Power Plant Engineering

Hydroelectric Plants

Hydroelectric Plants

WATER POWER

Hydro-electric projects harness water power for generation of electric energy. When water drops through a height, its energy is able to rotate turbines which are coupled to alternators. The electric power, P is given by

$$P = \frac{735.5}{75} QH \eta \text{ kilowatts}$$

where Q = Discharge (m^3/sec.); H = waterhead (m); η = Overall efficiency of turbine alternator set.

Example

A hydro-electric generating station is supplied from a reservoir of capacity 5 × 10^6 cubic metres at a head of 200 metres. Find the total energy available in kWh if the overall efficiency is 75%.

Solution

Weight of water available is

$$W = \text{Volume of water} \times \text{density}$$

$$= (5 \times 10^6) \times (1000) \qquad \text{(as mass of 1m}^3\text{ of water is 1000 kg)}$$

$$= 5 \times 10^9 \text{ kg} = 5 \times 10^9 \times 9{\cdot}81 \text{ N}$$

Electrical energy available = $W \times H \times \eta_{overall} = (5 \times 10^9 \times 9{\cdot}81) \times (200) \times (0{\cdot}75)$ watt sec

$$= 2.044 \times 10^6 \text{ kWh}$$

Example

Prove that the average power in a hydel station is given by

$$P = 3.14 \eta KAFHx10^{-4} kW$$

where A is the catchment area (km^2); F, the annual rainfall (in mm); H, the effective head (m); η, the plant efficiency; and K, the yield factor.

Solution

Catchment area A in sq cm = A $(10^3)^2$ $(100)^2$ sq cm

Annual rainfall $F_m = F \times 10^{-1}$ cm

$$\therefore \text{ Volume of water} = \left(Ax\frac{F}{10}\right)x10^{10}\, xK\, cu\, cm = AxFxKx10^3\, m^3$$

1 m^3 of water weighs 1000 kg.

Hence V m^3 of water weighs = AFK x 10^3 x 10^3 Kg = AFK x 10^6 Kg

$\therefore$ Weight of water available per second

$$= \frac{AFKx10^6}{365x60x60x24} = \frac{AFK}{31.5} kg$$

Given effective head of water = H m

$\therefore$ Work done/sec. = (weight of water/sec) x H

$$= \frac{AFKH}{31.5} kgm$$

or power $= \frac{AFKH}{31.5} kgm$

But 1 metric H.P. = 75 kg m

$\therefore$ Total H.P. developed = $\frac{Power}{75} x\eta = \frac{AFKH}{31.5} x \frac{\eta}{75}$

Power in kW = $\frac{AKFH\eta}{31.5x75} x0.746 = 3.14\eta KAHFx10^{-4}\ kW$

ADVANTAGES OF HYDRO-ELECTRIC PLANTS

Hydro-electric plants offer many distinct advantages over other means of power generation. These advantages can be summarised as under :

- The useful life of a hydro-electric plant is around 50 years as compared o around 25-30 years for a steam station.
- The hydro plants do not require any fuel. Their operating cost are, therefore, low. Since no fuel is required, there are no charges and problems of handling and storage of fuel ad disposal of ash.
- There are no standby losses in hydro plants. They can be run up and synchronized in a few minutes. The load can be adjusted rapidly.
- Hydro plants are more robust as compared to steam plants.
- The maintenance cost of hydro plants is very low as compared to that of steam and nuclear plants.
- Efficiency of hydro plants does not reduce with age. On the other hand efficiency of steam plants decreases with age.
- Generation of electric energy through hydro plants leads to conservation of coal and other fuels.
- The operation of thermal plants is totally dependent on efficient and quick transport of coal. Transport bottle-necks are likely to render thermal plants idle for long periods. Hydro plants are free from such bottle-necks.

- The operating personnel required for hydro plants are smaller in number as compared to those required for other plants.
- Hydro projects are generally multipurpose projects. In addition to electric power generation, they are also useful for irrigation, flood control, navigation etc.
- Hydro plants are free from air pollution due to smoke and exhaust gases.
- Hydro plants are located in remote areas where land costs are low.

DISADVANTAGES OF HYDROELECTRIC PLANTS

- The capital cost of the hydroelectric power plants is very high.
- Preparation of detailed project reports for hydroelectric power plants takes relatively longer period than for thermal power plants because reliable hydrological. geological seismological and environmental studies have to be carried out for a longer period.
- These plants are usually located in the hilly areas and plant site is difficult to access.
- Power generation is dependent on the nature, i.e. rainfall or quantity of water available. The output of a hydroelectric power plant is never constant because the rate of water flow to a river depends on monsoons and it is difficult to predict and control monsoons.
- A large number of hydropower projects having common river systems between adjoining states are held up on account of interstate aspects.
- Large storage-based hydroelectric power plants have environmental impact and rehabilitation issues.

SITE SELECTION FOR HYDRO-ELECTRIC PLANTS

- **Availability of water.** The river run-off data pertaining to many years should be available so that an estimate of the power potential of the project can be made.
- **Water storage.** Because of wide fluctuations in streams flows, storage is needed in most hydro-project to store water during high flow periods and use it during lean flow periods. He storage capacity can be calculated from the hydrograph or from mass curve or by using analytical methods.
- **Head of water.** An increase in effective head reduces the quantity of water to be stored and handled by penstocks, screens and turbines and therefore the capital cost of the plant is reduced.
- **Geological investigation.** Geological investigations are needed to see that the foundation rock for the dam and other structures in firm, stable, impervious and strong enough to withstand water thrust and other stresses. The area should also be free from earthquakes.
- **Water pollution.** Polluted water may cause excessive corrosion and damage to metallic structures. This may render the operation of the plant unreliable and

uneconomic. As such it is necessary to see that the water is f good quality and will not cause such troubles.

- **Sedimentation.** The capacity of storage reservoir is reduced due to the gradual deposition of silt. Silt may also cause damage to turbine blades. Silting from forest covered areas is negligible. On the other hand the regions subject to violent storms and not protected by vegetation contribute lot of silt to the run off. In some cases, this factor alone may render an otherwise suitable site unsuitable.
- **Environmental effects.** Hydro projects submerge huge areas and many villages. As such, he environmental effects are also important. The site should ensure safe and pleasing surroundings, avoid health hazards and preserve important cultural and historic aspects of the area.
- **Access to site.** Construction of a hydro project involves transport of huge amount of cement, steel, other building material and heavy machinery. As such, it is generally necessary to set up a new railway line and rail head for this purpose. The site selected should be such that the railway line and roads can be constructed and material and machinery transported.

CLASSIFICATION ACCORDING TO WATER FLOW REGULATION

Hydro plants can be classified, according to the extent of water flow regulation available, into following types :

- Run off river plants without pondage
- Run off river plants with pondage
- Reservoir plants. Most of the hydro-electric plants, everywhere in the world, belong to this category. When water is stored in a big reservoir behind a dam, it is possible to control the flow of water and use it most effectively. Storage increases the firm capacity of the plant. The plant can be used as a base load plant or as a peak load plant depending on the water stored in the reservoir, the rate of inflow and the system load. Grand Coulee plant in USA, Krasnoyarks Plant in USSR and Bhakra Plant in India are notable examples of reservoir plants.

OPTIMIZATION OF HYDRO-THERMAL MIX (COMBINED WORKING OF POWER PLANTS)

A hydroelectric power plant was earlier used as an exclusive source of power. However, it suffers seasonal variation of output proportional to the variation of water flow. To meet the variable load demand, large amount of water requires to be stored. At the times of low water flow rates the hydro plants cannot meet the maximum load. Again, if the maximum capacity of the station is based on the minimum water flow, this will prove uneconomical. There will be a great wastage of water over the dam for greater part of the year. Hence, the present trend is to use hydroelectric power in conjunction with thermal power in an interconnected system. This hydro-thermal mix is optimized to achieve minimum cost of power generation, which may be 30 per cent hydro-70 per cent thermal or 35 per cent hydro-65 percent thermal. Load sharing by hydro is maximum when the available flow of water is maximum, say during the monsoon months. As long as there is plenty of water stored in the reservoir the hydro part of the system carries the base load, with thermal plants taking the peaks. When water availability is low, say during the dry months of winter and spring, the steam plants take the base load and hydro plants meet the peak load. By interconnecting hydropower with steam, a great deal of saving in cost can be effected by way of the following.

- Reduction in necessary reserve capacity,
- Diversity of construction programmes.
- Higher utilization factors of hydro-plants.
- Higher capacity factors of thermal plants.

CLASSIFICATION ACCORDING TO LOAD

According to load, hydro plants can be classified as base load plants, peak load plants and pumped storage plant

Base load plants

They feed the base load of the system. Thus they supply almost constant load throughout and operate on a high load factor. Base load plants are usually of large capacity. Run off river plants without pondage and reservoir plants are used as base load plants. For a plant to be used as base load plant, the unit cost of energy generated by the plant should be low.

Peak load plants

They are meant to supply the peak load of the system. Run off river plants with pondage can be used as peak load plants during lean flow periods. Reservoir plants can, of course, be used as peak load plants also. Peak load plants have large seasonal storage. They store water during off-peak periods and are run during peak load periods. They operate at a low load factor. A special type of peak load plant is pumped storage plant.

- **Pumped storage plant.** It is a special type of plant meant to supply peak loads.

CLASSIFICATION ACCORDING TO HEAD

The difference in elevation of water surface between upstream and downstream of the turbine is the head under which the turbine acts. The turbines work under a wide range of heads varying from 2 to 2000 m. A classification of turbine based on head as follows.

Low head	2-15 m
Medium head	16-70 m
High head	71 -500 m
Very high head	Above 500 m

For low heads, only Kaplan or propeller turbines are used.

For medium heads either Kaplan or Francis turbines are used. For high heads either

Francis or Pelton turbines are used.

For very high heads, invariably Pelton turbines are used.

Low head plants

When water head is less than 30 m, the plant is called a low head plant. A dam or barrage across the river creates the necessary head.

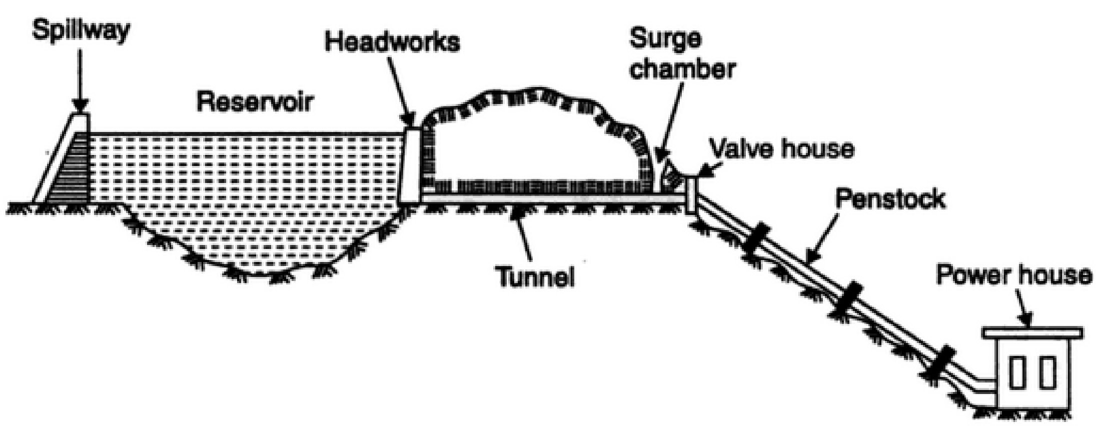
Medium head plants

Medium head plants operate at heads between 30 and 100 meters. An open channel brings water from main reservoir to the fore-bay from where penstocks carry water tot he turbines. Francis or Kaplan turbines are used.

High head plants

The plants operating at heads above 100 m are generally classified as high head plants. The civil works for these plants include dam, reservoir, tunnel, surge tank and penstock. Generally Francis turbines are used for heads below 200 m and Pelton turbines for still higher heads.

Following figure shows *high head power plant* layout.



Surplus water discharged by the spillway cannot endanger the stability of the main dam by erosion because they are separated. The tunnel through the mountain has a surge chamber excavated near the exit. Flow is controlled by head gates at the tunnel intake, butterfly valves at the top of the penstocks, and gate valves at the turbines. This type of site might also be suitable for an underground station.

The Pelton wheel is the common primemover used in high head power plants.

CIVIL ENGINEERING WORKS

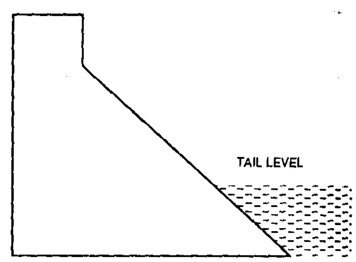
Storage Reservoir

Most of the rivers have non-uniform run offs. During rainy periods the run off is high but the power requirements are low because of the absence of irrigation load. It is, therefore, necessary to store water during excess flow periods so that the same may be used during lean flow periods. The storage reservoirs thus help in supplying water to the turbines according to the load on the plant. Low head plants requires very big storage reservoirs. The capacity of storage reservoir depends on the difference between run offs during high and lean flows and detailed hydrological studies over long periods are necessary to arrive at a suitable figure.

Dam

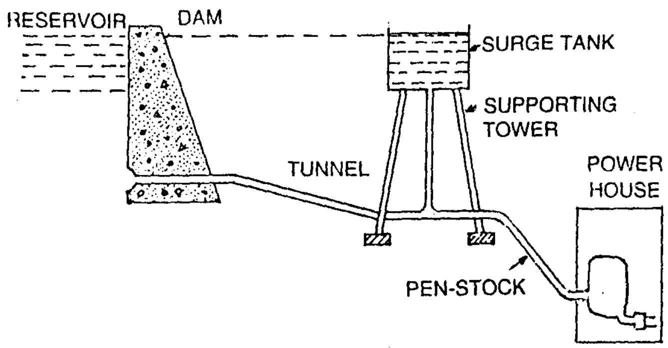
The function of a dam in a hydro electric project, is to create an artificial head and storage. It diverts the flow of water so that the same could be used for generation of power. It is the most expensive and important part of a hydro project. The selection of type of dam, for a particular location, depends on topography of the site, geological and sub-soil conditions etc. It should be safe, economical and aesthetic in appearance. Dams can be classified as masonry dams and earth dams.

Solid gravity concrete dam. This dam, made of concrete, is suitable for most sites. The height of dam depends on the strength of subsoil strata. Dam on earth foundation cannot be very high. However high dams can be built on rocky soil. Given figure shows a solid gravity concrete dam. It relies on its weight for the stability of the dam. The volume of concrete used in the construction of such a dam is very huge.



Surge Tank

The load on a generator keeps on fluctuating. Therefore the water intake to the turbine has to be regulated according to the load. A reduction in load on the alternator causes the governor to close the turbine gates. Sudden closure of turbine gates creates an increased pressure, known as water hammer, in the penstock. When the governor opens the turbine gates suddenly to admit more water, there is a tendency to cause a vacuum in the penstock. The function of the surge tank is to absorb these sudden changes in water requirements so as to prevent water hammer and vacuum.

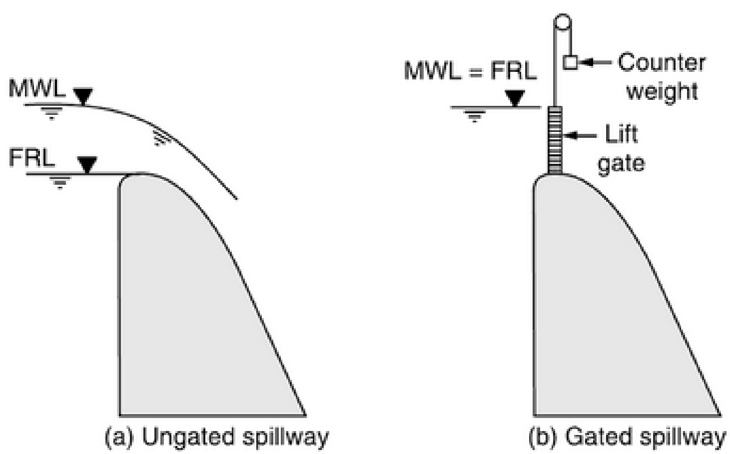


Penstock

A penstock carries water from the water storage system to the turbine. It may be a low pressure type or high pressure type. A low pressure penstock may be a canal, flume or a steel pipe. The high pressure penstock consists of thick steel pipes. The diameter mat be upto a few metres for large units. Each turbine has a separate penstock. Small size plants have penstocks of concrete. A penstock may be buried below earth surface or exposed.

Spillway

Every dam is provided with an arrangement to discharge excess water during floods. This arrangement may be a spillway or a by-pass tunnel or conduit. The spillway should be so designed as to discharge the major flood waters without damage to the dam but at the same time maintain a predetermined head. Spillways are classified as overflow spillway, chute spillway, side channel spillway, shaft spillway and siphon spillway.



Overfall spillways (FRL is full reservoir level; MWL is maximum water level)

Spillway is an important part of the dam complex and is located cither as a part of the main dam or separately at a suitable place near the dam.

HYDRAULIC TURBINE

Hydraulic turbines convert the energy of water into mechanical energy which drives the alternators. They are highly efficient (efficiency exceeding 90% at full load), simple in construction, can be controlled easily and pick up load in a very short time. They are built in all sizes upto about 1,000,000 h.p. with speeds varying from 100 rpm in large turbine to 1000 rpm in small turbines.

Hydraulic turbines can be classified into impulse and reaction turbines. Pelton wheel is an impulse turbine and suits high heads and low flows. The reaction turbine can be either Francis or Propeller. Francis turbine suits medium heads and medium flows whereas Propeller turbines are meant for low heads and high volume of water. Kaplan turbine is a special type of Propeller turbine having adjustable blades.

Specific Speed

Specific speed of a turbine is the speed of a scale model of turbine which develops 1 metric h.p. under a head of 1 metre.

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

Where, N_s is specific speed in metric units

N is speed of turbine in rpm

P_t is output in metric h.p.

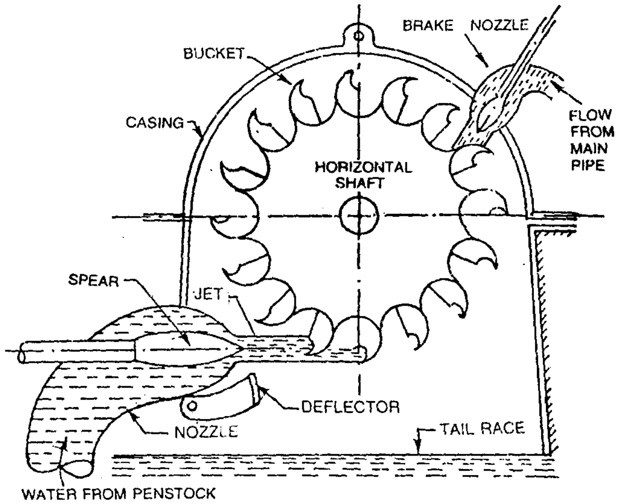
H is effective head in metres

A classification of turbine according to range of head and specific speed is an under :

Type of turbine	Head	Specific speed
Pelton	Above 200 m	10 - 50
Francis	30 m - 200 m	60 - 300
Propeller	Less than 30 m	300 - 1000

Pelton Turbine

A Pelton turbine works under large head and low quantity of water. The potential energy of water in the penstock is converted into kinetic energy in jet of water issuing from a nozzle. The pressure inside is atmospheric pressure. The water jet impinges on buckets fixed on the periphery of rotor and causes the motion of the rotor. After performing work, water discharges into the tail race.

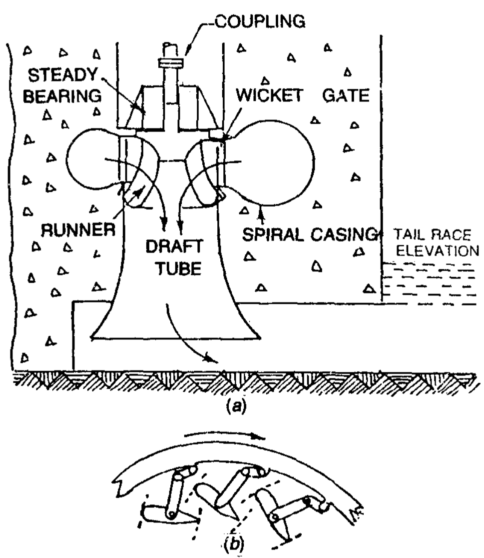


Each bucket is divided into two hemispherical cups with a ridge in the centre.

Most of the Pelton turbines have one jet though machines with two of four jets are also used. The rotor or runner is made of cast steel. Buckets are made of cast iron, bronze or stainless steel.

Francis Turbine

A reaction turbine develops power partly due to the velocity of water and partly due to the difference in pressure acting on the front and back of the runner buckets. A Francis turbine is a reaction turbine suitable for medium heads and medium flows. They are built in large sizes and are generally of vertical type to effect economy in space. The alternator is mounted above the turbine and is thus free from flooding.



A modern Francis turbine is an inward mixed flow reaction turbine. The water, under pressure, enters the runner from guide vanes radially and discharge out of the runner axially. The motion of water is controlled by movable inlet wicket gates, fixed around the runner, through which the water passes on its way from spiral casing to the runner. Since the pressure at inlet is more than that at outlet, the water flows in a closed circuit and the runner is always full of water. After doing work, water is discharged to the tailrace through a closed tube known as **draft tube** which has a gradually enlarging section.

Francis runners for low heads may be of cast iron but for heads above 100m, cast steel or bronze is preferred.

Draft tube

The draft tube serves the following two purposes:

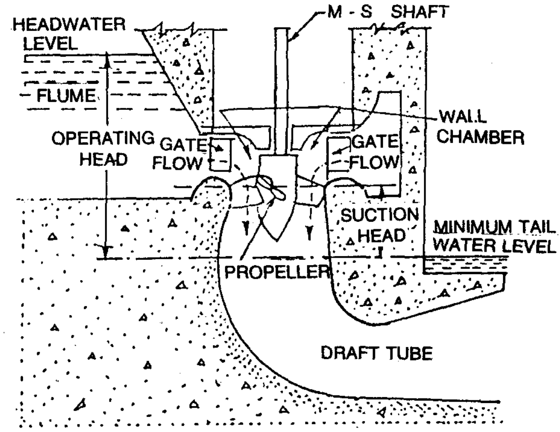
- It allows the turbine to be set above tail-water level, without loss of head, to facilitate inspection and maintenance.
- It regains, by diffuser action, the major portion of the kinetic energy delivered to it from the runner.

At rated load the velocity at the upstream end of the tube for modern units ranges from 7 to 9 m/s, representing from 2.7 to 4.8 m head. As the specific speed (it is the speed of a geometrically similar turbine running under a unit head and producing unit power) is increased and the head reduced, it becomes increasingly important to have an efficient draft tube. Good practice limits the velocity at the discharge end of the tube to 1.5 to 2.1 m/s, representing less than 0.3 m velocity head loss.

The following two types of draft tubes are commonly used : (i) The straight conical or concentric tube. (ii) The elbow type. Properly designed, the two types are about equally efficient, over 85%.

Propeller and Kaplan Turbines

All parts of a Kaplan turbine such as spiral casing, guide mechanism and draft tube except runner are similar to those of a Francis turbine. A Kaplan runner has only 3 to 6 blades as compared to 16-24 for a Francis runner. The smaller number of blades causes a reduction in contact surface and hence in frictional resistance. Further, in a Kaplan turbine water strikes the blades axially.



The speed of Kaplan turbines is more than that of Francis turbines and lies in the range of 400-1500 rpm, the high speed resulting in lower cost of runner and alternator and cheaper power house structure.

GOVERNING OF HYDRAULIC TURBINES

Governing of a hydraulic turbine means *speed regulation*. Under normal conditions the turbine should run at a constant speed irrespective of changes in load. This is achieved by means of a *governor* called *oil pressure governor*.

Governing of impulse turbine. The quantity of water rejected from the turbine nozzle and from striking the buckets may be regulated in one of the following ways :

- Spear regulation.
- Deflector regulation.
- Combined spear and deflector regulation.

The spear and deflector in all cases are operated by the servomotor mechanism.

Spear regulation

To and fro movement of the spear inside the nozzle alters the cross-sectional area of stream, thus, making it possible to regulate the rate of flow according to the load. Spear regulation is satisfactory when a relatively large penstock feeds a small turbine and the fluctuation of toad is small. With the sudden fall in load, the turbine nozzle has to be closed suddenly which way create water hammer in the penstock.

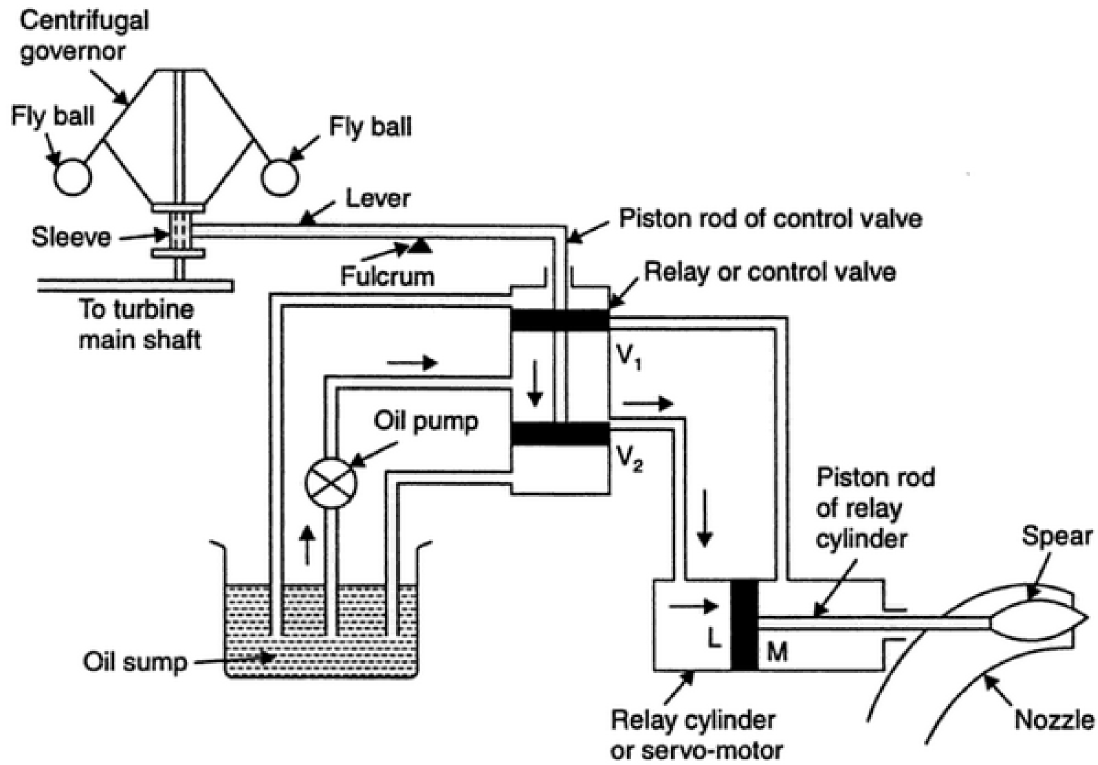
Deflector regulation

The deflector is generally a plate connected to the oil pressure governor by means of levers. When it is required to deflect the jet, the plate can be brought in between the nozzle and buckets, thereby diverting the water away from the runner and directing into the tailrace. Deflector control is adopted when supply of water is constant but the load fluctuates. The spear position can be adjusted by hand. As the nozzle has always a constant opening, it involves considerable wastage of water and can be used only when supply of water is abundant.

Combined spear and deflector regulation

Since both the above methods have some disadvantages, the modern turbines are provided with double regulation which is the combined spear and deflector control. Double regulation means regulation of speed and pressure. The speed is regulated by spear and the pressure is regulated by deflector arrangement.

Following figure shows an arrangement for governing of Pelton turbine when the turbine is running at the normal speed.



When the load on the generator *decreases*, the speed of the generator increases and consequently the speed of the turbine and hence centrifugal governor increases beyond the normal speed. Due to increased speed the fly-ball of the centrifugal governor move outwards/upwards (due to increased centrifugal force) causing upward movement of the sleeve. As the sleeve moves up, the lever (a horizontal lever, supported over a fulcrum, connects the sleeve and the piston rod of control valve) turns about the fulcrum and the piston rod of the control valve moves downward. Subsequently the V_1 closes and valve V_2 opens as shown in the figure. The oil, pumped from the oil sump to the control valve or relay valve, under pressure will flow through the valve V_2 to the servomotor (or relay cylinder) and will exert force on the face M of the piston of the relay cylinder. The piston along with piston rod and spear will move towards right. This will decrease the area of flow of water at the outlet of the nozzle and as a consequence of this the flow rate to the turbine is reduced and the speed of the turbine falls. After the speed of the turbine becomes normal the fly balls, sleeve, lever etc. will come to normal position.

On the other hand, when the load on the generator *increases*, the speed of the generator and hence that of the turbine and the centrifugal governor decreases due to which its (governor) balls move downward, the sleeve moves down and piston rod of the control valve moves in the upward direction. Subsequently valve V_1 opens and valve V_2 closes. The oil under pressure will move through valve V_1 and exert a force on face M of the piston. This will make the piston move towards left thereby increasing the area of flow of water at the outlet of the nozzle and hence increase the rate of flow of water to the turbine. As a result, the speed of the turbine will increase till it becomes normal.

SELECTION OF TURBINES

The following points should be considered while selecting the right type of hydraulic turbine:

- **Specific speed.** High specific speed is essential where head is low and output is large, because otherwise the rotational speed will be low which means cost of turbo-generator and power house will be high. On the other hand there is practically no need of choosing a high value of specific speed for high head installations, because even with low specific speed, high rotational speed can be attained with medium capacity plants.

- **Rotational speed.** Rotational speed depends on specific speed. Also the rotational speed of an electrical generator with which the turbine is to be directly coupled, depends on the frequency and number of pair of poles. The value of specific speed adopted should be such that it will give the synchronous speed of the generator.

- **Efficiency.** The turbine selected should be such that it gives the highest overall efficiency for various operating conditions.

- **Part load operation.** In general the efficiency at part-loads and overloads is less than normal. For the sake of economy the turbine should always run with maximum possible efficiency to get more revenue.

  When the turbine has to run at part or overload conditions Deriaz turbine is employed. Similarly, for low heads, Kaplan turbine will be useful for such purposes in place of propeller turbine.

- **Cavitation**. The installation of water turbines of reaction type over the tailrace level is effected by cavitation. The critical value of cavitation factor must be obtained to see that the turbine works in safe zone. Such a value of cavitation factor also effects the design of turbine, especially of Kaplan, propeller and bulb types.

- **Head**. (i) Very high heads (350 m and above). For heads greater than 350 m, *Pelton turbine* is generally employed and there is practically no choice except in very special cases. (ii) High heads (150 m to 350 m). In this range either *Pelton* or *Francis* turbine may by employed. For higher specific speeds Francis turbine is more compact and economical than the Pelton turbine which for the same working conditions would have to be much bigger and rather cumbersome. (iii) Medium heads (60 m to 150 m).

A *Francis* turbine is usually employed in this range. Whether a high or low specific speed unit would be used depends on the selection of speed.

RUN-OFF

Rain fall (used in a general sense) or precipitation may be defined as the total condensation of moisture that reaches the earth in any form. It includes all forms of rains, ice, snow, hail or sleet etc. "Evaporation" represents practically all of that portion of the rainfall that does not reach the point of ultimate use as stream flow. So, evaporation, includes all the rainfall that is returned to the atmosphere from land and water surfaces.

Thus total evaporation is:

- Evaporation from land and water surfaces.
- Evaporation by transpiration which is the vaporization of water from the breathing pores of vegetable matter.
- Atmospheric evaporation (evaporation while precipitation is falling).

Rain-fall is measured in terms of centimetres of water over a given area and over a given period (usually one year). The portion of the total precipitation that flows through the catchment area is known as "**Run-off**". The catchment area of a hydro site is the total area behind the dam, draining water into the reservoir.

Thus,

Run-off = Total precipitation - Total evaporation

Part of the precipitation is absorbed by the soil and seeps or percolates into ground and will ultimately reach the catchment area through the underground channels.

Thus.

Total run-off = Direct run off over the land surface + Run-off through seepage.

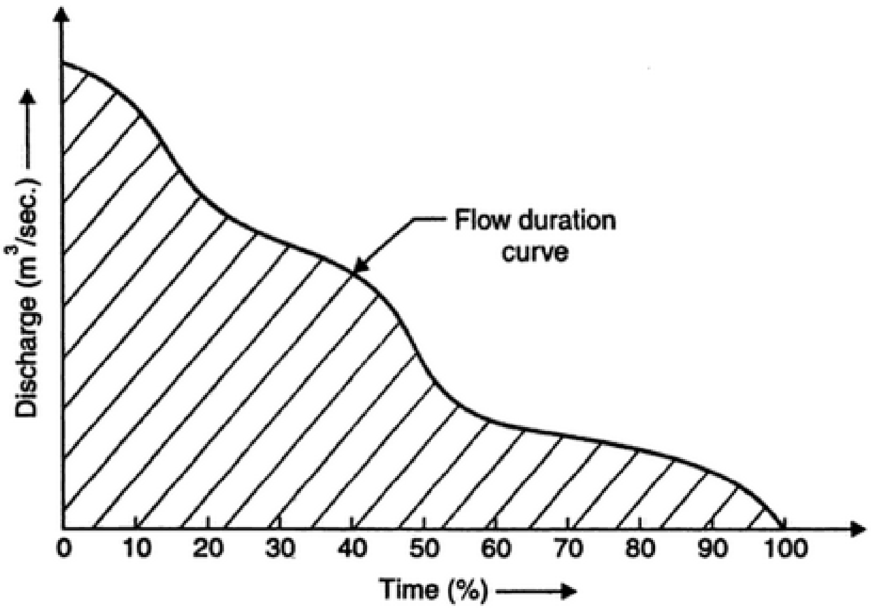
The unit of run-off are m/s.

FLOW DURATION CURVE

Refer to following figure. Flow duration curve is another useful form to represent the run-off data for the given time. This curve is plotted between flow available during a period versus the fraction of time. If the magnitude on the ordinate is the potential power contained in the stream How, then the curve is known as "power duration curve". This curve is a very useful tool in the analysis for the development of water power.

The flow duration curve is drawn with the help of a hydrograph from the available run-off data and, here it is necessary to find out the length of time duration which certain flows are available. This information either from run-off data or from hydrograph is tabulated. Now the flow duration curve taking 100 percent time on X-axis and run-off on Y"-axis can be drawn.

The area under the flow duration curve gives the total quantity of run-off during that period as the flow duration curve is representation of graph with its flows arranged in order of descending magnitude.



If the head of discharge is known, the possible power developed from water in kW can be determined from the following equation :

$$\text{Power (kW)} = \frac{wQH}{1000} x\eta_0$$

where Q = Discharge, m^3/sec, H = Head available, m, w = Weight density of water, N/m^3, and η_0 = Overall efficiency.

Uses of Flow Duration Curve

- A flow duration curve allows the evaluation of low level flows.
- It is highly useful in the planning and design of water resources projects. In particular, for hydropower studies, the flow duration curve serves to determine the potential for firm power generation. The Firm power is also known as the primary power. Secondary power is the power generated at the plant utilising water other than that used for the generation of firm power.
- If a sediment rating curve is available for the given stream, the flow duration curve can be converted into cumulative sediment transport curve by multiplying each flow rate by its rate of sediment transport. The area under this curve represents the total amount of sediment transported.
- The flow duration curve also finds use in the design of drainage systems and in flood control studies.

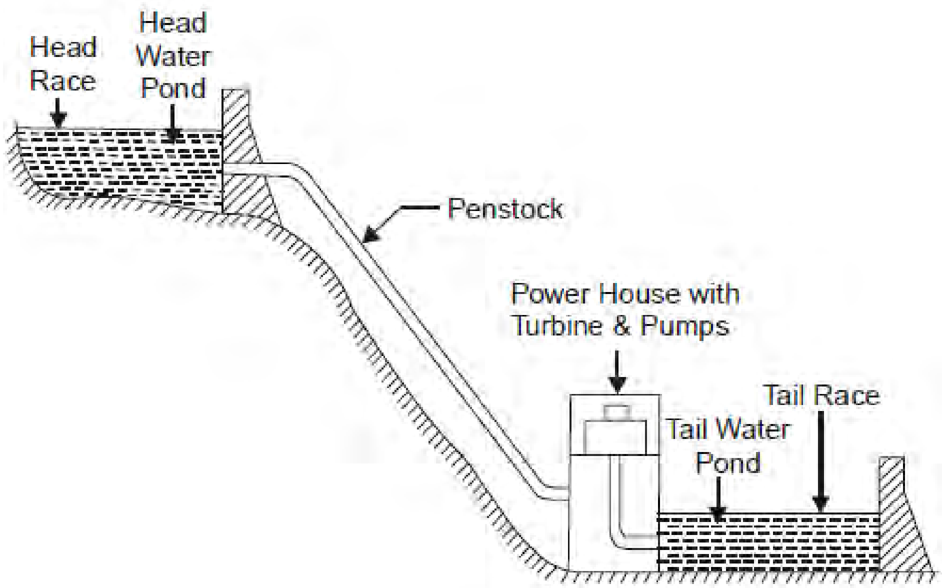
- A flow duration curve plotted on a log-log paper provides a qualitative description of the run-off variability in the stream. If the curve is having steep slope throughout, it indicates a stream with highly variable discharge. This is typical of the conditions where the flow is mainly from surface run-off. A flat slope indicates small variability which is a characteristic of the streams receiving both surface run-off and ground water run-off A flat portion at the lower end of the curve indicates substantial contribution from ground water run-off, while the flat portion at the upper end of the curve is characteristic of streams with large flood plain storage, such as lakes and swaps, or where the high flows are mainly derived from snowmelt.
- The shape of the flow duration curve may change with the length of record. This aspect of the flow duration curve can be utilised for extrapolation of short records.

Defects of Flow Duration Curve

- It does not present the flows in natural source of occurrence.
- It is also not possible to tell from flow duration curve whether the lowest flows occurred in consecutive periods or were scattered throughout the considered period.

PUMPED STORAGE POWER PLANTS

These plants supply the peak load for the base load power plants and pump all or a portion of their own water supply. The usual construction would be a tail water pond and a head water pond connected through a penstock. The generating pumping plant is at the lower end. During off peak hours-some of the surplus electric energy being generated by the base load plant, is utilized to pump the water from tail water pond into the head water pond and this energy will be stored there. During times of peak load, this energy will be released by allowing the water to flow from the head water pond through the water turbine of the pumped storage plant. These plants can be used with hydro, steam and i.e. engine plants. This plant is nothing but a hydraulic accumulator system and is shown in Fig. 11.9.



These plants can have either vertical shaft arrangement or horizontal shaft arrangement. In the older plants, there were separate motor driven pumps and turbine driven generators. The improvement was the pump and turbine on the same shaft with the electrical element acting as either generator or motor. The latest design is to use a Francis turbine which is just the reverse of centrifugal pump. When the water flows through it from the head water pond it will act as a turbine and rotate the generator. When rotated in the reverse direction by means of an electric motor, it will act as a pump to shunt the water from the tail water pond to the head water pond.

The efficiency of such a plant is never 100 per cent. Some water may evaporate from the head water pond resulting in the reduction in the stored energy or there might be run off through the soil.

MINI AND MICRO-HYDEL PLANTS

More emphasis is now being given on such plants. The natural water source in hilly terrain can be utilized for power generation with low-head standardized turbo-generator units. Its adverse effect on ecology is negligible. The mini-plants operate with 5 m - 20 m head producing about 1 MW to 5 MW of power, while micro-plants are still smaller and work under a head of less than 5 m and generate electricity between 0.1 MW to 1 MW. The potential energy source in India in this category is around 20,000 MW.

Example

A hydroelectric station is to be designed to operate at a mean head of 205 m and supplied from a reservoir lake having a catchment area of 1000 km^2 with average annual rain fall of 125 cm of which 80% is available for power generation. The expected load factor at the plant is 75%. Allowing a head loss of 5 m and assuming efficiency of the turbine and generator to *be respectively 90% and 95%, calculate suitable MW rating of the station. Comment also on the type of turbine to be installed.*

Solution

Given : Gross head = 205 m ; Catchment area = 1000 km^2 ; Average annual rainfall = 125 cm = 0.125 m ; Load factor = 75% or 0.75 ; Loss of head = 5 m ; η_T = 90% ; η_G = 95%.

Water available during the year = (1000 x 106) x 1.25 x 0.8 = 109 m^3.

Quantity of water available per sec

$$= \frac{10^9}{8760x3600} = 31.7\, m^3 / s$$

Available head, H = 205 - 5 = 200 m

Now, Average power produced,

$$P = wQH \times \eta_T \times \eta_G \text{ kW}$$

= 9.81 x 31.7 x 200 x 0.9 x 0.95 = 53177 kN (where, w = 9.81 kN/m^3)

= 53.2 MW

With a load factor of 75%, overall capacity of the station for which it should be designed

53.2/0.75= 70.9 MW

The type of turbine for a head of 200 m recommended is *Francis* turbine.

Problem

The following data is available for a hydro-power plant:

Available head = 130 m

catchment area = 2200 sq. km.

annual average rainfall = 150 cm

turbine efficiency = 86%

generator efficiency = 91%

percolation and evaporation losses = 18%

Determine power developed in MW taking load factor as unity.

Answer: 8.546 MW

Example (AMIE S13, 14, 15, 7 marks)

A single jet impulse turbine of 10 MW capacity is to work under a head of 500 m. If the specific speed of the turbine is 10, the overall efficiency is 80 per cent and the coefficient of velocity is 0.98, find the diameters of the jet and the bucket wheel. Assume the speed of the bucket wheel as 0.46 of the velocity of jet.

Solution

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

$\therefore$ $$N = \frac{N_s H^{5/4}}{\sqrt{P}} = \frac{10x(500)^{5/4}}{\sqrt{10x1000}} = 236.4\,rpm \quad \text{[P in kW]}$$

Velocity of jet $V = C_v\sqrt{2gH} = 0.98\sqrt{2x9.81x500} = 97.06\,m/s$

Speed of bucket wheel

V_b = 0.46 x 97.06 = 44.65 m/s

$$V_b = \frac{\pi DN}{60} = 44.65$$

$\therefore$ D = 3.61 m

$$\eta_0 = \frac{P}{\rho QgH} = \frac{P}{\rho(\pi/4)d^2VgH}$$

$$0.80 = \frac{10,000x10^3}{1000(\pi/4)d^2x97.06x9.81x500}$$

$\therefore$ Diameter of jet

d = 0.183 m

Example (AMIE W06, 10, 10 marks)

A Pelton wheel has to be designed for the following specifications.

Power to be developed = 6000 kW

Net head available = 300 m.

Speed = 550 rpm.

Ratio of jet diameter to wheel diameter = 1/10

Hydraulic efficiency = 0.85.

Assuming the velocity coefficient C_v = 0.98 and speed ratio, f = 0.46, find (a) the number of jets (b) diameter of each jet (c) diameter of the wheel and (d) the quantity of water required.

Solution

$$V_1 = C_v\sqrt{2gH} = 0.98\sqrt{2x9.81x300} = 75.19\,m/s$$

$$V_b = 0.46\sqrt{2x9.81x300} = 35.29\,m/s$$

$$\eta_0 = \frac{P}{\rho QgH} = \frac{6000x10^3}{1000xQx9.81x300} = 0.85$$

∴ $$Q = \frac{20}{9.81x0.85} = 2.4\,m^3/s$$

$$V_b = 35.29 = \frac{\pi Dx550}{60}$$

∴ D = 1.23 m

d/D = 1/10

∴ d = diameter of each jet = 0.123 m

Number of jets = $\frac{Q}{V_1(\pi/4)d^2} = \frac{2.4x4}{75.19x\pi x(0.12)^2} = 2.822 \approx 3$ jets

Example

A Kaplan turbine develops 10000 kW under a head of 12 m when the following conditions prevail. Speed ratio = 2, flow ratio = 0.65, diameter of hub = 0.3 limes the external diameter of the vane and the overall efficiency = 94 per cent. Estimate (a) the speed (b) the diameter of the runner and (c) the specific speed.

Solution

$$P = \rho QgH\eta x10^{-3}$$

$$10000 = Qx9.81x12x0.94$$

∴ Q = 90.37 m^3/s

Flow ratio $\phi' = \frac{V_{f1}}{\sqrt{2gH}} = 0.65$

∴ V_{f1} = 9.97 m/s

Area of flow

$$A_b = \frac{90.37}{9.97} = 9.064\,m^2$$

$$A_b = \frac{\pi}{4}\left(D^2 - d_h{}^2\right) = 9.064$$

$$D^2 - (0.3D)^2 = \frac{9.064x4}{\pi} = 11.54$$

∴ D = 12.682

Runner diameter = D = 3.56 m

Speed ratio $\phi = 2 = \frac{V_b}{\sqrt{2gH}} = \frac{V_b}{\sqrt{19.62x12}}$

Solving $V_b = 30.69 \text{ m/s} = \frac{\pi DN}{60}$

$\therefore$ $$N = \frac{30.69x60}{\pi x3.56} = 164.6 \, or \, 165 \, mm$$

Synchronous speed

$$N = \frac{120f}{p} = 165$$

$\therefore$ p = 36.36

Let 36 poles or 18 pairs of poles are taken.

Then $$N = \frac{120x50}{36} = 166.7 \, rpm$$

Specific speed

$$N_s = \frac{N\sqrt{P}}{H^{5/4}} = 746$$

Example

A hydroelectric plant produces 20 MW under a head of 20 m. If the overall efficiency of the plant is 72%. determine the type of turbine and the synchronous speed of generator.

Solution

$$P = \eta_0 \rho QgH$$

$$20x10^3 = 0.72x1000xQx9.81x20x10^{-3}$$

$\therefore$ Q = 141.57 m^3/s

The *Kaplan turbine* is selected because head available is low and flow rate is high. Let us select two units of Kaplan turbine for the reliability in operation. The capacity of each turbine is 10 MW. By assuming the specific speed equal to 350 for Kaplan turbine, we have

$$350 = \frac{N\sqrt{10000}}{20^{5/4}}$$

$\therefore$ N = 148.03

If the generator is directly coupled to turbine, then synchronous speed of generator is given by

$$N = \frac{120f}{p}$$

$$148.03 = \frac{120x50}{p}$$

∴ p = 40.53

Thus, if the number of poles is taken equal to 40. then the speed of generator is

$$N = \frac{120f}{p} = \frac{120x50}{40} = 150\,rpm$$

Example

The following data relates to a hydroelectric power plant:

Head = 400 m

Discharge = 4.5 m^3/s

Turbine efficiency = 82%

Specific speed = 60

Determine the power developed, the type of turbine and the speed of the turbine.

Solution

The total power P that can be developed is

$$P = \eta_0 \rho QgH$$

$$= 0.82x1000x4.5x9.81x400x10^{-3}$$

= 14479.56 kW

The *Pelton turbine* with multi jet (4 jets) is selected because head available is high and the specific speed is 60. Let us select two units of Pelton turbine for the reliability in operation. From the specific speed relation

$$60 = \frac{\sqrt{4}N\sqrt{14479.56/2}}{(400)^{5/4}}$$

∴ N = 630.71 rpm

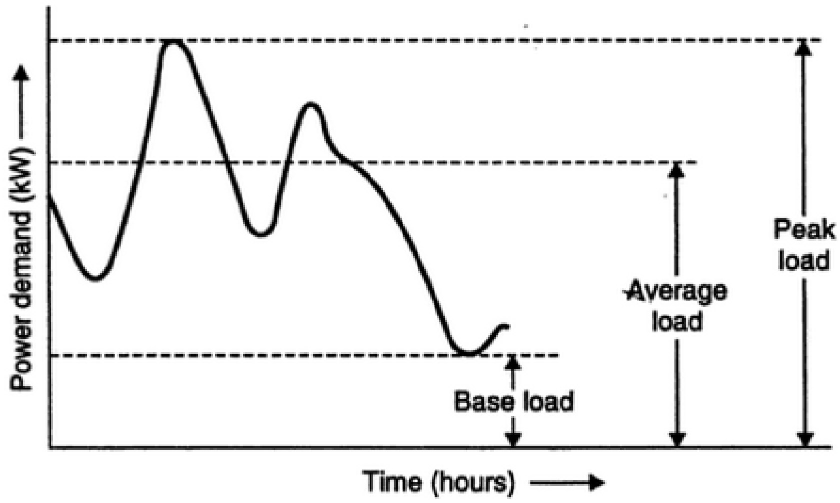
Example

A run off of 30 m /s is available at 7.5 m head for generating the power. The turbine efficiency is 85 per cent, (a) Is it feasible to develop this power by two turbines with rpm of 50 and the specific speed of turbine not greater than 450? (b) What type of runner will be used? What is the diameter of the runner if the speed ratio is 0.85?

Answer: (a) Feasible (b) Francis type (c) 3.93 m

LOAD CURVE

A load curve (or load graph) is a graphic record showing the power demands for every instant during a certain time interval. Such a record may cover 1 hour, in which case it would be an hourly load graph; 24 hours, in which case it would be a daily load graph ; a month in which case it would be a monthly load graph; or a year (8760 hours), in which case it would be a yearly load graph.



Load curve

Note that

- The area under the toad curve represents the energy generated in the period considered,
- The area under the curve divided by the total number of hours gives the average load on the power station.
- The peak load indicated by the load curve/graph represents the maximum demand of the power station.

Significance of load curves

- Load curves give full information about the incoming load and help to decide the installed capacity of the power station and to decide the economical sizes of various generating units.
- These curves also help to estimate the generating cost and to decide the operating schedule of the power station i.e., the sequence in which different units should be run.

Example

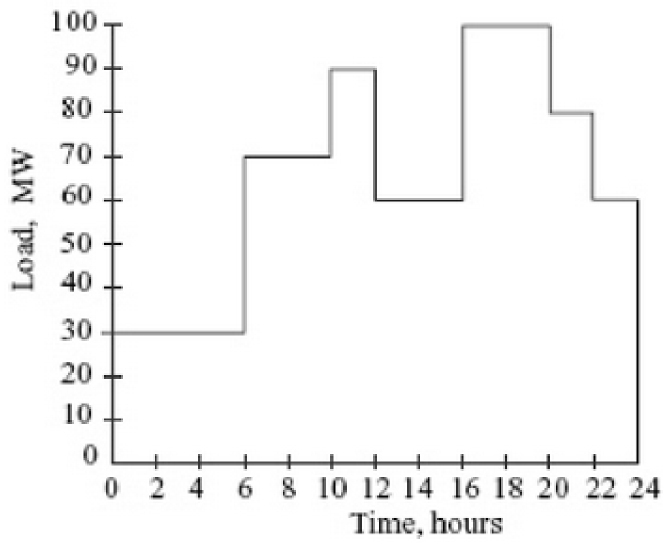
A power station supplies the following loads to the consumers:

Time in hours	*0-6*	*6-10*	*10-12*	*12-16*	*16-20*	*20-22*	*22-24*
Load in MW	*30*	*70*	*90*	*60*	*100*	*80*	*60*

(a) Draw the load curve and estimate the load factor of the plant, (b) Whatis the load factor of a standby equipment of 30 MW capacity if it takes up all loads above 70 MW? What is its use factor?

Solution

(a) See following figure.



Energy generated = area under the load curve

= 30 x 6 + 70 x 4 + 90 x 2 + 60 x 4 + 100 x 4

+ 80x2 + 60x2 = 180 + 280+ 180 + 240

+ 400 + 160+ 120 = 1560 MWh

Average load = 1560 MWh/24 h = 65 MW

Load factor = average load/peak load = 65/100 = 0.65

(b) If the load above 70 MW is supplied by a standby unit of 30 MW capacity, the energy generated by it

= 20 x 2 + 30 x 4 + 10 x 2 = 40 + 120 + 20 = 180 MWh

Time during which the standby unit remains in operation

=2 + 4 + 2 = 8h

Average load = 180 MWh/8h = 22.5 MW

Load factor = 22.5/30 = 0.75

Problem

The loads on a power plant with respect to time for 24 hours are given as follows:

Time (hours)	*0-6*	*6-8*	*8-12*	*12-14*	*14-18*	*18-22*	*22-24*
Load (MW)	*40*	*50*	*60*	*50*	*70*	*80*	*40*

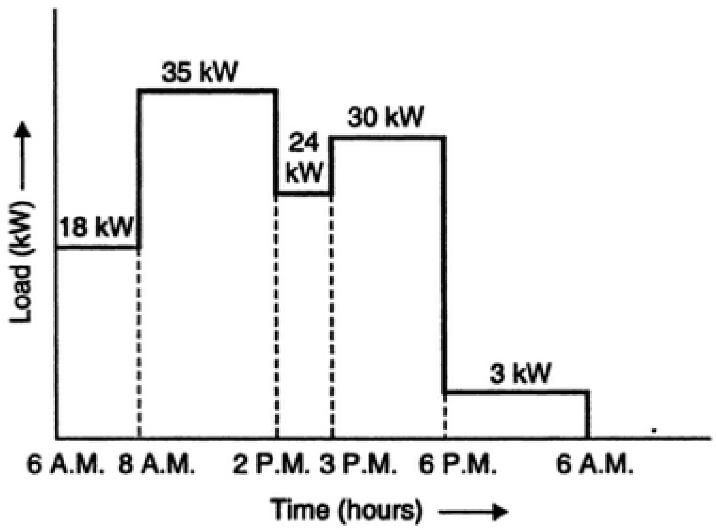
Draw the load curve and find out the load factor of the power station. If the loads above 60 M W are taken by a standby unit of 20 MW capacity, find out the load factor and the use factor of the standby unit.

Answer. 0.71, 0.75 and 0.60

LOAD DURATION CURVE

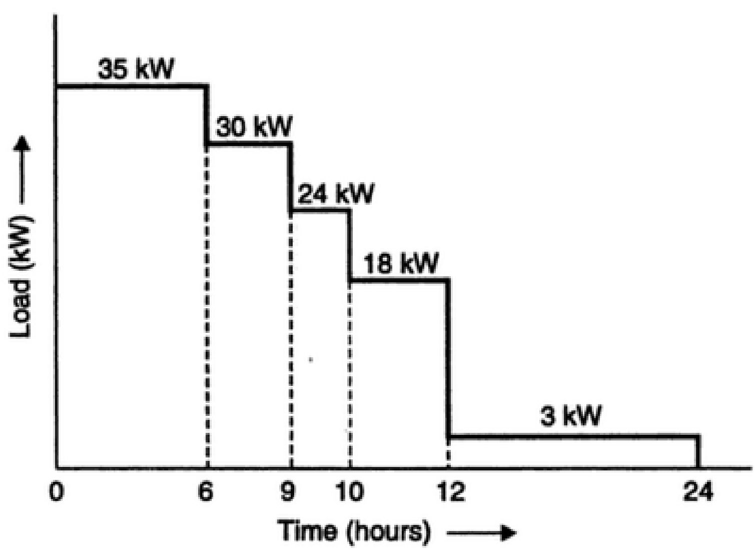
A load duration curve represents re-arrangements of all the load elements of chronological load curve in order of descending magnitude. This curve is derived from the chronological load curve.

Following figure shows a typical daily load curve for a power station.



Daily load duration curve

It may be observed that the maximum load on power station is 35 kW from 8 A.M. to 2 P.M. This is plotted in following figure.



Load duration curve

Similarly other loads of the load curve are plotted in descending order in the same figure. This is called load duration curve.

The following points are worth noting:

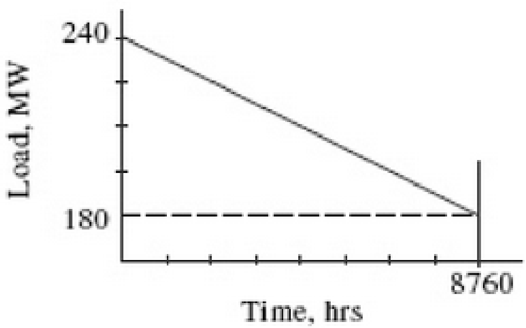
- The area under the load duration curve and the corresponding chronological load curve is equal and represents total energy delivered by the generating station.
- Load duration curve gives a clear analysis of generating power economically. Proper selection of base load power plants and peak load power plants becomes easier.

Example

A 300 MW thermal power station is to supply power to a system having maximum and minimum demand of 240 MW and 180 MW respectively in a year. Assuming the load duration curve to be a straight line, estimate the (a) load factor, (b) capacity factor.

Solution

Load duration curve is shown below.



Energy supplied per year = (180 MW x 8760 h) + (1/2)(240 – 180) MW x 8760 h

= 210 x 8760 MWh = 183.96 x 10^7 kWh

Average load = 183.96 x 10^7 kWh/8760 h = 210 x 10^3 kW

Load factor = average load/maximum demand = 210 Mw/240 MW = 0.875

Capacity factor = 210 x 8760/300 x 8760 = 0.70

Example (AMIE Winter 2012, 8 marks)

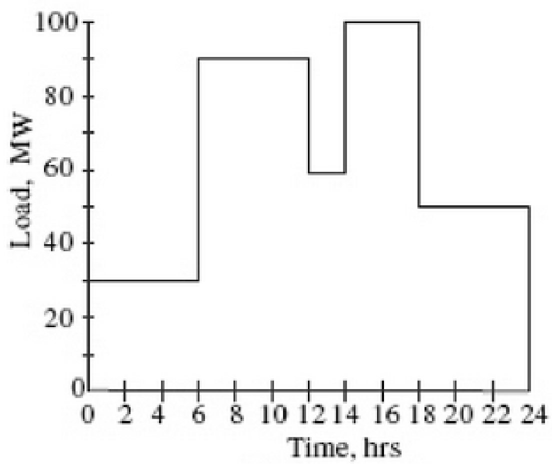
A power station has to supply load as follows:

Time (hours)	*0-6*	*6-12*	*12-14*	*14-18*	*18-24*
Load (MW)	*30*	*90*	*60*	*100*	*50*

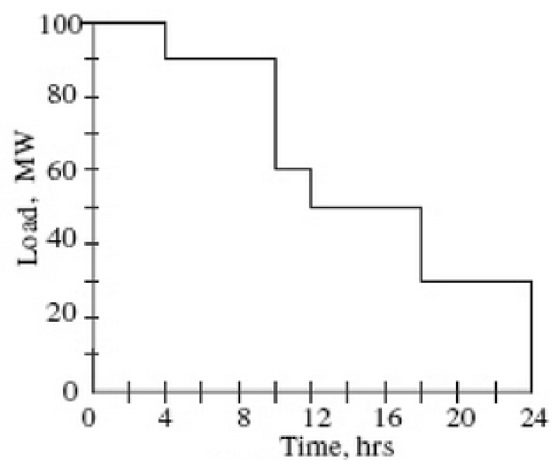
(a) Draw the load curve, (b) Draw the load duration curve, (c) Select suitable generating units to supply the load, (d) Calculate the load factor, (e) Calculate the capacity of the plant and the plant capacity factor.

Solution

The load curve and load duration curve have been drawn in Fig. (a, b).



(a) Load curve



(b) Load duration curve

Energy generated = 30 x 6 + 90 x 6 + 60 x 2 + 100 x 4 + 50 x 6

= 1540 MWh = 1540 x 10^3 kWh

Average load = 1540 x 10^3/24 kW

Maximum demand = 100 x 10^3 kW

Load factor = 1540 x 10^3/24 x 100 x 10^3 = 0.64

To supply the load, three generating units, each of 30 MW capacity, and one generating unit of 10 MW capacity will be selected. One additional unit will be kept as standby. Its capacity will be equal to that of the largest unit, i.e. 30 MW.

Load duration curve will indicate the operational schedule of different generating units, which will be as follows:

- One unit of 30 MW will run for 24 hours
- Second unit of 30 MW will run for 18 hours
- Third unit of 30 MW will run for 10 hours
- Fourth unit of 10 MW will run for 4 hours

Plant capacity = 30 x 4 + 10 x 1 = 130 MW

Capacity factor = energy generated/(capacity x operating time)

= 1540 x 10^3 kWh/(130 x 10^3 x 24 kWh) = 0.494

Example

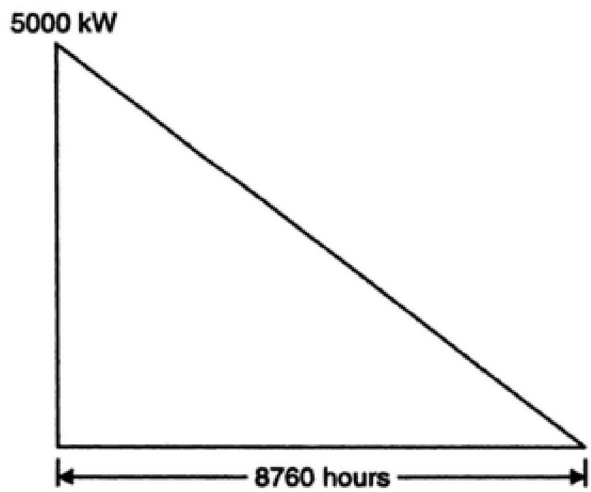
The estimated total annual operating costs and capital charges for two proposed power stations are given by the following expressions :

Annual cost for station A = Rs. (6,00,000 + 3.0 kW + 0.015 kWh)

Annual cost for station B = Rs. (7,50,000 + 5.0 kW + 0.014 kWh)

where kW represents the capacity of the station and kWh represents the total annual output.

The stations are to be used for supplying a load having a load duration curve as shown in following figure.



The ordinate of a point on this curve represents a certain load on the station and the abscissa represents the number of hours per year during which the load is equal to or exceeds this amount.

Which station should be used to supply the base load, what should be its installed capacity and for how many hours in a year should it be in operation to give the minimum total cost per unit generated ?

Calculate the total cost per unit generated under these conditions.

Solution

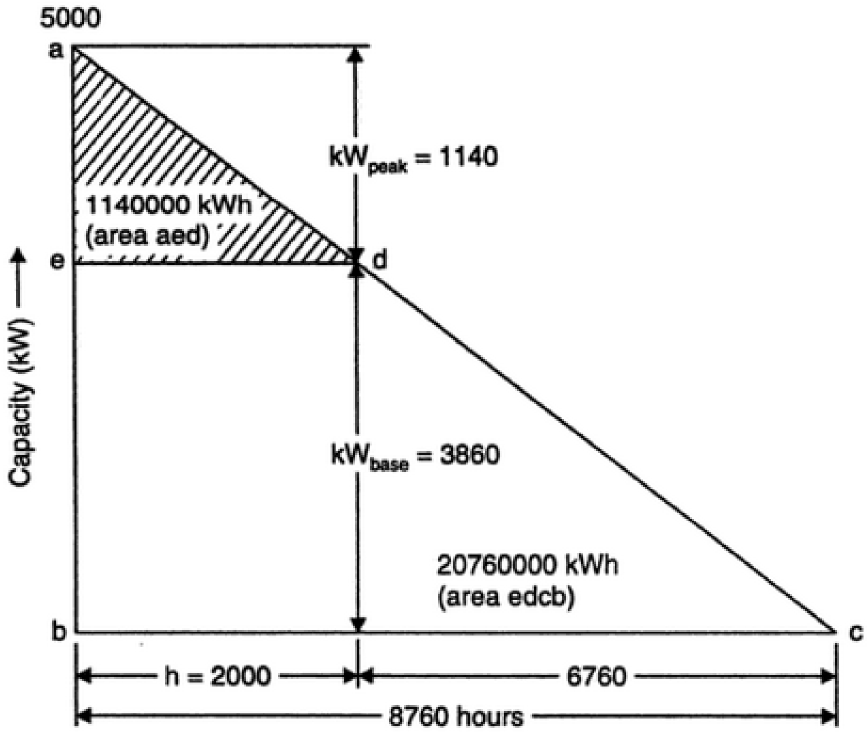
Let us consider the cost equations of the two stations. Since the operating cost of station B is less than that of A, so station B may be selected for supplying the base load.

Hours (h) for which the base load point is to be operated can be calculated as follows:

$$h = \frac{5-3}{0.015-0.014} = \frac{2}{0.001} = 2000\, hours$$

Hence the base load point is to be operated for 2000 hours and the peak load point plant for the remaining period. From the load duration curve, the capacity of the base load plant can be computed as follows.

Refer to following figure.



$$\frac{kW_{base}}{6760} = \frac{5000}{8760} \Rightarrow kW_{base} = 1140\,kW$$

Cost of generation

Total kWh supplied by peak load plant

$$= \frac{1140x2000}{2} = 11,40,000\,kWh$$

Total kWh supplied by base load plant

$$= \frac{5000x8760}{2} - 11,40,000 = 20760000\,kWh$$

Cost of generation per annum for *base load plant*

= Rs. (7,50,000 + 5 x 3,860 + 0.014 x 2,07,60,000)

= Rs. (7,50,000 + 19,300 + 2,90,640)

= Rs. 10,59,940.

Cost of generation per annum for *peak load plant*

= Rs. (6,00,000 + 3 x 1,140 + 0.015 x 11,40,000)

= Rs. (6,00,000 + 3,420 + 17,100)

= Rs. 6,20,520

Total cost = 10,59,940 + 6,20,520 = 16,80,460

Cost of generation per unit

$$= \frac{Total\,\cos t}{Total\,kWh\,\sup plied}$$

$$= \frac{1680460}{\left(\frac{5000x8760}{2}\right)} = Rs.0.0767$$

Example

The two power stations X and Y supply to a system whose maximum load 120 MW and minimum load is 12 MW during the year. The estimated costs of these stations an follows:

C_X = *Rs. (120 x kW + 0.028 x kWh)*

C_Y = *Rs. (115 x kW + 0.032 x kWh)*

If the load varies as a straight line, find for minimum cost of generation installed capacity of each station.

Solution

Given:

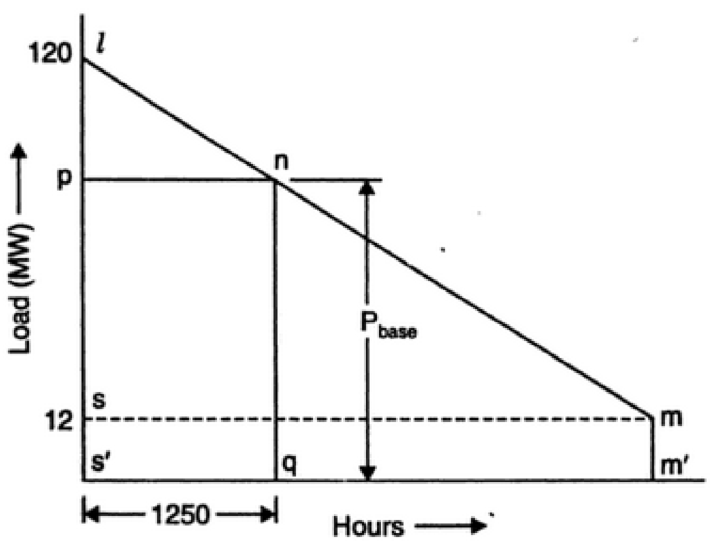
C_X = Rs. (120 x kW + 0.028 x kWh)

C_Y = Rs. (115 x kW + 0.032 x kWh)

i.e. $A_1 = 120, B_1 = 0.028$

and $A_2 = 115, B_2 = 0.032$

$\therefore$ $$h = \frac{A_1 - A_2}{B_2 - B_1} = \frac{120 - 115}{0.032 - 0.028} = 1250\,hours$$



From Δslms and lnp, we have

$$\frac{120 - P_{base}}{120 - 12} = \frac{1250}{8760} \Rightarrow P_{base} = 105\,MW$$

∴ P_{peak} = 120 – 105 = 15 MW

Installed capacity of each station

Installed capacity of base load plant,

P_{base} = 105 MW

Installed capacity of peak load plant = 15 x 1.22 = 18.3 MW.

Problem

The two power stations 1 and 2 supply to a system whose maximum load is 120 MW and minimum load is 12 MW during the year. The estimated costs of these stations are as follows:

C_1 *= Rs. (125 x kW + 0.0275 x kWh)*

C_2 *= Rs. (120 x kW + 0.03 x kWh)*

If the load varies as a straight line, find for minimum cost of generation installed capacity of each station.

Answer: 80 MW; 24 MW

Problem

The annual load duration curve of a station varies uniformly from 64000 kW to zero. The load is supplied by two stations whose cost equations are given as :

C_1 *= Rs. (84000 + 84 kW + 0.0116 kWh)*

C_2 *= Rs. (50000 + 44 kW + 0.02985 kWh)*

Find the minimum cost of generation in paise/kWh for the system.

Answer. 3 paise/kWh (approx.)

ASSIGNMENT

Q.1. (AMIE S10, 6 marks): Explain about the high head hydropower plant with a neat diagram.

Q.2. (AMIE W15, 5 marks): Draw and explain the working of hydropower plants.

Q.3. (AMIE S11, 4 marks): What are the merits and demerits of hydroelectric power station?

Q.4. (AMIE W12, S13, 17, 15, 5 marks): Explain with a neat sketch, a pumped storage plant. What are its advantages? Explain its working as a peak load plant.

Q.5. (AMIE S15, 4 marks): How are hydroelectric power plant classified?

Q.6. (AMIE W11, 5 marks): Classify hydroelectric power plants according to the quantity of water available.

Q.7. (AMIE S13, 4 marks): What are mini and micro-hydel plants? Why are they important now?

Q.8. (AMIE S11, 4 marks): What are the data needed for determination of requirement of the number of turbines in a power plant?

Q.9. (AMIE W10, S11, 12, 4 marks): Discuss the factors which should be considered while selecting a site for a hydroelectric power plant.

Q.10. (AMIE W10, S12, 13, 6 marks): Explain what do you understand by base load and peaking load. Why are base load plants loaded heavily?

Q.11. (AMIE W12, 5 marks): Explain the difference between base load and peak load stations? What are the factors considered in selecting a plant as base load plant or peak load plant?

Q.12. (AMIE W10, S13, 6 marks): What do you mean by load factor and capacity factor? When are they numerically equal? Explain the effect of the load factor on the cost of electricity generated.

Q.13. (AMIE W15, 5 marks): What is load duration curve? Explain the difference between base load and peak load power plants.

Q.14. (AMIE S17, 6 marks): What is flow duration curve?

Q.15. (AMIE S16, 6 marks): How is the most economical capacity of hydroelectric plant decided?

Q.16. (AMIE W11, 8 marks): Explain the advantages of pump storage plant as peak load plant is an interconnected system. Compare its economics with an old steam plant to be used for peak load operation as an alternative to pump storage plant.

Q.17. (AMIE W06, 10, S14, 6 marks): Define specific speed of a turbine. Derive its expression in terms of speed, power and head.

Q.18. (AMIE W15, 5 marks): Explain where back pressure and pass out turbines are used? Give the schematic layout.

Q.19. (AMIE S10, 12, 14, 8 marks): State the essential elements of a hydroelectric power plant. What is a surge tank? Why is it important in a hydro-plant? What is the function of a draft tube?

Q.20. (AMIE W12, S16, S17, 14 marks): Draw a neat sketch of storage type hydroelectric power plant. Explain the functions of different components used in storage type of hydraulic power plant.

Q.21. (AMIE W15, 4 marks): What is spillway? What are different spillways used in practice?

Q.22. (AMIE W11, 5 marks): Discuss different types of draft tubes used in hydel power plant.

Q.23. (AMIE W12, 5 marks): What do you understand by water hammer and what are its effect on power plant design?

Answer: A gate, or valve, al the end of the penstock pipe controls the discharge to the turbine. As soon as this governor-regulated opening is altered, the pipe flow has to be adjusted to the new magnitude of flow. In doing so, there are rapid pressure oscillations in the pipe, often accompanied by a hammering like sound. Hence, this phenomenon is called *water hammer*.

Q.24. (AMIE W13, 15, 12 marks): Explain the factors to be considered in selection of hydraulic turbine. Differentiate between Francis and Pelton turbine. Explain the various cost components of a hydraulic project.

Q.25. (AMIE W14, 15, 6 marks): Explain in brief the governing process in a hydraulic turbine.

Q.26. (AMIE W16, 6 marks): What are Kaplan turbines? How is a Kaplan turbine different from a propeller turbine? Explain the characteristic features of a Kaplan turbine.

Q.27. (AMIE W10, 5 marks): Explain the optimization of a hydro-thermal mix in meeting the power demand of a certain region.

Q.28. (AMIE S12, 12 marks): A Pelton wheel driven by two similar jets transmits 4 MW to the shaft when running at 400 rpm. The head from the reservoir level to the nozzle is 200 m and the efficiency of power transmission through the pipelines and nozzles is 90%. The jets are tangential to a 1.50 m diameter circle. The relative velocity decreases by 10% as the water traverses the buckets which are so shaped that they would, if stationary, deflect the jet by 165^0. Neglecting windage losses, estimate the (i) efficiency of the runner (ii) diameter of each jet.

Answer: 93.16%; 0.1614 m

Q.29. (AMIE S11, 6 marks): A hydroelectric power plant has a catchment area of 100 km^2. The available run-off is 50% with annual rainfall of 120 cm. A head of 200 m is available on an average. Efficiency of the power plant is 70%. Calculate the average power produced and capacity of the power plant.

Answer: 2613 kW; 22.9 x 10^6 kWh

Q.30. (AMIE S11, 6 marks): A hydroelectric station operates at a head of 50 m. The catchment area of reservoir is 500 km^2. The average rainfall is 1000 mm. 25% of the rainfall is lost on account of evaporation. Loss of head in penstock is 20%. Efficiency of turbine is 80% and generator is 90%. Calculate the capacity of the plant.

Answer: 3359.59 kW

Q.31. (AMIE S11, 8 marks): In a hydroelectric power plant, the flow rate of water is 450 m^3/s. The head is 30 m. The turbine efficiency is 85%. The generator is directly coupled with the turbine. The frequency of generation is 50 c/s. The number of poles of generator is 24. Estimate the number of turbines required, if

(i) Francis turbine is used with a specific speed of 300 rpm

(ii) Kaplan turbine is used with a specific speed of 700 rpm.

Answer: 16; 3

Q.32. (AMIE S10, 7 marks): A Francis turbine, with an overall efficiency of 75% is required to produce 148.25 kW power. It is working under a head of 7.62 m. The peripheral velocity is 0.26 (2 $gH^{1/2}$) and the radial velocity of the flow at inlet is 0.96 ($2gh^{1/2}$). The wheel runs at 150 rpm and hydraulic losses in turbine are 22% of the available energy. The discharge is radial. Calculate (i) guide blade angle (ii) wheel vane angle at inlet (iii) diameter of wheel at inlet (iv) width of wheel at inlet.

Answer: 32.62^0; $\theta = 37.75^0$; $D_1 = 0.4047$ m; $B_1 = 0.177$ m

Q.33. (AMIE S10, 4 marks): A turbine is to operate under a head of 25 m at 200 rpm. The discharge is 9 cusec. If the efficiency of the turbine is 90%, calculate the specific speed.

Answer: 159.46

Q.34. (AMIE W11, 10 marks): At a proposed site of hydroelectric power plant, the available head and discharge are 29 m and 342 m^3/sec., respectively. The generator is directly connected to the turbine. The frequency of generation is 50 cycles/sec and number of poles used is 24. Turbine efficiency is 89%. Find least number of machines required if (i) a Francis turbine with specific speed of 300 is used (ii) Kaplan turbine with a specific speed of 850 is used.

Answer: 14; 2

Q.35. (AMIE S17, 6 marks): A run-off rate 400 m^3/sec and head of 45 m is available at a site proposed for hydro electric power plant. Assume the turbine efficiency of 90% and speed of 200 rpm, find the least number of machines, all of equal size required if (i) Francis turbine not greater than 200 specific speed or (ii) Kaplan turbine not greater than 600 specific speed is used.

Q.36. (AMIE S11, 8 marks): A hydroelectric power station is supplied from a reservoir having an area of 100 km^2 and head of 100 m. If the overall efficiency of the plant is 70%, calculate the rate at which the water level will fall when the station is generating 20 MW.

Answer: 2.516 cm/day

Q.37. (AMIE W13, 8 marks): A proposed hydroelectric plant has catchment area of 520 km^2 with an average annual rainfall of 460 cm. The average annual head is 450 m. Assuming 40% energy losses and 50% load factor, estimate the installed capacity of the power station.

Answer: 401.8 MW

Q.38. (AMIE W11, S14, 12 marks): The annual load duration curve of a station varies uniformly from 62,000 kW to zero. The load is supplied by two stations whose cost equations are given as

C_1 = Rs. (83000 + 830 kW + 0.118 kWh)

C_2 = Rs. (51000 + 420 kW + 0.289 kWh)

Find the minimum cost of generation (in Rs/kWh) for the system.

Answer: ₹ 0.2952 per kWh

Q.39. (AMIE W12, 8 marks): A turbine is to run at 250 rpm under the available head of 25 m. The flow rate available is 9 m^3/sec. If the turbine efficiency is 90%, calculate (i) specific speed (ii) power generated (iii) speed and power, if head is reduced to 16 m.

Answer: 199.325; 1986.525 kW; speed = 200 rpm, power = 1017.1 kW

Q.40. (AMIE W16, 8 marks): A Kaplan turbine develops 10 MW under a head of 13 m where the following conditions prevail. Flow ratio 0.65; ratio of hub diameter to external range diameter is 0.3; speed ratio is 2; overall efficiency is 93%. Estimate (i) specific speed (ii) diameter of the runner (iii) speed.

Answer: 715; 3.37 m; 176.5 rpm

Q.41. (AMIE W13, 8 marks): A central power station has annual factors as follows: Load factor = 60%, capacity factor = 40%, use factor = 40%. Power station has a maximum demand of 20,000 kW. Determine (i) annual energy production (ii) reserve capacity over and above peak load and (iii) non operating hours in a year.

Answer: 105.12 x 10^6; 10,000 kW; 0

Q.42. (AMIE S16, 14 marks): A load duration curve of a system is a straight line, the maximum and minimum loads being 100 MW and 20 MW, respectively. The load is supplied by base load and peak load plants. The cost of both are given as follows:

For base load plant: Rs. 200/kW – year + 5 P/kWh

For peak load plant: Rs. 50/kW-year – 10 P/kWh

For minimum overall cost, determine the load shared by peak load plant and annual load factor for both stations.

Answer: Load factor (base load) = 76%; load factor (peak) = 17%

Q.43. (AMIE W14, 8 marks): Water for a hydroelectric power is obtained from a reservoir with a head of 100 m. Calculate the energy generated per cubic metre per hour, if the hydraulic efficiency is 85% and electrical efficiency is 90%.

Answer: 208.46 W

Q.44. (AMIE W15, 8 marks): The following data relates to a hydroelectric power plant: (i) head = 400 m (ii) discharge = 4.5 m^3/s (iii) turbine efficiency = 82% (iv) specific speed = 60. Determine the power developed, type of turbine and speed of turbine.

Answer: 14.47×10^3 kW; 891.7 rpm; slow Francis turbine or fast Pelton turbine

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