# Hydro-electric Power

Faraday had shown that when a coil is rotated in a magnetic field, electricity is generated. Thus, in order to produce electrical energy, it is necessary that we should produce mechanical energy, which can be used to rotate the 'coil'. The mechanical energy is produced by running a prime mover (known as turbine) by the energy of fuels or flowing water. This mechanical power is converted into electrical power by electric generator which is directly coupled to the shaft of the turbine, and is thus run by the turbine. The electrical power, which is consequently obtained at the terminals of the generator, is then transmitted to the area where it is to be used for doing work.

The plant or machinery which is required to produce electricity (i.e. Prime mover + Electric generator) is collectively known as the *Power plant*. The building, in which the entire machinery along with other auxiliary units is installed, is known as the *Power house*.

## 24.1. Thermal and Hydropower

As stated earlier, the turbine blades can be made to run by the energy of fuels or flowing water. When fuel is used to produce steam for running the steam turbine, then the power generated is known as *Thermal power*. The fuel which is to be used for generating steam may either be (i) an ordinary fuel such as coal, fuel oil, gas, etc., or (ii) atomic fuel or nuclear fuel. Coal is simply burnt to produce steam from water and is the simplest and the oldest type of fuel. Diesel oil, etc. may also be used as fuels for producing steam. Atomic fuels such as uranium or thorium may also be used to produce steam. When conventional type of fuels such as coal, oil, etc. (called fossils) are used to produce steam for running the turbines, the power house is generally called an *Ordinary thermal power station* or *Thermal power station*. But when atomic fuel is used to produce steam, the power station, which is essentially a thermal power station, is called an *Atomic power station* or a *Nuclear power station*. In an ordinary thermal power station, steam is produced in a water boiler, while in the atomic power station, the boiler is replaced by a nuclear reactor and steam generator for raising steam. The electric power generated in both these cases is known as *Thermal power* and the scheme is called *Thermal power scheme*.

But, when the energy of the flowing water is used to run the turbines, then the electricity generated is called the *Hydroelectric power*. This scheme is known as *Hydel scheme*, and the power house is known as *Hydel power station* or *Hydroelectric power station*. In a hydel scheme, a certain quantity of water at a certain potential head, is essentially made to flow through the turbines. The head causing flow, runs the turbine blades, and thus producing electricity from the generator coupled to the turbine. In this chapter, we are concerned with hydel schemes only.

## 24.2. Classification of Hydel Plants

### 24.2.1. Classification of Hydroplants on the Basis of Hydraulic Characteristics.

On the basis of this classification, the hydro plants may be divided into the following types:

(*i*) *Run-off river plants*

(*ii*) *Storage plants*

(*iii*) *Pumped storage plants*

(*iv*) *Tidal plants*

They are described below :

(*i*) **Run-off River Plants.** These plants are those which utilise the minimum flow in a river having no appreciable pondage on its upstream side. A weir or a barrage is sometimes constructed across a river simply to raise and maintain the water level at a pre-determined level within narrow limits of fluctuations, either solely for the power plant or for some other purpose where the power plant may be incidental. Such a scheme is essentially a low head scheme and may be suitable only on a perennial river having sufficient dry wheather flow of such a magnitude as to make the development worth while. [Pl. refer Fig. 24.2]

Run-off river plants generally have a very limited storage capacity, to supplement the normal flow. Such a small storage capacity, called **pondage,** is provided for meeting the hour to hour fluctuations of load or of streamflow over a day ; or occassionally, day to day fluctuations over a weekly cycle. When the available discharge at site is more than the demand (during off-peak hours), the excess water is temporarily stored in the pond on the upstream side of the barrage, which is then utilised during the peak hours.

The power stations constructed on diversion canals (Irrigation & Power Canals) called *Diversion canal plants*, can also be placed in this category.

The various examples of run-off river plants are : Ganguwal and Kotla power houses located on Nangal Hydel Channel, Mohammad Pur and Pathri power houses on Ganga Canal, and Sarda power house on Sarda Canal.

(*ii*) **Storage Plants.** A storage plant is essentially having an upstream storage reservoir of sufficient size, so as to permit sufficient carry-over storage from the monsoon season to the dry summer season, and thus to develop a firm flow substantially more than the minimum natural flow. In this scheme, a dam is constructed across the river, and the power house may be located at the foot of the dam such as in Bhakra, Hirakund, Rihand projects, etc. The power house may sometimes be located much away from the dam (on the down-stream side). In such a case, the power house is located at the end of tunnels which carry water from the reservoir. The tunnels are connected to the power house machines by means of pressure penstocks which may either be underground (as in Maithon and Koyna projects) or may be kept exposed (as in Kundah project).

When the power house is located near the dam, as is generally done in the low head installations ; it is known as *Concentrated fall hydroelectric development.* But when the water is carried to the power house at a considerable distance from the dam through a canal, tunnel, or penstock ; it is known as a *Divided fall development.*

(*iii*) **Pumped Storage Plants.** A pumped storage plant generates power during peak hours, but during the off-peak hours, water is pumped back from the tail water pool to the head water pool for future use. The pumps are run by some secondary power from some other plant in the system. The plant is thus primarily meant for assisting an existing thermal plant or some other hydel plant. A typical section for pumped storage plant is shown in Fig. 24.1.

During peak hours, the water flows from the reservoir to the turbine and electricity is generated. During off-peak hours, the excess power available from some other plant, is utilised for pumping water back from the tail pool to the head pool. This minor plant thus supplements the power of another major plant. In such a scheme, the same water is utilised again and again and no water is wasted.

For heads varying between 15 to 90 m, reversible pump turbines have been devised, which can function both as turbine as well as a pump. Such reversible turbines can work at relatively high efficiencies and can help in reducing the cost of such a plant. Similarly, the same electrical machine can be used both as a generator as well as a motor by reversing the poles. The provision of such a scheme helps considerably in improving the load factor of the power system.

(*iv*) **Tidal Plants.** Tidal plants for generation of electric power are the recent and modern advancements, and essentially work on the principle that there is a rise in sea water during high tide period and a fall *during the low ebb period*. The water rises and falls twice a day ; each fall cycle occupying about 12 hours and 25 minutes. The advantage of this rise and fall of water is taken in a tidal plant. In other words, the tidal range, *i.e.* the difference between high and low tide levels is utilised to generate power. This is accomplished by constructing a basin separated from the ocean by a partition wall and installing turbines in openings through this wall.

Water passes from the ocean to the basin during high tides, and thus running the turbines and generating electric power. During low tide, the water from the basin runs back to ocean, which can also be utilised to generate electric power, provided, special turbines which can generate power for either direction of flow are installed. Such plants are useful at places where tidal range is high. *Rance power station* in France is an example of this type of power station. The tidal range at this place is of the order of 11 metres. This power house contains 9 units of 38,000 k. watts.
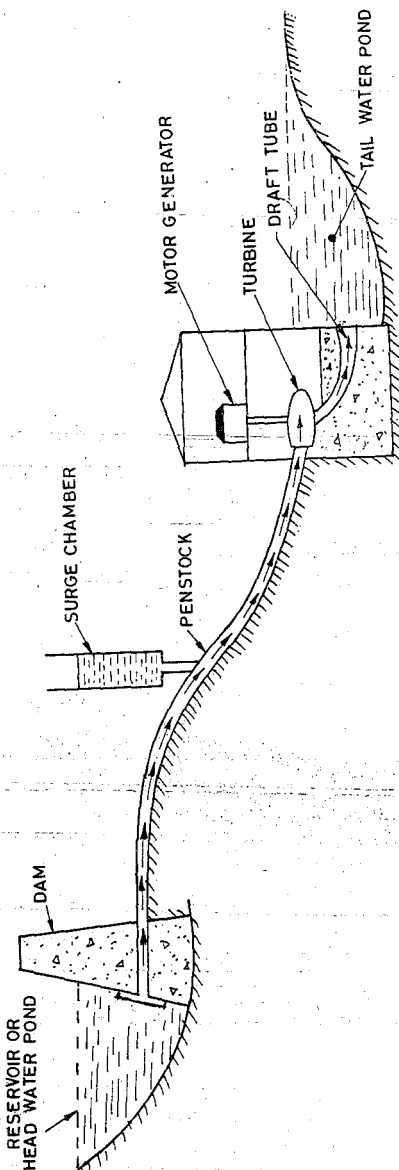


Fig. 24.1. Typical section *through a pumped storage plant.*

### 24.2.2. Classification of Hydroplants on the Basis of Operating Head on Turbines.

On this basis, the plants may be divided into the following types :

(*i*) *Low head scheme* (head < 15 m).

(*ii*) *Medium head scheme* (head varies between 15 to 60 m).

(*iii*) *High head scheme* (head > 60 m).

They are described below :

(*i*) **Low Head Scheme.** A low head scheme is one which uses water head of less than 15 metres or so. A run-off river plant is essentially a low head scheme. In this

(a) Run of river plant

(b) Diversion canal plant

Fig. 24.2. Low head schemes (in Plan)
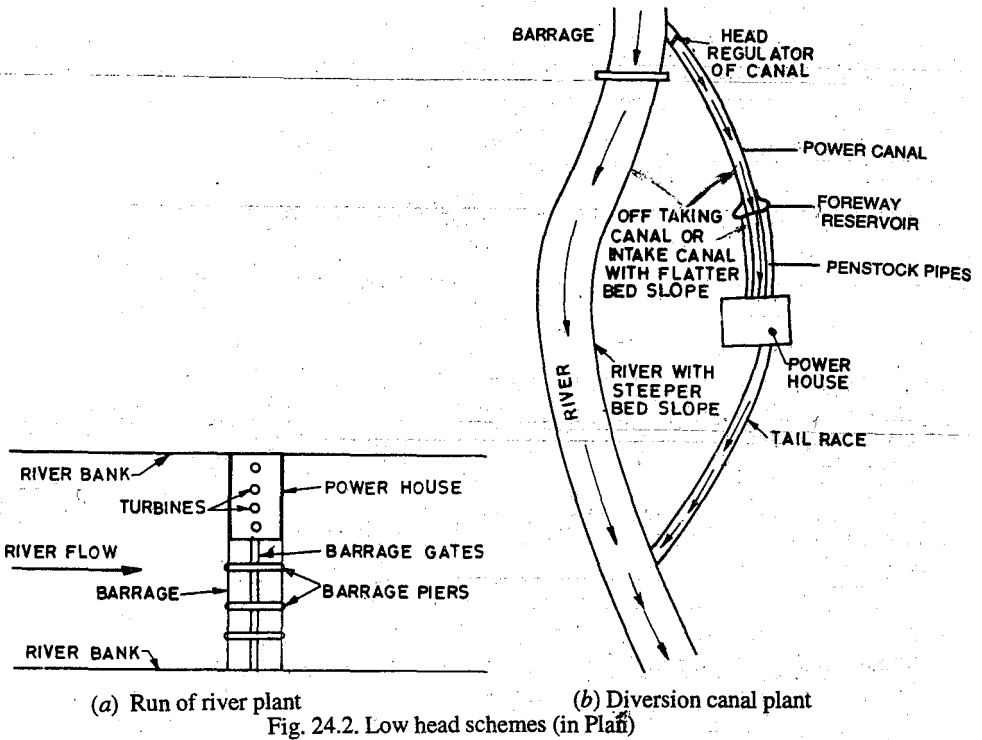
scheme, a weir or a barrage is constructed to raise the water level, and the power house is constructed either in continuation with the barrage [Fig. 24.2 (a)] or at some distance downstream of the barrage, where water is taken to the power house through an intake canal [Fig. 24.3 (b)].

(ii) **Medium Head Scheme.** A medium head scheme is one which uses water head varying between 15 to 60 metres or so. This scheme is thus essentially a dam reservoir scheme, although the dam height is mediocre. This scheme is having features somewhere between low head scheme and high head scheme.

(iii) **High Head Scheme.** A high head scheme is the one which uses water head of more than 60 m or so. A dam of sufficient height is, therefore, required to be constructed, so as to store water on the upstream side and to utilise this water throughout the year. High head schemes up to heights of 1,800 metres have been developed. The common examples of such a scheme are : Bhakra dam in (Punjab), Rihand dam in (U.P.), Hoover
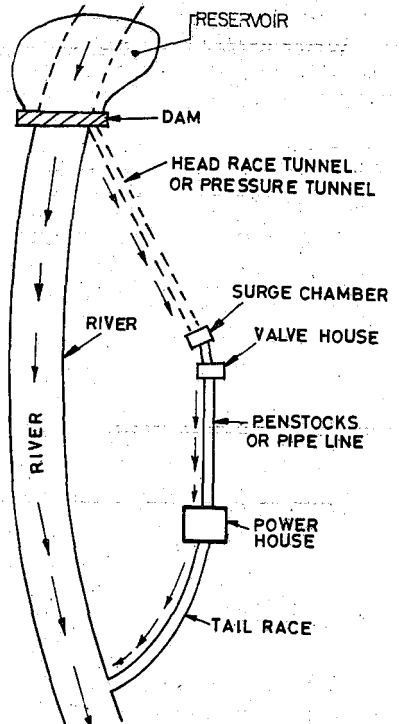


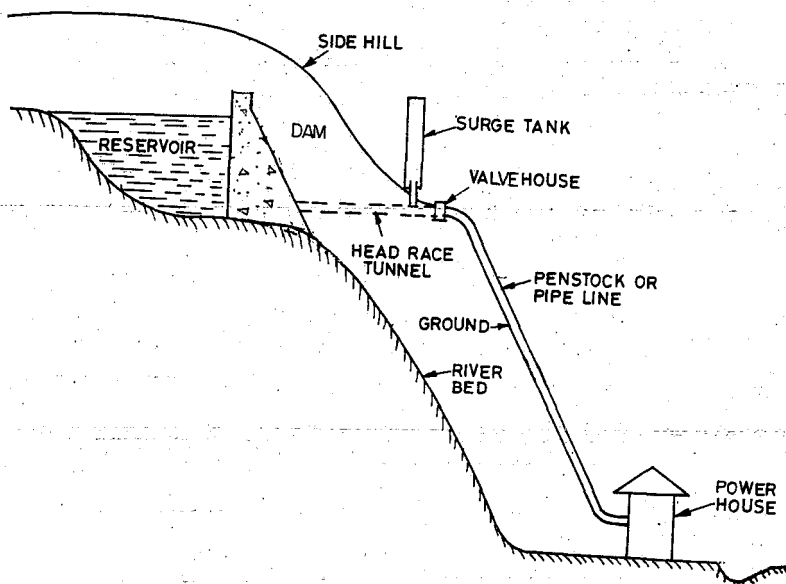Fig. 24.3. (a) Plan of a high head scheme.

Fig. 24.3. (b) Section through a high head scheme.

dam in (U.S.A.), etc. A typical plan and section of such a scheme are shown in Figs. 24.3 (a) and (b).

The naturally available high falls can also be developed for generating electric power. The common examples of such power developments are : Jog Falls in India, and Niagara Falls in U.S.A.

## 24.3. Important Terms and Definitions Connected with Hydropower

**24.3.1. Water Power Potential.** The amount of power generated when $Q$ cumecs of water is allowed to fall through a head difference of $H$ metres is given by

$$\text{Water energy} = \gamma_w \cdot Q \cdot H \qquad \qquad ...(24.1)$$

$$\text{where } \gamma_w \text{ is unit wt of water} = 9.81 \text{ kN/m}^3$$

$$= 9.81 \times Q \times H \text{ kN–m/sec. } (i.e. \text{ k watts})$$

Electrical energy (E.E.) or Power in k. watts, is therefore, given as :

$$P = 9.81 \, \eta \cdot Q \cdot H \text{ (k watts)} \qquad \qquad ...(24.2)$$

∴ Metric H.P. generated

$$= \frac{9.81 \, \eta Q \times H}{0.735} = 13.33 \, \eta QH \qquad (\because 1 \text{ m H.P.} = 0.735 \text{ kW}) \qquad ...(24.2a)$$

where $\eta$ is the overall efficiency of turbine, generator, etc.

Using 80% efficiency, we get

Electrical energy $= 9.81 \times 0.8 \times Q \cdot H \text{ kW}$

$$= 7.84 \cdot Q \cdot H \approx \textbf{8 QH kW} \qquad \qquad ...(24.2b)$$

where, $H$ is the design head in metres ; $Q$ is the design discharge in cumecs.

**24.3.2. Normal Water Level (N.W.L.).** The highest elevation of water level that can be maintained in the reservoir without any spillway discharge, either with a gated or a non-gated spillway, is known as Normal water level.

**24.3.3. Minimum Water Level (M.W.L.).** The elevation of water level which produces minimum net head on the power units (*i.e.* 65% of design head *H*) is known as minimum water level.

**24.3.4. Weighted Average Level (W.A.L.).** The level above and below which equal amounts of power are developed during an average year (*i.e.* 50% units between N.W.L. and W.A.L., and 50% units between W.A.L. and M.W.L.) is called weighted average level.

**24.3.5. Design Head.** It is the net head under which the turbine reaches peak efficiency at synchronous speed. Generally, the design head = W.A.L. − M.W.L. The difference of N.W.L. and M.W.L. is 125% of design head.

**24.3.6. Rated Head.** It is the head at which the turbine functioning at full gate opening will produce a power output, equal to that specified in the name plate of the turbine. This r̲ ̲ ̲ᵈ head should be equal to the design head of the turbine, so as to ensure maximum overall plant efficiency.

**24.3.7. Gross Head.** Gross head is the difference in the water level elevations at the point of diversion of water for the hydel scheme and the point of return of water back to the river.

**24.3.8. Operating Head.** Operating head is the simultaneous difference between the elevations of water surface in the *foreway* and the *tailrace*, after making due allowance for approach and exit velocity heads.

$$\therefore \text{ Operating head} = \text{T.E.L. at forway entrance} - \text{T.E.L. at tailrace exit.} \quad ...(24.3)$$

**24.3.9. Net Head or Effective Head.** The effective head is the net head applied to the turbine, and is given by the difference of head at the point of entry and exit of turbine, and includes the respective velocity and pressure heads at both places.

**24.3.10. Installed Capacity of the Power House.** The total capacity in kilowatts or million killowatts of all the turbine-generator units installed in a power house, is called its Installed capacity.

**24.3.11. Dependable Capacity.** It is the load carrying capability of the power house with respect to the load characteristics during a specified time interval, and is decided by the power factor, capability and the load on the power house.

**24.3.12. Load Factor (L.F.).** Load factor is defined as the ratio of the average load over a certain period of time to the peak load during the same period. Depending upon the period chosen, we may have different load factors, such as daily, monthly or annual load factors.

$$\therefore \quad \text{Load factor} = \frac{\text{Average load over a certain period}}{\text{Peak load during that period}} \quad ...(24.4)$$

If the area under a load curve[*] is plotted, it would evidently represent the energy consumed in kilowatt hours (kWh). Thus, an annual load factor may also be defined as the ratio of the actual energy consumed during that year to the peak demand assumed to continue for one year.

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[*] A graph plotted between time in hrs (on *x*-axis) and load in kW (on *y*-axis) is called a **load curve**.

∴ **Annual load factor**

$$= \frac{\text{Total yearly electrical units (kWh) produced}}{(\text{Max. power demand in kW}) \times 365 \times 24} \qquad ...(24.5)$$

**Note.** The maximum load determines the capacity of the units, while the load factor gives an idea of the degree of utilisation of the capacity. For example, an annual load factor of 0.6 would indicate that the machines are producing 60% of their yearly rated capacity (maximum production capacity).

**24.3.13. Demand Factor.** A consumer is provided with the connected load of a certain rating (kilo-watts). He may or may not use the whole load at one time, as the may use only a part of it. The ratio of the maximum demand at any particular time to the connected load is known as the *demand factor.*

**24.3.14. Capacity Factor or Plant Factor.** It may be defined as the ratio of average output of the plant for a given period of time to the plant capacity, *i.e.,*

$$\text{Capacity factor} = \frac{\text{Average Load(over a given period of time)}}{\text{Plant capacity}} \qquad ...(24.6 \; a)$$

In other words, the capacity factor is the ratio of the energy actually produced by the plant in any given period to the energy it would be capable of producing at its full capacity during that period. For example, if a plant with a capacity of 10,000 kW were to produce 40,000 kWh when operating for 100 hours, then

$$\text{Capacity factor} = \frac{\dfrac{40,000}{100}}{10,000} = 0.4 \text{ or } 40\%$$

Hence, capacity factor

$$= \frac{\text{Energy actually produced in a given time}}{\text{Max. energy that can be produced by the plant during that given time}} \qquad ...(24.6 \; b)$$

The capacity factor and load factor would become identical, if the peak load is equal to the plant capacity ; *i.e.* when plant is allowed to be used up to its max. capacity, or there is no *reserve capacity.* However, load factor would be different, if the plant is not used to full capacity.

Hence, in the above example, if the peak load is equal to 8000 kW (as against the station capacity of 10,000 kW), then

$$\text{Load factor} = \frac{\dfrac{40,000}{100}}{8,000} = 50\% \text{ as against the capacity factor of } 40\%.$$

Also, the **reserve capacity** would then be

$$\text{Peak load} = \frac{\text{Plant capacity}}{1 + R} \qquad ...(24.7)$$

where $R$ is Reserve capacity expressed as fraction of Plant capacity,

∴ $$8000 = \frac{10,000}{1 + R}.$$

or $$1 + R = \frac{10,000}{8,000}$$

or $$R = 0.25, i.e.\ 25\%.$$

(*i.e.* at 25% R.C. ; Peak load × 1.25 = Installed capacity

### 24.3.15. Utilisation Factor or Plant Use Factor. It is defined as :

$$\text{Utilisation factor (U.F.)} = \frac{\text{Water actually utilised for power production}}{\text{Water available in the river}} \qquad ...(24.8)$$

It the water head is assumed to be constant, then the utilisation factor would be equivalent to :

$$\text{U.F.} = \frac{\text{Max. power utilised}}{\text{Max. power available}} \qquad ...(24.9)$$

The value of utilisation factor usually varies from 0.4 to 0.9 for a hydel plant, depending upon the plant capacity, load factor and storage.

### 24.3.16. Firm Power.
The net amount of power which is continuously available from a plant without any break on firm or on guaranteed basis is known as *firm power*. This power should be available under the most adverse hydraulic conditions. The consumers can always be sure of getting this power.

### 24.3.17. Secondary Power.
The excess power available over the firm power during the off peak hours or during monsoon, etc. is known as *secondary power*. There is no guarantee for secondary power, and it is supplied to the consumers on 'as and when available' basis.

### 24.3.18. Power Factor. It is defined as

$$\text{Power factor} = \frac{\text{Actual power in kilowatts (kW)}}{\text{Apparent power in kilo volt–amperes (KVA)}} \qquad ...(24.10)$$

The power factor can never be greater than unity. Its value depends upon the relationship between the inductance and resistance in the load. A load with very little inductance such as lighting bulbs, will have a power factor close to unity. The usual system load has a power factor varying between 0.8 to 0.9, but if various induction motors are installed in the load, the power factor may be as low as 0.5. Since the electrical machines are generally rated in KVA, the actual power developed depends much upon the power factor. This is the reason, why most of the Electric Supply Undertakings, do stress upon their consumers, to reduce their inductance and improve their power factors.

**Example 24.1.** *The load on a hydel plant varies from a minimum of 10,000 kW to a maximum of 35,000 kW. Two turbo-generators of capacities 22,000 kW each have been installed. Calculate :*

   *(a) total installed capacity of the plant ;*

   *(b) plant factor ;*

   *(c) maximum demand ;*

   *(d) load factor ;*

   *(e) utilisation factor.*

**Solution.** (*a*) Since two generators, each of capacity 22000 kW are installed, we have

the *total installed capacity* $= 2 \times 22000 \text{ kW} = 44000 \text{ kW}.$ **Ans.**

From eqn. (24.6b), we have

(b) *Plant factor* (*i.e.* capacity factor)

$$= \frac{\text{Energy actually produced in time } t}{\text{Max. energy that can be produced in time } t}$$

$$= \frac{\dfrac{(10000+35000)}{2} \times t}{44000 \times t} = \frac{22500}{44000} = 0.511, \textit{i.e. } 51.1\%. \textbf{ Ans.}$$

(c) *Maximum demand* = 35000 kW (as given). **Ans.**

(d) *Load factor* $= \dfrac{\text{Average load over a certain period}}{\text{Peak load during that period}}$

$$= \frac{\dfrac{10000+35000}{2} \text{ kW}}{35000 \text{ kW}} = \frac{22500}{35000} = 0.643 \textit{ i.e. } 64.3\%. \textbf{ Ans.}$$

(e) *Utilisation factor* $= \dfrac{\text{Max. power utilised}}{\text{Max. power available}}$

$$= \frac{35000 \text{ kW}}{44000 \text{ kW}} = 0.795, \textit{i.e. } 79.5\%. \textbf{ Ans.}$$

**Example 24.2.** *A common load is shared by two hydel stations ; one being a base load station with 20 MW installed capacity, and the other being a stand-by station with 25 MW capacity. The yearly output of the stand-by station is $10 \times 10^6$ kWh and that of the base load plant as $110 \times 10^6$ kWh. The peak load taken by stand-by station is 12 MW and this station works for 2500 hours during the year. The base load station takes a peak of 18 MW. Find out :*

(a) *Annual load factors for both stations.*

(b) *Plant use factors for both stations.*

(c) *Capacity factors for both stations.*

**Solution.** We will work out all the required three factors for the base load plant first, and then for the other stand-by plant.

**For Base Load Plant.** For this base load station, data is given as :

Installed capacity   = 20 MW = $20 \times 10^3$ kW
Yearly output    = $110 \times 10^6$ kWh
Peak load taken   = 18 MW = $18 \times 10^3$ kW.

(a) Now, *Annual load factor*

$$= \frac{\text{Total energy (kWh) generated per year}}{\text{Max. power demand in kW} \times 365 \times 24}$$

$$= \frac{110 \times 10^6}{(18 \times 10^3) \times 365 \times 24} = \textbf{0.698}, \textit{i.e. } \textbf{69.8\%. Ans.}$$

(b) *Plant use factor* $= \dfrac{\text{Max. power utilised}}{\text{Max. power available}}$

$$= \frac{18000 \text{ kW}}{20 \times 10^3 \text{ kW}} = \textbf{0.9}, \textit{i.e. } \textbf{90\%. Ans.}$$

(c) *Capacity factor* $= \dfrac{\text{Av. energy utilised in a period (year)}}{\text{Max. energy that can be produced in that period}}$

$= \dfrac{110 \times 10^6}{(20 \times 10^3) \times (24 \times 365)} = 0.628, i.e.\ 62.8\%$ **Ans.**

**For stand by plant.** The data given for this plant is :

Installed capacity $= 25\ \text{MW} = 25 \times 10^3\ \text{kW}$

Yearly output in 2500 hrs $= 10 \times 10^6\ \text{kWh}$

Peak load $= 12\ \text{MW} = 12 \times 10^3\ \text{kW}.$

No. of working hours during the year $= 2500\ \text{hr}.$

(a) *Annual load factor*

$= \dfrac{\text{Total kWh generated per year}}{\text{Max. power demand in kW} \times (24 \times 365)}$

$= \dfrac{10 \times 10^6\ \text{kWh}}{(12 \times 10^3\ \text{kW}) \times (24 \times 365\ \text{h})} = 0.095, i.e.\ 9.5\%.$ **Ans.**

(b) *Plant use factor* $= \dfrac{\text{Max. power utilised}}{\text{Max. available power}}$

$= \dfrac{12 \times 10^3\ \text{kW}}{25 \times 10^3\ \text{kW}} = 0.48, i.e.,\ 48\%.$ **Ans.**

(c) *Capacity factor* $= \dfrac{\text{Av. output}}{\text{Station capacity}}$

$= \dfrac{10 \times 10^6\ \text{kWh}}{(25 \times 10^3\ \text{kW}) \times 2500\ \text{h}} = 0.16, i.e.\ 16\%.$ **Ans.**

## 24.4. Principal Components of a Hydro-electric Scheme

A hydroelectric development scheme ordinarily includes a diversion structure, a conduit (penstock) to carry water to the turbines, turbines and governing mechanisms, generators, control and switching apparatus, housing for the equipment, transformers and transmission lines to the distribution centres. In addition to these major components, trash racks at the entrance to penstock, canal and penstock gates, a foreway, a surge tank, and other appurtenances may be required. A tailrace channel from the power house back to the river must be provided, if the power house is situated at such a place that the draft tubes cannot discharge water directly into the river.

No two power development schemes are exactly alike and each will have its own unique problems of design and construction. The choice of a particular type of a plant at a given site depends upon various factors, such as :

(i) general available topography of the area ;

(ii) available head ;

(iii) available flow ;

(iv) availability of other type of power stations in the vicinity :

(v) requirements of power for industries, etc.

(vi) Political influences of the area, etc.

The major components of a hydroelectric scheme are described below :

(1) **The Foreway.** A foreway is a storage basin or any other large body of water situated just infront of intake. Its main function is to temporarily store the water which is rejected by the plant due to reduced load during off-peak hours, and also to meet the instantaneous increased demand when the load is suddenly increased. The foreway, therefore, absorbs the short interval variations in water demand and corresponding fluctuations in power load.

In many cases, when canal leads the water to the turbines, the canal itself may be large enough to absorb these flow variations. When the canal is long, its section is sometimes enlarged at the end, so as to provide necessary temporary storage. In many other cases, when a reservoir is constructed by building a dam, and the water is taken to the power house directly from the reservoir through penstocks, the reservoir itself acts as a foreway.

(2) **Intake Structure.** The foreway is provided with some type of intake structure, to direct water into the penstocks. Various types of intakes are used depending upon the local conditions.

Intakes should be provided with **trash racks** so as to prevent the entry of debris into the penstocks, and thus to avoid the possible damage to *wicket gates* and turbine runners or to avoid the choking up of the nozzles of the impulse turbines. They are made of thin flat steel bars placed 10 to 30 cm apart. The permissible velocity of water entering the trash racks is 0.6 to 1.6 m/sec.

A floating boom is often placed in the storage reservoir so as to trap as much ice and floating debris as possible, and thus to avoid their entry into the canal. At places, where severe winters do occur, provision is made so as to minimise the ice trouble in the foreway. The trash racks may be electrically heated, so as to prevent clinging of ice with them. Sometimes, an air-bubbler system which agitates the water in the vicinity of the trash rack and brings warmer water to the surface, is also used. The problem of ice automatically gets reduced, if the foreway pond is large enough, and the intake is at considerable depth.

The foreway must be provided with a spillway or a wasteway, a bypass channel, etc., so that the water can be disposed of safely, if such a need arises at any time. Syphon spillways may often be used advantageously for this purpose.

Besides trash racks, other accessories of an intake structure are :

(*i*) *Rakes and trolley arrangements* required to clear trash racks.

(*ii*) *Ice removal equipment,* such as a *floating boom, electrical heating device* for trash racks, etc., if necessary.

(*iii*) *Penstock closing gates* with their hoisting mechanisms.

(3) **Penstocks.** Penstocks are the huge diameter pipes which carry water under pressure from the storage reservoir to the turbines. The structural design of a penstock is essentially similar to that of any other pressure pipe. But, because of the possibility of sudden load changes, design against water hammer[*] is essential. Short length penstocks are generally designed to take this extra pressure by providing heavier pipe

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[*] Explained in previous chapter.

wall. Slow-closing valves are then provided, so as to reduce these extra pressures. However, in case of long penstocks, a *surge tank* is generally provided, so as to absorb water hammer pressures and to provide water to meet sudden load increases.

Penstocks are generally made of steel or reinforced concrete, though wooden-stave pipes are also sometimes used. If the distance of the power house from the foreway is small, separate penstocks are generally used for each turbine. But long penstocks are generally branched at the lower end, so as to serve several turbines.

Penstock closing gates are usually provided at the entrance in the foreway. The gate can be closed to permit repair of penstock. An air vent and vent pipe connecting the top of the penstock with the open air, is provided downstream from the gate. Such a vent permits the entry of air into the penstock, as soon as the gates are closed and water drawn off through the turbine wheels. In the absence of such an arrangement, serious negative pressures will be exerted on the penstocks and may cause the penstocks to collapse. The water in the vent pipe should not get frozen, otherwise, entry of air will be prevented. Before opening the main head gate, the penstock, if empty, should be filled through a bypass, so that surge of water may not damage the turbines.

The penstocks should be located at such a level that sufficient water depth (called **water seal**) is provided above the penstock entrance in the foreway. If this is not so, and too little water depth is available, vortices and whirlpools will tend to form, which may carry air into the penstocks and the turbine wheels, and thus lowering the turbine efficiency and causing undesirable pressure surges. The entrance of the penstocks should also be flared, so as to avoid any loss of head by contraction.

Sharp bends must be avoided in penstocks, because they cause loss of head and require special anchorages. The penstocks may either be buried under the ground or kept exposed. Exposed or uncovered penstocks are usually supported on cradles and carried across ravines on trestles. Uncovered penstocks are generally costlier because they require other appurtenances such as expansion joints, saddles, anchors, etc. ; but they are easily accessible for inspection and repairs. It is not advisable to partially bury the penstock pipes, as the region near the ground surface will be subjected to excessive deterioration due to local movements. In a few cases, the penstocks can be replaced by constructing a tunnel through a hill, if a considerable saving in length can be gained.

(4) **Surge Tank or Surge Chamber.** The simplest type of a surge chamber consists of a cylindrical chamber open to the atmosphere and connected to the penstocks, as close to the power house as possible (Fig. 24.4).
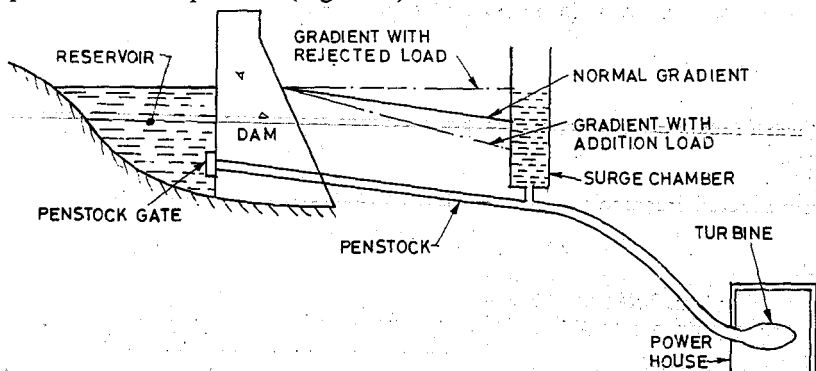


Fig. 24.4. Provisions of Surge chamber.

When the load is rejected by the power house turbines, the water level in the surge chamber rises, and decelerates the flow upstream of it. But when additional load comes, the immediate demand is met by drawing water from the surge chamber, which increases the flow gradient and thus accelerates the flow from the reservoir. When the load is steady, the water level in the surge chamber remains constant and at the level of normal hydraulic gradient line at that point, as shown in Fig. 24.4 A surge chamber, therefore, reduces the pressure fluctuations in the conduit pipe (*i.e.* penstocks) considerably, and thus prevents additional water hammer pressures from being exerted upon the walls of the conduit. The surge chamber should be high enough, to prevent any overflow of water, even at full load rejection.

Various types of surge chambers, such as (*i*) *Simple surge tank* (*ii*) *Throttled or Restricted orifice surge chamber,* (*iii*) *Differential surge chamber,* (*iv*) *Multiple surge chamber,* etc. are in use these days. The differential type of surge chamber is having a central riser pipe in addition to the main outer tank, as shown in Fig. 24.5.

Fig. 24.5.
Differential type of surge chamber.

The main advantage of differential type of surge tank over a simple tank lies in the fact that retarding and accelerating heads are developed more promptly in the former case than in the latter case. Hence, for a given amount of stabilising effect, the capacity of a differential type of surge chamber may be less than that of a simple elementary type.

(5) **Hydraulic Turbines.** Turbines are machines which convert hydraulic energy into mechanical energy. The mechanical energy so developed by the turbine is then used to generate electric energy by directly coupling the shaft of the turbine with the generator.

In general, a turbine consists of a wheel (called runner) which is provided with specially designed blades or buckets. The water having large hydraulic energy is made to strike the runner, and thus causing it to rotate. This rotation of the turbine runner is passed on to the generator by coupling the generator and turbine together through the turbine shaft. This results in rotating the generator armature, and thus producing electrical power, called hydroelectric power.

Hydraulic turbines may be divided into two classes :

   (*i*) Impulse turbines or Velocity turbines ; and

   (*ii*) Reaction turbines or Pressure turbines.

These are discussed below :

   (*i*) **Impulse turbines.** The important example of an impulse type of turbine is a *Pelton's wheel* or a *Pelton's turbine.* In such a turbine, all the available potential energy of water is converted into kinetic energy by passing the penstock water
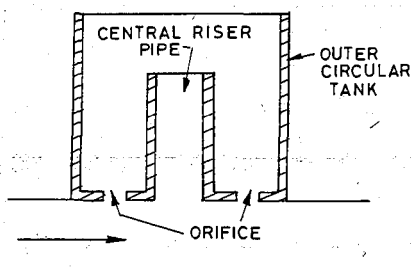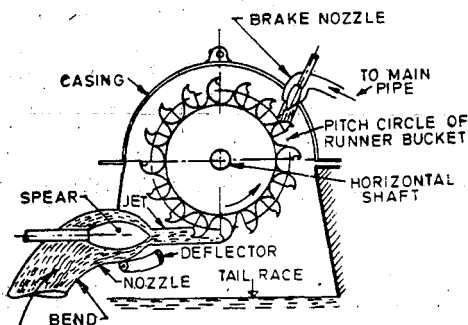
Fig. 24.6. Pelton's wheel (impulse turbine).

through a single nozzle. The water coming out of the nozzle in the form of free jet is made to strike on a series of buckets mounted on the periphery of a wheel (Fig. 24.6). This causes the wheel to revolve in open air, and water is in contact with only a part of the wheel at a time. The pressure of water is all along atmospheric, and thus there is no difference of pressure in the water at the inlet to the runner and at the outlet discharge to the tailrace. It also acts as a safeguard against accidents.

An impulse turbine is essentially a low speed turbine and is used for high heads of the order of 150 to 1,000 m (though heads of 1,700 to 1,800 m have been used in the world). Since it works under high heads, comparatively less quantity of water is required. It is, therefore used for high heads and low discharges.

(*ii*) **Reaction turbines.** The important examples of reaction turbines are : (*i*) *Francis turbine* ; and (*ii*) *Kaplan turbine.* A reaction turbine is one in which only a part of the potential energy of water is converted into velocity head (*i.e.* kinetic energy) and the balance remains as pressure head. Thus, the water entering the turbine possesses pressure as well as kinetic energy. The wheel is rotated under the action of both these forces. The water leaving the turbine also contains some pressure as well as velocity head. The pressure at the inlet is much higher than the pressure at the outlet. Since the entire flow takes place under pressure, a closed casing is absolutely necessary, so as to prevent any access of atmospheric air into the turbine. Since the water flows under pressure through such a turbine, the wheels of this turbine are submerged, and water enters all around the periphery of the wheel.

**Difference between Pelton's** (*i.e.* Impulse type) and **Francis** (*i.e.* Reaction type) **Turbines**

(1) In a Pelton's wheel, the total potential head is changed into kinetic head for affecting the motion of the runner ; while in a Francis wheel, only a part of it is converted.

(2) Water strikes only a few buckets at a time in Pelton's wheel ; while in Francis wheel, the water flows like that in a closed conduit. The runner is always full of water, and thus all the blades are simultaneously striken by water.

(3) In Pelton's wheel, the water falls freely to the atmosphere ; while in Francis wheel, the water is taken upto the tailrace by means of a closed draft tube, and thus, the whole passage of water is totally enclosed.

## Classification of turbines according to specific speed

The specific speed ($N_s$) of a turbine is the speed of geometrically similar turbine that would develop one metric horse power under a head of one metre. Specific speed is given by the equation

$$N_s = \frac{N\sqrt{P_t}}{H^{5/4}} \qquad \qquad ...(24.1)$$

where $N$ = Normal working speed of the turbine in RPM

$P_t$ = The turbine output in metric horse power

$H$ = Net or effective head in metres.

Table 24.1 shows the specific speeds of various turbines.

### Table 24.1. Specific Speeds of Various Turbines

| S. No. | Type of turbine | Limit of head in metres | Specific Speed in Revolution per minute [i.e. R.P.M.] |
|--------|-----------------|-------------------------|-------------------------------------------------------|
| 1. | Pelton turbine | Over 150 (High heads) | 10 to 35 |
| 2. | Francis turbine | 25 to 450 (Medium heads) | 60 to 300 |
| 3. | Kaplan and Propeller turbines[*] | 1 to 70 (Low heads) | 300 to 1,000 |

## Choice of a particular type of turbine

The selection of the type of a turbine primarily depends on head and load conditions. Different types of turbines can work satisfactorily only within a certain range of specific speeds (Table 24.1). At specific speeds greater than this usual range, there is a possibility of cavitation on the runner blades.

The variability of load also dictates the choice of a particular type of turbine. Say for example, for a head of 150 to 450 m or so ; from table 24.1, both Pelton's as well as Francis turbines can be used. But here the variability of load will influence the choice of a particular type. For higher range of heads, Pelton's wheel is preferred for part load operation in comparison to Francis turbine, although the Pelton's turbine involves higher initial cost. The quality of water also sometimes dictates the type of turbine to be chosen. For example, in the head range of 150 to 450 m, the choice of a Francis turbine is automatically ruled out, if sand is present in the water, because its runner will not be able to withstand its erosive action.

(6) **The Power House.** A power house is a building consisting of a *substructure* to support the hydraulic and electrical equipment and a *superstructure* to house and protect this equipment. For most of the plants which are equipped with reaction turbines, the substructure usually consists of a concrete block extending from the foundation to the generator floor with waterways (*i.e.* the scroll casings and draft tubes) formed within it. They are cast integrally while pouring concrete. The elevation of the turbine with respect to tail water level should be determined by the necessity of avoiding cavitation.

The superstructure is a building which generally accommodates the generators and excitors on the ground floor, and the switch board and control room on the mezzanine floor. Vertical turbines are placed just below the floor level beneath the generators, while horizontal turbines are placed on the ground floor along side the generators. The generating units are almost always arranged in a straight line across the direction of flow. A travelling crane spanning the width of the power house, is generally provided in every power house, so as to facilitate the lifting of heavy machines.

(7) **The Draft Tube.** The draft tube is a conduit which connects the outlet of a reaction turbine runner to the tailrace. Water, as it emerges out of the runner, flows through this pipe of gradually increasing diameter and comes to the tailrace level. The advantages of having a draft tube instead of letting the water fall directly into the atmosphere are :

(i) Effective pressure head is increased by an amount

$$= H_s + \frac{V_2^2 - V_3^2}{2g}$$

as explained below :

---

[*] Both Kaplan and Propeller turbines look alike and behave hydraulically in a similar fashion except that the Kaplan turbines have an additional arrangement of adjusting the inclination of the runner blades or vanes on the hub. This causes the Kaplan turbines to give higher efficiency even under part load conditions. *Kaplan turbines, cmpared to Propeller turbines, are therefore found to be more versatile, although costlier in their initial cost.*
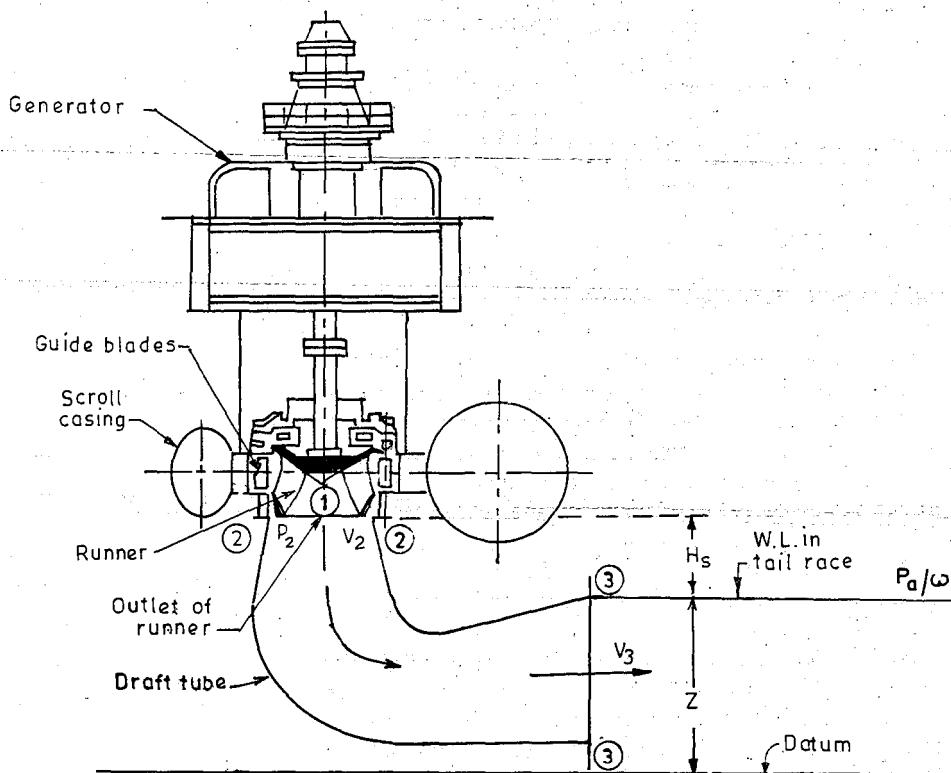
Fig. 24.7

Considering Fig. 24.7, we have

$$\frac{p_2}{\gamma_w} + Z + H_s + \frac{V_2^2}{2g} = \frac{p_a}{\gamma_w} + Z + \frac{V_2^2}{2g}$$

or

$$\frac{p_2}{\gamma_w} = \frac{p_a}{\gamma_w} + \frac{V_3^2}{2g} - \frac{V_2^2}{2g} - H_s = \frac{P_a}{\gamma_w} - \left( H_s + \frac{V_2^2}{2g} - \frac{V_3^2}{2g} \right)$$

Hence, the negative pressure created at the outlet of the runner

$$= H_s + \frac{V_2^2 - V_3^2}{2g} \; ;$$

this should not exceed the vacuum pressure of water.

So if by gradually increasing the diameter of this pipe, we are able to reduce the velocity $V_3 = 0$, then the net increase in head

$$= H_s + \frac{V_2^2}{2g}.$$

(*ii*) The draft tube permits the turbines to be installed at a higher level than the tailwater level, which facilitates the maintenance, etc. of the turbine.

*Outlet Gates.* The outlet of the draft tube should be provided with gates, so that the draft tube can be dewatered for repairs. If the span between tailrace piers is not too high, timber logs may be used for this purpose. However, for larger spans, steel stop logs or

steel gates are commonly used. A hoisting mechanism is also required for lifting the gates or stop logs.

(8) **The Tailrace.** The channel into which the water is discharged after passing through the turbines is known as the *Tailrace*. If the power house is close to the stream, the outflow may be discharged directly into the stream. But when the stream is far off from the power house, one may have to construct a channel of considerable length between the power house and the stream. The tailrace must be designed properly and should not be neglected. In many low-head plants, more of the gross head may be utilised at very low cost if full attention is paid to the tailrace design.

Proper design and maintenance of the tailrace is necessary, so as to avoid excessive aggradation (*i.e.* silting) or degradation (*i.e.* scouring) of its bed. Aggradation will raise the tail water level and reduce the gross available head at the plant. The degradation will lower the tail water level, and the process may proceed up to a point where the water level falls below the top of the draft tube. This will lead to unsatisfactory flow conditions, increased losses, reduced turbine efficiency, and possibility of cavitation and consequent damage to the turbine blades.

**Example 24.3.** *A run-off river plant is to be constructed across a river at a site where a net head of 22 m is available on the turbines. The river carries a sustained minimum flow of 26 cumecs as dry weather flow. Behind the power station, sufficient water pondage has been provided to supply daily peak load of demand with a load factor of 70%. Assuming the plant efficiency of 58%, determine :*

(i) *The maximum generating capacity of the generators to be installed at the power house.*

(ii) *The volume of pondage to be provided to supply the daily demand, assuming that the daily load pattern consists of average load for 21 hours and of peak load for 3 hours.*

**Solution.** The power produced (at dry weather flow) is given by eqn. (24.2), as

$$P = 9.81\,\eta \cdot Q \cdot H \text{ (in kW)}$$

$$\text{Here } \eta = 0.58$$
$$Q = 26 \text{ cumecs}$$
$$H = 22 \text{ m}$$

∴ $\qquad P = 9.81 \times 0.58 \times 26 \times 22 \text{ kW} = 3251 \text{ kW}$

$$\text{Load factor} \quad = \frac{\text{Av. load (Av. power)}}{\text{Peak load (Peak power)}}$$

∴ $\qquad 0.70 = \dfrac{3251}{\text{Peak load}}$

∴ $\quad$ Peak load $= \dfrac{3251}{0.7} = 4645 \text{ kW.}$

(i) Assuming there is no reserve capacity, we have the *Maximum capacity of the generators to be installed* = 4645 kW. **Ans.**

(ii) Excess water from pondage is drawn in order to meet the excess demand (demand in excess of average) for 3 hours.

Excess power reqd. to be developed during 3 hours

$$= \text{Peak demand} - \text{Av. demand}$$
$$= 4645 - 3251 = 1394 \text{ kW}$$

Excess discharge required for developing this excess power is given as

$$P = 9.81 \, \eta \cdot Q \cdot H$$

$$\therefore \qquad 1394 = 9.81 \times 0.58 \times Q \times 22$$

$$\therefore \qquad Q = \frac{1394}{9.81 \times 0.58 \times 22} = 11.15 \, m^3/sec.$$

This excess discharge is required for 3 hours each day.

$\therefore$ Required pondays per day

$$= 11.15 \times 3 \times 60 \times 60 = 12.04 \times 10^4 \, m^3 \quad \textbf{Ans.}$$

**Example 24.4.** *A run-off river plant with an installed capacity of 15,000 kW operates at 28% load factor when it serves as a peak load station :*

*(a) What should be the minimum discharge in the stream, so that it may serve as a base load station ? The plant efficiency may be assumed to be 80% when working under a head of 20 m.*

*(b) Also calculate the maximum load factor of the plant when the discharge in the stream is 35 cumecs.*

**Solution.** Installed capacity $= 15,000 \, kW$

$$\text{Load factor} = 28\%$$

$$\text{Load factor} = \frac{\text{Av. Load}}{\text{Peak Load}}$$

The installed capacity plant serving as peak load plant means that the Installed capacity = Peak load.

$$\therefore \qquad \text{Peak load} = \text{Installed capacity} = 15000 \, kW$$

$$\therefore \qquad 0.28 = \frac{\text{Av. load}}{15000}$$

$$\therefore \qquad \text{Av. load} = 15000 \times 0.28 = \textbf{4200 kW.}$$

*(a)* Now, when this plant has to serve as base load plant, it should develop average load, *i.e.* 4200 kW.

Hence, $Q$ reqd. to develop 4200 kW is given by :

$$P = 9.81 \, \eta \cdot Q \cdot H$$

or $\qquad\qquad 4200 = 9.81 \times 0.8 \times Q \times 20$

$$\therefore \qquad Q = \frac{4200}{9.81 \times 0.8 \times 20} = \textbf{26.78 cumecs. Ans.}$$

*(b)* When discharge in the stream is 35 cumecs, then power developed

$$= 9.81 \, \eta \cdot QH$$

$$= 9.81 \times 0.8 \times 35 \times 20 \, kW = \textbf{5488 kW.}$$

$$\text{Load factor} = \frac{\text{Av. power}}{\text{Peak power}} = \frac{5488 \, kW}{15000 \, kW} = 0.366, \, i.e. \, 36.6\%.$$

Hence, maximum load factor at 35 cumecs flow in the stream = **36.6 %. Ans.**

**Example 24.5.** *A run-off river plant is installed on a river having a minimum flow of 15 m³/sec. If the plant is used as a peak load plant operating only for 6 hours daily,[*] compute the firm capacity of the plant :*

*(a) without pondage ;*

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[*] Also called, *6 hours peaking plant.*

(b) *with pondage but allowing 8% water to be lost in evaporation and other losses. Head at the plant is 16 m, and the plant efficiency may be assumed as 80%.*

**Solution.** (a) Power developed by 15 m$^3$/sec discharge is given by

$$P = 9.81 \, \eta \cdot Q \cdot H$$
$$Q = 9.81 \times 0.8 \times 15 \times 16 = \textbf{1882 kW.}$$

This represents the firm capacity of the plant without pondage. **Ans.**

(b) With pondage, the total volume of water stored during 18 hours when the plant is not operating is

$$= 15 \times (18 \times 60 \times 60) \text{ m}^3 = 9.72 \times 10^5 \text{ m}^3$$

The loss of water due to evaporation, etc., per day

$$= 10\% \times 9.72 \times 10^5 \text{ m}^3 = 0.972 \times 10^5 \text{ m}^3$$

Net amount of available pondage per day

$$= (9.72 - 0.972) \, 10^5 \text{ m}^3 = 8.75 \times 10^5 \text{ m}^3$$

This daily pondage can supply a uniform $Q$, (reqd. for 6 hrs. only)

$$= \frac{8.75 \times 10^5}{6 \times 60 \times 60} \text{ m}^3/\text{sec} = 40.51 \text{ m}^3/\text{sec.}$$

∴ Total flow available for power generation (reqd. only for 6 hrs)

$$= (15 + 40.51) \text{ m}^3/\text{sec} = 55.51 \text{ m}^3/\text{sec}$$

∴ Power developed due to this discharge (*i.e.* firm power, because discharge is firm)

$$= 9.81 \cdot \eta \cdot Q \cdot H = 9.81 \times 0.8 \times 55.51 \times 16 = 6963 \text{ kW.}$$

Hence, the firm power developed by the plant (if pondage during rest hours is allowed) = **6963 kW.** **Ans.**

**Example 24.6.** *During a low water week, a river stream gets an average daily flow of 35 m$^3$/sec with daily fluctuations requiring a pondage capacity of about 16% of the daily flow.*

*A hydroelectric plant is to be located on this river, which will operate for 5 days a week, 24 hours a day, but will supply power at varying rates, such that the daily load factor is of 60%, corresponding to which the pondage required is 0.2 times the meanflow to the turbines. On saturdays and sundays, all the flow is ponded for use on rest of the days.*

*If the effective head on the turbine, when the pond is full is to be 26 m, and the maximum allowable fluctuation in pond level is 1.2 m, determine :*

*(i) the surface area of the pond to satisfy all the operating conditions ;*
*(ii) the weekly output at the switchboards in kWh.*

*Assume the turbine efficiency as 82% and generator efficiency as 90%.*

**Solution.**     $Q = 35 \text{ m}^3/\text{sec.}$

Now,  Daily flow $= 35 \times 24 \times 60 \times 60 = 3.024 \times 10^6 \text{ m}^3$

Pondage reqd. for discharge fluctuations

$$= 16\% \text{ of daily flow} = \frac{16}{100} \times 3.024 \times 10^6 \text{ m}^3$$

$$= 0.484 \times 10^6 \text{ m}^3 \qquad \qquad ...(i)$$

The discharge at the turbines is caused by the daily flow of 35 cumecs plus the discharge caused by the water stored during the two weekly rest days, *i.e.* saturday and sunday.

Now, *total water stored in 2 rest days*

$$= 2 \times \text{Daily flow} = 2 \times 3.024 \times 10^6 \text{ m}^3$$

$$= 6.048 \times 10^6 \text{ m}^3 \qquad \qquad ...(ii)$$

This stored water is utilised during the 5 working days in the week. Hence, the discharge obtained per day from this storage

$$= \frac{6.048 \times 10^6}{5} \text{ m}^3 = 1.2096 \times 10^6 \text{ m}^3.$$

The streamflow caused by this storage

$$= \frac{1.2096 \times 10^6}{24 \times 60 \times 60} \text{ m}^3/\text{sec} = 14 \text{ m}^3/\text{sec}.$$

∴ Total average flow to the turbines

$$= 35 + 14 = 49 \text{ m}^3/\text{sec}.$$

Hence, pondage required for load fluctuations

$$= 0.2 \times \text{Mean daily flow to turbines}$$

$$= 0.2 \times 49 \times (24 \times 60 \times 60) = 0.847 \times 10^6 \text{ m}^3 \qquad ...(iii)$$

Hence, the total ponding required

$$= (i) + (ii) + (iii)$$

$$= [0.484 \times 10^6 + 6.048 \times 10^6 + 0.847 \times 10^6] \text{ m}^3 = 7.379 \times 10^6 \text{ m}^3.$$

(*i*) With maximum variation of 1.2 m in pond level, we have the min. surface area of pond reqd. to accommodate $7.379 \times 10^6$ m$^3$ of water

$$= \frac{7.379 \times 10^6}{1.2} \text{ m}^2 = 6.15 \times 10^6 \text{ m}^2$$

$$= \frac{6.15 \times 10^6}{10^4} \text{ hectares} = \textbf{615 hectares.} \quad \textbf{Ans.}$$

Since the allowable max. fluctuation in pond level is 1.2 m, and the head at full level is 26 m, we have the average head on turbines

$$= \frac{26 + (26 - 1.2)}{2} = \frac{26 + 24.8}{2} = \frac{50.8}{2} = 25.4 \text{ m}.$$

(*ii*) ∴ Max. Power generated $= 9.81 \, \eta \cdot Q \cdot H.$

where η is the combined efficiency of turbines and generators

$$= 0.82 \times 0.90 = 0.738$$

$$Q = 49 \text{ m}^3/\text{sec}$$

$$H = 25.4 \text{ m}$$

∴ $\qquad P_{max} = (9.81 \times 0.738 \times 49 \times 25.4) \text{ kW} = 9001.4 \text{ kW}.$

With a daily load factor of 0.60, we have the average power developed = $0.6 \times$ Max. power

$$= 0.6 \times 9001.4 = 5400.8 \text{ kW.}$$

∴ Weekly power developed at the switchboard

$$= (5400.8 \times 5 \text{ days}) \text{ kW day}$$
$$= (5400.8 \times 5 \times 24) \text{ kWh} = 6,48,100 \text{ kWh}$$

Hence, weekly output at switchboard

$$= \textbf{6.481} \times \textbf{10}^5 \textbf{ kWh.} \quad \textbf{Ans.}$$

**Example 24.7.** *A run-of-stream station with an installed capacity of 15000 kW operates at 15% load factor when it serves as a peak load station. What should be the lowest discharge in the stream so that the station may serve as the base load station ? It is given that the plant efficiency is 75% when working under a head of 20 m.*

*(b) Also calculate the maximum load factor of the plant when the discharge in the stream rises to 20 cumecs.*

**Solution.** Installed capacity = 15000 kW

Load factor = 15%

Since the plant acts as peak load station, the installed capacity would be equal to the peak load.

Now,  Load factor $= \dfrac{\text{Average Load}}{\text{Peak Load}}$

∴  $0.15 = \dfrac{\text{Average Load}}{15000}$

∴  Average load $= 15000 \times 0.15 = \textbf{2250 kW.}$

In order that the plant can act as a base load station, it must supply 2250 kW average power. Using

$$P = 9.81 \, \eta \cdot Q \cdot H, \text{ we have}$$
$$P = 2250 \text{ kW}$$
$$\eta = 0.75 \quad \text{(given)}$$
$$Q = ?$$
$$H = 20 \text{ m.}$$

∴  $2250 = 9.81 \times 0.75 \times Q \times 20$

∴  $Q = \dfrac{2250}{9.81 \times 0.75 \times 20} = \textbf{15.31. m}^3\textbf{/sec.}$

Hence, the stream must carry a minimum discharge of 15.31 cumecs, in order to make the plant work as base load station. **Ans.**

(b) When $Q = 20$ cumecs, then power developed by the plant is given as :

$$P = 9.81 \, \eta \cdot QH$$
$$= 9.81 \times 0.75 \times 20 \times 20 = 2940 \text{ kW}$$

Load factor $= \dfrac{\text{Av. Load}}{\text{Peak Load}} = \dfrac{2940 \text{ kW}}{15000 \text{ kW}} = 0.196, \textit{i.e.} \textbf{ 19.6\%.} \quad \textbf{Ans.}$

**Example 24.8.** *The water turbines at a hydel storage plant produces 10,000 H.P.; when working under a net head of 30 m and with an overall efficiency of 80%. The inflow in the reservoir during a year is given below :*

**Table 24.1**

| Month | Inflow in million cu. m (M. cu. m) |
|-------|-------------------------------------|
| Jan. | 90 |
| Feb. | 80 |
| March | 73 |
| April | 80 |
| May | 70 |
| June | 98 |
| July | 120 |
| Aug. | 80 |
| Sep. | 96 |
| Oct. | 105 |
| Nov. | 100 |
| Dec. | 75 |

*Find (a) the minimum reservoir capacity reqd. to satisfy the uniform demand of water ; (b) the total quantity of water wasted during the year. Assume the reservoir to be full at the beginning of November. Use analytical method.*

**Solution.** The H.P. produced by turbines = 10,000

Since 1 H.P. = 0.736 kW, we have the power produced by turbines in kW units

$$= 10,000 \times 0.736 = 7360 \, kW.$$

Discharge reqd. to produce 7360 kW, $Q$, is given by

$$P = 9.81 \cdot \eta \cdot QH$$

where $\eta = 0.80$

$Q = ?$

$H = 30 \, m$

∴ $\qquad 7360 = 9.81 \times 0.80 \times Q \times 30$

or $\qquad Q = \dfrac{7360}{9.81 \times 0.80 \times 30} = 31.29 \, m^3/sec.$

∴ Flow reqd. during each month

$$= 31.29 \times (30 \times 24 \times 60 \times 60) = 81 \times 10^6 \, m^3 = \textbf{81 M. cum.}$$

It shows that 81 M. cum of flow is required to be compulsarily released in order to produce the requisite electric power. The inflow and this reqd. uniform outflow data is now analysed in Table 24.2 starting from Nov. onward (when reservoir is full) to

**Table 24.2**

| Month | Inflow in M. cum | Outflow in M. cum | Draft used from storage in M. cum. | Storage refill in M. cum. | Reservior depletion in M. cum | Water wasted M. cum |
|-------|------------------|-------------------|------------------------------------|---------------------------|-------------------------------|---------------------|
| Nov. | 100 | 81 | 0 | — | — | 19 |
| Dec. | 75 | 81 | 6 | — | 6 | — |
| Jan. | 90 | 81 | — | 6 | 0 | 3 |
| Feb. | 80 | 81 | 1 | — | 1 | — |
| March | 73 | 81 | 8 | — | 9 | — |
| April | 80 | 81 | 1 | — | 10 | — |
| May | 70 | 81 | 11 | — | 21 | — |
| June | 98 | 81 | — | 17 | 4 | — |
| July | 120 | 81 | — | 4 | 0 | 35 |
| Aug. | 80 | 81 | 1 | — | 1 | — |
| Sept. | 96 | 81 | — | 1 | — | 14 |
| Oct. | 105 | 81 | — | — | — | 24 |
| Σ | | | | | | 95 |

workout the storage used, refill, net reservoir depletion, and the water wasted, as shown in this table. The table is otherwise self explanatory.

(*a*) From this table, it can be seen that the max. reservoir depletion is **21 M. cum**, which evidently represents the minimum reservoir capacity required to satisfy the uniform demand. **Ans.**

(*b*) Total quantity of water wasted = **95 M. cum. Ans.**

## 24.5. Comparison of Hydro-power with Thermal Power with Reference to Indian Conditions

Water is available in abundance in India, and most of our important cities and other industrial or populated areas are situated within a maximum distance of say 500 km. from the main concentrations of hydro-resources. Hydro-power can, therefore, be easily developed in India along with other utilisations of our water resources, such as irrigation, navigation, flood control, city water supply, etc. The hydro-power has ultimately been found to be cheaper than the thermal power, although its exploitation entails large initial expenditure. It has been estimated, that on an average, the initial investment on a hydro project is about 25% more than that on a thermal project. But, the recurring cost on a hydro project is much less than that on a thermal project, and hence, the hydropower finally comes out to be more economical. Besides these economic considerations, hydropower has been mainly produced in India as a side product during the development of river valleys for irrigation and flood control.

Hydropower is much more important than thermal power in India, mainly because we do have almost inexhaustible water resources in our country, and the same is available in the vicinity of most of our needy areas. In sharp contrast to this, the coal, which is the only cheap and conventional source of thermal power, is confined only to a few regions, and has to be transported over long distances. Hence, in areas which are far away from coal bearing regions, hydropower is the only choice. Moreover, the amount of coal available in our country, is limited in quantity and, therefore, cannot be used infinitely without proper planning for the future. It can be stated that due to various inherent advantages which the hydropower possesses over thermal power, the use of hydropower has been found justifiable on overall economic considerations even in areas close to the collieries in Andhra Pradesh, Madhya Pradesh, Orissa, etc. But in areas, where hydropower has also been fully tapped, we have to think of nuclear or other thermal resources. *Pumped storage plants* may also be thought of in such areas, and their possibilities should also be investigated. ·

In addition to these advantages, the hydro power is considered to be environmental friendly as compared to thermal power, since thermal power generation causes tremendous air pollution, directly affecting the health of the public.

Besides all these advantages of hydropower over thermal power, there is one serious limitation of hydropower. The limitation is that the hydro power production is totally dependent upon rainfall. Though hydro-projects are designed on a very conservative basis of planning on minimum water that would be available for 90 out of 100 years from a catchment, still there may be some periods when reservoirs do not fill up. If this happens throughout the country, the power position will become difficult. This has

happened in 1972 monsoon, when practically all the reservoirs were only half full, resulting in a sudden and drastic power shortage.

Taking such contingencies into account, it can finally be concluded that we must develop a combined system of power production. Hydropower should be exploited to as much extent as possible, and sufficient thermal power reserve should be kept to supplement the hydropower during the times of water crisis.

## 24.6. Hydropower Potentials of India

India has a vast potential for hydropower generation, particularly in the northern and north-eastern regions. As per an estimate made by the Central Electricity Authority, the potential of the country is assessed at 84 G.W.[*] at 60% load factor[**] (i.e. 140 GW of installed capacity), which is equivalent to about 440 billion units+ (kWh) of annual energy generation at a power factor of 0.6. The basin wise distribution of hydropower potential and developed hydropower is shown in Fig. 24.8.

The development of hydropower began in India, sometimes in the year 1897, when a 300 kW power station was installed at Darjeeling. It was followed by a power station at Sivasamundram in Mysore State, in 1902. It was then followed by a 50 MW Tata Hydro Electric project of Bombay City in 1914. The process of installation of hydro power projects was slow before independence, but it gathered a lot of momentum after India became free. So much so, that the hydropower production which was hardly 0.5 GW[*] before independence has gone to as high a value as 13.2 GW (at 60% load factor) by the end of 8th five year plan (i.e. March 1997). Another 6 GW shall be available from the projects which are under construction, and 3 GW from the projects which have been cleared for execution.

As stated above, the 1997 figure of developed power of 13.2 GW and the total potential of 84 GW are the values at 60% load factor[**], which means that the presently installed capacity (1997) equals 13.2/0.6 = 22 GW, as against the potential (installed capacity) of 84/0.6 = 140 GW, respectively, as shown in Fig. 24.8.

This estimated economically exploitable hydropower potential of 84 GW (at 60% L.F.) for India is quite low in comparison to the corresponding World figure of 4200 GW. Against our potential of 84 GW or 440 bkWh[+], we have so far installed only 13.2 GW i.e. 69 bkWh[++], which is only about 15.7% of the potential of 84 GW (440 bkWh). It evidently shows that a lot of work is still left to be done in this direction. The power potentials and power exploited on different river basins of India are shown in Fig. 24.8. It can be seen from this figure that Brahmaputra river basin has the maximum potential (35 GW), though least (0.5 GW) has been exploited. A lot of work is also left to be done on Indus and Ganga basins.

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[*] 1 GW (giga watt) = $10^9$ watts = 1 million kW = 1 MkW
　1 TW (trillion watt) = $10^{12}$ watts. = $10^9$ kW = 1 billion kW = 1 b kW
　[**] 60% load factor means that the installed machines are run, on an average, to give output capacity equal to 60% of the station capacity. This is so, because machines will not always be run at the installed station capacity but will be run, on an average, at 60% of this capacity.
　[+] 84 GW is equivalent to = 84 × 365 × 24 (0.6 i.e. P.F) GWh = 441504 GWh : say 440 TWh. i.e. 440 b kWh.
　[++] 13 GW is equivalent to 13 × 365 × 24 × 0.6 (P.F) GWh = 68328 GWh : say ≈ 68 b kWh
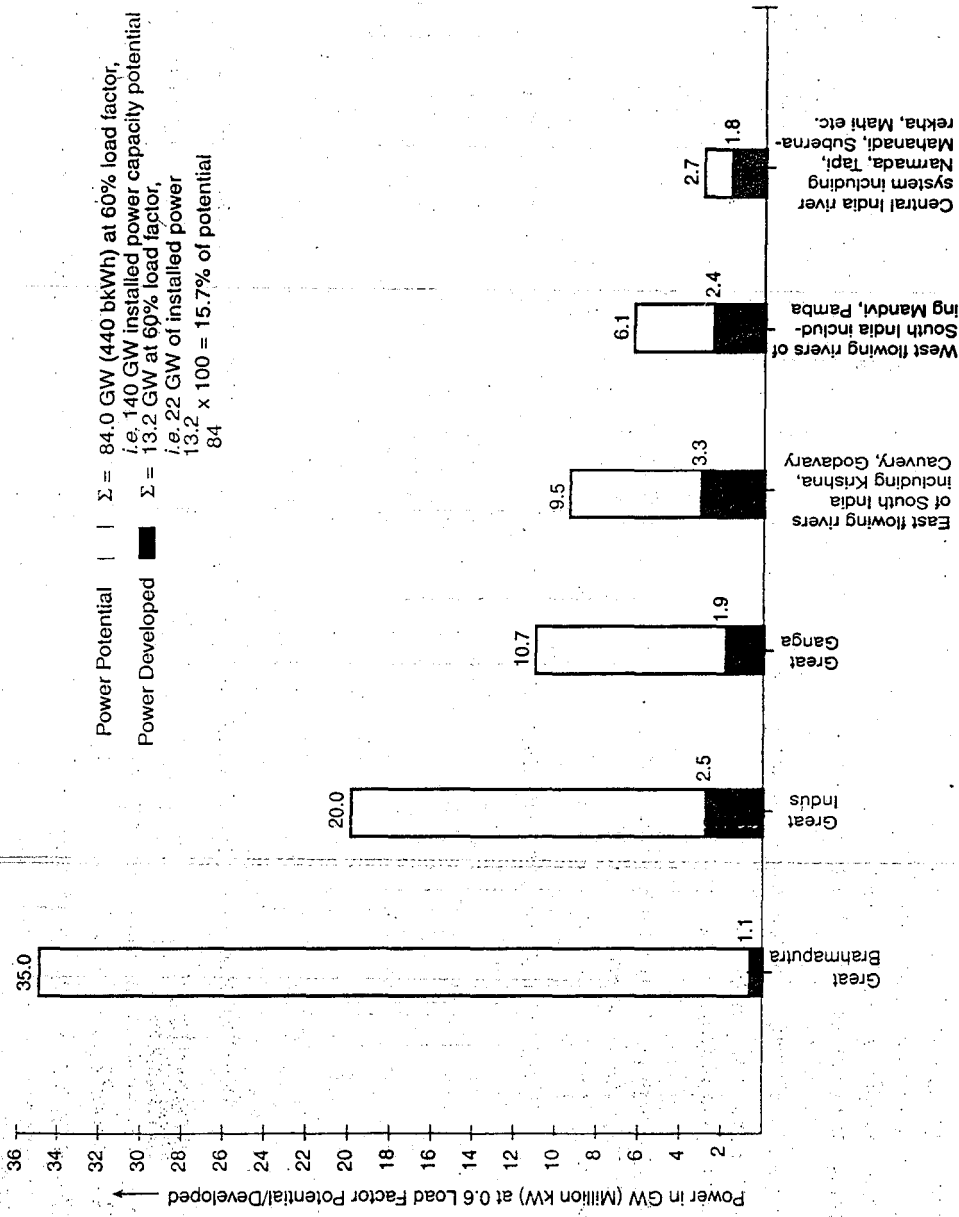
Fig. 24.8. Power potential and Power exploited in India upto 1997 (end of 8th plan) at 60% load factor

The developed hydropower capacities in India at the end of different plan periods in comparison to total power (*i.e.* hydro + thermal + nuclear) are indicated in table 24.3.

**Table 24.3. Developed Hydro Power and Total Power in India at 60% Load Factor**

| Year end | Installed capacity in GW (MkW) | | %age of hydropower w.r. to total power |
|---|---|---|---|
| | Hydropower | Total power (Hydro + Thermal + Nuclear + Others) | |
| 1950 | 0.34 | 1.71 | 19.6 |
| 1956 | 0.64 | 2.89 | 22.02 |
| 1960-61 | 1.15 | 4.65 | 24.7 |
| 1965-66 | 2.47 | 9.03 | 27.4 |
| 1968-69 | 3.54 | 12.96 | 27.4 |
| 1974-75 | 4.52 | 18.32 | 24.7 |
| 1983-84 | 8.34 | 39.30 | 21.9 |
| 1985-86 | 9.30 | 46.80 | 19.9 |
| 1989-90 | 11.14 | 64.73 | 17.3 |
| 1996-97 (end of 8th plan) | 13.2[*] (69 bkWh) | 83.0[**] (435 bkWh) | 15.9 |

*Against the potential target of 140 GW.
**Contains only about 2.5 MkW of nuclear power.

In India, the nuclear power generation is only about 3% of the total power generation, (including hydropower, thermal power, nuclear power and power from non-convention energy sources like wind power & solar power). The nuclear power is highly cost intensive[*], Whereas thermal power involves huge fuel and R of M (Running of Maintenance) cost particularly for plants located far away from coal mines, or petro gas locations. The disposal of waste coal ash and air pollution caused by thermal power is also a costlier exercise, as compared to the present day cost being incurred for disposal of radioactive nuclear wastes, since such wastes can, through an expensive reprocessing, may lead to recovery of very costly plutonium, which may offset the cost of reprocessing and solve the problem of disposal of such nuclear radioactive wastes.

The Indian *Department of Atomic Energy* (DAE) is, therefore, planning to step up production of nuclear power as to boost its generation from 3% to 8% of the total electricity generation in the next 15 years. Whereas, the Deptt of Atomic Energy has calculated the nuclear power to be cheaper than the thermal power on an annual discounting of capital cost at about 8%, yet these calculations, based on various assumptions, have not been accepted by many, such as from Mr. Ramana, a fellow at *the centre for Interdisciplinary Studies in Environment and Development Bangalore,* and Mr. Amulya K.N. from the *International Energy Initiative.* Be that as it may, we need a mixed bag of various types of powers, since coal is an exhaustible source and cannot continue for ever. Hence, the aim of DAE to increase nuclear power production should not be opposed by saying that it is costlier than the thermal power or because of its high initial cost.

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* The capital cost incurred on recent installation of two units of nuclear reactors of 220 MW each at the *Kaiga atomic power station ( Kaiga I & II)* was about Rs. 2900 crores with additional initial fuel loading cost of Rs. 1045 crores for heavy water and Rs. 84 crores for Uranium, as compared to Rs. 612 crores spent on installing *Raichur Thermal Power Station VII,* both plants being of similar size, of recent vintage, and far away from coal supplies.

## 24.7. Electricity Generation from Various Sources in the World

The electricity generation from different sources in bkWh in various countries of the world are shown in table 24.4.

### Table 24.4.Electricity Generation from Different Sources in Verious Countries of the World

| Name of Country | Total Electricity production in Billion kWh 1996 | % age of production of electricity from different sources | | | | |
|---|---|---|---|---|---|---|
| | | Hydro power % 1996 | Coal % 1996 | Oil % 1996 | Gas % 1996 | Nuclear power % 1996 |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Algeria | 20.7 | 0.7 | — | 3.6 | 95.7 | — |
| Argentina | 69.8 | 32.9 | 2.2 | 5.4 | 48.3 | 10.7 |
| Australia | 177.0 | 8.7 | 78.9 | 1.6 | 9.0 | — |
| Austria | 53.5 | 64.0 | 11.5 | 3.7 | 17.5 | — |
| Bangladesh | 11.5 | 6.4 | — | 6.5 | 87.1 | — |
| Belarus | 23.7 | 0.1 | — | 29.1 | 70.8 | — |
| Belgium | 75.2 | 0.3 | 24.2 | 1.7 | 14.6 | 57.6 |
| Bolivia | 3.2 | 63.0 | — | 6.2 | 29.6 | — |
| Brazil | 289.8 | 91.7 | 1.6 | 3.1 | 0.2 | 0.8 |
| Bulgaria | 41.5 | 4.0 | 41.9 | 3.2 | 7.2 | 43.6 |
| Canada | 570.6 | 62.4 | 16.2 | 1.6 | 2.9 | 16.3 |
| Chile | 30.8 | 54.8 | 35.1 | 8.4 | 1.0 | — |
| China | 1080.0 | 17.4 | 75.0 | 6.0 | 0.2 | 1.3 |
| Hong Kong, China | 28.4 | — | 98.4 | 1.6 | — | — |
| Colombia | 44.6 | 79.1 | 6.9 | 0.5 | 12.8 | — |
| Cuba | 13.2 | 0.7 | — | 92.2 | 0.1 | — |
| Czech Republic | 63.8 | 3.1 | 73.3 | 1.1 | 1.2 | 20.1 |
| Denmark | 53.6 | 0.0 | 74.0 | 10.8 | 10.7 | — |
| Egypt, Arab Republic | 57.6 | 18.8 | — | 37.1 | 44.1 | — |
| Finland | 69.4 | 17.1 | 31.8 | 1.9 | 12.3 | 28.1 |
| France | 508.1 | 12.8 | 6.1 | 1.5 | 0.8 | 78.2 |
| Germany | 550.6 | 4.0 | 55.0 | 1.4 | 8.7 | 29.1 |
| Ghana | 6.0 | 99.9 | — | 0.1 | — | — |
| Greece | 42.3 | 10.3 | 69.3 | 20.2 | 0.2 | — |
| Guatemala | 4.3 | 74.3 | — | 20.6 | — | — |
| Hungary | 35.1 | 0.6 | 28.3 | 12.6 | 18.1 | 40.4 |
| India | 435.1 | 15.9 | 73.2 | 2.8 | 6.2 | 1.9 |
| Indonesia | 67.1 | 13.3 | 25.9 | 25.4 | 32.0 | — |
| Iran, Islamic Republic | 90.9 | 8.1 | — | 37.1 | 54.7 | — |
| Iraq | 29.0 | 2.0 | — | 98.0 | — | — |
| Ireland | 18.9 | 3.8 | 48.4 | 14.2 | 33.2 | — |
| Israel | 32.5 | 0.2 | 68.9 | 30.9 | — | — |
| Italy | 239.5 | 17.6 | 10.6 | 48.9 | 21.0 | — |

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| Jamaica | 6.0 | 2.1 | — | 93.3 | — | — |
| Japan | 1003.2 | 8.0 | 18.2 | 21.0 | 20.2 | 30.1 |
| Jordan | 6.1 | 0.4 | — | 87.6 | 12.0 | — |
| Kenya | 4.0 | 81.6 | — | 8.8 | — | — |
| Korea Dem Republic | 35.0 | 64.3 | 35.7 | — | — | — |
| Kuwait | 25.5 | — | — | 21.7 | 78.3 | — |
| Malaysia | 51.4 | 10.1 | 6.4 | 12.3 | 71.2 | — |
| Mauritius | — | — | — | — | — | — |
| Mexico | 162.5 | 19.3 | 10.9 | 50.1 | 11.3 | 4.8 |
| Morocco | 12.4 | 15.7 | 44.9 | 39.4 | — | — |
| Myanmar | 4.3 | 38.3 | 0.1 | 15.9 | 45.7 | — |
| Nepal | 1.2 | 90.2 | — | 9.8 | — | — |
| Netherlands | 85.0 | 0.1 | 31.6 | 4.6 | 55.6 | 4.9 |
| New Zealand | 36.2 | 71.2 | 3.0 | 0.0 | 17.8 | — |
| Niger | — | — | — | — | — | — |
| Nigeria | 15.0 | 36.7 | — | 26.1 | 37.2 | — |
| Norway | 104.5 | **99.2** | 0.2 | — | 0.3 | — |
| Pakistan | 57.0 | 40.7 | 0.8 | 30.8 | 26.8 | 0.8 |
| Peru | 17.3 | 77.1 | — | 20.9 | 1.3 | — |
| Philippines | 36.7 | 19.3 | 13.2 | 49.6 | 0.1 | — |
| Poland | 141.2 | 1.4 | 96.8 | 1.2 | 0.3 | — |
| Portugal | 34.4 | 42.9 | 36.6 | 17.5 | — | — |
| Romania | 61.4 | 25.7 | 33.9 | 10.9 | 27.2 | 2.3 |
| Russian Federation | 846.3 | 18.2 | 18.5 | 9.4 | 40.4 | 12.9 |
| Saudi Arabia | 97.8 | — | — | 57.1 | 42.9 | — |
| Singapore | 24.1 | — | — | 78.7 | 18.6 | — |
| South Africa | 198.3 | 0.7 | 93.2 | — | — | 5.9 |
| Spain | 173.4 | 23.0 | 31.5 | 8.0 | 3.9 | 32.5 |
| Sri Lanka | 4.5 | 71.8 | — | 28.2 | — | — |
| Sweden | 139.6 | 36.9 | 3.0 | 5.2 | 0.3 | 52.5 |
| Switzerland | 55.6 | 51.0 | 0.0 | 0.5 | 1.2 | 45.2 |
| Syrian Arab Republic | 17.0 | 40.8 | — | 29.1 | 30.0 | — |
| Thailand | 87.5 | 8.4 | 20.0 | 39.3 | 42.0 | — |
| Turkey | 94.9 | 42.7 | 32.1 | 6.9 | 18.1 | — |
| United Arab Emirates | 19.7 | — | — | 17.1 | 82.9 | — |
| United Kingdom | 346.3 | 1.0 | 42.4 | 4.0 | 23.6 | 27.3 |
| United States | **3652.0** | 9.6 | 52.7 | 2.6 | 13.2 | 19.6 |
| Vietnam | 16.9 | 0.0 | 14.0 | 8.6 | 77.3 | — |

**Note.** Totals of Col. (2) to (7) infront of a particular country may not total to 100%, since other sources generating electricity, such as geothermal, solar & wind, are not shown here.

# PROBLEMS

**1.** (*a*) What is meant by Hydro-power ? Compare hydro-power with thermal power w.r. to Indian conditions.

(*b*) Enumerate the different types of hydel plants, and describe the 'storage plant'.

**2.** (*a*) How do you classify a hydro-electric scheme on the basis of its operating head.

(*b*) Define and differentiate between the following in connection with hydropower :

    (*i*) Firm and secondary power.

    (*ii*) Load factor, utilisation factor and plant factor.

    (*iii*) Installed and dependable capacity of a power house.

    (*iv*) Design head, rated head, gross head, operating head and effective head.

**3.** What are the principal components of a hydro-electric scheme ? Discuss the utility of each component.

**4.** (*a*) Write a brief note on the use and types of 'turbines' in a hydroelectric scheme.

(*b*) What is a 'surge tank', and what are its types and uses ?

(*c*) What is a 'draft tube', and what are its uses ?

**5.** Write short notes on :

    (*i*) Hydropower potential of India.

    (*ii*) Hydropower *vs.* thermal power.

    (*iii*) Surge tanks and their types.

    (*iv*) Hydraulic turbines and their types.

    (*v*) Trash racks.