CHAPTER 4

Generating Power Stations

4.1 Introduction

Electrical energy is generated by conversion of energy available in different forms from different natural sources such as pressure head of water, kinetic energy of blowing wind, chemical energy of fuels and nuclear energy of ratio active substances into electrical energy.

There are two ways of generating electrical power.

1. **Conventional Methods of Power Generation:** This method of power generation uses a prime-mover (turbine) for driving electrical machines (generators or alternators) which convert mechanical energy into electrical energy. The various popular methods of power generation by conventional methods are thermal, hydro and nuclear.
2. **Non-conventional Method of Power Generation:** In this method of power generation, electrical energy is generated without the use of prime-movers. The various non-conventional method of power generation include solar cells, fuels cells, thermoelectric generation, solar cell power generation, wind-power generation, geo-thermal power generation, tidal power generation etc.

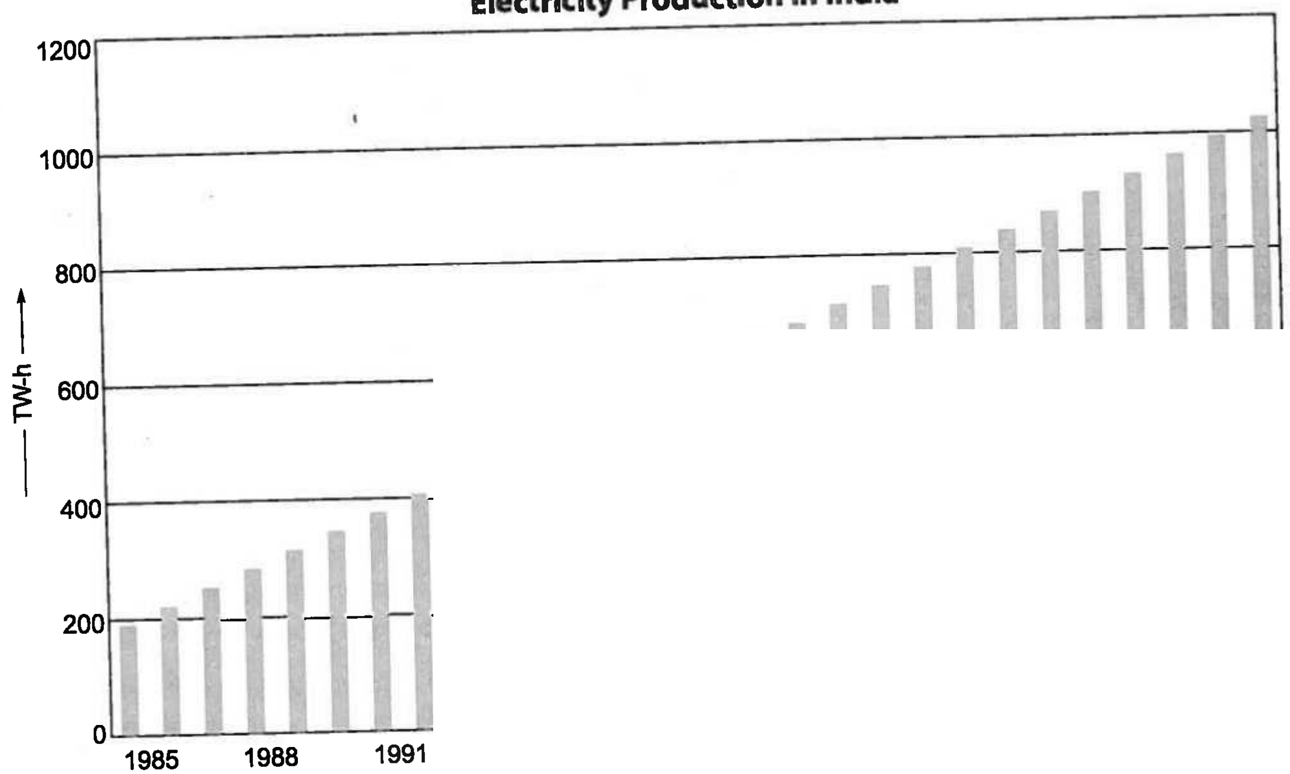
Various Sources of Energy

The various sources of energy are the sun, the wind, terrestrial heat or geothermal energy, ocean tides and waves, water, fuels and the atomic energy. The last three sources i.e. water, fuels and the atomic energy are most dependable and are commonly used for generation of electrical energy.

4.2 Electricity Sector in India

The electrical power installed capacity in India is 249.48 GW as of end June 2014. India became the world's third largest producer of electricity in the year 2013 with 4.8% global share in electricity generation surpassing Japan and Russia. Captive power plants have an additional 39.375 GW capacity. Non-renewable power plant constitute 87.55% of the installed capacity, and renewable power plants constitute the remaining 12.45% of total installed capacity. States such as Gujarat, Madhya Pradesh and other states provide continuous power supply. India will add between 600 GW to 1200 GW of additional new power generation capacity before 2050.

Electricity Production in India



Fig

Figure 4.1 shows the growth

India's Power Scnario

1. Installed capacity = 249
2. Non-renewable power p
3. Per capita total power c
4. India is world's 3rd large
5.

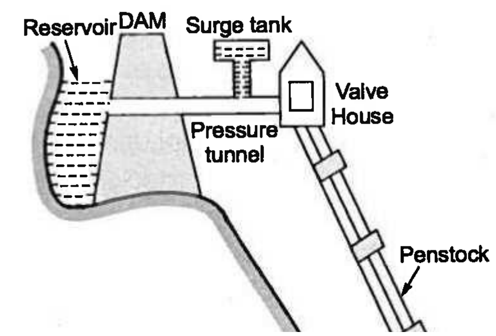
Types of power pla
Hydro-electric power pla
Renewable source powe
Natural gas power plant
Nuclear power plant
Oil based power plant
Coal based power plant

6. Total network technical

4.3 Hydro-electric Pow

Hydro-electric power is the plant is the power plant utilizing the energy.

Figure 3.2 shows the schematic arrangement of a hydro-electric plant.



Surge tank is located as close to the power station as possible. When the load demand is reduced on the power station then, it causes rise in water level in the surge tank which produces a retarding head and reduces the velocity of water in the penstock and hence avoiding the undesirable phenomenon called ***"Water hammer"***.

When the load on the plant is increased, the governor causes the turbine to open the gates in order to allow more water to flow through the penstock to supply the increased load and there is a tendency to cause a vaccum or a negative pressure in the penstock. Under such conditions, the additional water flows out of the surge tank. As a result, water in the surge tank falls, an accelerating head is created and flow of water in the penstock is increased.

Hence, surge tank helps in stabilizing the velocity and pressure in the penstock and reduces water hammer and negative pressure and vaccum. The surge tanks are usually provided at the junction of the pressure tunnel and the penstock.

7. **Penstock:** Penstock is a closed conduit which connects the forebay or surge tank to the scroll case of the turbine. In case of high head plants, a single penstock is provided. Penstocks are built of steel or reinforced concrete. When the penstock used is very long care must be taken to protect the conduit against water hammer. The thickness of penstock must be such that it can withstand both the normal hydrostatic pressure and also the sudden surges both above and below normal caused by fluctuations in load and by emergency conditions.
8. **Valves and Gates:** Gates are used in low head plants at the entrance to the turbine casing to shut-off the flow and provide for unwatering the turbine for inspection and repairs. Valves are used at the entrance to the turbine casing if a long or medium length penstocks is used in the hydro-power plant.
9. **Trash Racks:** Trash racks are used to prevent the ingress of floating and other material to the turbine. These are built up from long, flat bars set vertically or nearly so and spaced in accordance with the minimum width of water passage through the turbine.
10. **Tail Race:** After the useful work is done by water, it is discharged to the tail race.
11. **Draft Tube:** It is an air tight pipe of suitable diameter attached to the runner outlet and conducting water down from the wheel and discharging it under the surface of the water in the tail race. With the help of draft tube operating head on the turbine is increased resulting in increase in output and efficiency.
12. **Prime-movers or Water turbines:** In hydro-electric plants water turbines serve the purpose of prime mover which converts the kinetic energy of water into mechanical energy which is further utilized to drive the alternators generating electrical energy.

Classification of Water Turbines

Water or hydraulic turbines are classified in many ways which are as follows:

1. **On the basis of type of flow of water:**
   It is of four types namely:
   (a) Axial flow turbines: Kaplan turbine
   Here, water flows along the shaft axis
   (b) Inward radial flow turbines:
   Here, water flows radially
   (c) Tangential or peripheral flow turbines: Pelton wheel turbine
   Here, water flow tangentially
   (d) Mixed flow turbines: Francis turbine

2. **On the basis of action of water on moving blades:**
   These are of two types:
   (a) Impulse turbine:
   When the entire pressure of water is converted into kinetic energy in a nozzle and the jet thus formed drives the wheel, the turbine is called ***"impulse turbine"***.
   Example of impulse turbine is a pelton wheel turbine.
   (b) Reaction type turbine:
   If the water pressure combined with it's velocity work on the runner the turbine is known as the ***"reaction type turbine"***.
   Francis turbines, kaplan turbines and propeller turbines are examples of reaction type turbine.
3. **On the basis of water head:**
   They are classified as:
   (a) High head turbine (above 500 m): Pelton wheel turbine
   (b) Medium head turbine (head from 70 m to 500 m): Francis turbine
   (c) Low head turbine (head below 70 m): Kaplan turbine
4. **On the basis of specific speed:**
   "Specific speed" of the turbine is defined as the speed of a geometrically similar turbine that would develop one metric horse power under a head of one meter.

It is given by,

$$N_s = \frac{N\sqrt{P_t}}{h^{1.25}}$$

where, N_s = specific speed in metric unit
N = actual speed of turbine in rpm
h = water head in meters
P_t = output in horse power

The classification of turbines according to the range of specific speed is shown in table below.

Types of turbine	Specific speed in metric unit
Kaplan	300 - 1000
Propeller	300 - 1000
Francis	60 - 300
Pelton	10 - 50

***Table-4.1 :** Specific speed of various turbines*

Power Developed in a Hydro-electric Power Plant

The electrical power, P developed in a hydro-electric power plant is given by

$$P = \frac{0.736}{75} \cdot QWh\eta \text{ kW} = 9.81 \times 10^{-3} \times QWh\eta \text{ kW} \quad \text{...(Important result)}$$

where, W = specific weight of water in kg/m^3
Q = rate of flow of water in m^3/s
h = height of fall or water head in meter
η = overall efficiency of operation

Hydrology

Hydrology is the occurrence and distribution of water over and under the earth surface.
The various plots used in hydrology are as follows:

1. **Hydrograph:** Hydrograph is the graphical representation between discharge or flow with time. It is plotted with flow on the y-axis and time interval on the x-axis. Hydrograph indicates the power available from the stream at different times of the day or year. It is similar to load curve.
   A hydrograph provides the following informations:
   - The maximum and minimum run-off during the period.

- The average run-off during the period.
- The discharge at any time during the period under consideration.
- Total volume of discharge upto any time, given by the area under the curve upto that time.

2. **Flow-duration curve:** Flow-duration curve is used to determine the available power at site. It gives the relation between flows (plotted on vertical axis) and lengths of time (plotted on x-axis) during which they are available. Flow duration curve is a rearrangement of all the stream flow elements of a hydrograph in a descending order and is similar to load-duration curve.
A flow-duration curve can be used for the determination of minimum and maximum conditions of flow.
3. **Mass curve:** Mass curve is used to indicate the total volume of run-off in m^3 upon a certain time. The time may be in a day, month or year. Mass curve is obtained from records of average monthly flows. The slope of mass curve at any point gives the rate of flow at that time. It is used to determine the capacity of storage reservoir in hydro-projects. The capacity of the reservoir is given by the maximum ordinate between the mass curve and the demand line.

4.4 Pumped Storage Power Plants

It is a unique design of peak load plant in which the plant pumps back all or a portion of its water supply during low load period. In this type of power plant a tail race pond and a head race pond is connected through a penstock. Figure 4.3 shows a schematic diagram of a pumped storage power plant.

Construction and Working

The generating pumping plant is at the lower end. The plant utilizes some of the surplus energy generated by the base load plant to pump the water from the tail race water pond into the head race water pond during off peak hours. During peak hours the turbine drives the generator and the plant generates electrical energy while during off peak hours the generator operates as a motor and drives the turbine which now works as a pump raising the water from the tail water pond to the head water pond.

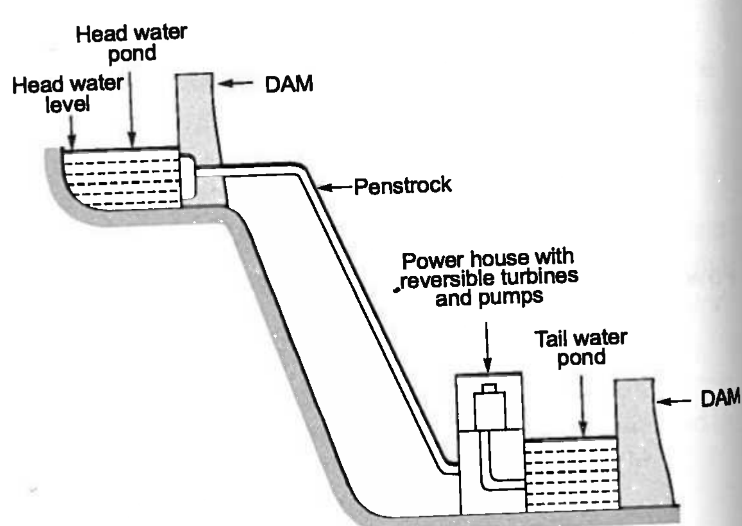


Figure-4.3 : *A pumped storage power plant*

The turbine used is a francis turbine (or DERIAZ) which is just the reverse of centrifugal pump. The arrangement so used in this type of power plant reduces the capital cost of the plant and improves the operating efficiency and thus results in economic operation. The efficiency of such plant is around 60-70 percent. Pumped storage power plants for peak load supply in interconnected systems are most suitable where the quantity of water available for power generation is insufficient but natural site for construction of high dam exists.

Advantages of Pumped Storage Power Plants

Following are few important advantages of a pumped storage power plant:

(*i*) They can be used for load frequency control.

(*ii*) When the load demand in the system is suddenly increased then, they can be immediately switched on to meet the extra demand.

(*iii*) Compared to steam and nuclear power plants, peak load can be supplied at a reduced cost when a pumped storage power plant is used.

(*iv*) The thermal and nuclear power plant can be operated almost at a unity load factor which ensures their economic operation.

(*v*) As they can quick start therefore, spinning reserve requirement of the system is reduced.

Disadvantage of a Pumped Storage Power Plant

The only disadvantage of such power plants is that they can not operate as an isolated power plant i.e. they can be operated only in inter-connected systems where other generating plants such as steam, nuclear and hydro-power plants are available.

Example - 4.1 **Consider the following statements:**

Assertion (A): Hydro-electric plants with large storage can be best used as base load plants having high load factor.

Reason (R): For a plant to be used as base plant, the unit cost of energy generated by the plant should be same.

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

Solution: (d)

(A) is false because hydro-electric plants with large storage is used as a peak load power plant.

Example - 4.2 **A hydro-electric station has to operate with a mean head of 50 m. It makes use of water collected over a catchment area of 200 km² over which the average annual rainfall is 420 cm with a 30% loss due to evaporation. Assuming the turbine efficiency as 85% and the alternator efficiency as 80% calculate the average power that can be generated.**

Solution:

As 30% of water is lost due to evaporation therefore, only 70% of water will be used for power generation. Hence, quantity of water available for utilization in a year is

$$Q = (\text{Catchment area} \times \text{average annual rainfall}) \times 0.7$$
$$= 200 \times 10^6 \times 4.2 \times 0.7 = 588 \times 10^6 \text{ m}^3$$

Given, $h = 50$ m

Overall power plant efficiency = Alternator efficiency × turbine efficiency
$$= 0.8 \times 0.85 = 0.68$$

So, total energy available $= \dfrac{9.81 QWh\eta \times 10^{-3}}{60 \times 60}$ kWh $\quad (W = 1000 \text{ kg/m}^3)$

$$= \frac{9.81 \times 588 \times 10^6 \times 50 \times 0.68}{60 \times 60} \text{ kWh} = 54.47 \times 10^6 \text{ kWh}$$

Also, average power is, $P = \dfrac{\text{Total energy available in kWh}}{24 \times 365}$

$$= \frac{54.47 \times 10^6}{8760} = 6.22 \text{ MW}$$

Example - 4.3 A hydro-electric power station is supplied from a reservoir having an area of 50 km^2 and head of 50 m. If the overall efficiency of the plant be 60%, then the rate at which the water level will fall when the station is generating 30 MW is given by

(a) 5.5 mm/hour (b) 3.28 mm/hour
(c) 7.40 mm/hour (d) 1.23 mm/hour

Solution: (c)

Given,

Catchment area, $A = 50\ km^2 = 5 \times 10^6\ m^2$

Water head, $h = 50$ m, W = density of water = 1000 kg/m^3

Average power generated, $P = 30$ MW

$= 9.81 \times QWh\eta \times 10^{-3}$ kW

or, Water discharge,

$$Q = \frac{P}{9.81 W h \eta \times 10^{-3}} = \frac{30 \times 10^3}{1000 \times 50 \times 9.81 \times 10^{-3} \times 0.6} = 101.9\ m^3$$

∴ Rate of fall of water level $= \frac{Q}{A} = \frac{101.9}{50 \times 10^6}$ m/s $= \frac{101.9}{50 \times 10^6} \times 3600 \times 10^3 = 7.33$ mm/hour

Example - 4.4 Match List-I (Classification of head) with List-II (Type of turbines) and select the correct answer using the codes given below the lists:

List-I
A. Low head, 2-15 m
B. Medium head, 15-70 m
C. High head, 70-500 m
D. Very high head > 500 m

List-II
1. Propeller or Kaplan
2. Kaplan or Francis
3. Pelton
4. Pelton or Francis

Codes:

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

Solution: (c)

Refer to previous article as explained for the solution.

Example - 4.5 The mean monthly discharge at a particular site is given below.

Months	Discharge (m^3/s)	Months	Discharge (m^3/s)
January	200	July	1600
February	400	August	1200
March	600	September	2000
April	2400	October	1200
May	1200	November	800
June	1800	December	400

Draw the hydrograph, flow-duration carve and mass curve. Determine the average inflow and the power that can be developed at an effective head of 90 m. Determine the capacity of the storage reservoir based on above one year data neglecting the losses due to storage, evaporation etc. Assume overall generation efficiency to be 80%.

Solution:

Average inflow of water is

$$Q = \frac{1}{12}[200 + 400 + 600 + 2400 + 1200 + 1800 + 1600 + 1200 + 2000 + 1200 + 800 + 400]$$

or, $Q = 1150\ m^3/s$

Also, power developed, $P = 9.81\ QWh\eta \times 10^{-3}$ kW

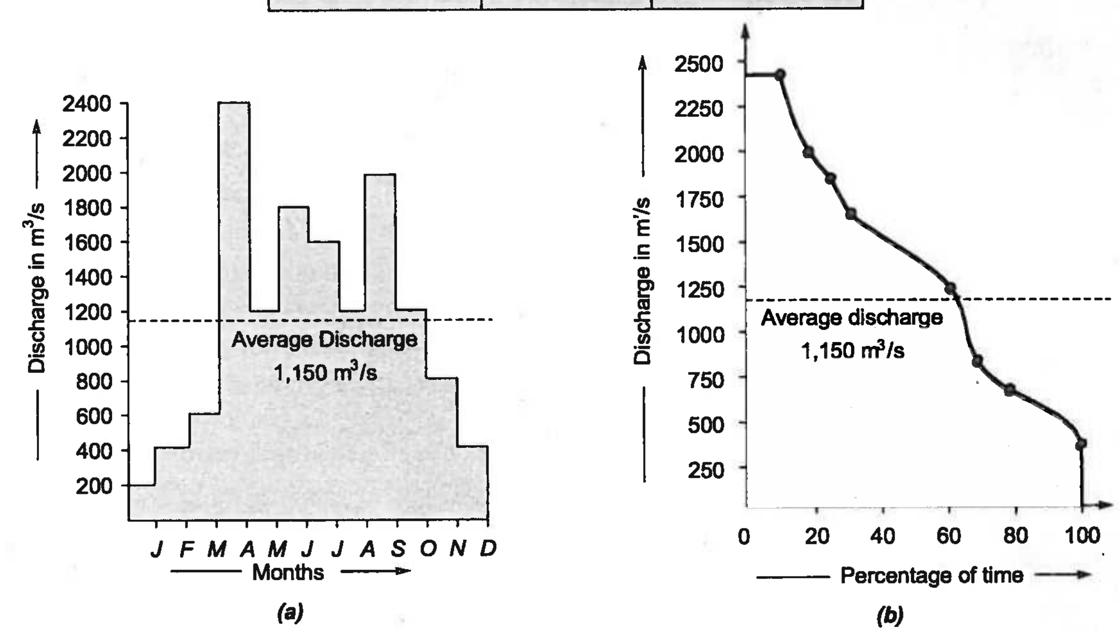
$= 9.81 \times 1000 \times 1150 \times 90 \times 0.8 \times 10^{-3}$ kW

or, $P = 812.26$ MW

The hydrograph is plotted as shown in Figure (a).

From hydrograph, flow-duration curve is drawn in Figure (b) by finding the length of time, during which certain flows are available. i.e. flow of 200 m^3/s is available for all the 12 months, flow of 400 m^3/s for 11 months, flow of 600 m^3/s for 9 months and so on. The table shown below is used for drawing the flow-duration curve.

Discharge (m^3/s)	Duration (in months)	Percentage time
200	12	100
400	11	91.66
600	9	75
800	8	66.66
1200	7	58.33
1600	4	33.33
1800	3	25.00
2000	2	16.67
2400	1	8.33

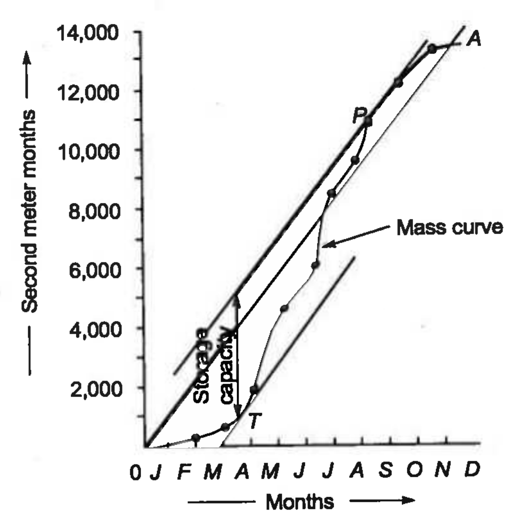


(a) Hydrograph (b) Flow duration curve

Now, for drawing mass-curve, the total second meter months at the end of various months of the year are calculated as follows.

Months	Discharge (m^3/s)	Accumulative run-off (sec-meter-month)
January	200	200
February	400	600
March	600	1200
April	2400	3600
May	1200	4800
June	1800	6600
July	1600	8200
August	1200	9400
September	2000	11400
October	1200	12600
November	800	13400
December	400	13800

Mass curve is plotted by taking the summation of the volume of water that can be stored and is represented by Figure (c).



(c) Mass curve

Example - 4.6 For harnessing low variable water heads, the suitable hydraulic turbine with high percentage of reaction and runner adjustable vanes is

(a) Kaplan (b) Francis
(c) Pelton (d) Impeller

Solution: (a)

Kaplan turbine is used for low variable water heads.

Example - 4.7 What are pumped storage plants? Describe with neat sketches the principle of operation of such a plant. Also, discuss the role of the plant in a large interconnected power system.

Solution:

Refer to the previous article of pumped storage power plant for detained solution.

4.5 Steam/Thermal Power Plants

More than 60% of electric power is produced by steam power plants in India. In steam power plants, the heat of combustion of fuels (coal, oil or gas) is utilized by the boilers to raise the steam at high pressure and temperature. The steam so produced is used to drive the steam turbines or sometimes steam engines coupled to generators and thus in generating electrical energy. Steam turbines or steam engines used in steam power plants not only act as prime movers but also as drives for auxiliary equipment, such as pumps, stokers fans etc.

Efficiency of Steam Power Plants

1. **Thermal efficiency of a steam power plant :** It is defined as the ratio of the heat equivalent of mechanical energy transmitted to the turbine shaft and the heat of combustion which is quite low (about 30%).
2. **Overall efficiency of a steam power plant :** It is defined as the product of thermal efficiency and electrical efficiency. The overall efficiency may be as high as 50%.

Remember

- The output of a steam power plant is about 29% due to the various losses occuring in the power plant. Boiler house losses (16%) and Turbine losses (55%) which constitute 54% losses in condenser and 1% in alternator.
  The steam in the condenser is at lowest temperature.
- The thermal efficiency increase with the increase in temperature and pressure of the steam entering the turbine.
- Thermal efficiency is increased by decreasing the pressure in the condenser which is around 0.04 kg/cm^2.

Super-critical Technology

When the temperature is above 600°C and pressure above 30 N/mm^2, water enters a super-critical phase and has properties between those of liquid and gas. Water in super-critical stage can dissolve a number of organic compounds and gases and on addition of hydrogen peroxide and liquid oxygen combustion process. The steam power plant working on this principle is called ***"super-critical plants"***.

Advantages of Super-critical Plants

The advantages include:

- NO_2 and SO_2 emissions are reduced and complete combustion of coal occurs.
- Cooling water requirements are reduced.
- System efficiency is increased and becomes more efficient.
- Efficiency of such power plants become as high as 40%.
- The overall efficiency is increased to around 50% above 700°C temperature.

Working of a Steam Power Plant

Steam power plant operates on the ***"Rankine cycle"***. The steam is expanded in turbine which produces mechanical power driving the alternator coupled to the turbine. The steam after expansion in prime mover is usually condensed in a condenser to be fed into the boiler again. Schematic layout of a modern coal-fired steam power plant is shown in Figure 4.4.

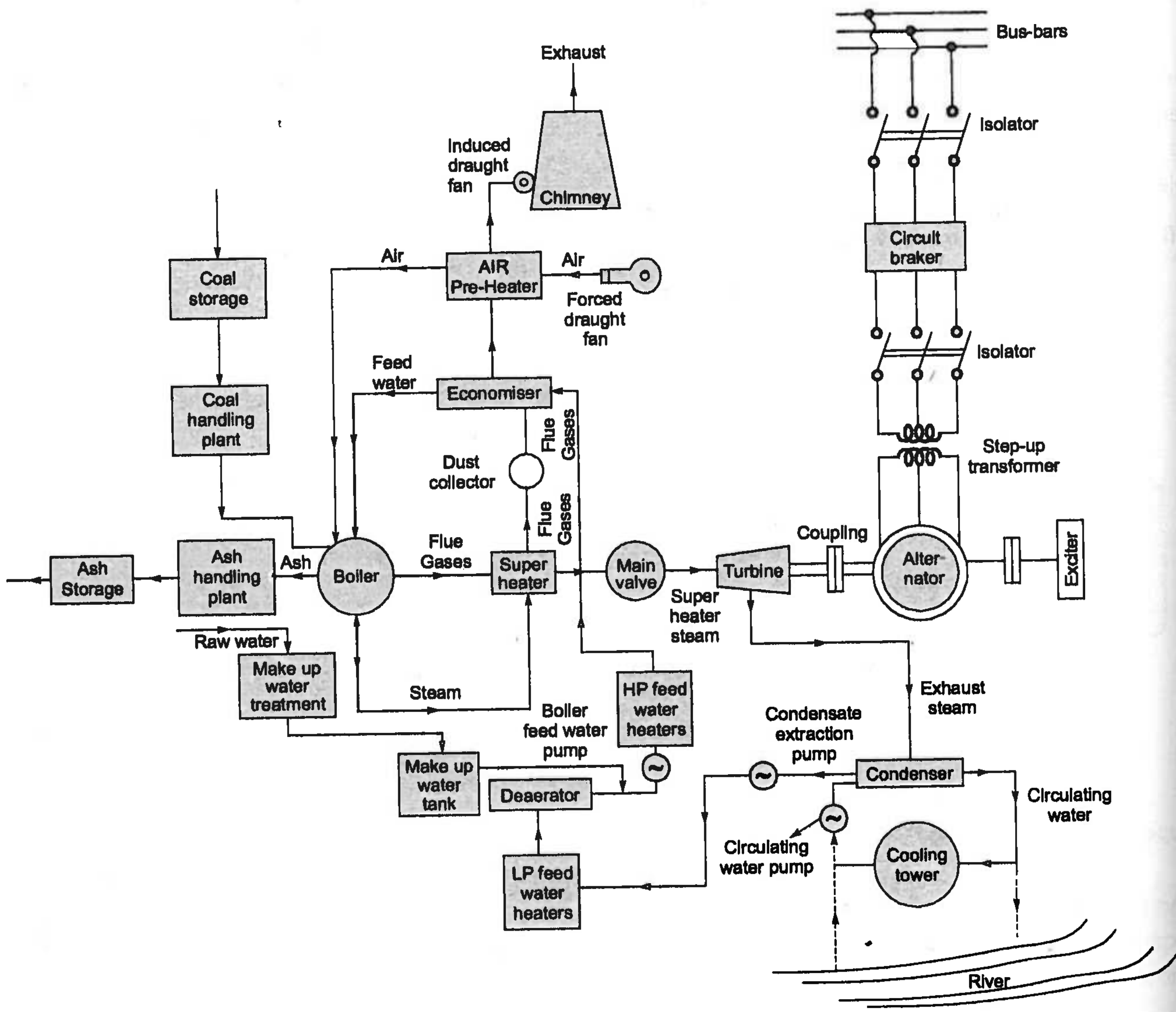


Figure-4.4 : Schematic layout of a modern coal-fired steam power plant

Constituents of Steam Power Plant

The various constituents are explained in detail as follows:

1. **Coal handling plant:** Coal is the most commonly used fuel in a thermal power plant. For a 200 MW power plant, 2000 tonnes of coal is required per day. The steam power plant should be located near the coal fields so that the cost of transportation of coal is reduced. Coal can be transported to coal storage yard from coal mines by means of river, by road and by rail. Generally, a railway siding line is taken into the power station and the coal is delivered either in the storage yard or close to the point of utility. The coal has to be carried to the boiler strokes or the coal preparation plant in the case of pulverised fuel firing. Handling of coal is done between the live storage and firing equipment. Gates and valves are included in the system for controlling the flow of coal according to the load on the power plant. Coal contains moisture, carbon, hydrogen, sulphur, nitrogen, oxygen and ash. It can be classified based on it's increasing order of calorific values as follows:

   Peat [Height moisture content (60 - 90%) and low carbon content, least preferred]
   Lignite (Transportation is difficult)
   Sub-bituminous (or Black lignite)
   Bituminous (Widely used in power plants. It is a cooking coal)
   Semi-bituminous (Highest heating values and best for power generation)
   Semi-anthracite (costlier)
   Anthracite (Highest carbon content, used for domestic purpose)
   Super-anthracite (It is a non-cooking coal and less used in power generation)

2. **Boilers:** Boilers convert water into steam and form one of the major equipments in steam power plants. Boilers used in steam power plants are of two types:

   (*i*) **Fire tube boilers:** In fire tube boilers, the tubes containing hot gases of combustion inside are surrounded with water. It is compact in size and have low initial cost. It's disadvantage is that it is extremely heavy and unwidely and there is chance of explosion. It can handle maximum pressure of 17.5 kg/cm^2.

   (*ii*) **Water tube boilers:** In water tube boilers the water is inside the tubes and hot gases outside the tubes. It consists of drums and tubes. The tubes are always external to drum. Compared to fire tube boiler it has high evaporation capacity, better efficiency of plant, high working pressure 80 kg/cm^2), safer in operation and occupy less space.

3. **Superheater:** A superheater is a device which removes the last traces of moisture from the saturated steam leaving the boiler tubes and also increase its temperature above the saturation temperature. Superheaters consists of groups of tubes made of steel. Superheaters are classified as ***radiant, convection*** or ***the combination of both***. ***"Radiant superheater"*** is located in the furnace between the furnace water-walls and absorb heat from the it's temperature falls with the increase in steam output. Convection superheater is located well back in the boiler tube tank, receives its heat entirely from fuel gases through convection. The temperature of convection superheater increases with the increase in steam output. It is more commonly used.

4. **Economiser:** Economiser is a device used to recover the heat from the flue gases on their way to chimney and raise the temperature of feed water and air supplied for combustion respectively. It increases the boiler efficiency (by 10-12%), causes reduction in fuel consumption and reduces temperature stresses in boiler joints. Economizer tubes are made of steel either smooth or covered with fins to increase the heat transfer surface area. The tubes are connected in parallel continuous loops. Figure 4.5 shows a straight tube return bend economizer.

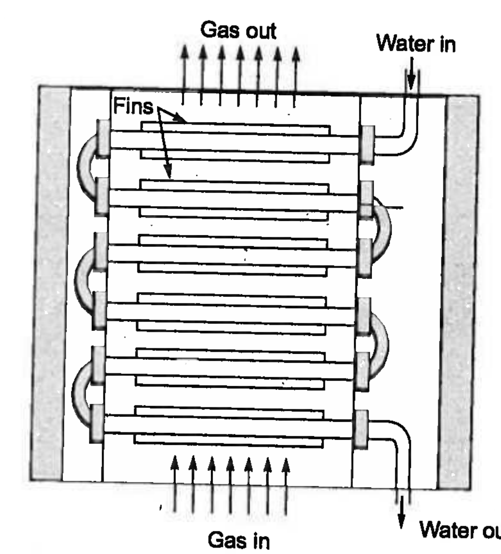


Figure-4.5 : Straight line return bend economizer

5. **Air pre-heaters:** It is used to recover the heat from the flue gases leaving the economizer and heat the incoming air required for combustion. In increases the overall efficiency of the boiler by raising the temperature of the furnace gases, by improving the combustion rate and efficiency. The air pre-heaters are of two types namely ***recuperative type*** and ***regenerative type***.

6. **Condensers:** After expansion through the prime mover, steam goes through the condenser which condenses the exhaust steam and also remove air and other non-condensable gases from steam while passing through them. The exhaust pressure may be lowered from the standard atmospheric pressure to about 25 mm of *Hg* absolute and thereby permitting expansion of steam, in the prime mover, to a very low pressure and increasing plant efficiency.
7. **Feed water heaters:** Feed water heater consists of HP feed water heater as well as low pressure (LP) feed water heater. These are used to heat the feed water by means of bled steam before it is supplied to the boiler. These heaters increases the overall plant efficiency.
8. **Spray ponds and cooling towers:** A large requirement of cooling water is met if the plant is located near a natural or artificial source of water such as river, sea, lake or canal. Cooling towers are made up of a wooden or metallic rectangular structure inside which is packed with baffling devices. The hot water is led to the tower top and falls down through the lower from the bottom and flows upward. The air vaporises a small percentage of water, thereby cooling the remaining water.
9. **Steam turbines:** The steam enters the nozzle and is cut by the rotor blades resulting in mechanical energy. According to the action of steam on moving blades, the steam turbines are of two types namely ***"impulse turbine"*** and ***"reaction turbine"***. In ***"impulse turbine"***, the steam expands completely in the stationary nozzles and the steam attains a high velocity and impinges against the blades fixed on the rotor periphery. Impulse turbines have high speed and gives optimum utilization of steam with a simple design. It has a long life. In a ***"reaction turbine"***, the steam does not expand in nozzles but expands as flows over the rotor blades and hence the blade acts as nozzles. It is a low speed turbine. Commercial turbines are series combination of impulse and reaction type turbines. The standard speeds are 3,000 rpm and 1500 rpm for coupling to 50 Hz alternators.
10. **Electrostatic precipitator:** The exhaust gases leaving the boiler contain particles of solid matter in suspension smoke, flyash, dust, soot and smoke. Fuel dust is greater with pulverised fuel. Removal of dust from the exhaust gases is very important. Basically gas cleaning devices called the dust collectors are classified into mechanical and electrical ones. Electrical ones include electrostatic precipitator. Electrostatic precipitator has an advantage of higher efficiency, low pressure drop, easy removal of collected particles and capacity of handling large volume of flue gases.

Example - 4.8 **In thermal power plants, the pressure in the working fluid cycle is developed by**

(a) condenser
(b) superheater
(c) feed water pump
(d) turbine

Solution: (c)

Example - 4.9 **A steam power station of 100 MW capacity uses coal of calorific value of 6,400 Kcal/kg. The thermal efficiency of the station is 30% and electrical generation efficiency is 92%. The total coal required (in tonnes) per hour when the plant is working at full load will be**

(a) 36.8 tonnes/hour
(b) 89 tonnes/hour
(c) 24.5 tonnes/hour
(d) 48.6 tonnes/hour

Solution: (d)

The overall efficiency of the power station is

$$\eta_{overall} = \eta_{thermal} \times \eta_{electrical} = 0.3 \times 0.92 = 0.276$$

kWh output generated by the plant in one hour = 10^5 kWh = $10^5 \times 860$ K Cal

So, heat input per hour $= \dfrac{10^5 \times 860}{\eta_{overall}} = \dfrac{10^5 \times 860}{0.276} = 311.6 \times 10^6$ K Cal

Hence, Consumption of coal per hour $= \dfrac{\text{Heat input per hour}}{\text{Calorific value of coal}}$

$$= \frac{311.6 \times 10^6}{6400} = 48687 \text{ kg or } 48686.59 \text{ kg}$$

$$= 48.687 \text{ tonnes} \approx 48.6 \text{ tonnes}$$

Thus, Coal required = 48.6 tonnes/hour

Example - 4.10 **Maximum efficiency of modern coal-fired steam-raising thermal power plants is restricted to about 0.35 (a low value), mainly because of**

(a) low alternator efficiency
(b) high energy loss in boiler
(c) low steam turbine mechanical efficiency
(d) high energy loss from turbine exhaust to condenser

Solution: (d)

The highest power loss in a steam power plant occurs in condenser (about 54%) due to which the maximum efficiency is limited to about 35%.

Example - 4.11 **A steam power plant spends ₹ 10.60 lakhs per annum for coal used in the plant. The coal has a calorific value of 5000 KCal/kg and costs ₹ 50 per tonnes. If the overall efficiency of the plant is 30%, then, the average load on the plant in kW will be**

(a) 3650
(b) 4220
(c) 5896
(d) 2585

Solution: (b)

Amount of coal consumed in one year $= \dfrac{\text{Coal bill per annum}}{\text{Cost of coal per ton}} = \dfrac{10.60 \times 10^5}{50}$

$= 21200$ ton $= 21.2 \times 10^6$ kg

∴ Heat output $= \eta_{overall} \times$ Heat of combustion

$= 0.3 \times 10.6 \times 10^{10} = 3.18 \times 10^{10}$ K Calories

so, Energy generated per annum $= \dfrac{3.18 \times 10^{10}}{860} = 36.9767 \times 10^6$ kWh or 4221 kW

(Since 1 kWh = 860 K Cal)

Thus, average load on the power station $= \dfrac{36.9767 \times 10^6}{365 \times 24} = 4220$ kW

Example - 4.12 **Draw a labelled schematic diagram of a typical thermal power station. How do you compare thermal plants with hydro-electric plants from the economic point of view.**

Solution:

Refer to previous article of thermal power plant for it's schematic diagram.

Comparison of thermal plants with hydro-electric power plants has been explained as follows.

S.No.	Cost incurred	Steam power plants	Hydro-electric power plant
1.	Cost of fuel transportation	Maximum because huge amount of coal is to be transported.	Nil
2.	Initial cost	Low	Very high due to the requirement of construction of dam.
3.	Running cost	High due to requirement of huge amount of coal.	Nil because no fuel is required unlink steam power plants.
4.	Maintenance cost	High because skilled employees are required.	Low
5.	Transmitted and distribution cost	Low because they are located near load centers.	High because they are located far away from load centers.
6.	Fixed cost (per annum)	13%	10%

Table-4.2

Example - 4.13 **A thermal station has an overall efficiency of 21% and 0.75 kg of coal is burnt per kWh of generated energy. The calorific value of coal will be**

(a) 5460 K Cal/kg **(b) 2400 K Cal/kg**

(c) 1560 K Cal/kg **(d) 6528 K Cal/kg**

Solution: (a)

Amount of heat produced per 0.75 kg of coal = $\dfrac{\text{Output in heat units}}{\text{Overall efficiency}}$

$$= \frac{1 \times 860}{0.21} = 4096.238 \text{ K Cal} \quad \text{(Since 1 kWh = 860 K Cal)}$$

Hence, Calorific value of coal = $\dfrac{4096}{0.75} = 5460$ K Cal/kg

4.6 Nuclear Power Plants

The need of nuclear power plant lies in the fact 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. Moveover, the reserves of fossil fuels like coal, oil and gas are fast depleting. Thus, there is 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. Currently in India, there are ***twenty one nuclear power reactors having a total installed capacity of* 5780 MW *(3.5% of total installed base)***. The various nuclear power stations in India are listed below in the Table 4.3.

Power station	Operator	State	Type	Units	Total capacity (MW)
Kaiga	NPCIL	Karnatka	PHWR	220 × 4	880
Kakrapar	NPCIL	Gujarat	PHWR	220 × 2	440
Kalpakkam	NPCIL	Tamil Nadu	PHWR	220 × 2	440
Narora	NPCIL	Uttar Pradesh	PHWR	220 × 2	440
Rawatbhata	NPCIL	Kota, Rajasthan	PHWR	100 × 1 220 × 1 220 × 4	1180
Tarapur	NPCIL	Maharashtra	PHWR	160 × 2 540 × 2	1400
Kudankulam	NPCIL	Tamil Nadu	VVER-1000	1000 × 1	1000
			Total	**21**	**5780**

Table-4.3 : *Various operating nuclear power plants in India*

Construction of Nuclear Power Plant and Layout

Coal or oil burning furnace and the boiler used in steam power plants are replaced by nuclear reactor and heat exchanger in nuclear power plants. The schematic arrangement of a nuclear power plant is shown in Figure 4.6.

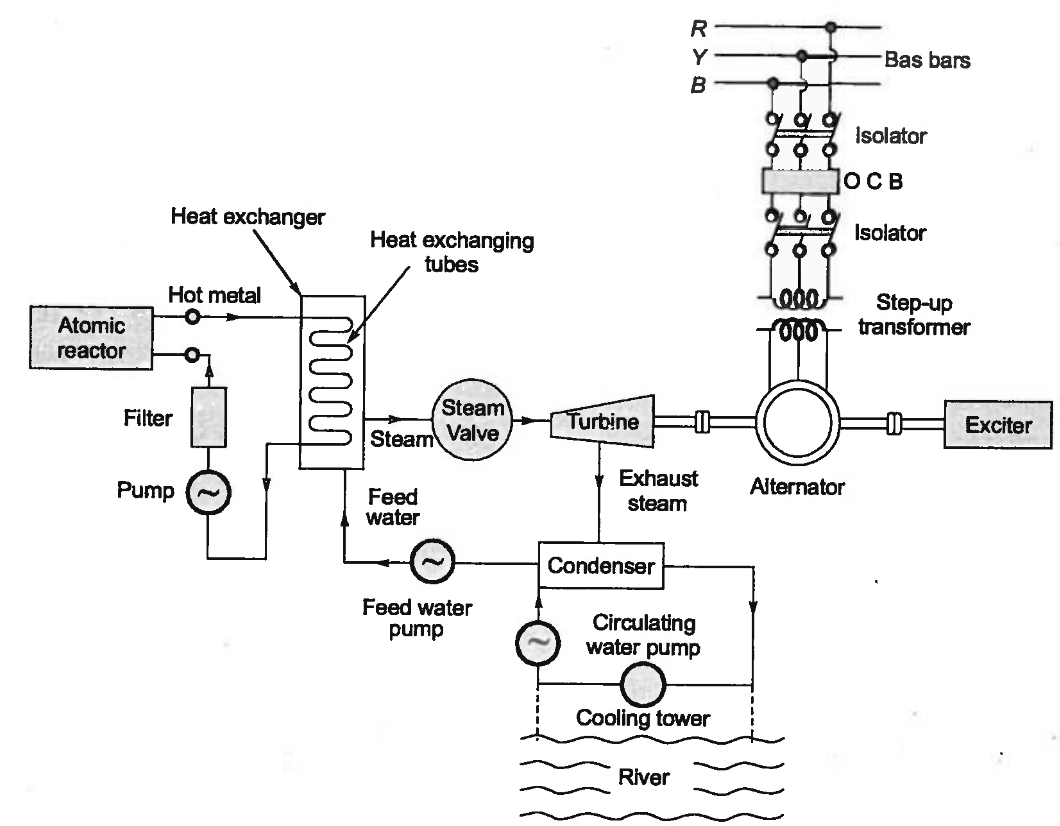


Figure-4.6 : *Schematic arrangement of a nuclear power plant*

A nuclear power plant consists of a ***nuclear reactor*** (for generating the heat), ***heat exchanger*** (for converting water into steam by using the heat generated in the nuclear reactor), ***steam turbine, alternator, condenser, exciter*** etc. The excess amount of heat energy produced in breaking of atoms of uranium or other similar metals of large atomic weight into metals of lower atomic weight by fission process in an atomic reactor is extracted by molten metal/pumping fluid like sodium or gas through the pile. The heat exchanger exchanges the heat produced in the reactor by circulation. In heat exchanger steam is produced which is utilized to drive gas turbine or steam turbine coupled to an alternator hence producing electrical energy.

Main Parts of Nuclear Reactor and Their Function

The various components of a nuclear reactor are shown in Figure 4.7.

The nuclear reactor, nuclear fuel is subjected to nuclear fission and the energy so produced is utilized to heat the coolant which may in turn generate steam or be used in gas turbine. The main function of a nuclear reactor is to control the emission and absorption of neutrons. A nuclear reactor consisting of various components are described one by one as follows:

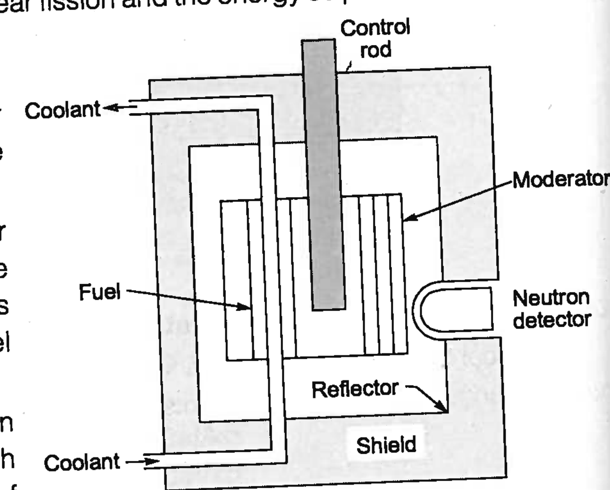


***Figure-4.7 :** Components of a nuclear reactor*

1. **Reactor core:** The reactor core contains a number of fuel rods made of fossil material. As the uranium gets oxidized rapidly, the fuel rods should be clad with aluminium, stainless steel or zirconium.
2. **Moderator:** Neutrons produced by the fission process have a very high kinetic energy which are termed as fast neutrons. The purpose of moderator material in the reactor core is to moderate or reduce the neutron speed to a value that increases the probability of fission occurance. The fast neutrons collide with the nuclei of moderator material, loose their energy and get slow down. ***Heavy water*** **(D_2O)** is an ideal moderating material used in many reactors inspite of its heavy cost. Other moderator materials used are ***Helium, Lithium, Berylium, Boron*** and ***Carbon.***
3. **Control rods:** The rate of fission of U-235 is controlled by means of control rods. With the help of control rod, the nuclear fission process can be shut-down automatically under emergency conditions ensuring the overall safety of the nuclear power plant during natural clamities. 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. ***Control rods are made up of Boron, Cadmium or hafnium.***
4. **Coolant:** The heat generated in the reactor is transferred to the heat exchanger with the help of a medium called ***"coolant"***. Coolant flows through and around the reactor core. It also helps in keeping the interior of reactor at the desired temperature. The materials used as coolant are
   - (*i*) **Gases:** Air, Helium, Hydrogen and CO_2.
   - (*ii*) **Liquid:** Light and Heavy water (D_2O).
   - (*iii*) **Metals:** Molten Sodium and Lithium.

NOTE

- Ordinary water is used as coolant and moderator in boiling water reactor (BWR).
- Pressurised water is used as coolant and moderator in pressurised water reactor (PWR).
- Liquid metals (Na and K) are used as coolant in fast reactors (operating at high temperature).

5. **Reflector:** Reflector completely surrounds the reactor core within the thermal shielding arrangement and bounces back most of the neutrons that escape from the fuel core. This helps in conserving the nuclear fuel, as the low speed neutrons returns thus helping in maintaining the chain reaction. It is made up of same material as the moderator.
6. **Thermal shielding:** Thermal shielding which is usually constructed from iron helps in giving protection from the deadly α and β particle radiations and γ-rays as well as neutrons given off by the process of fission with in the reactor. Coolant flows over the shielding to take away the heat.
7. **Reactor vessel:** Reactor vessel or a tank is used to enclose the reactor core, reflector and thermal shielding in the main body of the reactor. It is a strong walled container and provides the entrance and exit for the coolant and also the passages for it's flow through and around the reactor core.
8. **Biological shield:** ***Lead iron*** or ***concrete shields*** are used to enclose the whole of the reactor to prevent the escape or leakage of the fast neuctrons, slow neutrons, β-particle and γ-rays as these rays are very harmful for living beings.

Nuclear Reaction

- The nuclear reaction is associated with a release or absorption of energy. If there is a decrease in total mass after the reaction, then there will be release of energy and vice-versa. In a nuclear reactor nuclear fission occurs.
- **Nuclear fission:** The process of splitting of a heavy nucleus into two or more smaller nuclei is termed as ***"nuclear fission"***. This process is accompanied by the ejection of two or more neutrons and liberation of vast energy. The basic two reactions occuring in the process of nuclear fission are follows:

$$U_{92}^{235} + n_0^1 \rightarrow Ba_{56}^{139} + Kr_{36}^{94} + 3n_0^1 + \text{Energy}$$

$$U_{92}^{235} + n_0^1 \rightarrow Mo_{42}^{106} + Sn_{50}^{128} + 2n_0^1 + \text{Energy}$$

Remember

- Generally, 1 fission of U_{92}^{235} release an energy of 200 MeV = 3×10^{-11} Joules.
- 1 kg of pure U_{92}^{235} when fissioned releases energy equivalent to that by burning 3×10^6 kg of coal with a calorific value of 6000 KCal/kg.
- **Critical mass:** The minimum mass of fissionable material required to sustain a chain reaction is called the ***"critical mass"***. The critical mass for U_{92}^{235} is 10 kg.
- The nuclear fuel used in nuclear power plants are mainly natural uranium (U-235), enriched uranium, plutonium (used as secondary fuel) and U-233 (used as secondary fuel for breeder reactors). Out of the above natural uranium (U-235) is the parent material used as nuclear fuel because it is having higher fission percentage.

Multiplication Factor

The neutrons which are released in the fission reaction are all not used up in propagating the chain reaction as some of them are lost to the surroundings. In order to maintain the chain reaction, the number of neutrons after the fission should be slightly more than the number before it to allow for the scape or leak of neutrons from the reactor core. This ratio is known as ***"multiplication factor"*** and is defined as

$$K = \left(\frac{\text{Number of neutrons produced in one generation}}{\text{Number of neutrons produced in the preceeding generation}}\right)$$

Remember

- The value of K indicates the chain reaction will continue at a steady state (critical).
- If $K < 1$, the chain reaction stops and the system becomes subcritical.
- If $K > 1$, the chain reaction build-up and system becomes super-critical.
- The desired value of $K = 1$ (critical)
- At the time of starting of reactor, value of K is kept above unity so as to build-up the chain reaction and increase the power level. Once the required power level is attained, K is reduced to unity and is maintained at this value as long as the output rate is to be maintained.
- For shutting down the reactor K is reduced below unity stopping the chain reaction.

4.7 Concept of Base Load and Peak Load Power Plants

The load on a power plant varies from time to time as shown in Figure 4.8.

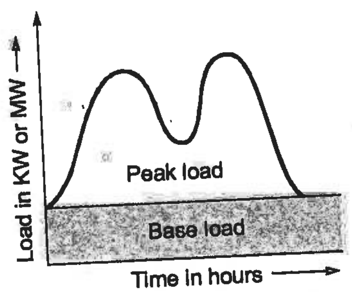


Figure-4.8 : Load variation on a power plant

The load on a power plant can be divided into two parts:

1. Base load power plant
2. Peak load power plant

1. Base load power plant:

- The unvarying load, which occurs almost the whole day on the power plant is called ***base load*** and power plants used to supply the base load are termed as ***base load power plants.***
- The power plants to be employed as base load power plants should have
  - (a) low operating cost.
  - (b) capability of working continuously for the long periods.
  - (c) requirement of few operating personnel and
  - (d) their repair should be economical and speedy.

2. Peak load and Power plants:

The various peak demands of the load over and above the base load of the power plant is called ***peak load*** and the power plants supplying the peak loads are termed as ***peak load power plants.***

- The power plants to be employed as peak load power plants should have the capability of starting quickly, synchronize quickly and should respond quickly to load variations.

Remember

- The hydro-electric plants should be employed for base load operation as far as possible because of their higher capital cost.
- During draught condition a hydro-electric plant may be used as a peak load power plant.
- A steam power plant gives minimum cost of generation per unit when employed as base load plant but, in order to save fuel it may be used as peak load plant.
- Nuclear power plants are suitable only for base load operation at high load factor of over 0.8.
- Gas turbine and pumped storage power plants are suitable for supplying peak loads.
- Due to a very high operating cost, diesel power plants play a very little role in bulk power generation and hence can be used to supply peak load.
- Hydro-electric plants with large storage is used as base load power plant.
- The run-off river power plant can be employed as a base-load power plant during rainy season while the steam power plant may supply the peak load when they are operated in combination. During dry season the steam power plant is used to supply the base load and run-off river power plant for supplying peak load when they are operated in combination.

4.8 Comparison of Various Types of Power Plants

S.No.	Items	Hydro-electric power plants	Steam power plants	Nuclear power plants
1.	Site requirement	Huge water with sufficient water head should be available at the site. Located far from load centers.	Located near the load center but, good transportation facility should be available to transport coal.	Located away from thickly populated areas to avoid radioactive pollution but, located near load center as possible.
2.	Space requirement	Very large due to reservoir.	Less than hydro-electric plants.	Less than hydro and steam power plants but, more than others.
3.	Auxiliaries requirements	Small	Large	Less than steam PP but, more than other PPs.
4.	Simplicity and cleanliness	Most simple and no air pollution.	Less clean due to ash handling and high air pollution.	Nuclear waste disposal a major problem but, no air pollution.
5.	Starting time	5-10 minutes	2-3 hours	2-3 hours
6.	Plant life	30-50 years	20-30 years	20-30 years
7.	Overall efficiency	Most efficient (80-85%)	30-40%	30-40%
8.	Erection period	10-15 years (maximum)	3-5 years	10-12 years
9.	Maintenance requirement	Very low	Quite high	Very high
10.	Capital cost	Quite high	Medium	Very high
11.	Operating cost	Minimum (25-30 paise per kWh)	Medium (₹ 1-1.25 per kHh)	Quite low (30-35 paise per kWh)
12.	Overall generating cost	₹ 1-2 per kWh	₹ 2-3 per kWh	₹ 1-2.5 per kWh
13.	Transmission and distribution cost	Very high as located far from load center.	Moderate	Moderate

Table-4.4

Example - 4.14 Explain the following terms with reference to a nuclear reactor (*i*) moderator (*ii*) coolant (*iii*) control rods (*iv*) reflector.

Solution:

Refer to previous article of nuclear power plant for the detained explanation.

Example - 4.15 Explain with a neat sketch the working of a nuclear power plant.

Solution:

Refer to Figure 4.6 of pervious article for detailed solution.

Example - 4.16 What is the approximate efficiency of a normal thermal power station?

(a) 30 - 40% (b) 45 - 55%
(c) 20 - 25% (d) 60 - 70%

Solution: (a)

Example - 4.17 Consider the following statements regarding the nuclear power plants.

1. A thermal reactor needs a moderator material.
2. In a nuclear reactor, multiplication factor is kept almost equal to one.
3. Nuclear power plants are used as peak load plants only.

Which of these statements are correct?

Solution: (b)

Statement 3 is false as nuclear power plants are only used as base load power plants at high load factor of over 0.8.

Example - 4.18 What is the total power installed capacity (approximate) in India?

(a) 1,75,000 MW (b) 2,25,000 MW
(c) 2,49,000 MW (d) 3,20,000 MW

Solution: (c)

Total installed capacity till June, 2014 = 249 GW (approximately).

Economics of Power Generation

The generating stations may be steam, hydro, nuclear, diesel or any other type. The power station should be as near as possible to the center of the load so that the transmission cost and losses are minimum. The other consideration for the design of the power station are reliability, minimum capital and operating costs.

For deciding the type and rating of generating power stations various important terms that should be kept in mind are described one by one as follows:

1. **The load curve:** It is the plot of the daily variation in load on the power station versus time (hourly or half hourly). A typical load curve is shown in Figure 4.9.

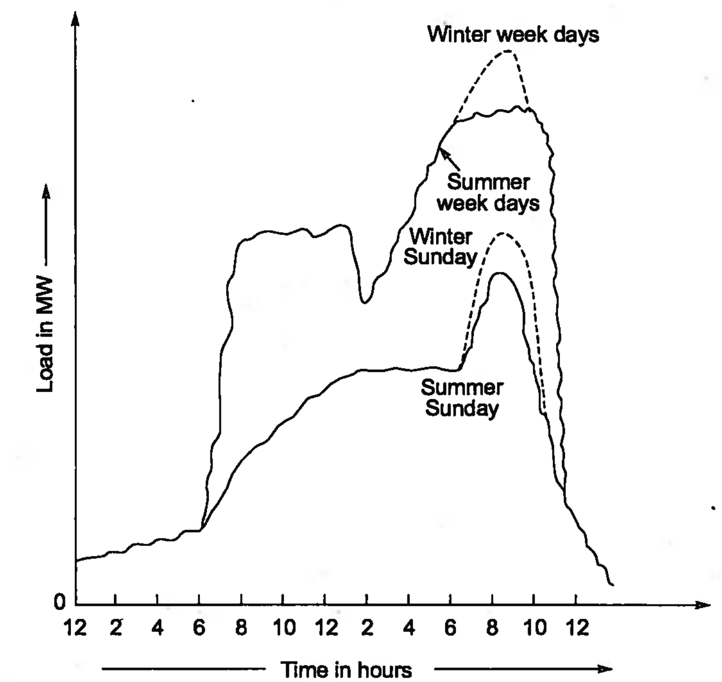


Figure-4.9: *A typical load curve*

The load curve provides the following information:

(*i*) the variation of load during different hours of the day.
(*ii*) the area under the curve gives the total units generated per day.
(*iii*) the peak of the curve represents the maximum demand on the station in a particular day.
(*iv*) the area under the curve divided by total number of hours gives the average load on the power station.
(*v*) the ratio of area under the curve to the total area of the rectangle in which it is contained gives the overall load factor.
(*vi*) it gives the idea about the size of the units to be installed and also in preparing the schedule of operation of the generating units.

2. **Load duration curve:** It indicates the variation of load with the loads arranged in descending order of magnitude versus time. Load duration curve gives the number of hours for which a particular load lasts during the day. The area under the load duration curve gives the total number of units generated for the period considered. It can be used to determine the load factor of the power station.
3. **Connected load:** It is the sum of the continous ratings of all the electrical equipment connected to the supply system.
4. **Maximum demand:** The greatest short time average demand occuring during a given period of time under consideration on the power station is known as maximum demand.
5. **Demand factor:**

(*i*) Demand factor is the ratio of actual maximum demand on the system to the total rated load connected to the system.

i.e. $$\text{Demand factor} = \left(\frac{\text{Maximum demand}}{\text{Connected load}}\right)$$

(*ii*) Demand factor is always less than unity.

6. **Average load:**

(i) Average load on the power station is the average of the loads occuring at the various events. It is the energy delivered in a given period divided by the number of hours in that period.

i.e. $$\text{Daily average load} = \frac{\text{kWh supplied in a day}}{24}$$

(ii) Similarly, monthly and annual average load can be calculated.

7. **Load factor:**

(i) Load factor is defined as the ratio of average load to the maximum demand during a certain period of time (i.e. day or a month or a year).

i.e. $$\text{Load factor} = \left(\frac{\text{Average load}}{\text{Maximum demand}}\right)$$

(ii) Load factor is always less than unity.

8. **Diversity factor:** It is defined as the ratio of sum of the individual maximum demands of all the consumers supplied by it to the maximum demand of the power station.

i.e. $$\text{Diversity factor} = \left(\frac{\text{Sum of individual maximum demand}}{\text{Maximum demand on power station}}\right)$$

Diversity factor is always greater than unity.

9. **Coincidence factor:**

(i) The reciprocal of the diversity factor is called the coincidence factor.

Mathematically, $$\text{Coincidence factor} = \left(\frac{1}{\text{Diversity factor}}\right)$$

(ii) Coincidence factor is always less than unity.

10. **Capacity factor or Plant factor:**

(i) It is defined as the ratio of average load to the rated capacity of the power plant.

i.e. $$\text{Capacity factor} = \left(\frac{\text{Average load}}{\text{Rated plant capacity}}\right)$$

(ii) Capacity factor gives the idea about the reserve capacity of the plant.

(iii) It can also be written as

$$\text{Capacity factor} = \left(\frac{\text{Maximum demand}}{\text{Rated plant capacity}}\right)\times\text{Load factor}$$

11. **Utilization factor:**

(i) It is defined as the ratio of maximum demand to the rated capacity of the power plant.

i.e. $$\text{Utilization factor} = \left(\frac{\text{Maximum demand on the power station}}{\text{Rated capacity of the power station}}\right)$$

(ii) Utilization factor is always less than unity.

12. **Plant use factor:** It is defined as the ratio of actual energy generated during a given period to the product of capacity of the plant and the number of hours the plant has been actually in operation during the period.

i.e. $$\text{Plant use factor} = \left(\frac{\text{Total kWh generated}}{\text{Rated capacity of plant}\times\text{number of operating hours}}\right)$$

13. **Spinning reserve:** It is the generating capacity connected to the bus and ready to take load.

NOTE: Higher the values of load factor and diversity factor, lower will be the overall cost per unit generated.

Example - 4.19 A generating station has a maximum demand of 100 MW, load factor of 65 percent, plant capacity factor 50 percent and plant use factor 75 factor. Find the

(i) daily energy produced.

(ii) the reserve capacity of the plant.

(iii) the maximum energy that can be produced daily if the plants are running all the time.

(iv) the maximum energy that can be produced daily if the plant are fully loaded (according to the operating schedule).

Solution:

Given:

Maximum demand, $MD = 100$ MW

Load factor, $LF = 0.65$

Plant capacity factor $= 0.5$

So, Average load $= MD \times LF = 100 \times 0.65 = 65$ MW

Also, Plant use factor $= 0.75$

(i) Daily energy produced $=$ Average load $\times 24 = 65 \times 24 = 1560$ MWh

(ii) $$\text{Plant capacity} = \frac{\text{Average load}}{\text{Plant capacity factor}} = \frac{65}{0.5} = 130\text{ MW}$$

∴ Plant reserve capacity $=$ Installed capacity $-$ Maximum demand $= 130 - 100 = 30$ MW

(iii) The maximum energy that can be produced daily if the plant are running all the time

$$= \frac{\text{Actual energy generated}}{\text{Plant capacity factor}} = \frac{1560}{0.5} = 3120\text{ MWh}$$

(iv) The maximum energy that can be generated daily if the plant operating schedule is fully loaded when in operation

$$= \frac{\text{Actual energy generated}}{\text{Plant use factor}} = \frac{1560}{0.75} = 2080\text{ MWh}$$

Example - 4.20 A power station has a maximum demand of 15000 kW. The annual load factor is 50% and plant capacity factor is 40%. What is the reserve capacity of the plant?

(a) 1875 kW **(b) 3750 kW**

(c) 6000 kW **(d) 7500 kW**

Solution: (b)

Given, $MD = 1500$ kW

Load factor, $$LF = 0.5 = \frac{\text{Average load}}{\text{Maximum demand}}$$

$$\text{Plant capacity factor} = \frac{\text{Average load}}{\text{Plant capacity}} = 0.4$$

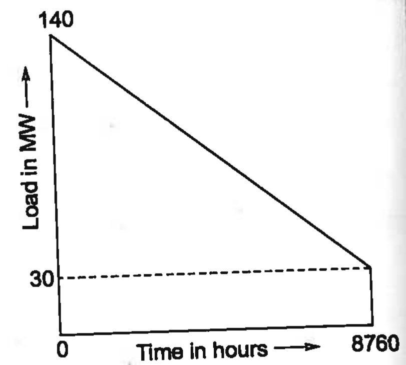
Now, $$\frac{LF}{PCF} = \frac{0.5}{0.4} = \left(\frac{\text{Plant capacity}}{\text{Maximum demand}}\right)$$

or, $$\text{Plant capacity} = \frac{5}{4}\times 15000\text{ kW} = 18750\text{ kW}$$

∴ Plant reserve capacity $=$ Plant capacity $-$ Maximum demand $= 18750 - 15000 = 3750$ kW

Example - 4.21 The yearly duration curve of a certain plant can be considered as a straight line from 140 MW to 30 MW as shown in the given figure. Power is supplied with one generating unit of 95 MW capacity and two units of 45 MW capacity each. Determine:

(*i*) Installed capacity
(*ii*) Load factor
(*iii*) Plant capacity factor
(*iv*) Maximum demand
(*v*) Utilization factor



Load duration curve

Solution:

(*i*) Installed capacity = 95 + 2 × 45 = 185 MW

(*ii*) $\text{Load factor} = \dfrac{\text{Average load}}{\text{Maximum demand}} = \dfrac{85}{140} \times 100 = 60.7\%$

(As maximum demand = 140 MW and average load = $\dfrac{140+30}{2} = 85$ MW)

(*iii*) $\text{Plant capacity factor} = \dfrac{\text{Average load}}{\text{Plant capacity}} = \dfrac{85}{185} = 0.46 = 46\%$

(*iv*) Maximum demand = 140 MW

(*v*) $\text{Utilization factor} = \dfrac{\text{Maximum demand}}{\text{Rated capacity}} = \dfrac{140}{185} = 0.757 = 75.7\%$ or 75.67%

Example - 4.22 In order to have lower cost of power generation

(a) the load factor and diversity factor should be low.
(b) the load factor 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.

Solution: (b)

Both the load and diversity factor should be high so that the total cost of per unit generated becomes minimum.

Important Expressions

1. Specific speed of a turbine is given by $\left[N_S = \dfrac{N\sqrt{P_t}}{h^{1.25}} \right]$

2. Power developed in a hydro-electric power plant is given by

$$P = \frac{0.736}{75} QWh\eta \text{ kW} = 9.81 \times 10^{-3} QWh\eta \text{ kW}$$

$$= 9.81\, Qh\eta \text{ kW} \quad (W = \text{density of water} = 1000 \text{ kg/m}^3)$$

3. Two basic nuclear reaction occuring in the process of nuclear fission are

$$U^{235}_{92} + n^1_0 \rightarrow Ba^{139}_{56} + Kr^{94}_{36} + 3n^1_0 + \text{Energy}$$

$$U^{235}_{92} + n^1_0 \rightarrow M0^{106}_{42} + Sn^{128}_{50} + 2n^1_0 + \text{Energy}$$

4. **Economic of power generation:**

(*i*) $\text{Demand factor} = \left(\dfrac{\text{Maximum demand}}{\text{Connected load}}\right)$ (< 1)

(*ii*) $\text{Daily average load} = \left(\dfrac{\text{kWh supplied in a day}}{24}\right)$

(*iii*) $\text{Load factor} = \left(\dfrac{\text{Average load}}{\text{Maximum demand}}\right)$ (< 1)

(*iv*) $\text{Diversity factor} = \left(\dfrac{\text{Sum of individual maximum demand}}{\text{Maximum demand of power station}}\right)$ (> 1)

(*v*) $\text{Coincidence factor} = \left(\dfrac{1}{\text{Diversity factor}}\right)$ (< 1)

(*vi*) $\text{Plant capacity factor} = \left(\dfrac{\text{Average load}}{\text{Plant capacity}}\right) = \left(\dfrac{\text{Maximum demand}}{\text{Rated plant capacity}}\right) \times \text{load factor}$

(*vii*) $\text{Utilization factor} = \left(\dfrac{\text{Maximum demand on the power station}}{\text{Rated capacity of the power station}}\right)$ (< 1)

(*viii*) $\text{Plant use factor} = \left(\dfrac{\text{Total kWh generated}}{\text{Rated capacity of plant} \times \text{Number of operating hours}}\right)$

Student's Assignments 1

Q.1 The mean monthly discharge for 12 months at a particular site of a river is given below:

Month	Discharge (in millions of m³ per month)	Month	Discharge (in millions of m³ per month)
January	1000	July	2500
February	800	August	3000
March	600	September	2400
April	500	October	2000
May	200	November	1500
June	1500	December	1500

Draw hydrograph for the given discharge and find the average monthly flow. Calculate the power available at mean flow of water if the available head is 90 m and overall efficiency of generation is 80%.

Q.2 A medium capacity storage type hydro-electric power plant covers 1200 km² area. The annual rainfall in catchment area is 160 cm. The head available at the power site is 360 m. Assuming 25% of the rainfall is lost in evaporation and percolation, find the average power developed by the power plant and maximum demand. Take overall efficiency of the plant as 75% and load factor 0.5.

Q.3 Given the following data of a power station:

(*i*) Annual maximum demand on station –100 MW.
(*ii*) Maximum demands of different types of load supplied –40 MW, 30 MW, 25 MW and 20 MW.
(*iii*) Average load factor of the station –50% and
(*iv*) Capacity of station –2 units of 50 MW each and one unit of 25 MW.

Determine:
(a) the number of units (kWh) supplied annually
(b) diversity factor and
(c) utilization factor

Student's Assignments 1 Explanations

1. 1458.33×10^6 m^3/month; 397.4 MW
2. 120.95 MW; 241.9 MW
3. (a) 438×10^6 kWh (b) 1.15 (c) 0.83

Student's Assignments 2

Q.1 Which is a non-conventional source of energy?
(a) Fossile fuels
(b) Radio-active substances
(c) Geothermal, ocean tides and waves
(d) Water

Q.2 The power output from a hydro-electric power plant depends on
(a) type of dam, type of catchment area and discharge.
(b) type of dam, head and system efficiency
(c) discharge, head and system efficiency
(d) type of turbine, type of dam and type of catchment area

Q.3 A hydro-electric power station is supplied from a reservoir of capacity 3×10^7 m^3 at a head of 150 m. The overall efficiency of the plant is 70%. Energy available from the plant will be
(a) 12.2625×10^6 kWh
(b) 8.58375×10^6 kWh
(c) 1.25×10^6 kWh
(d) 0.875×10^6 kWh

Q.4 In a hydro-electric power plant
(a) operating cost is low and initial cost is high.
(b) operating cost is high and initial cost is low.
(c) both operating cost as well as initial cost area high.
(d) both operating cost as well as initial cost are low.

Q.5 Hydrograph is similar to
(a) load-duration curve
(b) mass curve
(c) energy load curve
(d) chronological load curve

Q.6 The area under a flow-duration curve represents
(a) total units of energy available
(b) total power available at site
(c) total quantity of run-off during that period
(d) maximum rate of run-off during that period

Q.7 A penstock is used as a conduit between
(a) the steam chest and the turbine in a thermal station
(b) the dam and the turbine in a hydro-station
(c) the turbine and the discharge drain
(d) the heat exchanger and the turbine in a nuclear power plant

Q.8 The function of a surge tank is to
(a) supply water at constant pressure
(b) relieve water hammer pressures in the penstock pipe
(c) produce surge in the pipe line
(d) none of these

Q.9 The draft tube is provided to
(a) raise the water surface of the steam to create an artificial head
(b) reduce the effect of water hammer
(c) increase the acting head on the water wheel
(d) none of these

Q.10 For high head and low discharge the water turbine used is
(a) Pelton wheel (b) Kaplan turbine
(c) either (a) or (b) (d) Francis turbine

Q.11 Pump storage schemes are used to improve
(a) the diversity factor
(b) the load factor
(c) the reactive power capacity
(d) the plant capacity factor as well as the load factor of the power system

Q.12 Operating cost of steam power station is
(a) less than that of nuclear power plants.
(b) less than that of diesel/gas turbine power plants.
(c) less than that of hydro-electric power plants.
(d) is the same as that of nuclear power plant.

Q.13 As the size of a thermal generating unit increases, the capital cost per kW of installed capacity
(a) increases
(b) decreases
(c) remains the same
(d) may increase or decrease

Q.14 A super critical boiler is one that operates above the pressure and temperature of the following values
(a) 100 kg/cm^2 and 540°C
(b) 218 kg/cm^2 and 540°C
(c) 100 kg/cm^2 and 373°C
(d) 218 kg/cm^2 and 373°C

Q.15 In a thermal power plant, the feed water coming to the economiser is heated using
(a) HP steam
(b) LP steam
(c) direct heat in the furnace
(d) flue gases

Q.16 In a superheater
(a) pressure rises and temperature drops
(b) temperature rises and pressure drops
(c) temperature rises and pressure remains unchanged
(d) pressure rises and temperature remains the same

Q.17 In a steam power plant heat from the flue gases is recovered in
(a) a condenser
(b) a chimney
(c) economiser and air preheater
(d) a desuper heater

Q.18 In a steam turbine cycle, the lowest pressure occurs in
(a) condenser (b) turbine inlet
(c) boiler (d) superheater

Q.19 The modern steam turbines are
(a) reaction turbines
(b) impulse turbines
(c) impulse reaction turbines
(d) none of these

Q.20 The coal that has highest ash content is
(a) lignite (b) coking coal
(c) bituminous coal (d) steam coal

Q.21 The proper indication of incomplete combustion is
(a) the smoking exhaust from chimney
(b) high temperature of flue gas
(c) high CO content in flue gases at exit
(d) high CO_2 content in flue gas at exit

Q.22 Electrostatic precipitator is installed between
(a) induced fan and chimney
(b) air preheater and induced fan
(c) economiser and air preheater
(d) boiler furnace and economiser

Q.23 The efficiency of a nuclear power plant is less than that of a conventional fuel fired plant because of
(a) less rejection of heat in the condenser
(b) higher temperature conditions
(c) higher pressure conditions
(d) low temperature and pressure conditions

Q.24 The nuclear energy is measured in
(a) MeV (b) MW
(c) MJ (d) none of these

Q.25 Which of the following materials can't be used as a moderator
(a) Deuterium (b) Graphite
(c) Heavy water (d) Beryllium

Q.26 Heavy water is used in nuclear power plant as
(a) fuel (b) coolant
(c) moderator (d) Both (b) and (c)

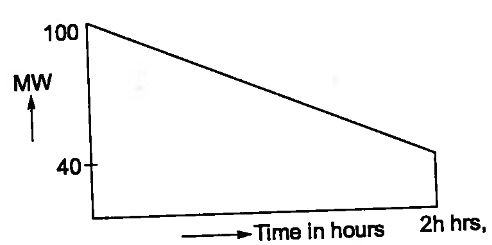
Q.27 The function of reflector in a nuclear reactor is to
(a) bounce back most of the neutrons that escape from the fuel core
(b) reduce the speed of the neutrons
(c) stop the chain reaction
(d) all of the above

Q.28 The main draw-backs of gas turbine power plants are
(a) low overall efficiency, noisy operation and limited unit capacity
(b) inability of using coal or heavy residual petroleum as fuels
(c) both (a) and (b)
(d) high initial cost, poor reliability and large space requirements

Q.29 The area under the load curve represents
(a) system voltage
(b) maximum demand
(c) energy consumed
(d) average demand

Q.30 Demand factor is defined as the ratio of
(a) average load to maximum demand
(b) maximum demand to connected load
(c) connected load to maximum demand
(d) maximum demand to average load

Q.31 Load factor of the curve shown in figure below is



(a) 80% (b) 70%
(c) 60% (d) 50%

Q.32 Two areas *A* and *B* have equal connected loads. However, load diversity in area *A* is more than in area *B*. Then
(a) maximum demands of the two areas would be equal.
(b) maximum demand of *A* would be more than that of *B*.
(c) maximum demand of *B* would be more than that of *A*.
(d) maximum demand of *A* may be more or less than that of *B*.

Direction of Questions (33 to 35):
Each of the following question consists of two statements, one labelled the **'Assertion (A)'** and the other labelled the **'Reason (R)'**. Examine the two statements carefully and decide if the Assertion (A) and Reason (R) are individually true and if so whether the Reason (R) is correct explanation of the Assertion (A). Select your answers to these questions using the codes given below:

Codes:
(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not a correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

Q.33 Assertion (A): Availability of storage may convert an uneconomical hydroproject into an economical one.
Reason (R): Storage increases the firm capacity of the power plant and increase in firm capacity of hydro-plant means dispensing with the alternative steam capacity.

Q.34 Assertion (A): As the load factor of the power plant increases, the cost per kWh of the energy generated decreases.
Reason (R): Higher load factor means greater average load, resulting in larger number of units generated for a given maximum demand or capacity, and thus there is a distribution of standing charges over a large number of units supplied and therefore reduction in unit cost.

Q.35 Assertion (A): Nuclear power plants are very useful to be used as peak load plants.
Reason (R): The capital cost of nuclear power plants is very high and operating cost is quite low.

Q.36 Match **List-I (Turbine)** with **List-II (Type of turbine)** and select the correct answer using the code given below the lists:

List-I
A. Pelton wheel
B. Francis turbine
C. Kaplan turbine

List-II
1. Inward radial flow reaction turbine
2. Axial flow reaction turbine
3. Tangential flow impulse turbine

Codes:

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

Q.37 Match **List-I (Power plant)** with **List-II (Application)** and select the correct answer using the code given below the lists:

List-I	List-II
A. Nuclear	**1.** Base load
B. Diesel	**2.** Standby
C. Gas turbine	**3.** Base or peak load
D. Hydro	**4.** Peak load

Codes:

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

Q.38 Match **List-I (Power plant)** with **List-II (Feature)** and select the correct answer using the code given below the lists:

List-I
A. Hydro
B. Steam
C. Diesel
D. Gas turbine

List-II
1. Low capital cost
2. High operating cost
3. Very large space requirement
4. Large auxiliaries requirement

Codes:

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

Answer Key:

1. (c)	**2.** (c)	**3.** (b)	**4.** (a)	**5.** (d)
6. (c)	**7.** (b)	**8.** (b)	**9.** (c)	**10.** (a)
11. (d)	**12.** (b)	**13.** (b)	**14.** (b)	**15.** (d)
16. (c)	**17.** (c)	**18.** (a)	**19.** (c)	**20.** (a)
21. (c)	**22.** (b)	**23.** (d)	**24.** (a)	**25.** (a)
26. (d)	**27.** (a)	**28.** (c)	**29.** (c)	**30.** (b)
31. (b)	**32.** (c)	**33.** (a)	**34.** (a)	**35.** (d)
36. (c)	**37.** (d)	**38.** (b)		

Student's Assignments 2 Explanations

2. (c)
Power output from a hydro-electric power plant is given by

$$P = \frac{0.736}{75} QWh\eta$$

where, Q = discharge of water (m³/sec)
W = density of water = constant (1000 kg/m³)
h = water head (meter)
η = efficiency

3. (b)

$$P = \frac{0.736}{75} QWh\eta$$

= Output power
Here, density of water,
$W = 100 \text{ kg/m}^3$
so, $P = 9.81\, Qh\eta$
Given, $h = 150$ m, $\eta = 0.7$ and discharge $= 3 \times 10^7 \text{ m}^3$
$\therefore \quad P = 9.81 \times 3 \times 10^7 \times 150 \times 0.7$ kW/sec
$= 3.09015 \times 10^{10}$ kW/sec
so, energy available from the plant is

$$E = \frac{3.09015 \times 10^{10}}{3600} \text{ kWh}$$

$= 8.58375$ kWh

4. (a)

Hydro-electric power plant have high initial cost due to the requirement of construction of dam. Since no fuel is required for running it therefore, operating cost is low.

10. (a)

Higher the head, lower is the discharge of water. As Pelton wheel turbine has highest operating head therefore, it will also have lowest discharge of water.

12. (b)

The operating cost of steam power plant is more than that of nuclear and hydro-power plants but less than that of diesel/gas turbine power plant.

13. (b)

It is more economical to use a large thermal generating unit than using several smaller thermal generating units.

16. (c)

The main function of a superheater in a thermal power plant is to remove the last traces of moisture from the saturated steam leaving the boiler tubes and also increase it's temperature above the saturation temperature while keeping the pressure of the steam constant.

18. (a)

Lowest pressure occurs in condenser which is used for condensing steam (high pressure) to water (low pressure).

31. (b)

Let the total time be 24 hours.

Then, from given current, average load

$$= \left(\frac{40 \times 24 + \frac{1}{2} \times 24 \times 60}{24} \right) \text{MW} = 70 \text{ MW}$$

$\therefore$ Also, maximum demand = 100 MW

so, $$\text{load factor} = \frac{\text{Average load}}{\text{Maximum demand}}$$

$$= \frac{70}{100} = 0.7 = 70\%$$

32. (c)

$$\text{Diversity factor} = \frac{\Sigma\text{kW rating of all equipment connected to system}}{\text{Maximum demand}}$$

Since, diversity factor of area B is less than that of area A therefore, maximum demand in area B will be more than that in area A.

35. (d)

Nuclear power plants are used as a base load power plant. Hence, A is false.