HEAVY WATER COOLED AND MODERATED(CANDU Type) REACTOR:

This reactor was first developed by Canada and is, therefore, known as CANDU type reactor. The word CANDU stands for "Canadian Deuterium Uranium". These reactors are meant for those countries which do not have uranium enrichment facilities. Enrichment of uranium is costly affair and such reactors use natural uranium as fuel.

Fuel Used: Natural Uranium is used as a fuel.

Moderator & Coolant: Heavy water is used as both coolant and moderator.

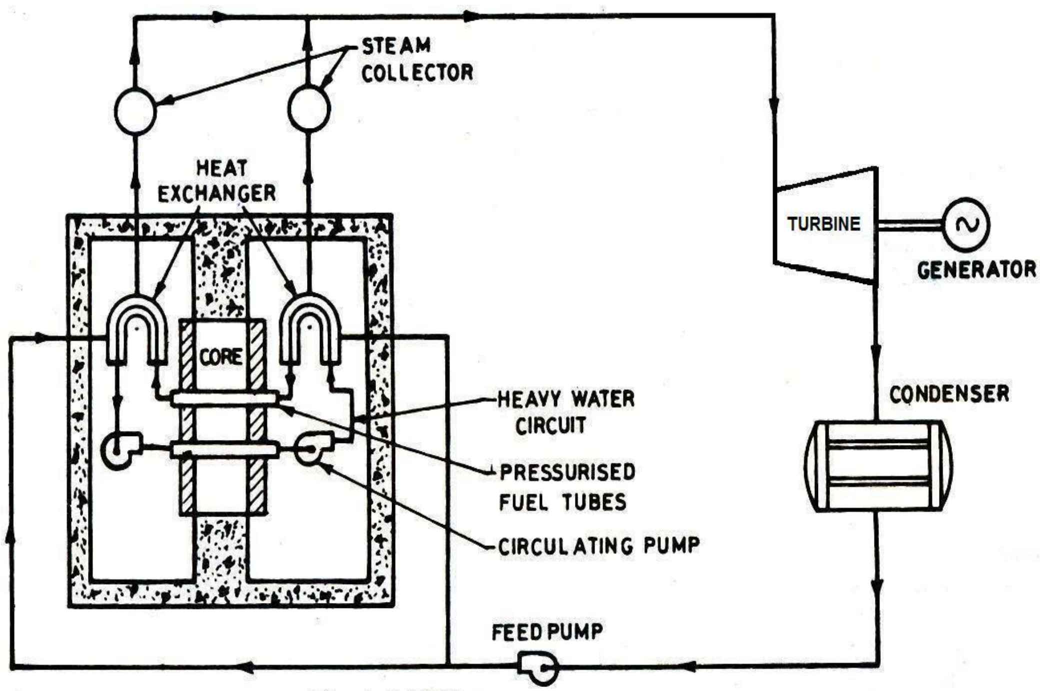


Fig. A CANDU type reactor.

Operation:

The primary and secondary circuits are similar to pressurized water reactor. The coolant heavy water is passed through the pressurized fuel tubes and heat-exchanger. Heavy water is circulated in the primary circuit in the same way as with a PWR and the steam is raised in the secondary circuit transferring the heat in the heat exchanger.

From the condenser the condensate is given to the heat exchanger as shown in the figure through a feed water pump. In the heat exchanger the condensate is converted in to steam by utilizing the heat of the coolant and this steam is collected from steam collectors, as shown in the figure and then expanded in the steam turbine.

Control rods are not required in this reactor, reactor control being achieved by varying the moderator level in the reactor.

Advantages:

1. Fuel need not be enriched.
2. Reactor control is simple because of absence of control rods.
3. Low fuel consumption.
4. The moderator (heavy water) is more effective in slowing down neutrons.

Disadvantages:

1. High cost of heavy water.
2. Problem of leakage and very high standard of design etc…

4) GAS COOLED REACTOR:

Fuel used:

Fuel used is “Natural Uranium”.

Coolant:

A gas cooled reactor employs a gas(CO_2 or Helium) as coolant instead of water.

Moderator:

Graphite is used as moderator.

Operation:

This type of reactor employs a gas (CO_2 or Helium) as coolant. A heat exchanger is necessary. Gas is circulated through the reactor core and the heat exchanger by means of a blower or a gas compressor. Even though gas is inferior to water from the point of view of heat transfer properties but it offers a number of advantages which do not exist with water. However because of its poor heat transfer qualities a large quantity of gas is required for circulation.

This results in increased consumption of auxiliary power. In this way advantage of higher thermal efficiency is to a large extent lost and overall plant efficiency is low.

Advantages:

1. Gas cooled reactor is safer than water cooled reactor.
2. Less severe corrosion problem.
3. Possibility of use of natural uranium as fuel.
4. Contamination problems are moderate.
5. Low pressure coolant and relatively high reactor temperature.

Disadvantages:

1. Poor heat transfer characteristics.
2. Relatively large size of reactor because of use of natural uranium fuel and graphite moderator.
3. Extremely low power density.
4. Low steam pressure and temperature.
5. Large energy consumption by gas blowers or heat exchangers.

5) LIQUID METAL COOLED REACTOR:

This type of reactor has been developed to overcome the difficulties faced in pressurization of water and the drawbacks of gas cooled reactors while retaining their advantages.

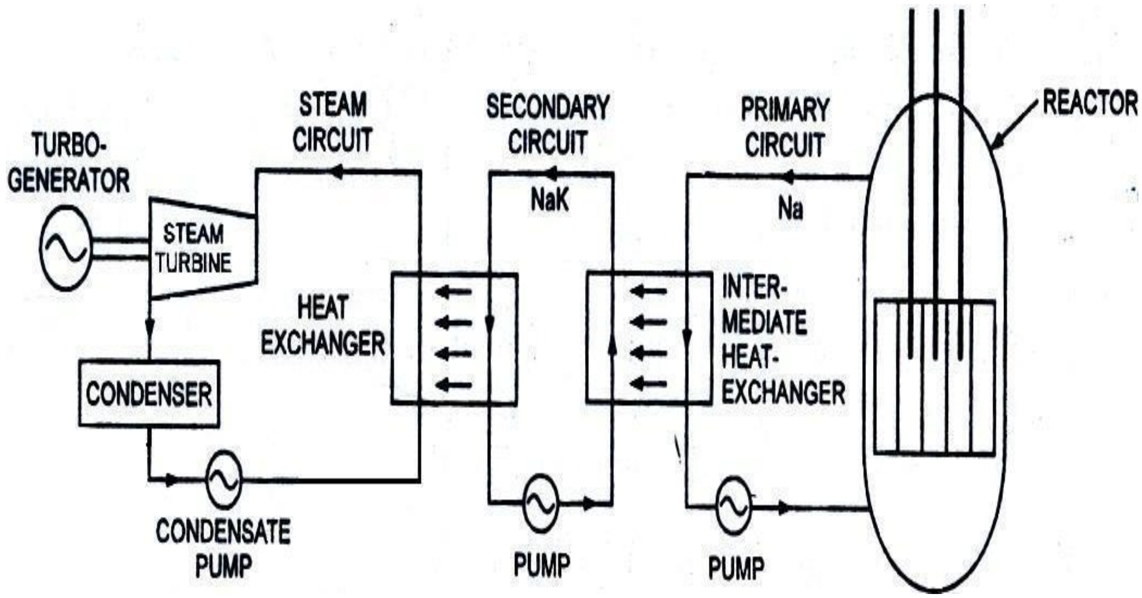
Metals in liquid state have good thermal conductivity and high temperature can be attained at moderate pressure.

However, handling of sodium introduces difficulties because of its activity in reactor core. It is therefore necessary to employ two heat transfer circuits so that radio-active sodium does not come in contact with the steam circuit.

Fuel used: Enriched Uranium alloy or Uranium carbide clad with stainless steel.

Moderator: Graphite is used as moderator.

Coolant: Liquid sodium is used as coolant.



Operation:

1) Sodium is circulated through reactor core and an intermediate heat exchanger where the heat from sodium (Na) is transferred to the "Nak" liquid metal which gives up heat in the heat exchanger to generate steam.
2) Nak alloy has a lower melting point and therefore allows higher heat absorption.

Advantages:

1) Steam can be generated at high temperature and pressure.
2) Reactor size is small.
3) Metals in liquid state have good thermal conductivity.
4) Reduced corrosion problems.
5) High reactor temperatures.

Disadvantages:

1) The primary and secondary circuits should be shielded.
2) Requirement of enriched Uranium.

6) FAST BREEDER REACTOR:

A breeder reactor is a nuclear reactor in which the fertile material is converted into fissile material at a rate higher than at which the fissile material is consumed. In order to convert the fertile material into fissile material, it uses the fast neutrons released from the fission reaction by the fissile material, hence the name “Fast Breeder Reactor”.

Fuel used:

Fissile Materials: Enriched Uranium (U-235, U-233)or Plutonium (Pu-239).

Fertile Materials: Uranium (U-238) or Thorium (Th-232).

Moderator: No moderator.

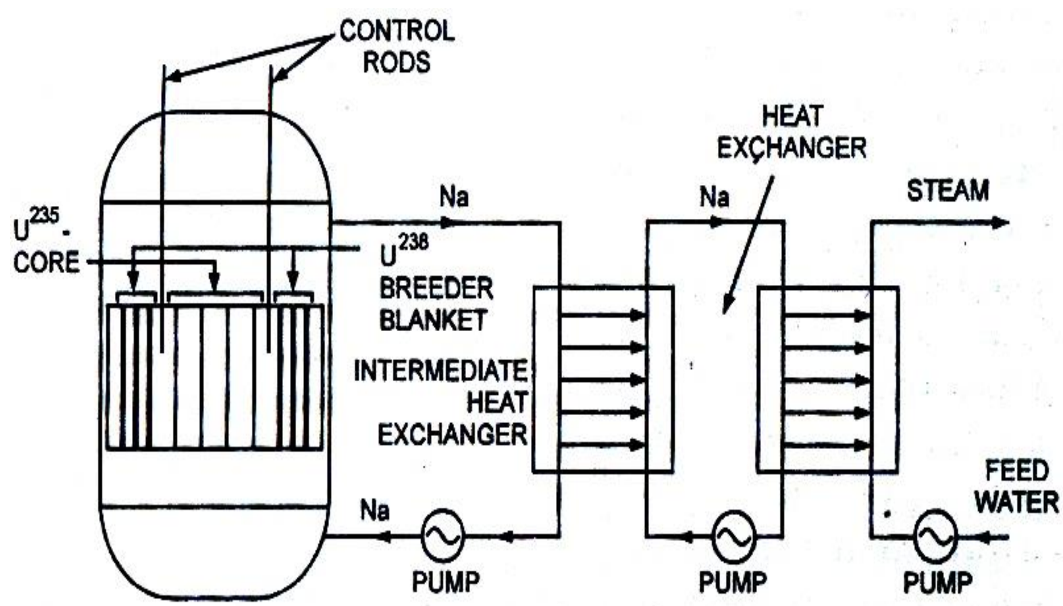
Coolant: Liquid metals like sodium or potassium are used as coolant.

Operation:

A fast breeder reactor is a small vessel in which the required quantity (corresponding to critical mass) of enriched uranium or plutonium is kept without a moderator.

The fissionable fuel core is surrounded by a blanket of fertile material (U-238 or Th-232).

The fertile material (U-238 or Th-232) absorbs neutrons produced by the fissioning of U-235 and produces fissile material Pu-239 or U-233 respectively.



Fast Breeder Reactor

Two heat exchanges are required in this plant. The reactor core is cooled by liquid metal (sodium or potassium). In the second heat exchanger the coolant is again liquid sodium/ potassium, which transfers heat to feed water to generate steam. This prevents the possibility of a sodium-water reaction with the radio-active sodium.

Advantages:

1) We can convert the fertile material in to fissile material, by that we can utilize the total fuel for fission process.
2) Metals in liquid state (coolants) have good thermal conductivity.
3) No requirement of moderator reduces the cost.

Disadvantages:

1) The primary and secondary circuits should be shielded.
2) Requirement of enriched Uranium.

Note:

1) The size of the core just sufficient to maintain a chain reaction is the "**critical size**". The critical size depends on the type of fuel used. For enriched uranium fuel, the critical size of core is less compared to other fuels.
2) The amount of the Uranium required in a reactor to maintain chain reaction by producing enough neutrons is called the **"critical mass"** of uranium.
3) **Fissile** materials are the materials which can readily undergo fission process. Examples are U-233, U-235, and Pu-239.
4) **Fertile** materials are the materials which cannot readily undergo fission process. Examples areU-238and Th-232. By using Breeder Reactors we can convert fertile material into fissile material, and hence can be used for the fission process.

2.11 Reactor Control:

$$k = \frac{\text{Number of neutrons in any one generation}}{\text{Number of neutrons produced in the preceding generation}}$$

K= "neutron multiplication factor" and depends on several factors:

the probability of neutron generation by fission (increase)
the probability of escape from the core (loss)
the probability of absorption by other than fuel (loss)
K>1: exponential growth (not good) reactor is supercritical

K=1: steady state population, = constant (good) reactor is critical
K<1: exponential decay (shut down mode) reactor is subcritical

2.12Nuclear Fission and Fusion:

	Nuclear Fission	Nuclear Fusion
Definition	Fission is the splitting of a large atom into two or more smaller ones.	Fusion is the fusing of two or more lighter atoms into a larger one.
Natural occurrence of the process	Fission reaction does not normally occur in Nature	Fusion occurs in stars, such as the sun
Byproducts of the reaction	Fission produces many highly radioactive particles	Few radioactive particles are produced by fusion reaction, but if a fission "trigger" is used, radioactive particles will result from that
Conditions	Critical mass of the substance and high-speed neutrons are required	High density, high temperature environment is required
Energy Requirement	Takes little energy to split two atoms in a fission reaction	Extremely high energy is required to bring two or more protons close enough that nuclear forces overcome their electrostatic repulsion.
Energy Released	The energy released by fission is a million times greater than that released in chemical reactions, but lower than the energy released by nuclear fusion.	The energy released by fusion is three to four times greater than the energy released by fission
Nuclear weapon	One class of nuclear weapon is a fission bomb, also known as an atomic bomb or atom bomb.	One class of nuclear weapon is the hydrogen bomb, which uses a fission reaction to "trigger" a fusion reaction
Energy production	Fission is used in nuclear power plants	Fusion is an experimental technology for producing power
Fuel	Uranium is the primary fuel used in power plants.	Hydrogen isotopes (Deuterium and Tritium) are the primary fuel used in experimental fusion power plants.

2.13 Types of Radiations:

The important radiations, from the point of view of healthy physics, are α rays, β rays, γrays and neutrons.

a) α rays are nuclei of helium atom $_2He^4$. They are heavy particles carrying positive charge. They cannot penetrate skin. Still they can cause internal hazard if ingested.

b) β rays are electrons and travel at the speed of light. They have greater penetrating power due to their smaller size. Since they are negatively charged, they are repelled by negatively charged material. Over-exposure to β rays can cause skin burns. Their penetrating power is also low and a thin sheet of metal or a brick wall is sufficient to stop them.

c) γ rays are electromagnetic radiations of short wave length. They have high energy and are very penetrating. They are capable of causing considerable damage, especially to organic materials. Over exposure to γ rays causes blood diseases, undesirable genetic effects, anemia etc. Larger exposure may cause death with in hours of exposure. They cannot be completely stopped by any material. However, thick lead and concrete can attenuate them considerably.

d) Neutrons are produced in fission with a wide range of energies up to about 10 MeV. They have no charge but are highly penetrating. Their effects are similar to those of γ rays

2.14 Effects of Ionizing Radiation:

- Ionizing radiation has sufficient energy to knock bound elections out of an atom or molecule
- Includes alpha/beta particles and gamma/x-rays
- Can form highly reactive free radicals with unpaired electrons
- For example, $H_2O \rightarrow [H_2O^{\cdot}] + e^-$
- Rapidly dividing cells in the human body are particularly susceptible to damage by free radicals
- Radiation can be used to treat certain cancers and Graves disease of the thyroid
- However, ionizing radiation can also damage healthy cells
- Biological damage determined by radiation dose, type of radiation, rate of delivery, and type of tissue

Moderate radiation sickness

- Nausea and vomiting within 12 to 24 hours
- Fever
- Hair loss
- Vomiting blood, bloody stool
- Poor wound healing
- Any of the mild radiation sickness symptoms

- Can be fatal to sensitive individuals

Severe radiation sickness

- Nausea and vomiting less than 1 hour after exposure
- Diarrhea
- High fever
- Any symptoms of a lower dose exposure
- About 50% fatality

Very severe radiation sickness

- Nausea and vomiting less than 30 minutes after exposure
- Dizziness
- Disorientation
- Low blood pressure
- Any symptoms of a lower dose exposure
- > 50% fatality

2.15 Shielding:

Adequate shielding has to be provided to guard personnel and delicate instruments. The various materials used for shielding are:

(a) Lead: It is common shielding material, has high density (11.3 gram/cm^3) and is invariably used due to its low cost.

(b) Concrete: Its density is 2.4 gram/cm^3 and is less efficient than lead.

(c) Steel: Its density is 7.8 gram/cm^3. It is not efficient shielding material but has good structural properties.

(d) Cadmium: Its density is 8.65 gram/cm^3. It can absorb slow neutrons by a nuclear reaction.

In a nuclear power reactors a thermal shield of several cms. Thick steel surrounded by about 3 m thick concrete is used. Water, in concrete, slows down fast neurons. Iron, barium or steel turnings are mixed in concrete to attenuate gamma rays and absorb thermal neutrons.

2.16Nuclear Waste:

- Contains radioactive fission products
- Can be hazardous for thousands of years
- Half-life of Pu-239 is 24,110 years
- Fission products, if released, can build up in the body and be fatal
- Almost all nuclear waste is stored where it was generated
- Nuclear reactor that can produce more fissionable material than it consumes (recovering Pu-239 from U-235)
- Outside the US, countries reprocess their Spent Nuclear Fuel(SNF) using breeder reactors
- Geologic burial is the safest option for disposing of highly radioactive spent fuel

Assignment-Cum-Tutorial Questions

SECTION – A:-

1. Which of the following fuel material occurred naturally?
   - **a. U^{235}**
   - b. Pu^{239}
   - c. Pu^{241}
   - d. U^{-233}

2. The function of a moderator is to
   - **a. absorb the part of the Kinetic energy of the neutrons**
   - b. extract the heat
   - c. reflect back some of the neutrons
   - d. start the reactor

3. Which of the following is not used as moderator?
   - a. water
   - b. heavy water
   - c. graphite
   - **d. boron**

4. When the control rods are inserted into the reactor, K (Multiplication factor) becomes

   - a. 0
   - b. >1
   - c. 1
   - **d. <1**

5. The function of coolant is to
   - **a. extract heat from reactor**
   - b. slow down neutrons
   - c. control the reaction
   - d. reflect the neutrons

6. Which of the following has highest moderating ratio?

   - **a. D_2O**
   - b. H_2O
   - c. Carbon
   - d. Helium

7. In pressurized water reactor
   - a. light water is used as coolant
   - **b. light water is used as coolant and moderator**
   - c. heavy water is used as coolant
   - d. heavy water is used as coolant and moderator

8. In which of the following reactors, heat exchanger is not used?

a. Pressurized water reactor
b. Boiling water reactor
c. CANDU reactor
d. Gas cooled reactor

9. Gas cooled reactors are _____ moderated.

a. Light water
b. Heavy water
c. Graphite
d. Beryllium

10. In Sodium-Graphite reactor, sodium is used as

a. Coolant
b. Moderator
c. Reflector
d. All of the above

11. One atomic mass unit is equivalent to

(a) 931.4 MeV (b) 251.2 MeV (c)120.4 MeV

12. The first nuclear power plant installed in india is

(a) Kota (Rajasthan) **(b) Tarapur (Maharashtra)**

(c) Kalpakkam (TN) (d) Narora (U.P.)

13. One kilogram of natural uranium gives energy equivalent to about

(a) 100 kg of coal (b) 1000 kg of coal

(c) 5000 kg of coal **(d) 10,000 kg of coal**

14. Which of the following are the fertile materials

(a) U_{238} and Th_{232} (b) U_{238} and Th_{239}

(c) U_{233} and Pu_{239} (d) U_{238} and Pu_{239}

15. Fast breed reactors are best suited for India owing to

(a) large thorium deposits (b) large plutonium deposits

(c) large uranium deposits (d) none of the above

16. The operation of a nuclear reactor is controlled by controlling the multiplication factor defined as

$$k = \frac{\text{Number of neutrons in any one generation}}{\text{Number of neutrons produced in the preceding generation}}$$

The power level of the reactor can be increased by

(a) Raising the value of k above 1 and, keeping it at that raised value
(b) Raising the value of k above 1, but later bringing it back to k=1
(c) Lowering the value of k below 1 and, keeping at that lowered value
(d) Lowering the value of k below 1, but later bringing it back to k=1

17. Thermal shielding is provided to
(a) Absorb the fast neutrons
(b) Protect the operating personnel from exposure to radiations
(c) Prevent the reactor wall from getting heated
(d) All of the above

18. Tarapur atomic power station has
(a) CANDU reactor
(b) BWR
(c) PWR
(d) Gas cooled reactor

19. consider the following moderators used in nuclear reactors:

1. Graphite 2. Beryllium 3. Heavy water

Their correct sequence in increasing order of their neutron absorption cross- section is

a. 1,3,2
b. 2,1,3
c. 3,1,2
d. 3,2,1

20. Which of the following statements are correct

1. Nuclear fission occurs whenever a uranium nucleus reacts with a neutron
2. Nuclear fission is accompanied by the release of neutrons and gamma rays
3. About 200 MeV of energy is released in the fission of a uranium nucleus
4. Energy from the fission of uranium nucleus is released mainly as the kinetic energy of the neutrons and the energy of gamma radiations

Select the correct answer using the codes given below.

(a) 1,2,3 and 4
(b) 2 and 3
(c) 2,3 and 4
(d) 1 and 4

SECTION – B:-

1. Discuss the factors for the choice of site for a nuclear power plant?
2. Explain the different Nuclear materials used in a Nuclear power station?

3. Explain the basic components of nuclear reactor and explain function of each component?
4. Draw the schematic diagram of nuclear power station and discuss its operation?
5. Distinguish between thermal and fast breeder reactors.
6. Explain the following with respect to Nuclear power station
    i. Isotope
    ii. Atomic mass unit
    iii. Binding energy and mass defect
7. Describe with help of neat sketch, the construction and working of pressurized water reactor (PWR).What are its advantages and disadvantages?
8. Discuss the advantages and disadvantages of nuclear power station?
9. What are the functions of moderator and control rods in a nuclear reactor?
10. Write short notes on Radiation hazards and shielding in nuclear power stations.
11. What is meant by nuclear fission and chain reaction?
12. Discuss the boiling water reactor and mention its merits and demerits?
13. An atomic power reactor can deliver 300 MW. If due to fission of each atom of $_{92}U^{235}$ the energy released is 200 MeV, calculate the mass of uranium fissioned per hour. **[Ans:13.17g]**

14. What is the power output of a $_{92}U^{235}$ reactor if it takes 30 days to use up 2kg of fuel? Given that energy released per fission is 200MeV and Avogadro's number=$6{\cdot}023 \times 10^{26}$ per kilomole. **[Ans:63.2W]**

SECTION – C:-

GATE /IES QUESTIONS

1. Match List I with List II and select the correct answer using the code given below the lists: [IES-2012]

List-I	List-II
a. Moderator	1. Boron
b. Control rod	2. Concrete
c. Coolant	3. Graphite
d. Shield	4. Sodium

(A) a(3), b(1), c(4), d(2)
(B) a(2), b(1), c(4), d(3)
(C) a(3), b(4), c(1), d(2)
(D) a(2), b(4), c(1), d(3)

2. Uranium-238 is represented by 92U238. What does it represent? [IES-2008]

(a) 92 neutrons and 238 protons (b) 92 protons and 238 neutrons
(c) 92 neutrons and 146 protons **(d) 92 protons and 146 neutrons**

3. Consider the following nuclear fuels: 1. Pu239 2. U235 3.U233 4. Th232 What is the correct sequence of the above nuclear fuels in order of increasing half life? [IES-2008]

(a) 1-2-3-4 **(b) 1-3-2-4** (c) 2-4-3-1 (d) 4-1-2-3

4. Which one of the following is the correct statement? A nuclear fission is initiated when the critical energy as compared to neutron binding energy atoms is [IES 2006]

(a) Less (b) same **(c) more** (d) exactly two times

5. What is the function of heavy water in a nuclear reactor? [IES 2006]

(a) It serves as a coolant
(b) It serves as a moderator
(c) It serves as a coolant as well as a moderator
(d) It serves as a neutron absorber

6. Which one of the following pairs of materials is used as moderators in nuclear reactors? [IES-1995]

(a) Heavy water and zirconium (b) Zirconium and beryllium
(c) Cadmium and beryllium **(d) Beryllium and heavy water.**

7. S.I. unit for radioactivity is [IES-1992]

(a) Joule (b) a.m.u (c) Curie **(d) Becquerel**

8. With natural uranium, which of the following is used as moderator? [IES-1990]

(a) Heavy water (b) Graphite (c) Beryllium **(d) All the above**

Unit-III

Hydel and Gas power stations

Learning Objectives:

- To familiarize the working principle of hydro power plant.
- To list out the advantages and disadvantages of hydro power plant.
- To introduce various components of a hydro power plant.
- To determine the power output of a hydro power plant.
- To understand the working principle of gas turbine power plant
- To introduce various components of a gas turbine power plant

Syllabus:

Hydel and Gas power stations
Introduction, Advantages and disadvantages of hydro plants, Selection of site, block diagram approach of hydroelectric power plant, Definition of terms Dam, spillways, head, surge tank, penstocks and classification of hydro power plants, power output equation. Gas power stations: Introduction, Advantages and disadvantages, schematic arrangement of gas turbine power plant, principle of operation and components: compressor, regenerator, combustion chamber, gas turbine.

Course outcomes:

Students will be able to

3.1Select an appropriate location for Hydro power station.

3.2Explain the single line diagram of the Hydro power station.

3.3Describe the functions of various components of Hydro power station.

3.4Classify Hydro power stations.

3.5Explain the working principle and components of gas power station.

Hydro power stations

3.1 INTRODUCTION

Hydro electric power is the power obtained from the energy of falling water where as hydro electric power plant is the power plant utilizing the potential energy of water at a high level for the generation electrical energy. Hydro electric power generation is the generation of electric power by generator which is driven by turbine being rotated by water.

The energy of water utilized for hydro electric power generation may be kinetic or potential. Kinetic energy of water is its energy in motion and is a function of mass and velocity while potential energy is a function of the water level from the earth surface (called the head). In either case continuous availability of water is a basic requirement. For this purpose water collected in natural lakes and reservoirs at high altitudes may be made use of or water may be artificially stored by constructing dams across flowing streams.

There are two reasons for the extensive development of water power.

1. The tremendous increase in demand of electric power for industrial, agricultural, commercial and domestic purposes.
2. The high cost of fuels (coal and oils), and the limited resources.

A water power site is usually developed to supply electric power to a newly and a specially established industry or town or to provide additional power to an already existing or proposed interconnected electric power system.

3.2 Advantages & Disadvantages

Advantages

1. The plant is simple in construction, does not pollute the atmosphere.
2. The plant is highly reliable and it is cheapest in operation and maintenance.
3. The load can be varied quickly & the rapidly changing load demands can be met easily.
4. These plants are robust and have got longer life compared thermal and nuclear plants.
5. Starting time is also low comparative to other plants.
6. These plants can be used as base load or peak load plants.

Disadvantages

1. It requires large area.
2. Its construction cost is enormously high and takes longer time.
3. Long transmission lines are required as the plants are located in hilly areas which are quite away from the load centers.
4. The power generation depends on the availability of water, which depends on weather conditions.
5. The firm capacity of hydro electric plants is low compared to thermal, nuclear plants.

   Note: - Firm power capacity of a power station is defined as the theoretical power that the plant is supposed to produce all the time.

Firm Capacity = Plant efficiency × Plant Gross capacity

3.3 SELECTION OF SITE FOR A HYDRO ELECTRIC POWER PLANT

The following factors should be considered while selecting the site of a Hydro power station.

1. **Quantity of water available:-**

   This is estimated on the basis of measurements of stream flow over as long a period as possible. Previous records of rainfall are studied; minimum and maximum quantity of water available during the year is estimated. After allowing for losses due to evaporation and percolation the net volume of water available for power generation can be determined.

2. **Storage of water:-**

   Since storage of water in a suitable reservoir at a height or building of dam across the river is essential in order to have continuous supply during the dry season, therefore, convenient accommodation for the erection of a dam or reservoir must be available. The storage capacity can be determined from the hydrograph or from mass curve or by using analytical methods. For selection site for the dam a careful study of geology and topography of the catchment area is required to see whether the natural foundation can be used to the best advantage.

3. **Water head:-**

In order to utilize the potential energy of water effectively, we have to provide a sufficient head to the water level. The availability of water head depends upon the topography of the area. Availability of head of water has considerable effect on the cost and economy of power generation. An increase in effective head reduces the quantity of water to be stored and handled by penstocks, and turbines and therefore, capital cost of the plant is reduced. In order to determine the most effective and economical head it is necessary to consider all possible factors which affect it.

4. **Distance of power station site from load centers:-**

   In case the load center is away from the site, the cost of transmission line and the losses occurring in the line will increase, that will increases the transmission cost considerably.

5. **Accessibility of the site:-**

   The site should be easily accessible by rail as well as by road. i.e., adequate transportation facilities must be available or there should be possibility of providing the same so that the necessary equipment and machinery could be easily transported.

6. **Water pollution:-**

   Polluted water may cause excessive corrosion and damage to the metallic structures. Hence availability of good quality of water is essential.

7. **Large catchment area:-**

   The reservoir must have a large catchment area, so that level of water in the reservoir may not fall below the minimum required in dry season.

   Note: - The catchment area is the area bounded by water sheds which drains into a stream or river across which the dam has been built at a suitable place. (Simply natural resources like rivers, seas, etc.)

8. **Availability of land: -**

   The land available should be cheap in cost and rocky in order to withstand the weight of the large building and heavy machinery.

3.4 HYDROLOGY

The hydrology or hydrograph deals with the occurrence and distribution of water over and under the earth surface.

In other words it is the study of hydrological cycle, in which the water rises by evaporation from sea, river etc.., and is carried over the land, where it falls as precipitation, which flows to transpiration or flows back to ocean, sea, river etc.., then rises again by evaporation. The major phases in the hydrological cycle or **evaporation, precipitation** and **stream flow**.

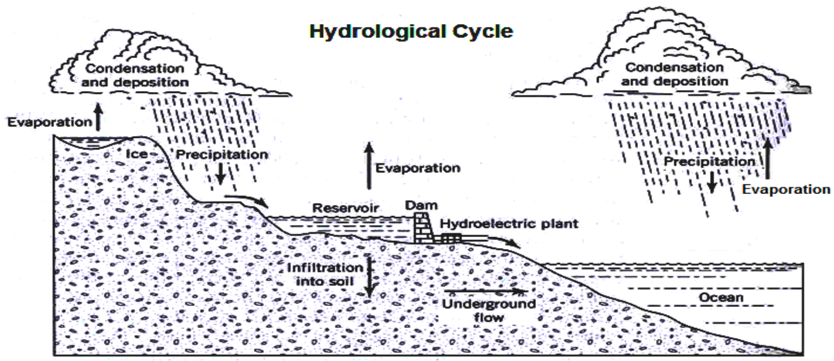


Fig3.1:Hydrology Cycle

3.5TERMINOLOGY USED IN HYDROLOGY

The main terminology used in hydrology is defined as follows.

1) PRECIPITATION:-

Precipitation in general sense is called as rainfall. This includes all the water that falls from atmosphere to the earth surface. It is mainly of two types.

i) Liquid precipitation (normal rain fall)

ii) Solid precipitation (Snow, ice, hail…)

2) EVAPORATION:-

Evaporation is defined as the transfer of water from liquid state to a vapour state. It represents practically that entire portion of the rainfall that does not reach the point of ultimate use as stream flow. So evaporation includes all the rain fall that is returned to the atmosphere from the land and water surfaces.

Thus total evaporation includes,

i) Evaporation from land and water surfaces.

ii) Evaporation by transpiration.

iii) Atmospheric evaporation (evaporation while precipitation is falling).

3) SEEPAGE:-

Some part of the precipitation is absorbed by the soil and seeps or percolates into the ground. This process is known as '**Seeping'.**

Generally seepage loss is considerably less compared to evaporation loss. So in run-off calculations we can neglect seepage loss.

4) RUN-OFF:-

Run-Off can be defined as that part of the precipitation which is available as stream flow. The unit of Run-Off is **m^3/sec**.

RUN-OFF = TOTAL PRECIPITATION – TOTAL EVAPORATION

5) PONDAGE:-

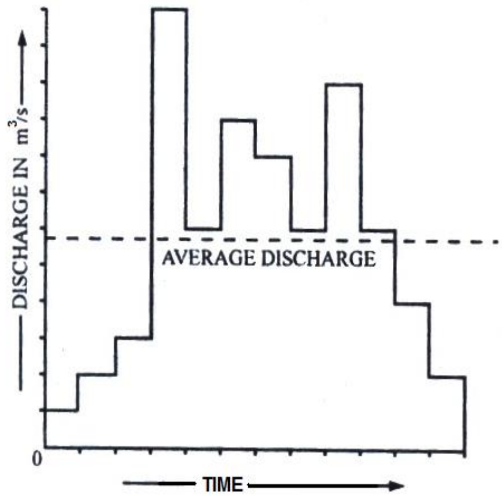
A small storage is sometimes used to meet the fluctuating demand for a small period. When the power house is far away from the main storage, a small pondage should be provided near the power house to meet the fluctuating demand.

6) HYDRO GRAPH:-

It is a graphical representation between discharge (or flow) and time, where the X-axis is represented by time in terms of hours, days, weeks or months and Y-axis is represented by flow or discharge in cubic meter per second. Generally the flow or discharge is considered as number of cubic meters of water in second per a square kilometer (area).

A hydro graph provides the following information,

1) The Discharge at any time during the period under considerations.
2) The Average and Maximum, Minimum Run-Off during the period.
3) Total volume of discharge up to any time, given by the area under the curve up to that time.



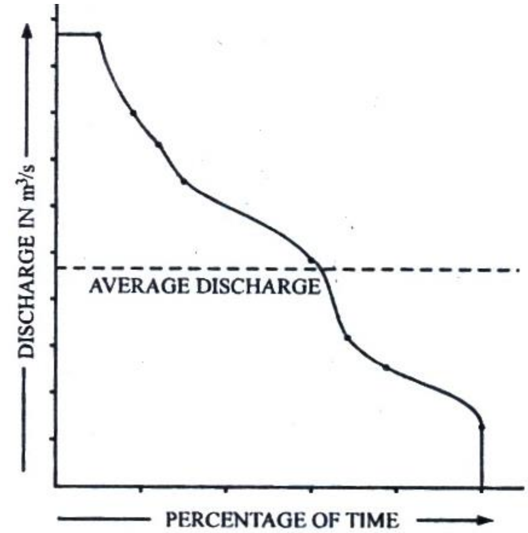


Fig 3.2: Hydro Graph **Fig 3.3: Flow Duration Graph**

7) FLOW DURATION CURVE:-

It is a very convenient form of Hydrograph. Flow duration curve is a re-arrangement of all the stream flow elements of a hydrograph in a descending order.

A Flow Duration graph provides the following information,

1) The area under flow duration curve represents total quantity of run-off during the period.
2) A flow duration curve may be used for determination of the Average and Maximum, Minimum conditions of flow.

8) MASS CURVE:-

A mass curve is a plot of cumulative volume of water that can be stored from stream flow versus time in terms of hours, days, weeks or months. If the rainfall is uniform throughout the year, the mass curve would be a straight line having uniform slope.

A Mass curve provides the following information,

1) The slope of this curve at any point gives the rate of flow at that time.
2) Mass curve is used to determine the capacity of storage reservoir in Hydro electric projects.

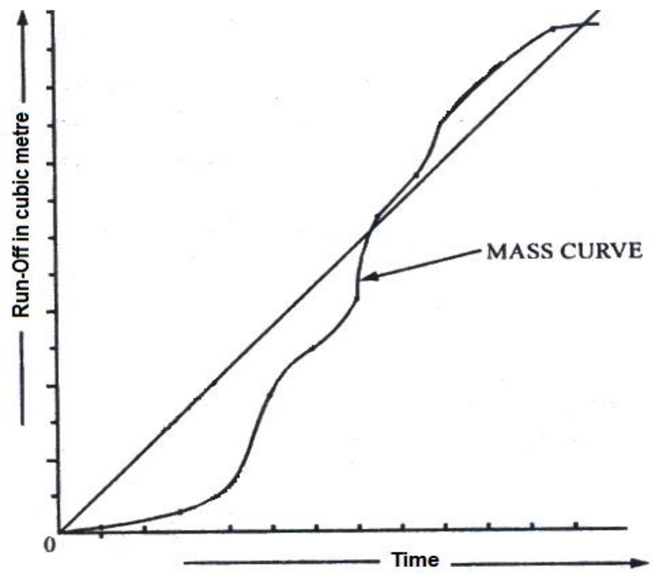


Fig 3.4:Mass curve

Note: - Drawing of these curves (Hydro Graph, Flow duration Graph, Mass Curve) is very helpful in the selection of site for a Hydro electric Power Plant.

3.6EXPRESSION FOR POWER DEVELOPED IN A HYDRO ELECTRIC PLANT

Let W = Density of water in Kg/m^3 (generally = 1000 Kg/m^3).

Q = Rate of flow or discharge in m^3/sec.

H = Head in meters.

η = Overall efficiency of the plant.

The electric Power developed by Hydro Electric Power Plant is given by,

$$P = WQH\eta \times 9.81 \times 10^{-3} \text{ kW}$$

3.7 SCHEMATIC ARRANGEMENT OF A HYDRO ELECTRIC POWER PLANT

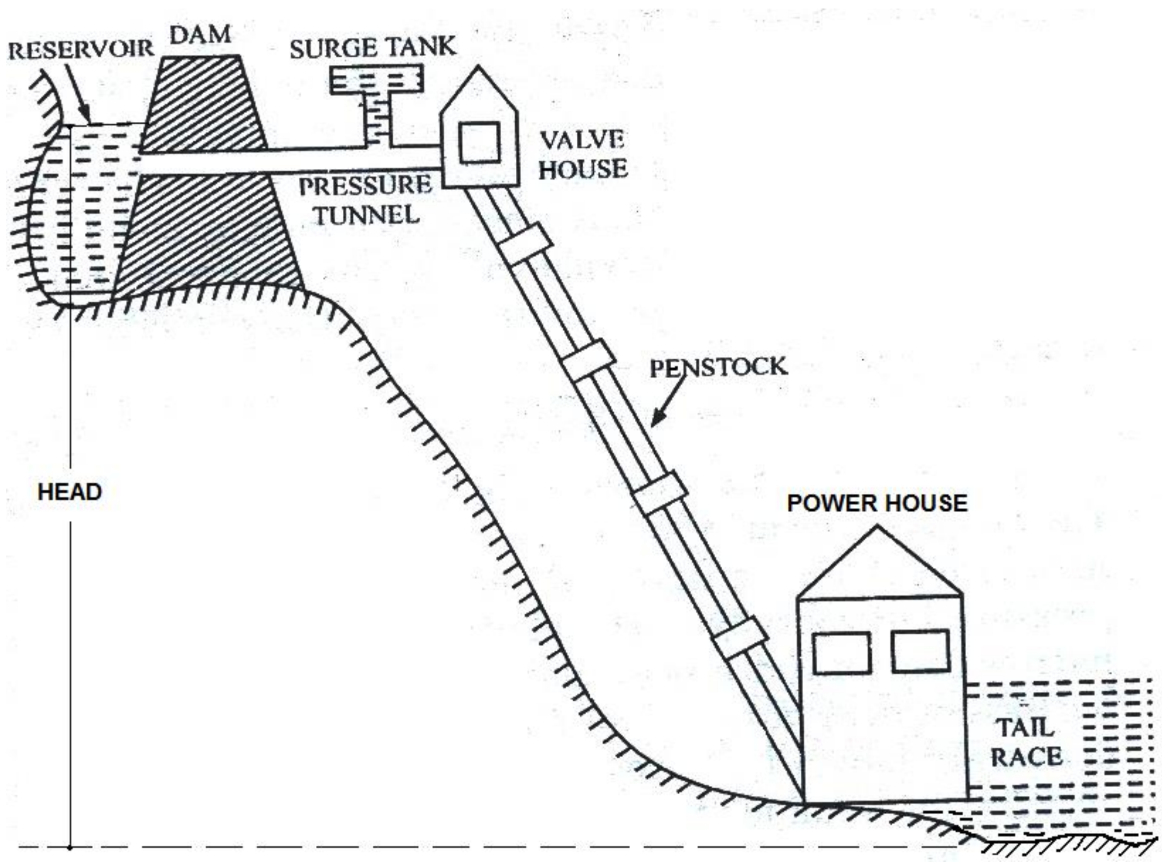


Fig 3.5:schematic arrangement hydro electric power plant

PRINCIPLE OF OPERATION:-

We know that the chief requirement for hydro electric power plant is the availability of water in huge quantity at sufficient head and this requirement can be met by constructing a dam across a river or lake or reservoir.

In a hydro electric power station, electricity is generated by using potential, kinetic energy of water. Water from the river or the reservoir behind the dam, at a suitable head, is taken through the 'forebay' tothe intake and then penstocks to the turbine. Then the turbine will rotate, which drives an alternator, thus electricity is produced. The speed of the turbine set mainly depends on water head.

A typical hydro electric power plant consisting of the following elements.

1. Reservoir	7. Penstock
2. Dam	8. Prime Mover
3. Pressure Tunnel	9. Power House
4. Surge Tank	10. Draft Tube
5. Valve House	11. Tail Race
6. Forebay	12. Spill Way

1. Reservoir:-

It is the basic requirement of a hydro electric plant. Its purpose is to store water which may be utilized to run the prime mover to produce electrical power. A reservoir stores water during the rainy season and supplies the same during the dry season and thus it helps in supplying water to the turbine according to the load on the power plant throughout the year.

2. Dam:-

The function of a dam is to provide a head of water to be utilized in the water turbine. A dam also increases the reservoir capacity. Simply it supports the reservoir, and a Pressure tunnel is taken off from the reservoir to valve house.

3. Valve House:-The valve house contains various valves like,

i) Main sluice valves for controlling water flow to the power station,

ii) Automatic isolating valves for cutting off water supply in case the penstock bursts.

4. Surge Tank:-

A surge tank is provided just before the valve house for better regulation water pressure in the system.

The sudden changes in load causes the changes in the governor positions leads to some pressure variations in the penstock. This may results in “water hammer” phenomenon. This may be accomplished by providing a small storage tank called surge tank to overcome hammer effect.

5. Forebay:-

A Forebay may be considered as an enlarged body of water just above the intake to store water temporarily to meet the hourly load fluctuations.

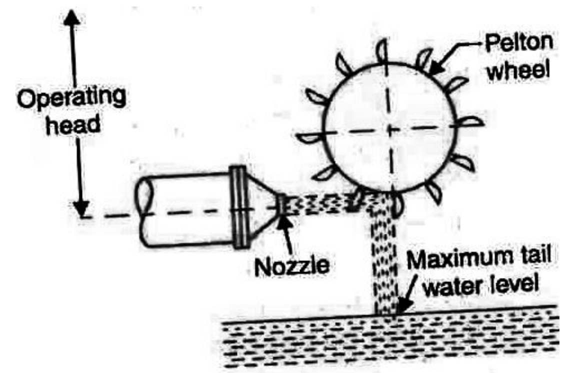
When the Hydro electric plants are located just at the base of the dam, no Forebay is required because the reservoir itself serves the purpose of forebay. However, where the plants are situated away from the storage reservoir, a forebay is needed.

6. Penstock:-

From the valve house water is carried to turbine through pipes of large diameter made of steel or reinforced concrete, called the penstock.

7. Prime Mover:-

The purpose of prime mover is to Convert hydraulic energy (Potential, Kinetic) of water into mechanical energy, which is further utilized to drive the alternators generating electricity. Commonly used prime movers are Pelton wheel, Francis, Kaplan, and Propeller turbines.



Pelton Wheel Turbine Arrangement

Fig3.6:

8.PowerHouse:-

The power house consists of the turbine and all other electrical equipments like generators and etc.., to produce electrical power.

9. Draft Tube:-

An air tight pipe of suitable diameter used to discharge water down by turbine into tail race.

10. Tail Race:-

The water after having done its useful work in the turbine is discharged to the tail race which may be lead to the same stream or to another one.

11. Spill Way:-

This may be considered as a safety valve for reservoir. A spill way serves to discharge excess water in the reservoir beyond the full permissible level. It discharges the overflow water to downstream side when the reservoir is full, a condition mainly arising during flood periods, Heavy rainy seasons etc.., These are generally constructed of concrete and provided with water discharge opening shut off by metal control gates at Dam.

3.8 CLASSIFICATION OF HYDRO POWER PLANTS

There are three different methods of classifying hydro-electric plants. The classification may be based upon

1) Quantity of water available.
2) Available head.
3) Nature of load.

I) Classification of Hydro-electric plant according to Quantity of water available

According to this classification the plants may be divided into

a) Run-Off river plants without pondage.
b) Run-Off river plants with pondage.
c) Reservoir plants.

a) Run-Off river plants without pondage:-

As the name indicates this type of plant does not store water, the plant uses water as it comes. The plant can use water only as and when available. i.e., the generation of power is possible only when there is availability of water. The firm capacity of such plant is very low, since the supply of water is not uniform throughout the year.

b) Run-Off river plants with pondage:-

Usefulness of a run-off river plant is increased by pondage. Pondage permits storage of water during the off-peak periods and use of this water during the peak periods. The pondage increases the storage increases the storage of water which increases the firm capacity of the plant.

c) Reservoir plant:-

Majority of hydro-electric plants are of this type. When water is stored in a big reservoir it is possible to control flow of water. The storage increases the firm capacity. Such a plant has better capacity and can be used efficiently throughout the year and it can be used either as a base-load plant or as a peak load plant.

II) Classification of Hydro-electric plant according to Available head

Hydro-electric plants may be classified into:

a) Low head b) Medium head c) High head plants.

a) Low head Plant :

If the head of the plant is below **60m**, then those plants are called as low head plants. In this case a small dam is built across the river to provide the necessary head. In such plants **Francis, Propeller or Kaplan** types of turbines are used. Also no surge tank is required.

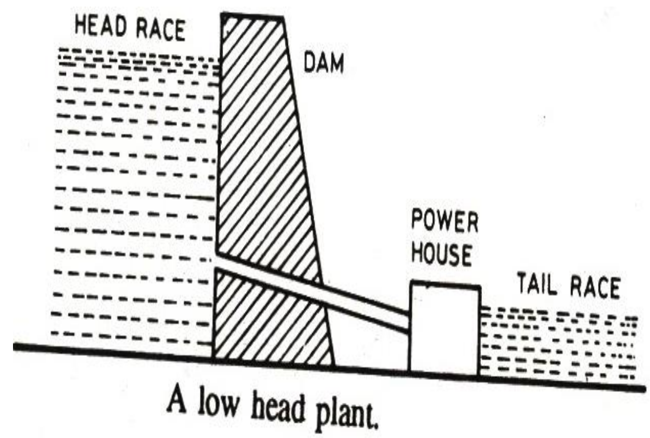


Fig 3.7: Low Head Power Plant

b) Medium head plant :

In these plants the head varies from **60m-300m**. The forebay provided at the beginning of the penstock serves as water reservoir for such plants. In these plants water is generally carried in open canals from main reservoir to the forebay and then to the power house through the penstock. The forebay itself works as surge tank.

The common prime movers used in these plants are **Francis, Propeller and Kaplan turbines**.

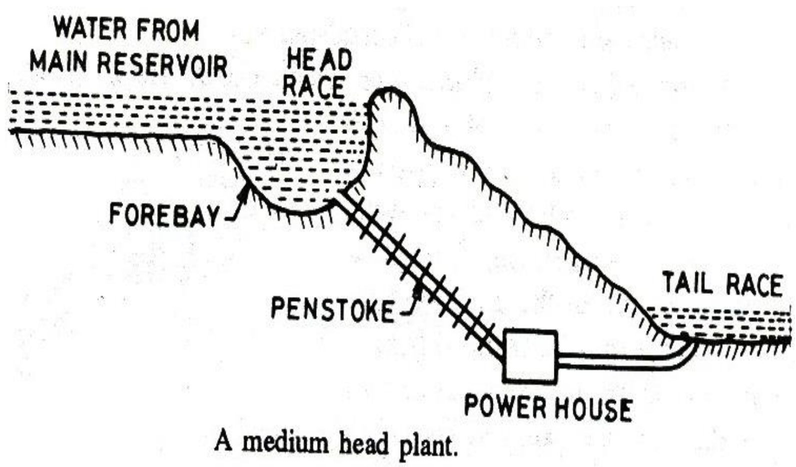


Fig 3.8: Medium Head Power Plant

c) High head plants :-

The plants having head **above 300m** called High head plants. For these plants Pelton wheel turbine is used as prime mover.Majority of hydro-electric plants are of this type

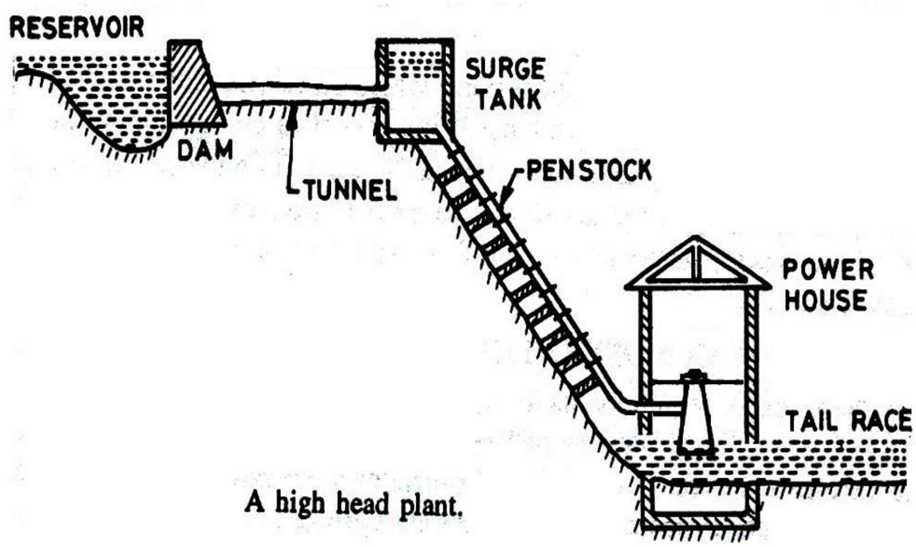


Fig 3.9: High Head Power Plant

III) Classification of Hydro-electric plant according to Nature of load

Hydro-electric plants may be classified into:

a) Base load Plant.

b) Peak load Plant.

c) Pumped storage plant for peak load.

a) Base load plant:-

The average load that exists always on the power plant in a particular time period is called the base load. The Power plants used to supply power for this loads are called Base load plants. (Or) The plants, which can take up load on the base portion of load curve, are known as Base load plants.

Ex:-Run-Off river plants and reservoir type plants are used as base load plants. (The load factor of the base load plants is high)

b) Peak load plants:-

The maximum load that exists on the power plant at a particular time is called the peak load at that time. The Power plants used to supply power for this loads are called Peak load plants. These plants supply power corresponding to the load at the top portion of the load curve.

Ex:- Run-Off river plant with pondage, reservoir plants are used as peak load plants.

c) Pumped storage plant: -

This is a unique design of peak load plant in which the plant pumps back all or a portion of water supply during low load period. During the peak load period water is drawn from the head water pond through the penstock to operate the turbine. The pumping back from the tail race pond to the head water pond is done during off-peak period.

These plants can be operated only in interconnected systems, where other generating plants (steam, nuclear, etc..,) are also available. **This plant acts as a generator during peak load period and acts as a motor during off-peak load period.**

For this type of power plant **reversible-turbine-pump units are used**. Such a unit can be used as a turbine while generating power in peak load periods and acts as a pump while pumping water back to storage in off-peak load periods.

Advantage:-

The major advantage of a pumped storage plant is that it decreases the operating cost of a steam plant or nuclear plant, etc.., which when working in combination with it.

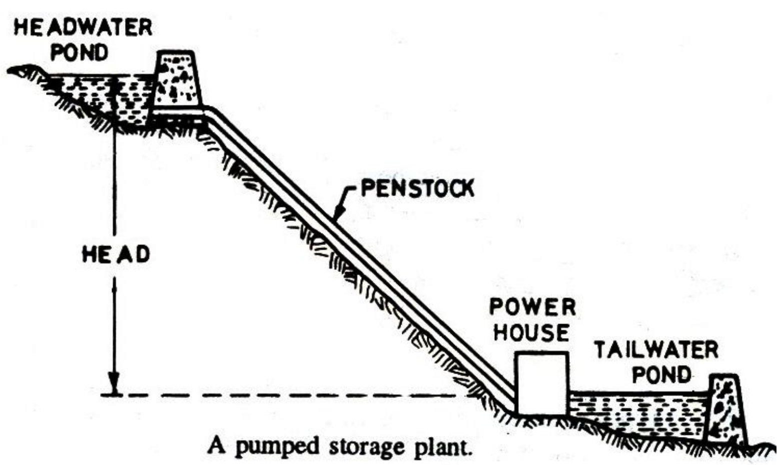


Fig 3.10: Pumped Storage Power Plant

IMPORTANT FORMULAS

- ✓ Firm Capacity = Plant efficiency × Plant Gross capacity.
- ✓ Run-off = Total precipitation – Total evaporation.
- ✓ The electric Power developed by Hydro Electric Power Plant is $P = WQH\eta \times 9.81 \times 10^{-3}$ kW
- ✓ Load Factor = $\frac{\text{Average Power Demand}}{\text{Maximum Power Demand}}$

GAS TURBINE POWER PLANTS

3.9 Introduction:

A generating station which employs gas turbine as the prime mover to drive an alternator for the generation of electrical energy is known as a Gas Turbine Power Plant. In a gas turbine, the working medium is either a mixture of combustion products and air or heated air at a certain pressure.

The principle of gas turbine power plant is that a Turbo-compressor compresses working medium (air) to a high pressure and is led to the combustion chamber where heat is added to air, thus raising its temperature. Heat is added to the compressed air either by burning fuel in the chamber or by the use of air heaters. This high pressure and high temperature working medium is then expanded in a gas turbine coupled to the generator (or alternator).

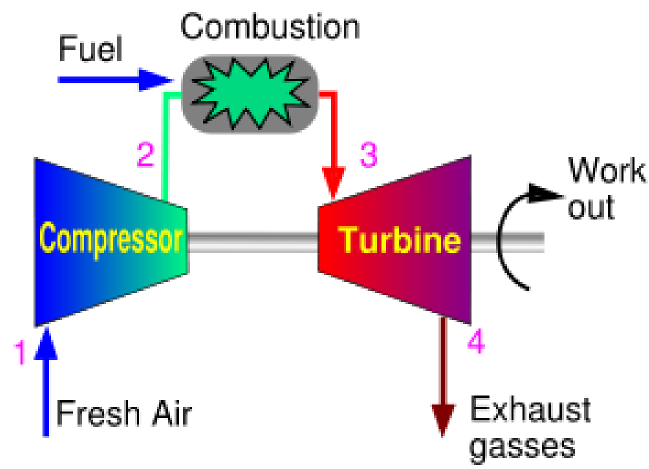


Fig 3.11: Gas Turbine Power Plant

The overall efficiency of a gas turbine as a prime mover is limited due to the fact that a large portion of the power developed by the turbine is used in driving the compressorand also by the temperature safely attainable. Thus two factors that need improvement are the design of the compressor and design of turbine with suitable materials to withstand high temperatures. A lot of research work is in progress in this direction.

3.10 ADVANTAGES & DISADVANTAGES OF GAS TURBINE POWER PLANTS

ADVANTAGES

1) Gas turbines are much simpler in construction and operation than steam turbines.
2) It can be started quickly from cold conditions, hence quickly respond to load changes.
3) High reliability and simple lubrication system.
4) Installation time is less compare to steam power plant.
5) The initial & operating costs are much lower than that of equivalent steam power station

DISADVANTAGES

1) There is a problem for starting the unit. It is because before starting the turbine; the compressor has to be operated for which power is required from some external source. However, once the unit starts, the external power is not needed as the turbine supplies the necessary power to the compressor.
2) Since a greater part of power developed by the turbine is used in driving the compressor, the net output is low.
3) The overall efficiency of such plants is low about 20%.

3.11APPLICATIONS OF GAS TURBINE POWER PLANTS

1. Majority of gas turbine power plants are usually used for driving generators and supplying peak loads in other types of power plants (steam and hydro-electric power plants), because they can be started and loaded quickly. Other reasons for it are low initial costs and higher fuel costs.
2. Such a plant is used as a starting plant for driving auxiliaries in other power plants.
3. A large number of such plants are used as standby power plants.
4. Gas turbine power plants are also used as base-load power plants where fuel oil or natural gas is cheap and easily available.
5. Such plants can be used in parallel with tidal power plants.

3.12 SCHEMATIC ARRANGEMENT OF GAS TURBINE POWER PLANT:

The schematic arrangement of a gas turbine power plant is shown in Fig.. The main components of the plant are

(i)Compressor (ii) Regenerator (iii) Combustion chamber (iv) Gas turbine (v) Alternator

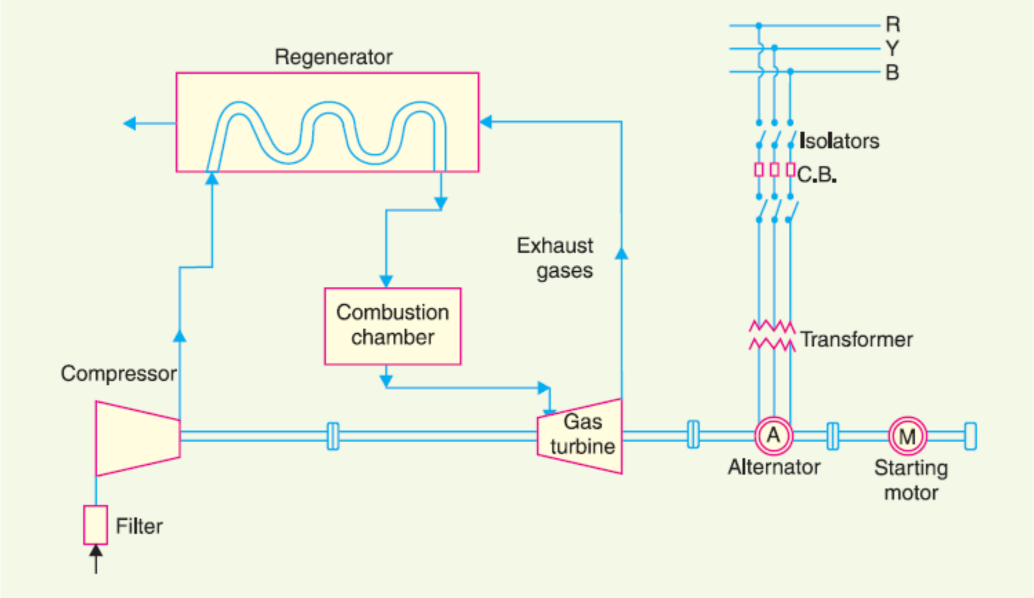
(vi) Starting motor

(i) Compressor: The compressor used in the plant is generally of rotatory type. The air at atmospheric pressure is drawn by the compressor via the filter which removes the dust from air. The rotatory blades of the compressor push the air between stationary blades to raise its pressure. Thus air at high pressure is available at the output of the compressor.

(ii) Regenerator:A regenerator is a device which recovers heat from the exhaust gases of the turbine. The exhaust is passed through the regenerator before wasting to atmosphere. A regenerator consists of a nest of tubes contained in a shell. The compressed air from the compressor passes through the tubes on its way to the combustion chamber. In this way, compressed air is heated by the hot exhaust gases.

(iii) Combustion chamber: The air at high pressure from the compressor is led to the combustion chamber via the regenerator. In the combustion chamber, heat is added to the air by burning oil. The oil is injected through the burner into the chamber at high pressure to ensure atomisation of oil and its thorough mixing with air. The result is that the chamber attains a very high temperature (about 3000oF). The combustion gases are suitably cooled to 1300oF to 1500oF and then delivered to the gas turbine.

(iv) Gas turbine: The products of combustion consisting of a mixture of gases at high temperature and pressure are passed to the gas turbine. These gases in passing over the turbine blades expand and thus do the mechanical work. The temperature of the exhaust gases from the turbine is about 900oF.



Schematic arrangement of gas turbine power plant.

Fig.3.12

(v) Alternator: The gas turbine is coupled to the alternator. The alternator converts mechanical energy of the turbine into electrical energy. The output from the alternator is given to the bus-bars through transformer, circuit breakers and isolators.

(vi) Starting motor: Before starting the turbine, compressor has to be started. For this purpose, an electric motor is mounted on the same shaft as that of the turbine. The motor is energized by the batteries. Once the unit starts, a part of mechanical power of the turbine drives the compressor and there is no need of motor now.

Assignment-Cum-Tutorial Questions

SECTION-A:

1. Hydro power plant is suitable as:
   a) Base load plant b) Peak load plant c) Both d) None

2. Hydro plant installed capacity depends on
   a) Storage b) discharge c) head d) none

3. For high power output which turbine is used
   a) Francis b) Kaplan c) pelton d) propeller

4. A Kaplan turbine is
   a) Inward flow, impulse turbine b) outward flow, reaction turbine
   c) High head mixed flow turbine **d) low head mixed flow turbine**

5. The efficiency of pumped storage plant is generally about:
   a) 95% b)85% c)65% d)40%

6. Which of the following have generally salient pole construction?
   a) Alternators used in thermal plants **b) alternators used in hydro plants**
   c) Both a & b d) none

7. A surge tank stabilizes
   a) Sudden rise of electric power**b) pressure difference in water**
   c) Sudden loss of electric load d) generation

8. Advantage of hydro-electric power station is
   (A) low operating cost
   (B) free from pollution problems
   (C) no fuel transportation problems
   (D) all of the above

9. Water hammer effect is developed in
   a) Surge tank b) water turbine **c) penstock** d) draft tube

10. For low head and high discharge, the hydraulic turbine used is
    (A) Kaplan turbine (B) Francis turbine
    (C) Pelton wheel (D) Jonual turbine.

11. A gas turbine works on

(A) Carnot cycle **(B) Brayton cycle** (C) Dual cycle (D) Rankine cycle

12. Maximum efficiency of an open cycle gas turbine is nearly

(A) 30% (B) 40% (C) 50% (D) 60%.

13. Compressor used in gas turbines is

(A) Reciprocating compressor (B) plunger type compressor

(C) Screw compressor **(D) multistage axial flow compressor**.

14. Which auxiliary of gas turbine consumes most of the power?

(A) Burner (B) Combustion chamber **(C) Compressor** (D) Fuel pump.

15. Gas turbine is widely used in

(A) pumping stations **(B) aircraft** (C) locomotives (D) automobiles.

16. In pumped storage
(A) Power is produced by means of pumps
(B) Water is stored by pumping to high pressures
(C) Downstream water is pumped up-stream during off load periods
(D) Water is re circulated through turbine.

17. A graphical representation between discharge and time is known as
(A) Monograph (B) Hectograph (C) Topograph **(D) Hydrograph**.

18. In a hydro-electric plant a conduct system for taking water from the intake works to the turbine is known as
(A) Dam (B) Reservoir **(C) Penstock** (D) Surge tank.

19. A Pelton wheel is
(A) inward flow impulse turbine (B) Outward flow impulse turbine
(C) Inward flow reaction turbine **(D) Axial flow impulse turbine.**

20. Running away speed of a Pelton wheel is
(A) Actual operating speed on no load (B) Full load speed
(C) No load speed when governor mechanism fails (D) 90% greater than the normal speed.

21. Outward radial flow turbines
(A) are impulses turbines (B) are reaction turbines
(C) are partly impulse partly reaction turbines **(D) may be impulse or reaction turbines**.

22. Peak load power plants is

a) Pumped storage plant b) diesel plant c) nuclear plants **d) both 1&2**

23. The electrical power developed by a hydro power plant in KW is given by the expression

a) 9.81 x WQHη x 10^{-3} b) 75x WQHη

C) 19.81 x WQHη x 10^{6} d)none

24. The specific speed N_s of a turbine is given by the expression

a) $N_s = \sqrt{PN}/H^{1.5}$ **b) $N_s = \sqrt{PN}/H^{1.25}$** c) $N_s = \sqrt{PN}/H^{2/3}$ d) None

25. Cost of operation of which plant is least?

(A) Gas turbine plant (B) Thermal power plant

(C) Nuclear power plant **(D) Hydroelectric plant.**

SECTION-B:

I) DESCRIPTIVE QUESTIONS

1. List out the advantages and disadvantages of hydroelectric plants?
2. Enumerate the factors affecting site selection of hydroelectric plants?
3. Explain in detail the classification of hydroelectric plant based on water head level?
4. Discuss the classification of hydro plants based on regulation of water flow?
5. Explain in detail various components and function of a hydroelectric generation system?
6. Explain the phenomenon of 'water hammer' in hydro-electric power station.
7. Define the following
   a) Flow duration curve b) hydrograph c) Mass curve
8. Explain the working of a gas turbine power plant with schematic diagram?
9. Why hydroelectric stations have high transmission and distribution costs?
10. Give the comparison of thermal power plant, hydro power plant, gas plant and nuclear power plant on the basis of initial cost, running cost, efficiency, land requirement, starting time and life time?
11. Why is regenerator used in gas turbine power plant?
12. What are merits and demerits of gas turbine power plant?

II) PROBLEMS

1. A hydro-electric generating station is supplied from a reservoir of capacity 5 x10^{6} cubic metres at a head of 200 metres. Find the total energy available in kWh if the overallefficiency is 75%. [**Ans:2.044x 10^{6} KWh**]

2. It has been estimated that a minimum run off of approximately 94 m3/sec will beavailable at a hydraulic project with a head of 39 m. Determine (i) firm capacity (ii) yearly gross output. Assume the efficiency of the plant to be 80%. [**Ans:252x 10^{6} KWh**]

3. Water for a hydro-electric station is obtained from a reservoir with a head of100 meters. Calculate the electrical energy generated per hour per cubic meter of water if the Hydraulic efficiency be 0·86 and electrical efficiency 0·92**.**

[Ans:775KWh]

4. A hydro-electric power station has a reservoir of area 2·4 square kilometers andCapacity 5 .106 m3. The effective head of water is 100 meters. The penstock, turbine and generation Efficiencies are respectively 95%,90% and 85%.

[**Ans: 9,89,175KWh;9.47cm]**

(i) Calculate the total electrical energy that can be generated from the power station.

(ii) If a load of 15,000 kW has been supplied for 3 hours, find the fall in reservoir level.

5. A hydro-electric station has an average available head of 100 meters and reservoir capacity of 50 million cubic meters. Calculate the total energy in kWh that can be generated, assuming hydraulic efficiency of 85% and electrical efficiency of 90**%.** **[Ans:10.423 x10 ^{6} KWh]**

SECTION-C:

1. For harnessing low variable water heads, the suitable check for coverage in text with high percentage of reaction and runner adjustable vanes is **GATE 2004**
   a. **Kaplan** b. Franics c, pelton d.none
2. A hydraulic turbine having rated speed of 250 rpm is connected to a synchronous generator .In order to produce power at 50 Hz, the number of poles required in the generator are **GATE 2004**
   a.6 b.12 c.16 d.24
3. In hydro power stations,what is an enlarged body of water just above the intake and used as a regulating reservoir ,called **IES 2006**
   a.spillways **b.forebay** c.reservoir d.penstock

UNIT IV
SUBSTATIONS

Learning Objectives:

- To classify the substations
- To compare outdoor and indoor substations
- To introduce the various equipments in a substation.
- To understand the bus-bar arrangements in a substation
- To list out the advantages and disadvantages of GIS.

Syllabus:

Air insulated substations & Gas insulated substations:

Classification of substations:- Indoor & Outdoor substations: Substations layout showing the location of all the substation equipment. Bus bar arrangements in the Sub-Stations and their classification, Advantages of Gas insulated substations.

Learning outcomes:

Students will be able to

- Classify the substations
- Compare outdoor and indoor substations
- Describe the functions of various equipments in a substation
- Explain the bus-bar arrangements in a substation.
- Discuss the advantages of GIS over AIS.

4.1INTRODUCTION:

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 substation:

(i) It should be located at a proper site. As far as possible, it should be located at the centre ofgravity of load.

(ii) It should provide safe and reliable arrangement. For safety, consideration must be given tothe 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.

4.2 Classificationof Sub-Stations:

There are several ways of classifying sub-stations. However, the two most important ways of classifying them are according to (1) service requirement and (2) constructional features.

1. **According to service requirement.**A sub-station may be called upon to change voltagelevel 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 electricsupply 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 leveli.e.incomingand 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 factorof 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 frequencyare known as frequency changer sub-stations. Such a frequency change may be required for industrial utilization.

(v) Converting sub-stations. Those sub-stations which change a.c. power into d.c. power arecalled converting sub-stations. These sub-stations receive a.c. power and convert it into d.c. powerwith 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 industrialconcerns are known as industrial sub-stations.

2. **According to constructional features:**A sub-station has many components (e.g.circuitbreakers, switches, fuses, instruments etc.) which must be housed properly to ensure continuous and reliable service. According to constructional features, the sub-stations are classified as:
   i. Indoor substation.
   ii. Outdoor substation.
   iii. Underground substation.
   iv. Pole mounted substation.

(i) **Indoor substation:** For voltage up to 11 kV, the equipment of substation is installed indoor because of economic considerations. However, when the atmosphere is contaminated with impurities, these sub-stations can be erected for voltages upto 66 kV.

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

(iii) **Underground sub-stations.** In thickly populated areas, the space available for equipmentand building is limited and the cost of land is high. Under such situations, the sub-station is created underground.

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

4.3 Comparison between Outdoor and Indoor Sub-Stations:

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 beacuse 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.

4.4 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 maincomponent employed to change the voltage level. Depending upon the purpose served, transformer sub-stations may be classified into :

(i) Step up substation.
(ii) Primary grid substation.
(iii) Secondary substation.
(iv) Distribution substation.

Fig. 4.1 shows the block diagram of a typical electric supply system indicating the position of above types of sub-stations. 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.

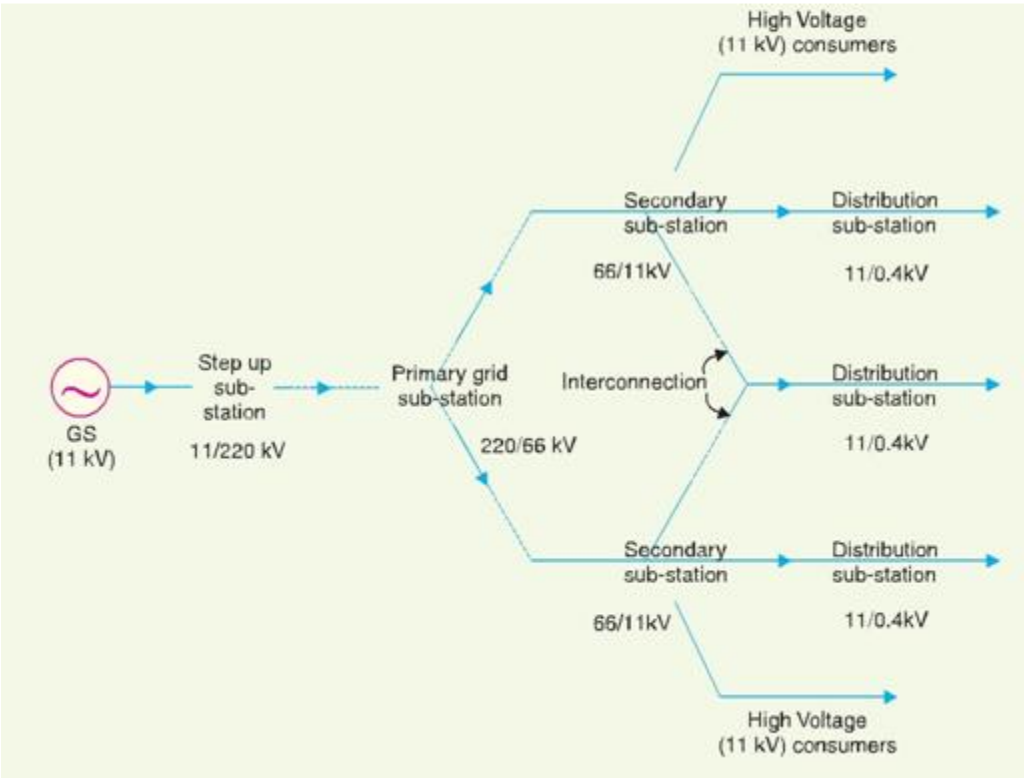


Fig 4.1 block diagram of a typical electric supply system

(i) Step up substation. The generation voltage (11 kV in this case) is stepped up to highvoltage (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 substation. 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 received 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 substation. From the primary grid sub-station, electric power is transmitted at66 kV by 3-phase, 3-wire system to various secondary sub-stationslocated 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 distributionsub-stations. These sub-stations are located near the consumer's 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.

4.5 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 4.2 (i) shows the layout of pole-mounted sub-station whereas Fig. 4.2 (ii) shows the schematic connections. The transformer and other equipment are mounted on H-type pole (or 4-pole structure).

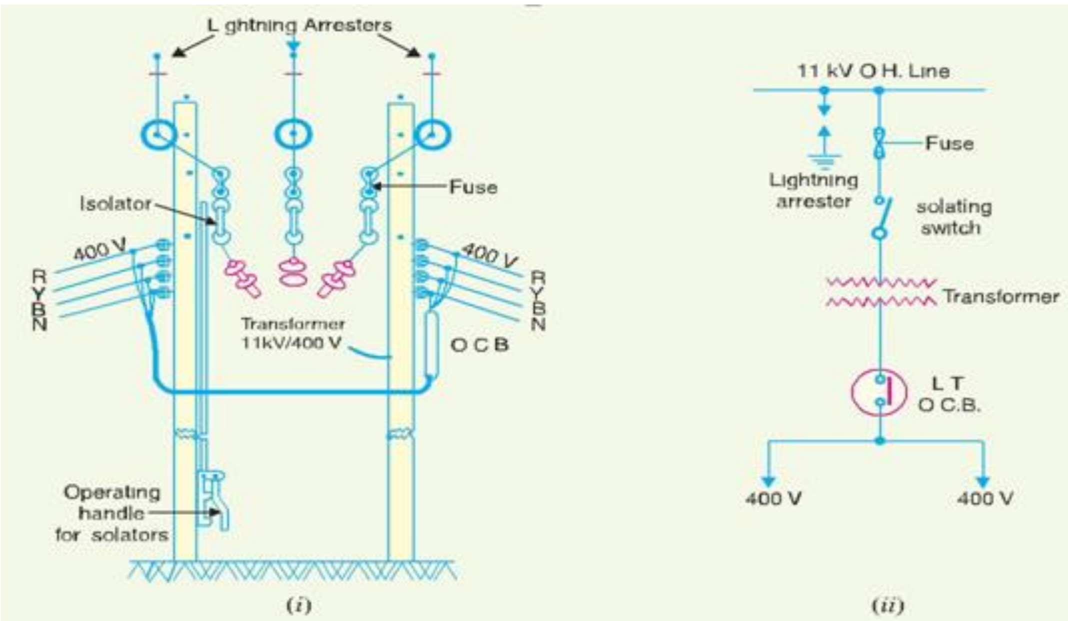


Fig 4.2 Schematic connections

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. The pole-mountedsub-stations are generally used for transformer capacity up to 200 kVA. The following points may be noted about pole-mounted sub-Stations :

(i) There should be periodical check-up of the dielectric strength of oil in the transformer andO.C.B.

(ii) In case of repair of transformer or O.C.B., both gang isolator and O.C.B. should be shut off.

4.6 Underground Sub-Station:

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. Fig. 4.3 shows a typical underground sub-station.

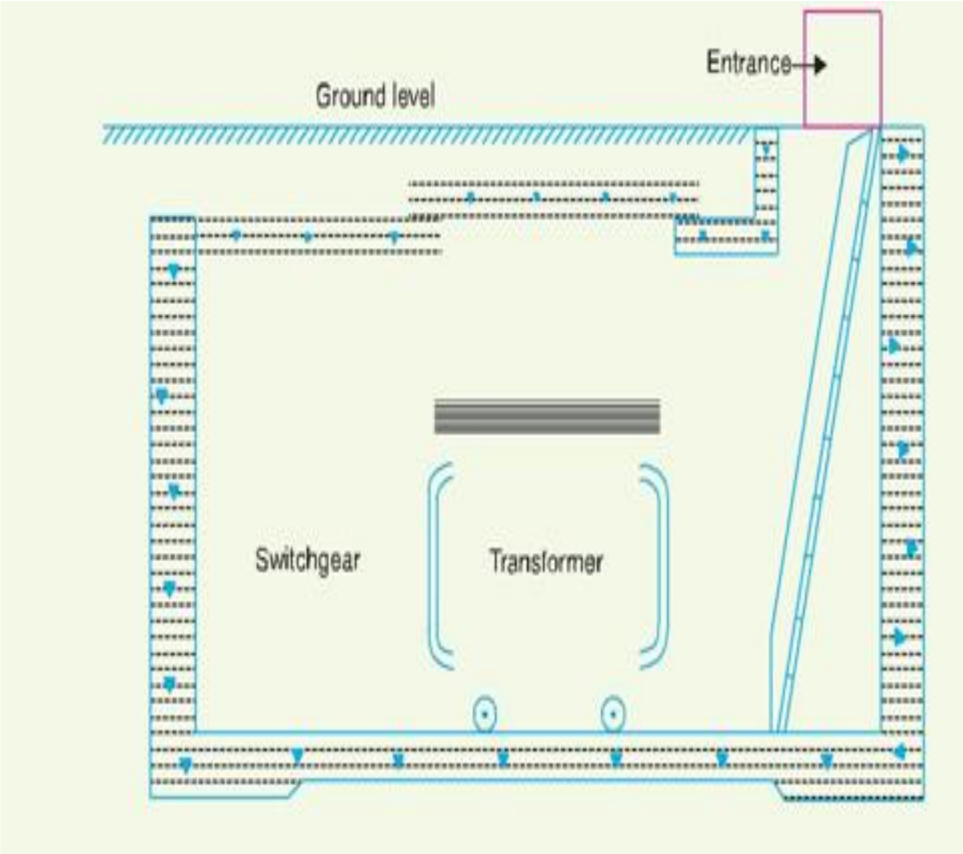


Fig. 4.3 a typical underground sub-station.

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.

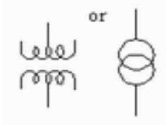
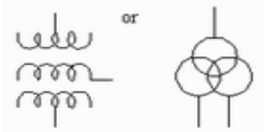
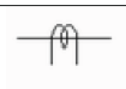
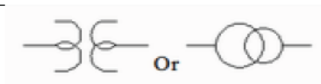
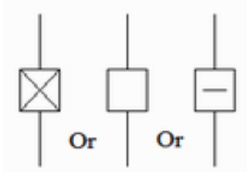
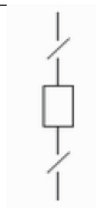
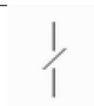
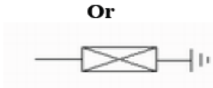
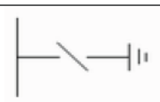
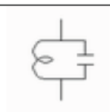
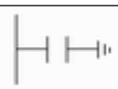
(iv) There should be good ventilation.

(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 thepremises.

4.7 Symbols for Equipment in Sub-Stations:

Some of the standard symbols used to represent substation components are given in Table below:

Sl No	Electrical components	Symbols
1	**AC Generator**	
2	**Bus Bar**	
3	**Power transformer -Two winding**	
4	**Three winding transformer**	
5	**Current Transformer (CT)**	
6	**Voltage transformer or Potential transformer (PT)**	
7	**Circuit Breaker (CB)**	
8	**Circuit breaker with isolator**	
9	**Isolator or Group Operating Switch(GOS)**	
10	**Lighting Arrestor (LA)**	 **Or** 
11	**Earth Switch (ES)**	
13	**Wave or Line trap**	
14	**Coupling Capacitor (CC)**	

4.8 Equipment in a Transformer Sub-Station:

The equipment required for a transformer sub-station depends upon the type of sub-station, service requirement and the degree of protection desired. However, in general, a transformer sub-station has the following main equipment :

1. BUS-BARS. When a number of lines operating at the same voltage have to be directly connected electrically, bus-bars are used as the common electrical component. Bus-bars are copper or Aluminum 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

2. 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 ex-ample, 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.

3. ISOLATING SWITCHES. In sub-stations, it is often desired to disconnect a part of the system forgeneral 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.

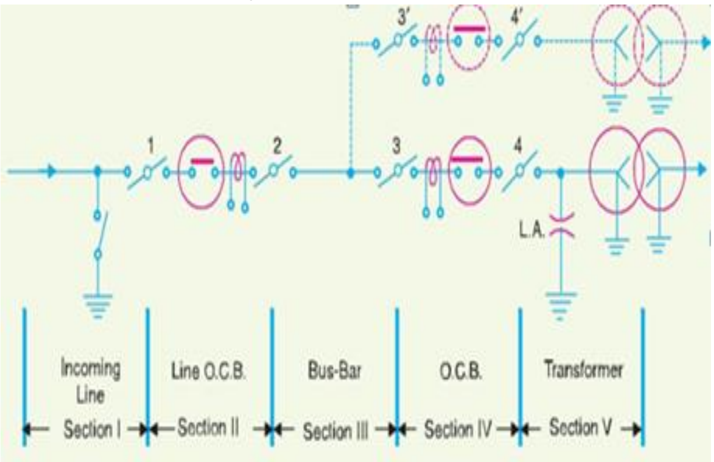


Fig. 4.4 shows the use of isolators in a typical sub-station.

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.

4. CIRCUIT BREAKER. A circuit breaker is equipment which can open or close a circuit undernormal 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.

5. POWER TRANSFORMERS. A power transformer is used in a sub-station to step-up or step-downthe 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 substations; although 3 single phase bank oftransformers 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.

6. INSTRUMENT TRANSFORMERS. The lines in sub-stations operate at high voltages and carrycurrent 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 orcurrents 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 transformerwhich 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 connected 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 voltageto 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.

7. 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.

8. MISCELLANEOUS EQUIPMENT. In addition to above, there may be following equipment in asub-station :

Lightning arresters (LA): Lightning arresters are the protective devices used for protection of equipment from lightning strokes. They are located at the starting of the substation and also provided near the transformer terminals.

Earth switch: It is a switch normally kept open and connected between earth and conductor. If the switch is closed it discharges the electric charge to ground, available on the uncharged line.

Wave trap: This equipment is installed in the substation for trapping the high frequency communication signals sent on the line from remote substation and diverting them to the telecom panel in the substation control room.

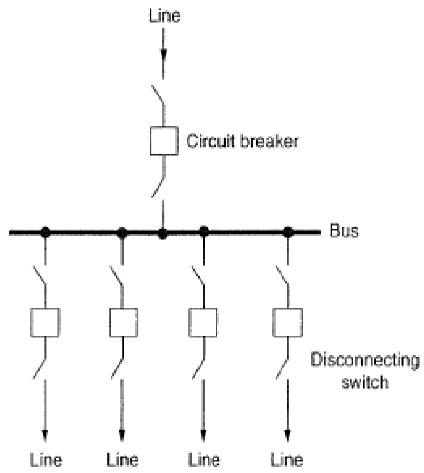
Coupling capacitor: A coupling capacitor is used in substations where communication is done by AC power line. It offers very low impedance to high frequency carrier signal and allows them to enter the line matching unit and blocks the low frequency signal.

4.9 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 substations:

1. Single bus-bar system.

As the name suggests, it consists of a single bus-bar and all theincoming 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.



A typical single-bus scheme.

a. Merits

1. Low Cost
2. Simple to Operate
3. Simple Protection

b. Demerits

1. Fault of bus or any circuit breaker results in shut down of entire substation.
2. Difficult to do any maintenance.
3. Bus cannot be extended without completely de-energizing substations.

c. Remarks

1. Used for distribution substations up to 33kV.
2. Not used for large substations.
3. Sectionalizing increases flexibility.

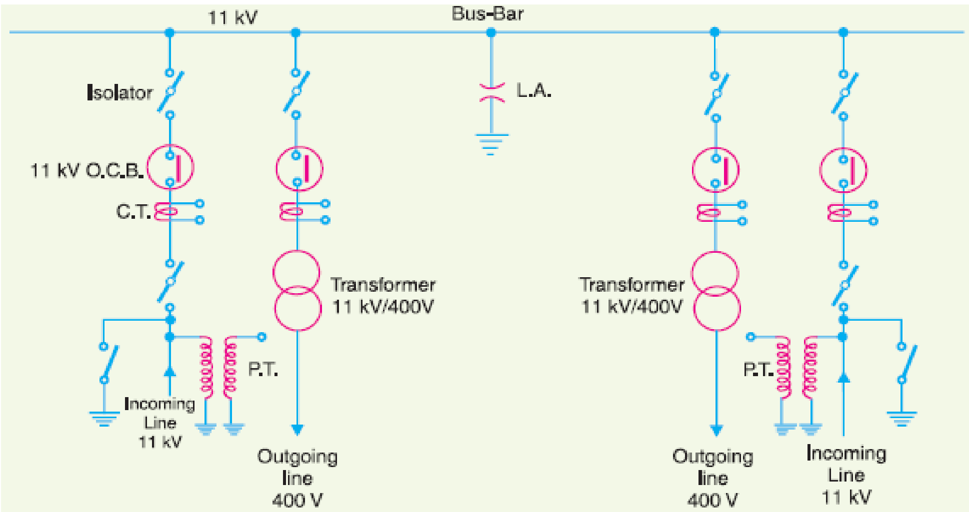


Fig 4.5 Single bus-bar arrangement in a Sub-station.

Fig. 4.5 shows single bus-bar arrangement in a sub-station. 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.

2. Single bus-bar system with Sectionalisation.

In this arrangement, the single bus-bar isdivided 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 reenergizing that section only, eliminating the possibility of complete shutdown. This arrangement is used for voltages up to 33 kV.

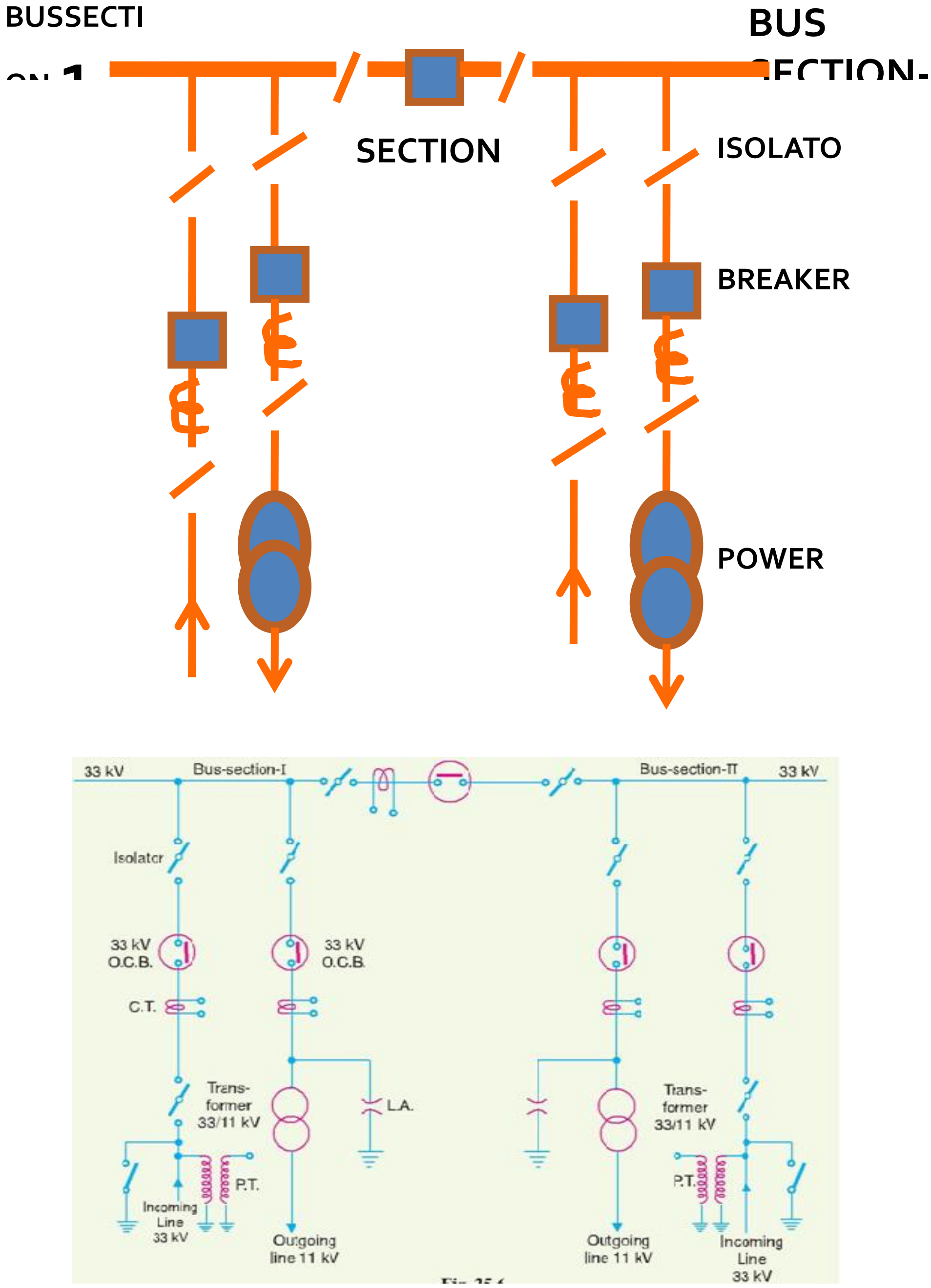
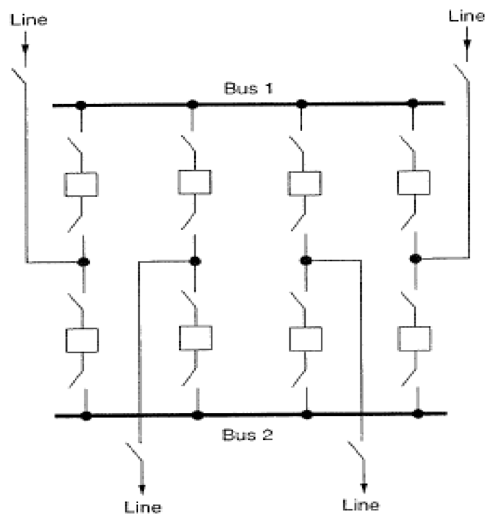


Fig. 4.6bus-bar with sectionalisation

Fig. 4.6 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.

3. Double bus with Double Breaker Arrangement:



A typical double bus-double breaker scheme.

a. Merits

1. Each has two associated breakers
2. Has flexibility in permitting feeder circuits to be connected to any bus
3. Any breaker can be taken out of service for maintenance.
4. High reliability

b. Demerits

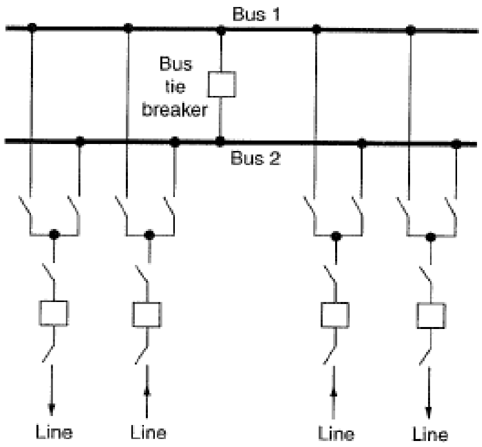
1. Most expensive
2. Would lose half of the circuits for breaker fault if circuits are not connected to both the buses.

c. Remarks

1. Not used for usual EHV substations due to high cost.
2. Used only for very important, high power, EHV substations.

4. Double (orduplicate) Bus single breaker:

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 consists 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 occurring on it, the continuity of supply to the circuit can be maintained by transferring it to the spare bus-bar. For voltages exceeding 33kV, duplicate bus-bar system is frequently used.



A typical double bus-single breaker scheme.

a. Merits

1. Bus1 or bus2 may be isolated for maintenance
2. Circuit can be transferd readily with the help of tie breaker and isolator
3. High flexibility

b. Demerits

1. Extra bus-coupler circuit breaker necessary.
2. Bus protection scheme may cause loss of substation when it operates.
3. High exposure to bus fault.
4. Line breaker failure takes all circuits connected to the bus out of service.
5. Four isolators per circuit
6. Bus couplers failure takes entire substation out of service.

c. Remarks

Most widely used for 66kV, 132kv, 220kV and important 11kv, 6.6kV, 3.3kV Substations.

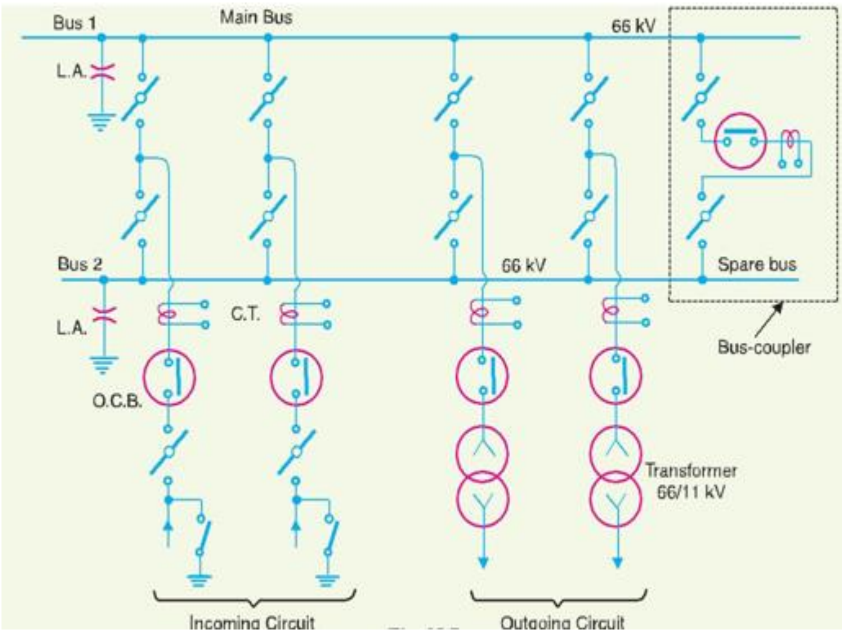
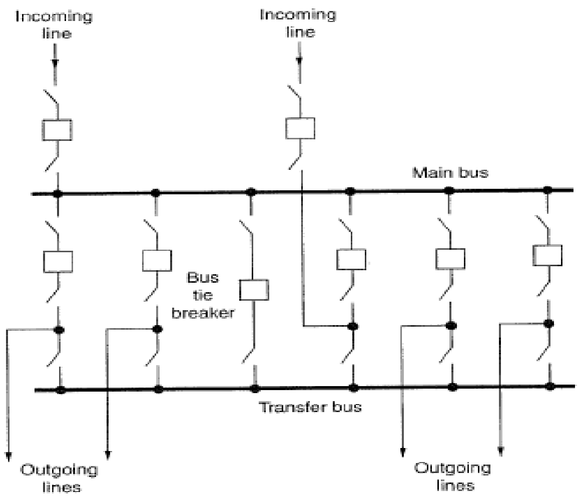


Fig. shows the arrangement of duplicate bus-bar system in a typical sub-station. The two 66kV incoming lines can be connected to either bus-bar by a bus-bar coupler. The two 11 kV outgoing lines are connected to the bus-bars through transformers (66/11 kV) and circuit breakers.

5. Main and Transfer Bus Scheme:



A typical main-and-transfer bus scheme.

a. Merits

1. Low initial & ultimate cost
2. Any breaker can be taken out of service for maintenance.

b. Demerits

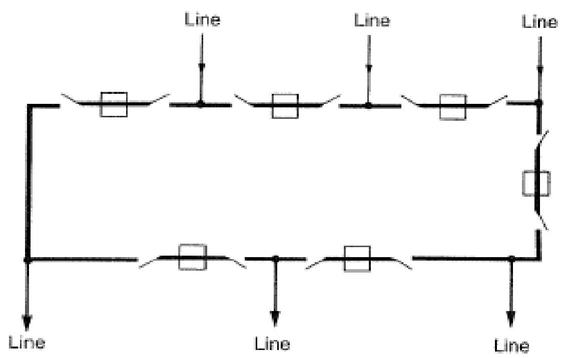
1. Requires one extra breaker coupler.
2. Switching is somewhat complex when maintaining a breaker.
3. Fault of bus or any circuit breaker results in shutdown of entire substation.

c. Remarks

1. Used for 110kV substations where cost of duplicate bus bar system is not justified.

6. **Ring Bus arrangement:**

- In this ring main bus bar scheme arrangement, breakers are connected in ring and circuits (feeders or branches) are connected between the breakers. There will be same number of circuits(feeders or branches) as the number of breakers in the arrangement.
- During normal operation all the breakers are closed



A typical ring bus scheme.

Advantages:

- Low cost
- Flexible operation for breaker maintenance
- Any breaker can be taken out of service without interrupting load
- Power can be fed from both the direction
- It requires only one breaker per circuit.\

Demerits

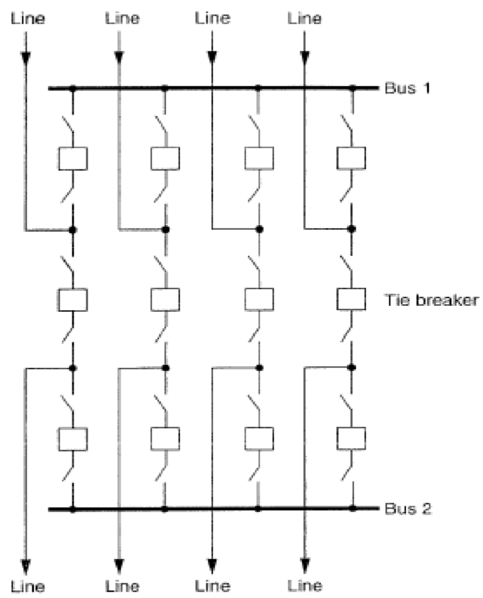
1. If fault occurs during bus maintenance, ring gets separated into two sections.
2. Auto-reclosing and protection complex.
3. Requires VT's on all circuits because there is no definite voltage reference point. These VT's may be required in all cases for synchronizing live line or voltage indication
4. Breaker failure during fault on one circuit causes loss of additional circuit because of breaker failure.

Remarks

- Most widely used for very large power stations having large no. of incoming and outgoing lines and high power transfer.

7. **One and half breaker scheme**

- In One and half breaker scheme, two circuits are connected between the three circuit breakers. Hence one and half breaker name was coined for this type of arrangement. Under normal operating conditions all the breakers are closed and both the bus bars are energized



A typical breaker-and-a-half scheme.

Advantages:

- Most flexible operation possible
- High reliability
- Bus failure will not remove any circuit from service

Disadvantages:

- High cost
- Relaying is somewhat complicated since the middle breaker must responsible for both the circuits on either direction and should operate

Summary of Comparison of Switching Schemes

Switching Scheme	Advantages	Disadvantages
1. Single bus	1. Lowest cost.	1. Failure of bus or any circuit breaker results in shutdown of entire substation. 2. Difficult to do any maintenance. 3. Bus cannot be extended without completely de-energizing the substation. 4. Can be used only where loads can be interrupted or have other supply arrangements.
2. Double bus-double breaker	1. Each circuit has two dedicated breakers. 2. Has flexibility in permitting feeder circuits to be connected to either bus. 3. Any breaker can be taken out of service for maintenance. 4. High reliability.	1. Most expensive. 2. Would lose half the circuits for breaker failure if circuits are not connected to both buses.

3. Main-and-transfer	1. Low initial and ultimate cost. 2. Any breaker can be taken out of service for maintenance. 3. Potential devices may be used on the main bus for relaying.	1. Requires one extra breaker for the bus tie. 2. Switching is somewhat complicated when maintaining a breaker. 3. Failure of bus or any circuit breaker results in shutdown of entire substation.
4. Double bus-single breaker	1. Permits some flexibility with two operating buses. 2. Either main bus may be isolated for maintenance. 3. Circuit can be transferred readily from one bus to the other by use of bus-tie breaker and bus selector disconnect switches.	1. One extra breaker is required for the bus tie. 2. Four switches are required per circuit. 3. Bus protection scheme may cause loss of substation when it operates if all circuits are connected to that bus. 4. High exposure to bus faults. 5. Line breaker failure takes all circuits connected to that bus out of service. 6. Bus-tie breaker failure takes entire substation out of service.
5. Ring bus	1. Low initial and ultimate cost. 2. Flexible operation for breaker maintenance. 3. Any breaker can be removed for maintenance without interrupting load. 4. Requires only one breaker per circuit. 5. Does not use main bus. 6. Each circuit is fed by two breakers. 7. All switching is done with breakers.	1. If a fault occurs during a breaker maintenance period, the ring can be separated into two sections. 2. Automatic reclosing and protective relaying circuitry rather complex. 3. If a single set of relays is used, the circuit must be taken out of service to maintain the relays (common on all schemes). 4. Requires potential devices on all circuits since there is no definite potential reference point. These devices may be required in all cases for synchronizing, live line, or voltage indication. 5. Breaker failure during a fault on one of the circuits causes loss of one additional circuit owing to operation of breaker-failure relaying.
6. Breaker-and-a-half	1. Most flexible operation. 2. High reliability. 3. Breaker failure of bus side breakers removes only one circuit from service. 4. All switching is done by breakers. 5. Simple operation; no disconnect switching required for normal operation. 6. Either main bus can be taken out of service at any time for maintenance. 7. Bus failure does not remove any feeder circuits from service.	1. 1½ breakers per circuit. 2. Relaying and automatic reclosing are somewhat involved since the middle breaker must be responsive to either of its associated circuits.

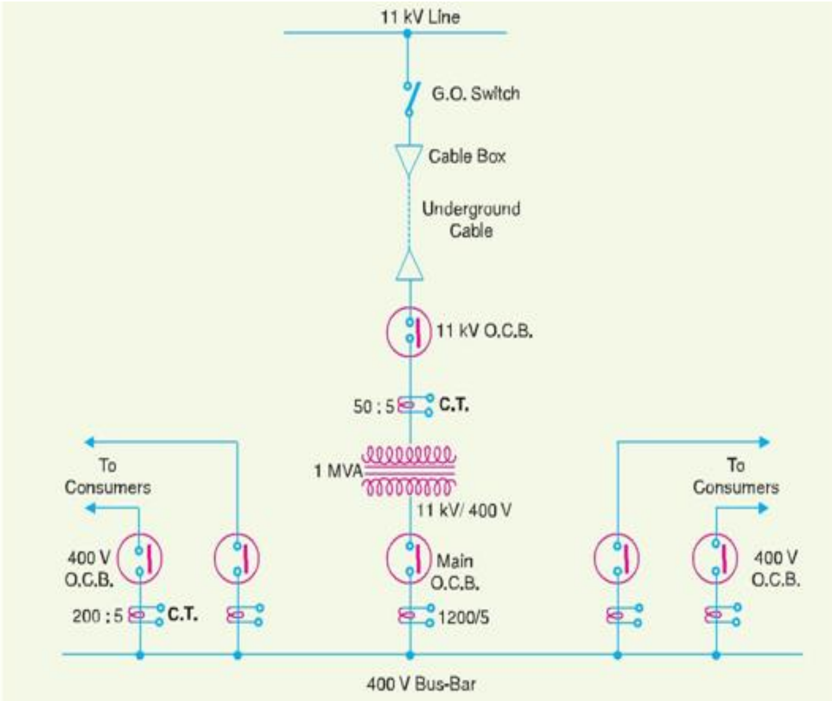
4.10 Key Diagram of 11 kV/400 V Indoor Sub-Station:

Fig.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 installednear 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 undergroundcable. 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 meteringand indicating instruments and relay circuits.

GAS INSULATED SUBSTATIONS

4.11 Introduction:

SF_6 Gas insulated substations(GIS) are preferred for voltage ratings of 33kV, 110kV, 220kV, 400kV and above. In such a substations, the various equipments like circuit breakers, busbars, isolators, load break switches, current transformers, voltage transformers, Earthing switches etc. are housed in metal enclosed modules filled with SF_6 gas. The SF_6 gas provides the phase to ground insulation and phase to phase insulation. As the dielectric strength of SF_6 gas is higher than air, the clearances required are smaller. The overall size of each equipment and the complete substation is reduced to about 10% of conventional air-insulated substations. GIS are installed indoor.

The various modules of GIS are factory assembled and are filled with SF_6 Gas at a pressure of about 3 kg/cm^2 . There after they are taken to site for final assembly. Such substations are compact and can be installed conveniently on any floor of a multi-storied building or in an underground substation. The installation time is substantially reduced. Such installations are preferred in cosmopolitan cities, industrial town ships etc. Where cost of land is very high and higher cost of SF_6 insulated switchgear (GIS) is justified by saving due to reduction in floor area requirement. They are also preferred in heavily polluted areas where dust, chemical fumes and salt layers can cause frequent flashovers in conventional outdoor air-insulated substations.

The SF_6 Gas insulated substations (GIS) contain the same components as in the conventional outdoor substations. All the live parts are enclosed in metal housing filled with SF_6 gas. The live parts are supported on cast resin insulators. Some of the insulators are designed as barriers between neighboring modules such that the gas does not pass through them. The entire installation is sub-divided in to compartments which are gas tight with respect to each other. There by the gas monitoring system of each compartment can be independent and simpler.

The enclosures are of non-magnetic material such as aluminium or stainless steel and are earthed. The gas tightness is provided by static 'O' seals placed between machined flanges. The O-rings are placed in the grooves such that after assembly, the O-rings get squeezed by about 20%. Quality of material and dimension of grooves and O- seals are important to ensure gas-tight performance.

The GIS has gas monitoring system. The gas density in each compartment is monitored. If pressure drops slightly, the gas is automatically tapped up. With further gas leakage, the low pressure alarm is sounded or automatic tripping or lock-out occurs.

The SF_6 Gas insulated substations (GIS) have been developed during 1970's and are extremely popular in USA, Europe, Japan, Middle-East countries etc. These GIS installations have been executed in India (1989). They are compact and require very modest maintenance.

4.12 Introduction to SF_6 (Sulfur Hexafluoride):

The history of SF_6 Gas began in 1900 when it was first synthesized. It was found when sulphur was burnt in an atmosphere of fluorine. Its remarkably high dielectric strength, good physical properties and chemical stability make it insulant for use in electrical apparatus. It is non-toxic, has superior cooling characteristics and substantially greater dielectric strength. It also has exceptional arc quenching properties and its use in electrical equipment eliminates fire hazards, allows for considerable reduction in size and improves the reliability of the system. However SF_6 also has some disadvantages. It decomposes into lower fluorides of sulphur under arcing and these by products are toxic and corrosive.

Properties of SF_6 gas:

Some of the outstanding properties of SF_6 gas are:

a) High dielectric strength
b) Unique arc quenching ability
c) Excellent thermal stability
d) Good thermal conductivity

In addition to these electrical and thermal properties, SF_6 has many physical and chemical properties which make it an excellent dielectric for the electrical power industry. They are:

SF_6 is:

a) Chemically inert
b) Non-toxic
c) Non –flammable
d) Non-corrosive
e) Non-condensable at low temperatures

These combined electrical, physical, chemical and thermal properties of SF_6offer many advantages when used in power switchgear. They are:

a) Increased safety
b) Reduction in size
c) Reduction in weight
d) Simplified design
e) Reliability of operation
f) Noiseless operation
g) Ease of installation
h) Ease of handling
i) Ease of maintenance

SF_6 consists of 21.95% sulphur and 78.05% fluorine. Its structure is such that all six fluorine atoms are at the corners of a regular octahedron with the sulphur atom at the centre.

Advantages of SF_6 Insulated substations:

Metal clad switchgear using SF_6 insulation provides new solutions to the problems of high voltage equipment since they offer the following advantages:

a) **Compactness:** The reduction in area by use of metal enclosed substation can be about 90% for 250kV and 95% for 500kV systems when compared with an open air substation.

   Main advantage of GIS over AIS is its phase to phase spacing decreases significantly. This is more effective in urban environment where land and its size is at a premium Minimum size required for Air Insulated Substation of 400 kV is 46,864.5m^2 (235m*199m) and it is approximately equal to 11.6 acres. On the other hand if we use GIS the size of building required is 522.45m^2 (12.15m*43m).

b) Height of substation also plays a very vital role undertaking the structural size.

c) In AIS height of highest element of substation is 28m high. Meanwhile GIS has building height equal to 11m for 400kV substation. Overall compound size is about 10,672 m^2 . From the above stated analysis it is observed that GIS is much smaller than AIS in size.

d) They provide total protection against environmental influences such as pollution, rain, fog etc.

e) There are no disturbances from switching noise.

f) They provide complete protection against accidental contacts with live parts.

g) They require minimum maintenance

h) As pre-fabricated units are used to a large extent, their installation time is reduced and commissioning work is simplified.

i) The gas-tight enclosure offers excellent protection against atmospheric over-voltages.

j) The modular principle of design for the individual components provides SF_6 switchgear with flexibility for the choice of arrangement and future expansions.

All these factors make the operational life of GIS from 40to 50 years as compared to life of AIS of 25 to 30 years.

Using GIS not only decreases our size but it also has many advantages in the form of cost and maintenance.

Safe: Isolated gas stations are very safe and operating personnel are protected by metal casings earthed. While work station mode staff can affect the compartment.

Reliable: The complete closure of all active parts protected against deterioration of the insulation system.

Space saving: SF6 circuit breakers facilities occupy only 10% of the space required for conventional systems.

Economic: Initial investment required for installation, but the cost can be comparable to lower maintenance, a reliable, and secure against conventional mail.

Maintenance: Careful selection of materials, good design and high quality manufacturing ensure a long life with virtually no maintenance.

Underweight: Low weight thanks to its aluminum case corresponds to foundations and buildings at low cost.

Shop mounted: Install quick work secured by a vast assembly and testing of complete hollow or large units in the factory before.

The cost is higher compared to conventional air insulated substation.

SF6 gas supply and gas supply at the site is problematic. Normally, this type of internal units is nice and requires separate building maintaining cleanliness is very important. Dust or moisture inside the compartment causes burrs, when an internal fault occurs, the cut-off period will be very long. The effect of damage can be severe. When considering the global warming potential (GWP) of a representative network of urban distribution of cells that a minor contribution. However, other network components such as cables and transformers play a decisive role - whether used or AIS GIS technology.

Environmental factors don't effected by Gas Insulated Substation and it is even more suitable for harsh environmental and climatic conditions like humidity, saline, polluted atmosphere comprises of industrial exhaust.

Main Drawbacks:

- High cost compared to conventional substation(AIS).
- Excessive damage in case of internal fault.
- Diagnosis of internal fault and rectifying takes very long time (high outage time).
- SF6 gas pressure must be monitored in each compartment.
- Reduction in the pressure of the SF_6 gas in any module results in flash over and faults.
- SF6 causes ozone depletion and global warming.

Requirements of SF_6 Insulated Metal clad switchgear:

The requirements of SF_6 insulated switchgear are similar to those of conventional switchgear. However the former has fundamental characteristics, which must be taken into account in the design to ensure optimum operation. The most important requirements are the following:

a) The insulation level is ensured only if the insulating gas is maintained at an adequate pressure. Continuous gas pressure monitoring is therefore necessary and is a peculiar feature for this type of substations.
b) The metal clad switchgear must be subdivided into gas tight compartments to limit outages resulting from excessive gas leakage and the propagation of damages due to internal faults.
c) The whole switchgear must be divided into independent compartments so that any arcing fault in one compartment should not affect other compartment.

d) In the case of a flashover in any compartment of the installation, the faulty compartment has to be isolated by the disconnectors. Therefore disconnectors must have independent compartments, which can withstand the rated voltage during the period of maintenance.

Locations for which SF_6 GIS is preferred:

The locations where SF_6 is preferred due to technical and economic advantages over open terminal air insulated substations include:

1) Large towns
2) Industrial complexes
3) Mountainous regions, valleys
4) Underground substations
5) Deserts
6) Off-shore substations

etc...

4.13Components Of GIS:

Main components of Gas Insulated Substation are

1. Bus bar
2. Disconnect or (line or bus)
3. Earthing Switch
4. Voltage Transformer
5. Current Transformer
6. Feeder Disconnect or
7. Feeder Earthing Switch
8. Lightening or Surge Arresters
9. Cable termination
10. Control Panel (control cube)

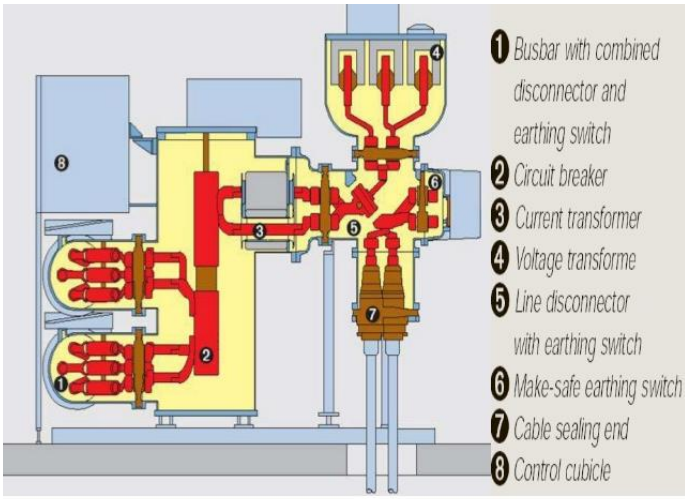


Fig. Essential parts of Gas Insulated Substation

Assignment-Cum-Tutorial Questions

SECTION – A:

1. A sub-station ------------------- some characteristic of electric supply. [**changes]**

2. Most of the sub-stations in the power system change ------------------ of electric supply **[voltage level]**
3. An ideal location for the substation would be at the ------------------- of load. **[centre of gravity]**
4. Pole- mounted substations are used for -------------------- distribution **[secondary]**
5. The voltage rating of the transformer in a pole-mounted sub-station is ------------- **11kV/400V**
6. Single bus bar arrangement in sub stations is used for voltages less than --------------- **33kV**

7. For voltages greater than 33 kV -------------------- bus-bar arrangement is employed. [**duplicate]**
8. The kVA rating of transformer in a pole-mounted sub-station does not exceed---------- **[200 kVA]**
9. An indoor sub-station is ------------- expensive than outdoor sub-station. [**more]**
10. Fault location is --------------------- in an outdoor sub-station than indoor sub-station. [**easier]**
11. Single bus bar arrangement

    (a) is cheapest in initial as well as maintenance cost.
    (b) Provides simple operation and relaying system
    (c) has the drawback that there will be complete shut down when fault occurs on the bus itself
    (d) all of the above

12. Which of the following bus-bar arrangements has the lowest cost?
    (a) Single bus-bar arrangement
    (b) Ring bus-bar arrangement
    (c) Duplicate bus-bar arrangement
    (d) Double main and transfer bus arrangement

13. Which of the following bus-bar arrangements is the most expensive?
    (a) Single bus-bar arrangement
    (b) Ring bus-bar arrangement
    (c) Duplicate bus-bar arrangement
    (d) Double main and transfer bus arrangement

14. In a substation current transformers are used to:
    a) Measuring purpose
    b) Protection purpose connecting to relays

c) Both (a) and (b)
d) None of the above

15. In substation which of the device is a carrier communication device:
a)CVT
b)Earth conductor
c)Wave trap
d) Lightning arrestor

16. Which of the following bus bar arrangement is generally employed in distribution system:
a) One-and-half breaker arrangement
b) Main and transfer arrangement
c) Ring main distribution system
d) Single bus bar arrangement system

17. The size of Gas Insulated Substation is significantly small compared to conventional
Substation because:
a) High electronegative property of SF6 gas
b) High dielectric property of SF6 gas
c) High Insulation property of SF6 gas
d) All the above

18. Current rating is not necessary in case of
(A) Isolators
(B) Circuit breakers
(C) Load break switches
(D) Circuit breakers and load break switches.

19. In outdoor substation, the lightening arresters is placed nearer to
(A) the isolator
(B) the current transformer
(C) the power transformer
(D) The current breaker.

20. At what pressure is the SF_6 gas filled in the whole installation of GIS Sub stations?
a. 3kg/cm²
b. $5kg/cm^2$
c. $3kg/m^2$
d. $5\ kg\ /\ m^2$

21. In a substation the equipment used to limit short circuit current level is

(A) Series reactor (B) Coupling capacitor

(C) Lightening switch (D) Isolator.

22. Which of the following equipment is not installed in a substation ?

(A) Shunt reactors **(B) Exciters**

(C) Voltage transformers (D) Series capacitors.

23. Outdoor sub-station requires ----------------- space

(a) more
(b) less
(c) equal

24. The possibility of fault escalation is ---------------- in outdoor substation than that of indoor substation
(a) more
(b) less
(c) equal

25. Majority of distribution substations are of ---------------- type
a) pole-mounted
(b) indoor
(c) outdoor

26. Power factor correction substations are generally located at the ----------------- end of a transmission line.
a) sending
(b) receiving
(c) middle

27. Underground substations are generally located in --------------------------
(a) Thickly populated areas
(b) villages

28. A bus coupler circuit breaker is utilized in a substation for
(a) joining the transmission line with station bus-bar
(b) joining main and transfer bus in a substation
(c) joining the generator with transfer
(d) joining the neutral of the generator with earth

29. Bus- coupler is very essential in
(a) Single bus-bar arrangement
(b) Ring bus-bar arrangement
(c) Double bus Double breaker arrangement
(d) main and transfer bus.

30. Gas Insulated Substation is employed where:
a) Where there is less space available
b) For high altitude substations
c) In terrain region
d) All the above

31. Which of the gas is used in gas insulated substation:

a)Nitrogen+SF6
b)Hydrogen+SF6
c)SF6
d) None of the above

32. A bus bar is rated by:

a) Current only
b) Voltage only
c) Current, voltage and frequency
d) Current, voltage, frequency and short circuit current

33. Isolators are used to disconnect a circuit when

(A) line is on full load

(B) line is energized

(C) circuit breaker is not open

(D) there is no current in the line.

34. Tap changing transformers are used for

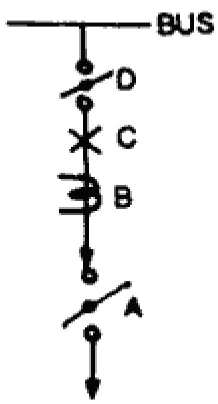
(A) stepping up the voltage

(B) stepping down the voltage

(C) both stepping up and stepping down the voltage

(D) supplying low voltage current for instruments.

Questions 35 to 37 refer to figure given below :



35. A section of a single bus scheme is shown in the figure. In this figure B represents

(A) Isolator

(B) Circuit breaker

(C) Current transformer

(D) Inductance.

36. An isolator is represented by

(A) A

(B) B

(C) C

(D) A and D.

37. C represents

(A) circuit breaker

(B) Mho's relay

(C) Earth switch

(D) None of the above.

SECTION - B

II) Descriptive Questions

1. What is a substation and briefly discuss the classification of substations?
2. Give the comparison of outdoor and indoor sub-stations.
3. Discuss the layout of a substation through a suitable line diagram showing the location of all the substation equipment.
4. What are the different types of bus bar arrangements used in sub stations? Illustrate your answer with suitable diagrams?
5. Write a short note on the sub-station equipment.
6. Explain the Pole mounted substation?
7. Explain the main and transfer bus bar system with circuit diagram?
8. Compare gas insulated substations with air insulated sub stations?
9. Explain the construction aspects of gas insulated substation?
10. Design 11kV/400V indoor substation showing location of all equipment?
11. What are the properties of SF_6 gas?
12. What are the advantages of GIS.

UNIT-V

ECONOMIC ASPECTS OF POWER GENERATION

Learning Objectives:

- To understand the Load curve and load duration curve
- To introduce the various terms and factors for variable load problem
- To Discuss the CostsofGenerationandtheirdivision

Syllabus:

Economic Aspects of Power Generation:

Load curve, load duration and integrated load duration curves, Discussion on economic aspects: connected load, maximum demand, demand factor, load factor, diversity factor, capacity factor, utilization factor and plant use factors- Numerical Problems. Costs of Generation and their division into Fixed, Semi-fixed and Running Costs.

Learning outcomes:

Students will be able to

- ✓ Draw the Load curve and load duration curve
- ✓ Explain various factors for the variable load problems.
- ✓ Discuss the Costs of Generation and their division

5.1 Introduction:

The load on a power station varies from time to time due to uncertain demands of the consumers and is known as **variable load on the station.**

A power station is designed to meet the load requirements of the consumers. An ideal load on the station, from stand point of equipment needed and operating routine, would be one of constant magnitude and steady duration. However, such a steady load on the station is never realized in actual practice. The consumers require their small or large block of power in accordance with the demands of their activities. Thus the load demand of one consumer at any time may be different from that of the other consumer. The result is that load on the power station varies from time to time.

Effects of variable load. The variable load on a power station introduces many perplexities in its operation. Some of the important effects of variable load on a power station are

(*i*) Need of additional equipment. The variable load on a power station necessitates to have additional equipment. By way of illustration, consider a steam power station. Air, coal and water are the raw materials for this plant. In order to produce variable power, the supply of these materials will be required to be varied correspondingly. For instance, if the power demand on the plant increases, it must be followed by the increased flow of coal, air and water to the boiler in order to meet the increased demand. Therefore, additional equipment has to be installed to accomplish this job. As a matter of fact, in a modern power plant, there is much equipment devoted entirely to adjust the rates of supply of raw materials in accordance with the power demand made on the plant.

(*ii*) Increase in production cost. The variable load on the plant increases the cost of the pro-duction of electrical energy. An alternator operates at maximum efficiency near its rated capacity. If a single alternator is used, it will have poor efficiency during periods of light loads on the plant. Therefore, in actual practice, a number of alternators of different capaci-ties are installed so that most of the alternators can be operated at nearly full load capacity. However, the use of a number of generating units increases the initial cost per kW of the plant capacity as well as floor area required. This leads to the increase in production cost of energy.

5.2 Load Curves:

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

The load on a power station is never constant; it varies from time to time. These load variations during the whole day (i.e., 24 hours) are recorded half-hourly or hourly and are plotted against timeon the graph.

The curve thus obtained is known as daily load curve as it shows the variations of load w.r.t. time during the day. Fig. 5.1 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 P.M. 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.

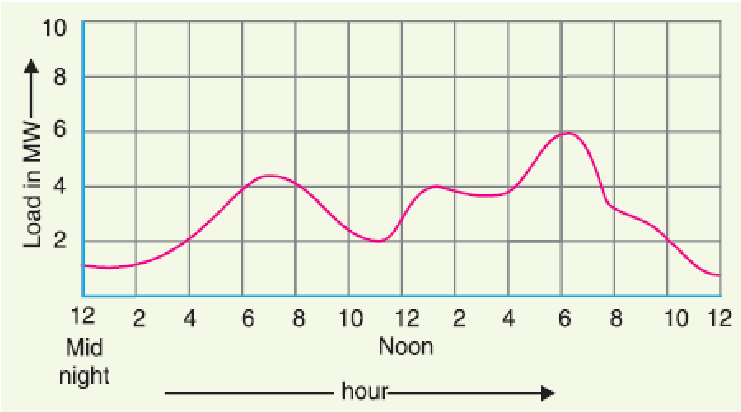


Fig 5.1

Importance: The daily load curves have attained a great importance in generation as they supply 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.

Units generated/day = Area (in kWh) under daily load curve.

(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.

$$\text{Average load} = \frac{\text{Area(inkWh)underdailyloadcurve}}{\text{24 hours}}$$

(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.

Load factor

$$= \frac{\text{Averageload}}{\text{Maxdemand}} = \frac{\text{AverageloadX 24}}{\text{MaxdemandX 24}} = \frac{\text{Area(inkWh)underdailyloadcurve}}{\text{Totalareaofrectangleinwhichtheloadcurveiscontained}}$$

(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.

5.3 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.

(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. 5.1, the maximum demand on the power station during the day is 6 MW and it occurs at 6 P.M. 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 i.e.,

$$\text{Demand factor} = \frac{\text{Maximumdemand}}{\text{Connectedload}}$$

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.

$$\text{Daily average load} = \frac{\text{No.ofunits(kWh)generaterdinaday}}{24\ \text{hours}}$$

$$\text{Monthly average load} = \frac{\text{No.ofunits(kWh)generaterdinamonth}}{\text{Noofhours}\,inamonth}$$

$$\text{Yearly average load} = \frac{No.of units(kWh) generaterdinayear}{8760\ hours}$$

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

$$\text{Load factor} = \frac{Averageload}{Maxdemand}$$

If the plant is in operation for T hours,

$$\text{Load factor} = \frac{AverageloadXT}{MaxdemandXT} = \frac{UnitsgeneratedinThours}{MaxdemandXThours}$$

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 i.e.,

$$\text{Diversity factor} = \frac{Sumofindividualmax.demands}{Max.demandonpowerstation}$$

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 i.e.,

$$\text{Plant capacity factor} = \frac{\text{Actualenergyproduced}}{\text{Maxenergythatcouldhavebeenproduced}} = \frac{\text{AvgdemandXT}}{\text{PlantcapacityXT}} = \frac{\text{Averagedemand}}{\text{Plantcapacity}}$$

Thus if the considered period is one year,

$$\text{Annual plant capacity factor} = \frac{\text{AnnualkWhoutput}}{\text{PlantcapacityX 8760}}$$

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 i.e.

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

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 :

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

Average load = Max. demand X L.F.

Units generated/annum = Average load (in kW) XHours in a year
= Max. demand (in kW) X L.F X 8760

5.4 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.5.2 (i) shows the daily load curve. The daily load duration curve can be readily obtained from it. It is clear from daily load curve [See Fig. 5.2 (i)], that load elements in order of descending magnitude are: 20 MW for 8hours; 15 MW for 4 hours and 5 MW for 12 hours. Plotting these loads in order of descending magnitude, we get the daily load duration curve as shown in Fig.5.2 (ii).

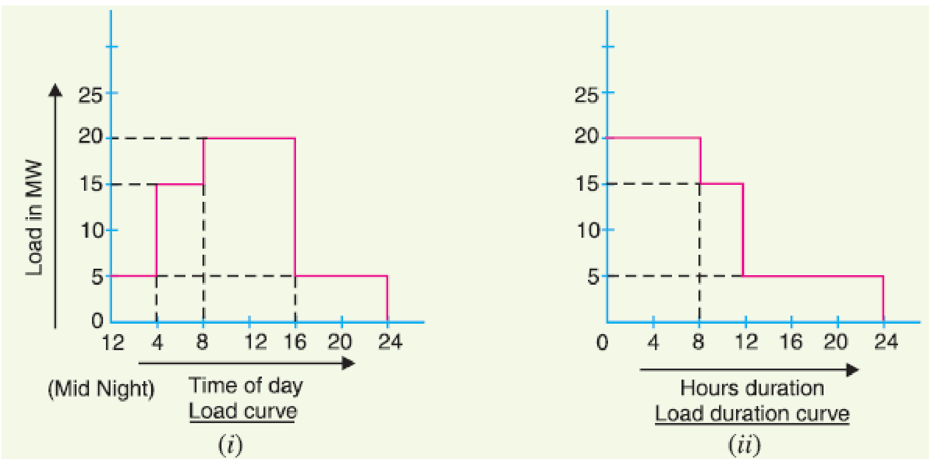


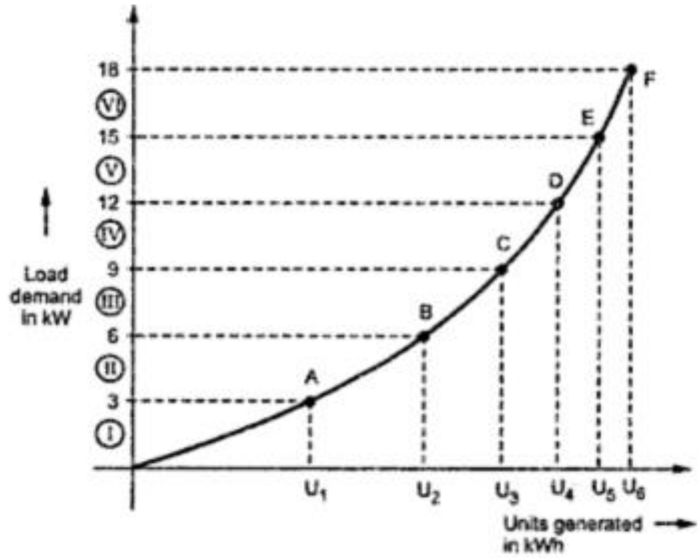
Fig 5.2

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.

Integrated Load Duration Curve:

A plot of number of units generated (kWh) for a given demand (kW) is called integration load duration curve.



5.5 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 (e.g., electric lamp), inductive (e.g., 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 (i.e., 24 hours) e.g., 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 conditionersand 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 up to 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.

5.6 Importance of High Load Factor

The load factor plays a vital role in determining the cost of energy. Some important advantages of high load factor are listed below :

(*i*) *Reduces cost per unit generated* : A high load factor reduces the overall cost per unit generated. The higher the load factor, the lower is the generation cost. It is because higher load factor means that for a given maximum demand, the number of units generated is more. This reduces the cost of generation.

(*ii*) *Reduces variable load problems* : A high load factor reduces the variable load problems on the power station. A higher load factor means comparatively less variations in the load demands at various times. This avoids the frequent use of regulating devices installed to meet the variable load on the station

5.7 Base Load and Peak Load on Power Station:

The changing load on the power station makes its load curve of variable nature. Fig. 5.3 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

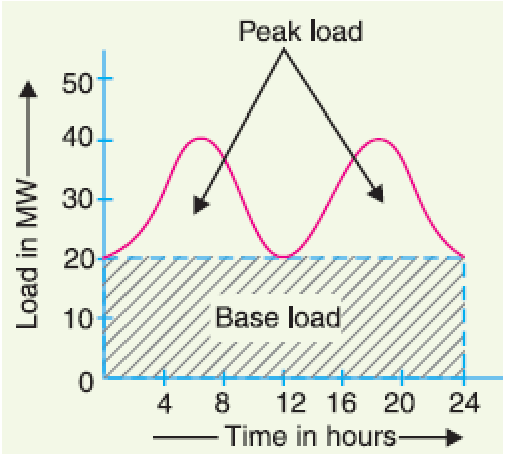


Fig 5.3

(i) Base load: The unvarying load which occurs almost the whole day on the station is known as base load. Referring to the load curve of Fig, it is clear that20 MW of load has to be supplied by the station at all times of day and night i.e. throughout 24 hours. Therefore, 20 MW is the base load of the station. 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.

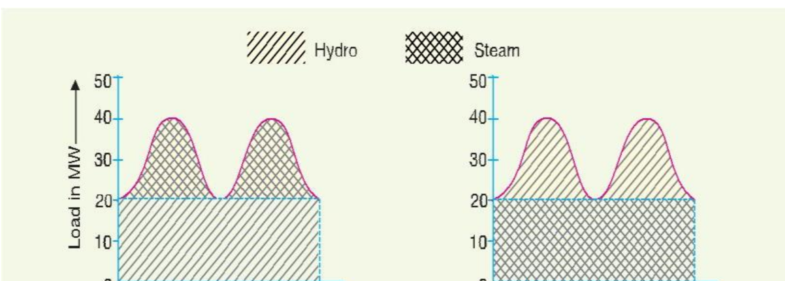
(ii) Peak load: The various peak demands of load over and above the base load of the station
is known as peak load. Referring to the load curve of Fig, it is clear that there are peak demands of load excluding base load. These peak demands of the station generally form a small part of the total load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

5.7.1 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*).



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*).

5.8 Economics of Power Generation:

The art of determining the per unit (i.e., one kWh) cost of production of electrical energy is known as economics of power generation. The economics of power generation has assumed a great importance in this fast developing power plant engineering. A consumer will use electric power only if it is supplied at reasonable rate. Therefore, power engineers have to find convenient methods to produce electric power as cheap as possible so that consumers are tempted to use electrical methods.

Cost of Electrical Energy:

The total cost of electrical energy generated can be divided into three parts, namely ;

(i) Fixed cost ;
(ii) Semi-fixed cost ;
(iii) Running or operating cost.

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

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

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

Expressions for Cost of Electrical Energy:

The overall annual cost of electrical energy generated by a power station can be expressed in two forms viz three part form and two part form.

(i) Three part form: In this method, the overall annual cost of electrical energy generated is divided into three parts viz fixed cost, semi-fixed cost and running cost i.e.

Total annual cost of energy = Fixed cost + Semi-fixed cost + Running cost

= Constant + Proportional to max. demand + Proportional to kWh generated.

= Rs (a + b kW + c kWh)

Where a= annual fixed cost independent of maximum demand and energy output.

b = constant which when multiplied by maximum kW demand on the station gives the annual semi-fixed cost.

c = a constant which when multiplied by kWh output per annum gives the annual running cost.

(ii) Two part form: It is sometimes convenient to give the annual cost of energy in two part form. In this case, the annual cost of energy is divided into two parts viz., a fixed sum per kW of maximum demand plus a running charge per unit of energy. The expression for the annual cost of energy then becomes:

Total annual cost of energy = Rs. (A kW + B kWh)

whereA = a constant which when multiplied by maximum kW demand on the station gives the annual cost of the first part.

B = a constant which when multiplied by the annual kWh generated gives the annual running cost.

It is interesting to see here that two-part form is a simplification of three-part form. A little reflection shows that constant “a” of the three part form has been merged in fixed sum per kW maximum demand (i.e. constant A) in the two-part form.

Assignment-Cum-Tutorial Questions

SECTION – A:-

1. A load curve is a plot of

(A) Load versus generation capacity

(B) Load versus current

(C) Load versus time

(D) Load versus cost of power.

2. For economy in generation power

(A) diversity factor should be high

(B) plant utilization factor

(C) load factor should be high

(D) load factor and diversity factor should be low.

3. Which of the following category of consumers can provide highest load factor ?

(A) A domestic consumer

(B) A continuous process plant

(C) A steel melting unit using arc furnace

(D) A cold storage plant.

4. The load of a consumer is generally measured in terms of

(A) Volts

(B) Amperes

(C) Ampere hour

(D) kW.

5. The normal connected load of a domestic consumer is usually

(A) up to 10 kW

(B) 10 to 20 kW

(C) 25 to 50 kW

(D) 50 to 100 kW.

6. Load factor during a period is

(A) Average Load / Installed Capacity

(**B) Average Load / Maximum Load**

(C) Maximum Load / Average Load

(D) Maximum Load / Installed Capacity.

7. Which of the following installation provides peaked load ?

(A) Arc furnace

(B) Air conditioner

(C) Air compressor running continuously

(D) Cold storage plant.

8. Demand factor is the

(A) Maximum Demand / Average Demand

(B) Maximum Demand / Connected Load

(C) Average Demand / Maximum Demand

(D) Connected Load / Maximum Demand.

9. During summer months the increased load is due to

(A) increased water supply

(B) vacations in institutions

(C) increased business activity

(D) increased use of fans and air conditioners.

10. In a system if the base load is the same as the maximum demand, the load factor will be

(A) 1

(B) Zero

(C) Infinity

(D) 1 percent.

11. A system having connected load of 100 kW, peak load of 80 kW. base load of 20 kW and average load of 40 kW, will have a load factor of

(A) 40%

(B) 50%

(C) 60%

(D) 80%.

12. Load due to one tonne air conditioner is nearly

(A)100W

(B) 200 to 500 W

(C) 1 kW to 2 kW

(D) 5 kW to 10 kW.

13. Load due to a ceiling fans is nearly

(A) 10W

(B) 40 to 50 W

(C) 100 to 200 W

(D) 250 W to 2000 W.

14. Which domestic utility item has highest power rating ?

(A) Refrigerator

(B) Ceiling fan

(C) Tube light

(D) Electric iron.

15. A stereo with two 10 watt loudspeakers will provide electrical load of

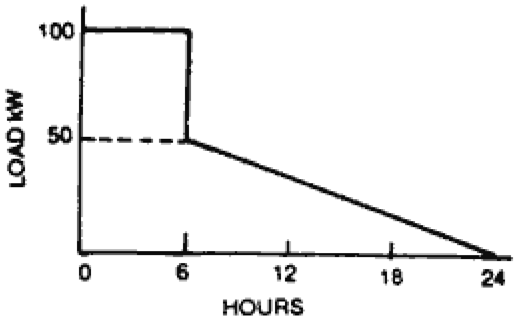
(A) more than 12 W

(B)12 W

(C) less than 6 W

(D) 6 W.

Questions 16 to 18 refer to the figure below.



16. The load of a system is shown in the figure above. The load factor of the system is

(A) 0.778

(B) 0.667

(C) 0.438

(D) 0.331.

17. Load factor for the 0-6 hour period alone is

(A) 0.438

(B) 0.876

(C) 0.999

(D) 1.0.

18. Load factor for the period 6-24 hours period is

(A) 0.438

(B) 0.5

(C) 0.876

(D) 1.0.

19. Which plant can never have 100% load factor ?

(A) Nuclear power plant

(B) Hydro electric plant

(C) Peak load plant

(D) Base load plant.

20. Which meter is installed at the premises of a consumer for recovery of charges of electrical energy

(A) Voltmeter

(B) Ammeter

(C) kVA meter

(D) kWh meter.

21. For certain industrial applications the energy requirement is 500 kWh. If the heat losses are 20 percent the total energy to be made available will be

(A) 5000 kWh

(B) 4000 kWh

(C) 6000 k Wh

(D) 6000 kWh.

22. A consumer finds that after running 10 kVA equipment on full load for six hours his energy consumption was 48 kW. It can be concluded that

(A) the load factor of the consumer for the day was unity

(B) the maximum demand of the consumer was 10 kW

(C) the equipment was drawing reactive power only

(D) power factor of the equipment was 0.8.

23. Which equipment provides fluctuating load ?

(A) Lathe machine

(B) Exhaust fan

(C) Welding transformer

(D) All of the above.

24. A power plant supplying energy to a city will usually experience peak demand

(A) from midnight to early morning

(B) 8 AM to 12 noon

(C) 2 PM to 6 PM

(D) 6 PM to 12 PM.

25. The ratio, maximum demand of the installation / sum of individual maximum demands is known as

(A) Demand factor

(B) Plant use factor

(C) Diversity factor

(D) Plant capacity factor.

26. In a power plant a reserve generating capacity which is in operation but not in services known as

(A) Hot reserve

(B) Cold reserve

(C) Spinning reserve

(D) Firm power.

27. Five consumers having peak demands of A, B, C, D, and E have individual load factors of 0.5. It can be concluded that

(A) their combined load factor will be 0.5

(B) their peak demand during the day will be (A + B + C + D + E)

(C) their combined power consumption in a day will be 12 (A + B + C + D + E)

(D) their average demands are equal.

28. In an interconnected system consisting of a nuclear power stations, steam station and diesel generating station, which plant can be used as base load plant ?

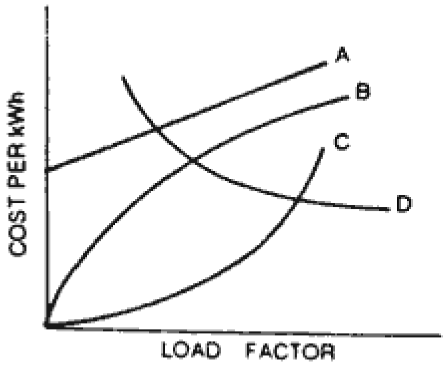
(A) Steam station

(B) Diesel generation plant

(C) Nuclear power station

(D) Any of the above.

29. In the figure shown below which curve represents the variation of cost of generation per kWh with the load factor, for a thermal power plant ?



(A) curve A

(B) curve B

(C) curve C

(D) curve D.

30. Connected load is

(A) The rating in kw of the installed electrical load of the consumer

(B) the maximum load that a consumer puts on at any time

(C) Part of the load which always remains on at the consumer ends

(D) Average load of the consumer during a specified period.

31. Fuel transportation cost is least in

(A) Diesel generating plant

(B) Steam power stations

(C) Nuclear powers plants.

32. Capital cost per MWh is highest in case of

(A) steam power plants

(B) diesel engine power plants

(C) nuclear power plants

(D) hydroelectric power plants.

33. A steam power station will run with maximum efficiency when it is run

(A) at low steam pressures

(B) on pulverized coal

(C) at higher speeds

(D) near full load.

34. Which of the following is likely to result in lower efficiency of a power station ?

(A) Varying loads

(B) Low voltage generation

(C) Low turbine speeds

(D) Non-automatic controls.

Questions 35 to 37 refer to the following information

The following factors are associated with power plant operation

I. High efficiency

II. High availability

III. Quick starting

IV. Low capital cost.

35. Which factor is least important for base load plants ?

(A) I

(B) II

(C) III

(D) IV.

36. Which two factors are of significant requirement for base load plant ?

(A) I and II only

(B) III and IV only

(C) II and III only

(D) I and IV only.

37. Which two factors are of importance for peak load plant ?

(A) I and III only

(B) II and III only

(C) I and IV only

(D) III and IV only.

38. Which plant can never have 100% load factor ?

(A) Nuclear power plant

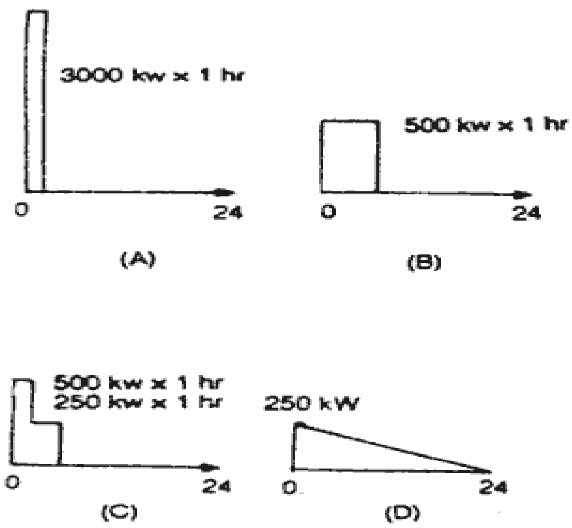
(B) Hydro electric plant

(C) Peak load plant

(D) Base load plant.

Questions 39 to 43 refer to the following data:

four loads as shown in figure given below are connected to a power station. Abscisse is time from 0 to 24 hrs in all cases, Ordinate represents the load in kW.



39. Which load has the lowest average demand ?

(A) Load A

(B) Load B

(C) Load C

(D) Load D.

40. Which loads offer the identical average load ?

(A) A and B

(B) B and C

(C) C and D

(D)A, B and D.

41. The peak load on the plant is

(A) 3000 kW

(B) 3500 kW

(C) 4000 kW

(D) 4250 kW.

42. The load factor of the plant supplying power to these loads will be nearly

(A) 11%

(B) 15%

(C) 18%

(D) 21%.

43. The diversity factor of the plant supplying these loads will be

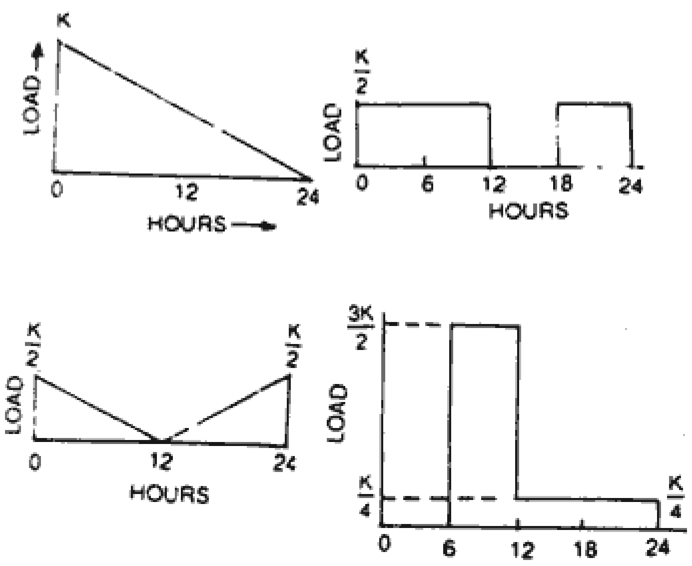
(A) 0.5

(B) 1.0

(C) 1.5

(D) 0.2.

Questions 44 to 50 refer to the figure given below:



Four different loads connected to a power Plant are shown in the figure.

44. Which load has the least value of average load?

(A) Load A

(B) Load B

(C) Load C

(D) Load D.

45. Which load has the highest value of average load ?

(A) Load A

(B) Load B

(C) Load C

(D) Load D.

46. Which load has the least load factor ?

(A) Load A

(B) Load B

(C) Load C

(D) Load D.

47. Which load has the highest load factor ?

(A) Load A

(B) Load B

(C) Load C

(D) Load D.

48. If all the loads are connected to single source of power, the maximum load on the station will be

(A) 9k / 4

(B) 2k

(C) 3k

(D) 7 / 4k

49. The maximum load on the station will occur at

(A) 0 hr

(B) 6 hr

(C) 9 hr

(D) 12 hr.

50. In the above case load factor of the station will be

(A) 0.29

(B) 0.31

(C) 0.44

(D) 0.56.

Questions 51 to 54 refer to the data given below:

The annual peak load on a 30 MW power station is 25 MW. The power station supplies loads having maximum demands of 10 MW, 8.5 MW, 5 MW and 4.5 MW. The annual load factor is 45%.

51. The average load is

(A) 1025 kW

(B) 1125 kW

(C) 1425 kW

(D) 1625 kW.

52. Total energy supplied in a year is

(A) 9,875,000 kWh

(B) 8345,000 kWh

(C) 7450,000 kWh

(D) 6395,000 kWh.

53. Diversity factor is

(A) 3.80

(B)1.02

(C) 1.12

(D) 1.22.

54. Demand factor is

(A) 0.75

(B) 0.83

(C) 0.89

(D) 0.45.

55. A power station has annual load factor of 50% and capacity factor of 40%. If the maximum demand is 15 MW, the reserve capacity of the plant is

(A) 1250 kw

(B) 2500 kw

(C) 3750 kw

(D) 4750 kw.

56. Which of the following appliance will offer the maximum load ?

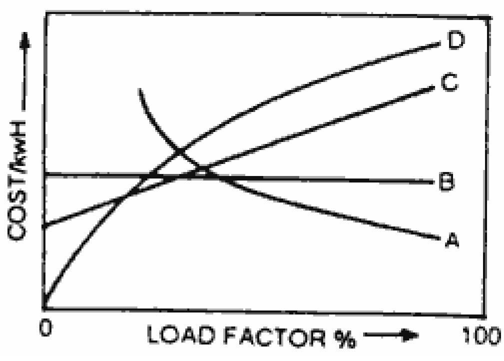
(A) Toaster

(B) Refrigerator

(C) Hot plate

(D) Electric iron.

57. In the figure shown below which curve represents the variation of cost of power generation per kWh in a plant, with load factor ?



(A) curve A

(B) curve B

(C) curve C

(D) curve D.

58. The highest point on a load curve represents

(A) Average demand

(B) Diversion field demand

(C) Peak demand

(D) None of the above.

SECTION – B:-

1. Define the following
   a. Connected load
   b. Demand factor
   c. Plant capacity factor

2. What do you understand by the load curve? What information's are conveyed by a load curve?

3. Explain the terms load factor and diversity factor. How do these factors influence the cost of generation?

4. Discuss the different classifications of costs of electrical energy.

5. A generating station has the following daily load cycle

Time(hrs)	0-6	6-10	10-12	12-16	16-20	20-24
Load(MW)	30	40	20	70	50	40

Draw the load curve and find

a. maximum demand

b. units generated per day

c. average load and load factor

[70MW, 1020 x 10^3 kwh,60.71%]

6. The annual load duration curve of a certain power station can be considered as a straight line from 20MW to 4MW. To meet this load, three turbine- generator units, two rated at 10 MW each and one rated at 5MW are installed. Determine

i. installed capacity
ii. plant factor
iii. units generated per annum and
iv. load factor
v. utilization factor.

[25MW, 48%, 105.12x10^6 kwh, 80%]

7. A power station is to feed four regions of load whose peak loads are 12,7,10 and 8 MW. The diversity factor at the station is 1.4 and the average annual load factor is 65%. Determine the following :

(i) Maximum demand on the station
(ii) Annual energy supplied by the station
(iii)Suggest the installed capacity.

[26.42MW, 150484.2MWh, 31.704MW]

8. A power supply is having the following loads

Type of load	Max. demand(KW)	Diversity of group	Demand factor
Domestic	15000	1.25	0.7
Commercial	25000	1.2	0.9
Industrial	50000	1.3	0.98

If the overall system diversity factor is 1.5 determine

a. the maximum demand

b. connected load of each type

[Rs.44530, Rs.45150]

9. A generating station has a max demand of 15MW and the daily load on the station is as follows 10 PM – 5 AM 2500KW 1 PM – 4 PM 10,000KW

5 AM – 7 AM 3000KW 4 PM – 6 PM 12,000KW
7 AM – 11 AM 9000KW 6 PM – 8 PM 15000KW
11 AM – 1 PM 6000KW 8 PM – 10 PM 5000KW

Determine the size and number of generating units, plant load factor, Plant capacity factor, use factor and reserve capacity of the plant.

[3x5000+2x2000+1x1000,45.97%, 34.48%, 97.93%, 500kw]

SECTION – C:-

GATE/IES Questions:

1. A power station has a maximum demand of 2500 kW and number of kWh generated per year is 45x 10^5. The load factor is **(IES-2015)**

(a) 1 0·25%

(b) 20.5%

(c) 41%

(d) 82%

2. The thermal and electrical efficiencies of a I 00 MW steam station are respectively 30% and 92%. The coal used has a calorific value of 6400 kcal/kg. For the supply of full-load rated capacity the coal consumption in kg/hour would be approximately **(IES-2014)**

(a) 24340

(b) 32450 .

(c) 48690

(d) 64910

3. A generating station has 500 MW maximum demand and annual load factor of 50%, capacity factor of 40%. The reserve capacity of the plant is **(IES-2014)**

(a) 125 MW

(b) 625 MW

(c) 500 MW

(d) 725 MW

4. A power generating station has a maximum demand of lOOO MW. The annual load factor is 75% and plant capacity factor is 60%. Calculate the reserve capacity. **(IES-2013)**

(a) 250 MW

(b) 500 MW

(c) 750 MW

(d) 1250 MW

5. In order to have lower cost of power generation : **(IES-2013)**

(a) The load factor and diversity factor should be low

(b) The load factor and diversity factor should be high

(c) The load factor should be low but diversity factor should be high

(d) The load factor should be high but diversity factor should be low.

UNIT-VI

TARIFF METHODS

Learning Objectives:

- To understand the objectives and Desirable Characteristics of a Tariff
- To Discuss the types of tariff

Syllabus:

Tariff Methods: Desirable Characteristics of a Tariff Method. Tariff Methods: Simple rate, Flat Rate, Block-Rate, two-part, three –part, and power factor tariff methods.

Learning outcomes:

Students will be able to

- ✓ Explain the characteristics of a tariff
- ✓ Discuss the types of tariff

TARIFF

6.1Introduction:

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 (e.g., industrial, domestic and commercial) while fixing the tariff. This makes the problem of suitable rate making highly complicated.

6.2 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 e.g., metering equipment, billing etc.
(iv) A suitable profit on the capital investment.

6.3 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 (i.e., 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. Therefore, 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.

6.4Types of Tariff:

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

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

Disadvantages:

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

2. Flat rate tariff: When different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff. In this type of tariff, the consumers are grouped into different classes and each class of consumers is charged at a different uniform rate. For instance, the flat rate per kWh for lighting load may be60 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.

3. Block rate tariff: When a given block of energy is charged at a specified rate and the succeeding blocks of energy are charged at progressively reduced rates, it is called a block rate tariff. In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block. The price per unit in the first block is the highest and it is progressively reduced for the succeeding blocks of energy. For example, the first 30 units may be charged at the rate of 60 paisa per unit ; the next 25 units at the rate of 55 paisa per unit and the remaining additional units may be charged at the rate of 30 paisa 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.

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

Total charges = Rs (b X kW + c X kWh)

where, b = charge per kW of maximum demand

c = charge per kWh of energy consumed

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

Advantages:

(i) It is easily understood by the consumers.

(ii) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantages:

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

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

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

6. Power factor tariff: The tariff in which power factor of the consumer's load is taken in to consideration is known as power factor tariff. In an a.c. 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 known 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.

7. Three-part tariff: When the total charge to be made from the consumer is split into three parts viz., fixed charge, semi-fixed charge and running charge, it is known as a three-part tariff. i.e.,
Total charge = Rs $(a + b \times kW + c \times kWh)$
wherea = 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 (i.e., a) to two-part tariff, it becomes three-part tariff. The principal objection of this type of tariff is that the charges are split in to three components. This type of tariff is generally applied to big consumers.

Unit VI

Assignment-Cum-Tutorial Questions

SECTION – A:-

1. The flat rate for power load is generally ……… than the lighting load. **lower**
2. In block rate tariff, the rate of energy in first one or two blocks is …… because ……. charges are merged into …… charges. **high, fixed, running**
3. The block rate tariff is mostly applicable to ……. consumers. **domestic**
4. A big consumer is charged at a lower rate than a small consumer because …….. **it improves the load factor**
5. Maximum demand tariff is not applied to domestic consumers because ………. **their maximum demand is small.**
6. A consumer whose load conditions do not deviate from ideal one should be charged at ………… rate than the one whose load conditions change appreciably. (***lower***)
7. A consumer who consumes more electrical energy should pay …… fixed charges per unit. (***less***)
8. The ideal tariff for any type of consumer is ……. tariff. (***three-part***)
9. The maximum kVA demand of the consumer is ……. proportional to power factor. (***inversely***)
10. Two tariffs are offered

(P) $. 200 plus 5 cents per unit

(Q) A flat rate of 30 cents per unit

From the above it can be concluded that

(A) Tariff P will give lower charges up to 800 kWh

(B) Tariff P will give lower charges for consumption of more than 800 units

(C) Tariff Q will give lower charges for consumption of more than 800 kWh

(D) Both will give identical charges beyond 1500 kWh.

11. What is the difference between two part tariff and maximum demand tariff?
   a. A separate meter is used.
   b. A separate maximum demand meter is used.

c. Semi fixed charges are also included.
d. All of these.

12. This tariff is applied for which kind of consumers?

a. Big consumers.
b. Small consumers.
c. Residential consumers.
d. All of these.

14. Why is this tariff not applicable to domestic consumers?

a. Low maximum demand.
b. Low load factor.
c. Lower energy consumption.
d. Low power factor.

15. Why is a big consumer charged at a lower rate than the small consumer?

a. Their maximum demand is small.
b. It improves the load factor.
c. Both (a) and (b).
d. None of these.

16. What is the power factor tariff?

a. It considers only maximum demand.
b. It considers only semi fixed charges and the power factor.
c. It considers only power factor.
d. It considers the load factor.

17. What is consequence of low power factor?

a. Increases the rating of station equipments only.
b. Only line losses increases.
c. Both (a) and (b).
d. Neither of these.

18. A consumer having lower power factor contributes towards which factor?

a. Semi fixed charges.
b. Fixed charges.
c. Running charges.
d. Penalty is imposed.

19. Which tariff is also known as the average power factor tariff?

a. Sliding scale tariff.
b. kW tariff.
c. kVAR tariff.
d. kVA maximum demand tariff.

Section:-B

1. What do you understand by tariff ? Discuss the objectives of tariff.
2. Describe the desirable characteristics of a tariff.

3. Explain with examples:

(i) flat rate tariff
(ii) block rate tariff
(iii) two part tariff
(iv) power factor tariff

4. Explain two part and three part tariff.

5. A generating station has a maximum demand of 50,000 kW. Calculate the cost per unit energy generated from the following data:

(i) Capital cost=Rs. 95x 10^6
(ii) Annual load factor=40%
(iii)Annual cost of fuel and oil=Rs. 9x10^6
(iv)Interest and depreciation=12%
(v) Taxes, wages and salaries etc.=Rs. 7.5 x10^6

6. A consumer takes a steady load of 250 kW at a power factor of 0.8 lagging for 10 hours per day and 300 days per annum. Estimate the annual payment under each of the following tariffs.

(i) Rs. 1.20 per kWh + 1200 per kVA per annum
(ii) Rs. 1.20 per kWh + 1200 per kW per annum+ 25 paise per kVAh

[Rs.1275000, Rs. 1340625]

7. Compare the annual cost of supplying a factor load having a maximum demand of 1MW at a load factor of 50% by energy obtained from

i) Nuclear power plant and

ii) Public supply

Nuclear Power Plant:

Capital Cost = Rs. 50,000

Cost of Fuel = Rs. 600 per 1000 kg

Fuel consumption = 30 g per kwh generated

Maintenance Cost etc. = Rs. 0.005 per kwh generated

Wages = Rs. 20,000 per annum

Interest and Depreciation = 10%

Public Supply:

Rs. 50 per kW+ Rs. 0.03 per kWh generated.

8. An industrial consumer having a max demand of 100 kW, maintain a load factor of 60%. The tariff rates are Rs 900 per kVA of max demand per annum plus Rs.1.8 per kWh of energy consumed. If the average power factor is 0.8 lagging, calculate the load energy consumed per annum and the annual electricity bill. Also work out the overall cost per kWh consumed?

[525600kwh, Rs. 1058580, Rs. 2.02 per kwh]

9. Two types of tariff are available for a factory working 8 hrs a day for 360 days a year.

(i).H.V supply at 5 paise per unit plus Rs 4.5 per month per KVA of max demand.

(ii).L.V supply at Rs 5 per month per KVA at max demand plus 5.5 paise per month.

The factory has an average load of 200 KW at 0.8 pf and max demand of 250 KW at pf 0.8.The H.V equipment costs Rs 50 per KVA and losses can be taken as 40%.The interests and depreciation charges are 12%.calculate differences in costs between two systems. Comment on the results.