

Module 5

HYDROPOWER ENGINEERING

LESSON

1

PRINCIPLES OF HYDROPOWER ENGINEERING

Instructional objectives

On completion of this lesson, the student shall learn about:

1. Potential of hydropower that may be generated from a stream
2. Hydropower potential in India and the world
3. Types of hydropower generation plants
4. layouts of hydropower plants

5.1.0 Introduction

The water of the oceans and water bodies on land are evaporated by the energy of the sun's heat and gets transported as clouds to different parts of the earth. The clouds travelling over land and falling as rain on earth produces flows in the rivers which returns back to the sea. The water of rivers and streams, while flowing down from places of higher elevations to those with lower elevations, lose their potential energy and gain kinetic energy. The energy is quite high in many rivers which have caused them to etch their own path on the earth's surface through millions of years of continuous erosion. In almost every river, the energy still continues to deepen the channels and migrate by cutting the banks, though the extent of morphological changes vary from river to river. Much of the energy of a river's flowing water gets dissipated due to friction encountered with its banks or through loss of energy through internal turbulence. Nevertheless, the energy of water always gets replenished by the solar energy which is responsible for the eternal circulation of the Hydrologic Cycle.

Hydropower engineering tries to tap this vast amount of energy available in the flowing water on the earth's surface and convert that to electricity. There is another form of water energy that is used for hydropower development: the variation of the ocean water with time due to the moon's pull, which is termed as the tide. Hence, hydropower engineering deals with mostly two forms of energy and suggest methods for converting the energy of water into electric energy. In nature, a flowing stream of water dissipates throughout the length of the watercourse and is of little use for power generation. To make the flowing water do work usefully for some purpose like power generation (it has been used to drive water wheels to grind grains at many hilly regions for years), it is necessary to create a head at a point of the stream and to convey the water through the head to the turbines which will transform the energy of the water into mechanical energy to be further converted to electrical energy by generators. The necessary head can be created in different ways of which two have been practically accepted.

These are:

1. Building a dam across a stream to hold back water and release it through a channel, conduit or a tunnel (Figure 1)

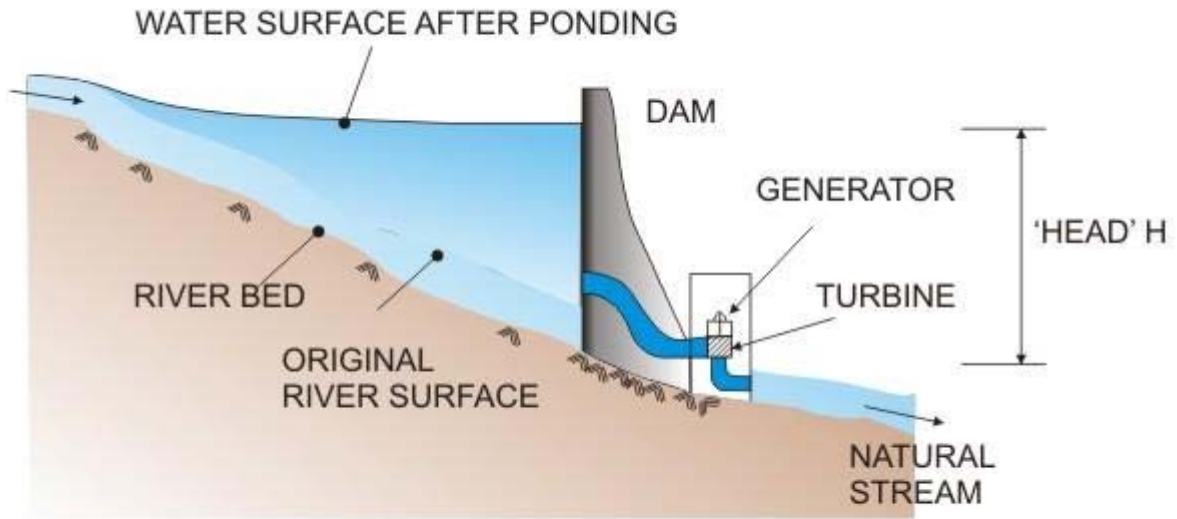


FIGURE 1. Creation of head by constructing a dam

2. Divert a part of the stream by creating a low-head diversion structure like barrage. (Figure 2)

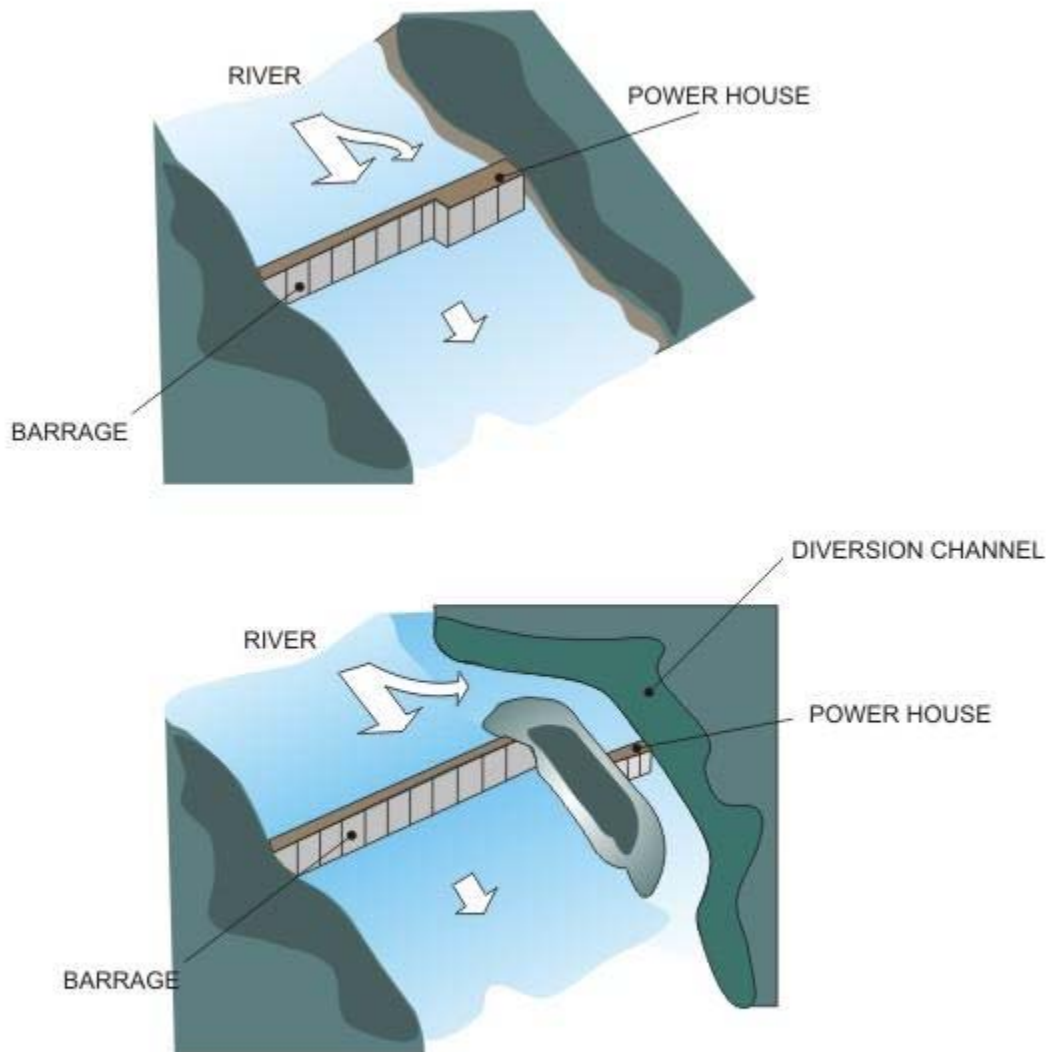
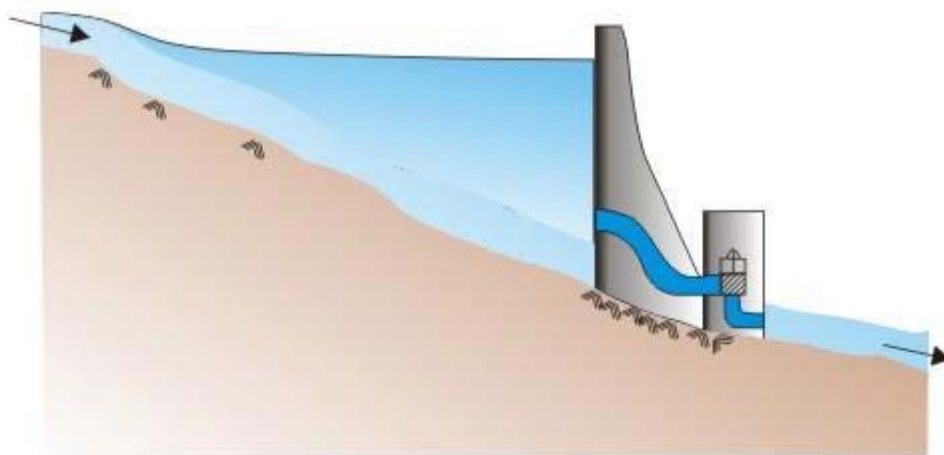
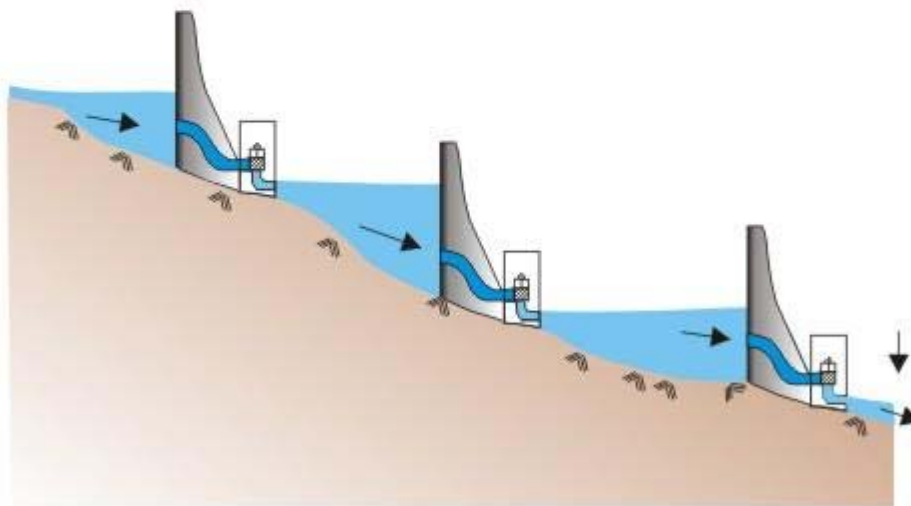


FIGURE 2. Power generation through streamflow diversion
 (a) Power house as a part of diversion structure
 (b) Power house on diversion channel

A series of integrated power developments along the same watercourse form what may be called a multistage hydroelectric system in which each portion of the river with a power plant of its own is referred to as a stage (Figure 3). The head created by a dam put across a lowland river usually ranges from 30 to 40m. In mountainous terrain, it may run over 200m.



(a)



(b)

FIGURE 3 . (a) Single-stage hydro-power development scheme
(b) Cascade or Multi-stage hydro-system

The following sections briefly discuss the issues related to the fundamentals of hydropower project development.

5.1.1 Hydropower potential

Electricity from water is usually referred to as Hydro-Power, where the term 'hydro' is the Greek word for water and hydropower is the energy contained in water. It can be converted in the form of electricity through hydroelectric power plants. All that is required is a continuous inflow of water and a difference of height between the water level of the upstream intake of the power plant and its downstream outlet.

In order to evaluate the power of flowing water, we may assume a uniform steady flow between two cross-sections of a river, with **H** (metres) of difference in water surface elevation between two sections for a flow of **Q** (m³/s), the power (**P**) can be expressed as

$$P = \gamma Q \left(H + \frac{v_1^2 - v_2^2}{2g} \right) \quad [\text{Nm/s}]$$

where **v**₁ and **v**₂ are the mean velocities in the two sections. Neglecting the usually slight difference in the kinetic energy and assuming a value of γ as 9810N/m², one obtains the expression of power as

$$P = 9810QH \quad [\text{Nm/s}]$$

Since an energy of 1000Nm/s can be represented as 1kW (1kilo-Watt), one may write the following:

$$P = 9.81QH \quad [\text{kW}]$$

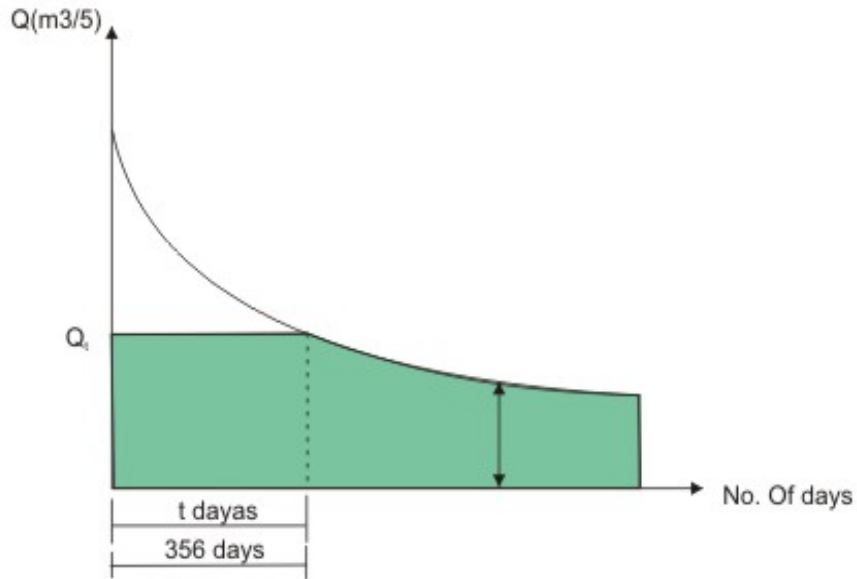
The above expression gives the theoretical power of the selected river stretch at a specified discharge.

In order to evaluate the potential of power that may be generated by harnessing the drop in water levels in a river between two points, it is necessary to have knowledge of the hydrology or stream flow of the site, since that would be varying everyday. Even the average monthly discharges over a year would vary. Similarly, these monthly averages would not be the same for consecutive years. Hence, in order to evaluate the hydropower potential of a site, the following criteria are considered:

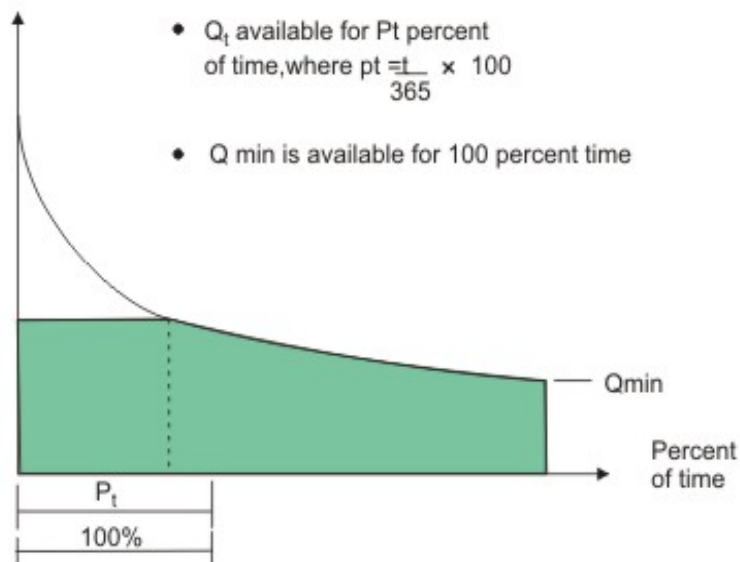
1. Minimum potential power is based on the smallest runoff available in the stream at all times, days, months and years having duration of 100 percent. This value is usually of small interest
2. Small potential power is calculated from the 95 percent duration discharge
3. Medium or average potential power is gained from the 50 percent duration discharge
4. Mean potential power results by evaluating the annual mean runoff.

Since it is not economically feasible to harness the entire runoff of a river during flood (as that would require a huge storage), there is no reason for including the entire magnitude of peak flows while calculating potential power or potential annual energy.

Hence, a discharge-duration curve may be prepared (Figure 4) which plots the daily discharges at a location in the decreasing order of magnitude starting from the largest daily discharge observed during the year and going upto the minimum daily discharge.



(a)



(b)

FIGURE 4. Flow curve for one year (a) expressed in time; (b) expressed in percentage of time

From this annual discharge curve, a truncation is made at a discharge Q_t which is the discharge corresponding to a time of 't' days, where t can be the median (say, 182 days or 50 percent duration, denoted by (Q_{182} or $Q_{50\%}$), or a higher Q_t (t less than 182 days) can be selected by specialists who are familiar with the local conditions and future plans for power supply. Accordingly, the annual magnitude of potential (theoretical) energy can be computed in KWh as below and referring to Figure 4:

$$E_p = 24 \times 9.81H \left(Q_t + \sum_i^{365} Q_i \right)$$

$$\approx 235H \cdot A \quad (\text{in kWh})$$

Where Q_i denotes the daily mean flow during the period 365-t days and A, the hatched area cut by Q_t , where the area under the curve has a unit $m^3 \times \text{day/s}$.

The massive influx of water in the hydrologic cycle has an estimated potential for generating, on a continuous basis, 40,000 billion units (TWh) of power annually for the whole world (CBIP, 1992). Hydropower potential is commonly divided into three categories:

- a) **Theoretical** : 40,000 TWh
- b) **Technical** : 20,000 TWh
- c) **Economical** : 9,800 TWh

The terms used above are explained below:

Theoretical

The gross theoretical potential is the sum of the potential of all natural flows from the largest rivers to the smallest rivulets, regardless of the inevitable losses and unfeasible sites.

Technical

From technical point of view, extremely low heads (less than around 0.5m), head losses in water ways, efficiency losses in the hydraulic and electrical machines, are considered as infeasible. Hence, the technically usable hydro potential is substantially less than the theoretical value.

Economic

Economic potential is only that part of the potential of more favourable sites which can be regarded as economic compared to alternative sources of power like oil and coal. Economically feasible potential, therefore, would change with time, being dependent upon the cost of alternate power sources. This potential is constantly updated and shows an increasing trend with the exhausting stock of fossil fuel.

The following table taken from CBIP (1992) shows a continental break-up of world's economical hydropower potential. Asia is seen to be endowed with the maximum hydropower potential.

Region	Available potential (Billion units)
Asia (except C.I.S and Russia)	2700
C.I.S and Russia	1100
Africa	1590
North America	1580
South America	1910
Europe(except C.I.S and Russia)	720
Oceania	200
Total	9800

Some nations have enough hydropower to become exporters of electricity. Switzerland, for example, exports electricity to neighbouring France and Italy. Nepal, Bhutan, Peru and Laos are similarly blessed with abundant hydro resources. Within India, Meghalay is probably the only state generating hydropower more than its requirements and exports power to the neighbouring state of Assam.

In India, it has been estimated by the Central Electric Authority, that the hydroelectric potential of the entire country is around 84,044MW at 60 percent load factor. The annual energy contribution of this potential would be about 600 billion units including seasonal/secondary energy which is the additional energy generation in any year above the firm annual energy. Basin wise potential within the country is shown in Figure 5.

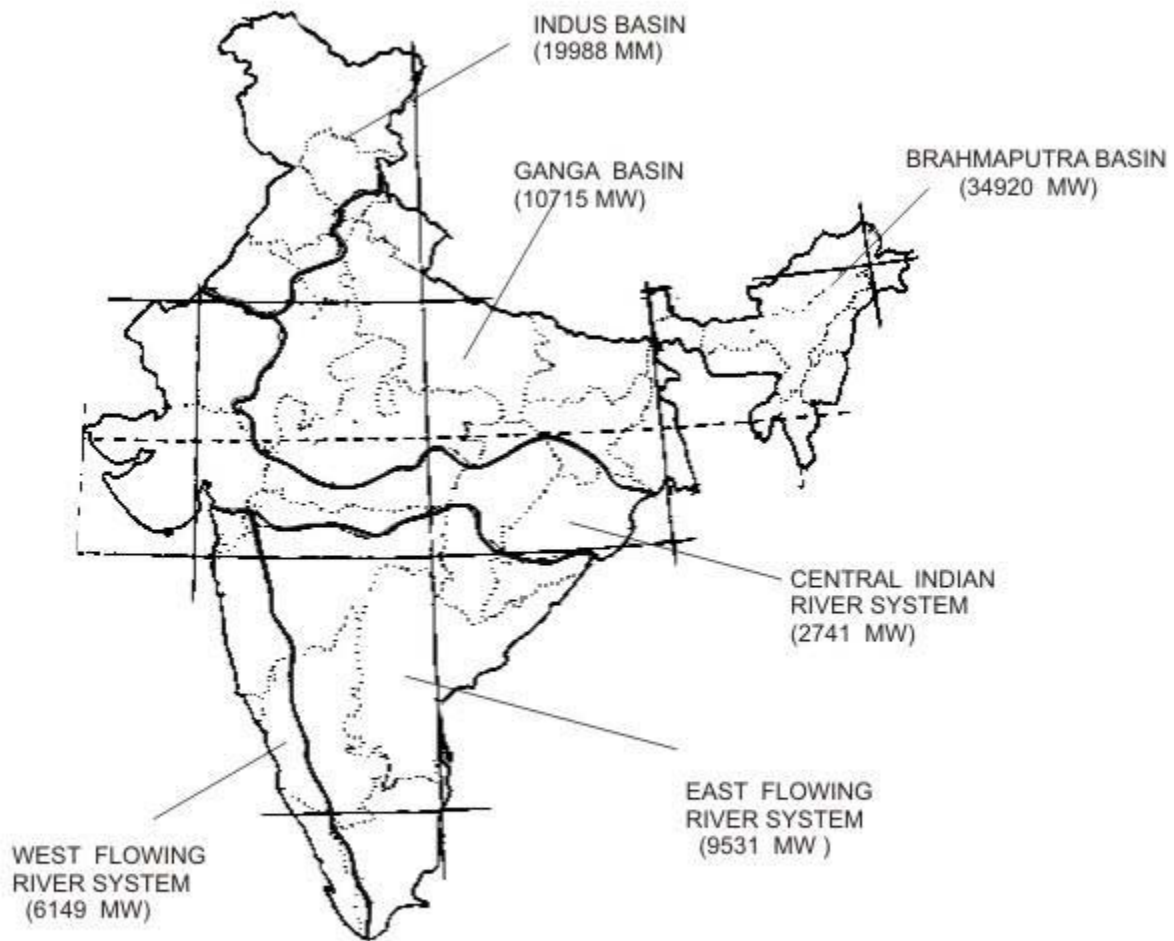


FIGURE 5. Basin-wise hydro power potential of India.

5.1.2 Types of hydroelectric projects

Hydroelectric plants are classified commonly by their hydraulic characteristics, that is, with respect to the water flowing through the turbines that run the generators. Broadly, the following classifications, made are shown in Figure 6.

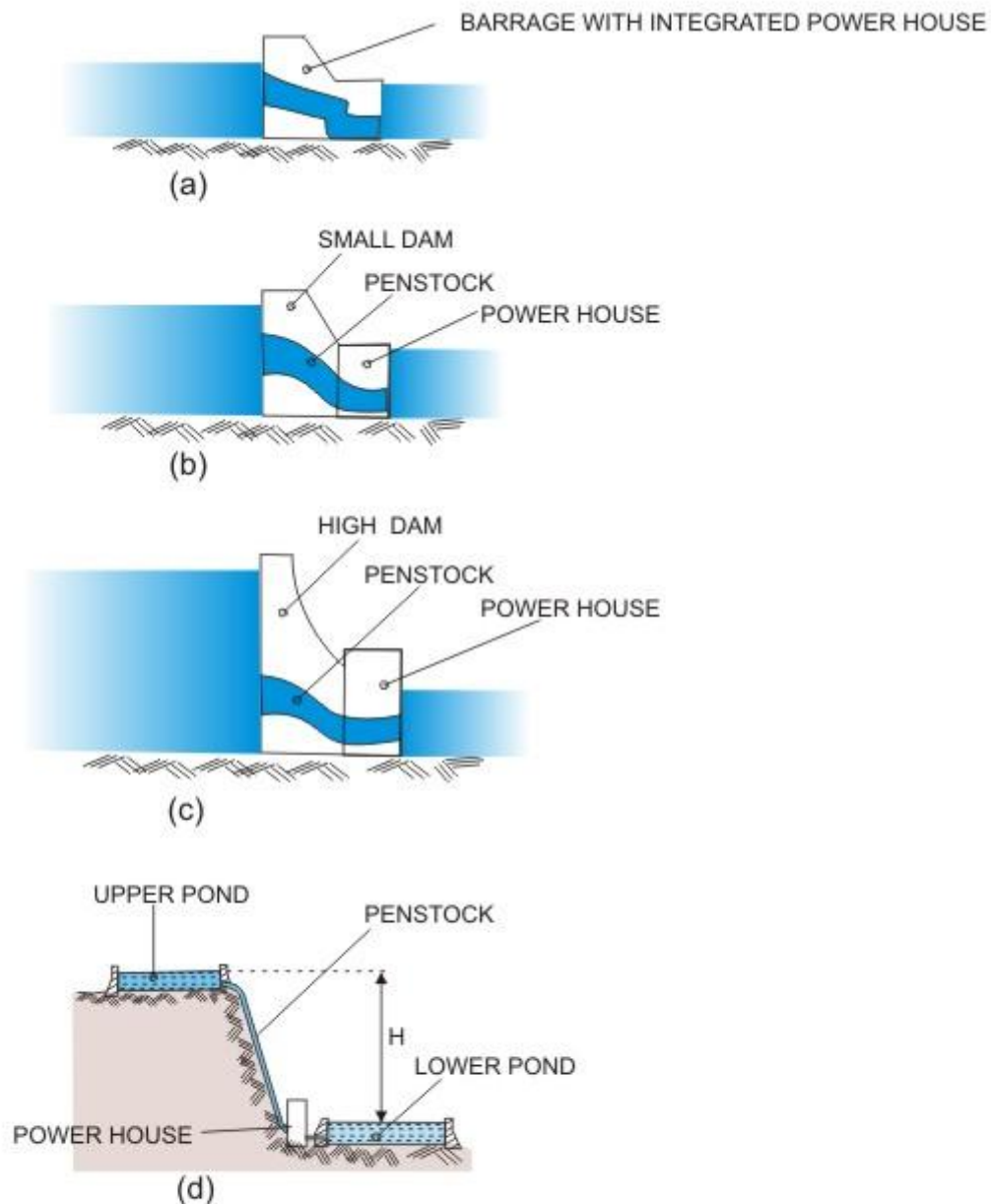


FIGURE 6. Types of hydroelectric schemes

- (a) Run-of-river without pondage (little or no storage)
- (b) Run-of-river with pondage (storage suitable to balance diurnal variation in power generation)
- (c) Storage schemes (reservoirs to store excess water of flood flows)
- (d) Pump-storage schemes

1. Run-of-river schemes

These are hydropower plants that utilize the stream flow as it comes, without any storage being provided (Figure 6a). Generally, these plants would be feasible only on such streams which have a minimum dry weather flow of such magnitude which makes

it possible to generate electricity throughout the year. Since the flow would vary throughout the year, they would run during the monsoon flows and would otherwise remain shut during low flows. Of course, the economic feasibility of providing the extra units apart from the regular units have to be worked out. Further, the monsoon tailwater in rivers with flat slopes becomes higher, causing the plants to become inoperative. Run-of-river plants may also be provided with some storage (Figure 6b) to take care of the variation of flow in the river as for snow-melt rivers, emerging from the glaciers of Himalayas. During off-peak hours of electricity demand, as in the night, some of the units may be closed and the water conserved in the storage space, which is again released during peak hours for power generation. A schematic cross sectional view of a typical run-of-river scheme is shown in Figure 7.

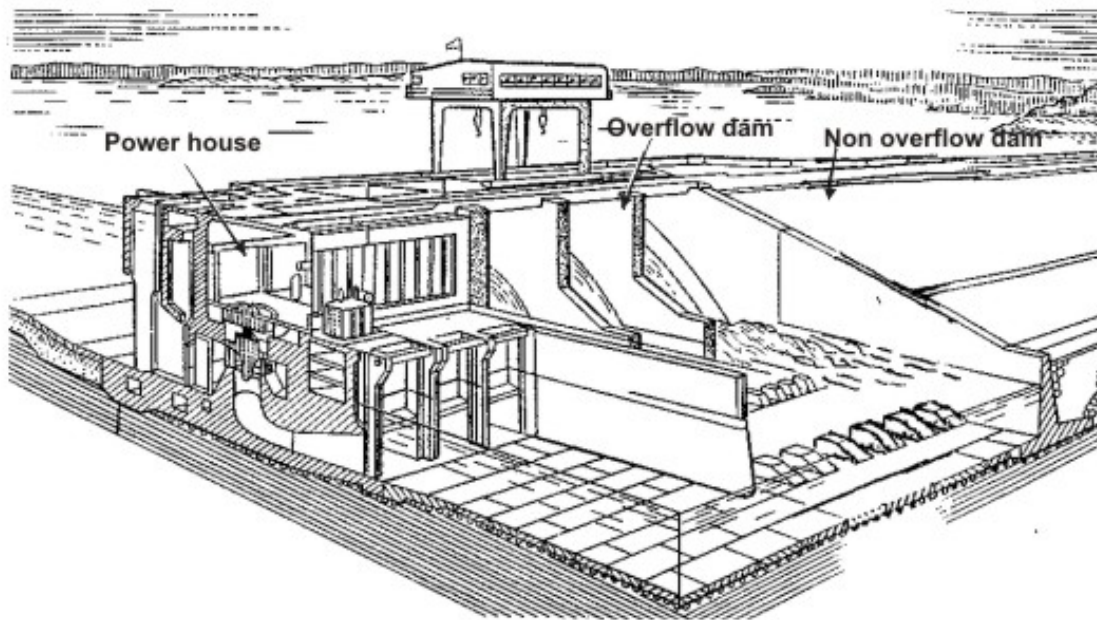


FIGURE 7. A typical run of-river hydroelectric station using a dam and an in-stream power house

2. Storage schemes

Hydropower plants with storage are supplied with water from large storage reservoir (Figure 6c) that have been developed by constructing dams across rivers. Generally, the excess flow of the river during monsoon would be stored in the reservoir to be released gradually during periods of lean flow. Naturally, the assured flow for hydropower generation is more certain for the storage schemes than the run-of-river schemes. A typical schematic cross sectional view of a storage scheme power plant is shown in Figure 8.

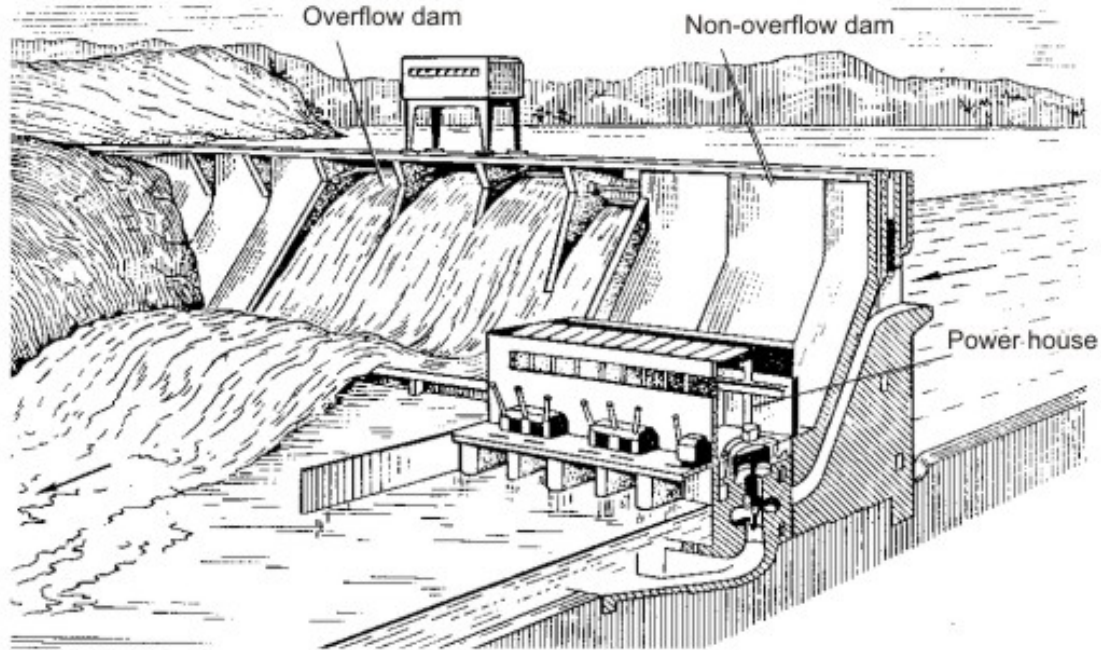


FIGURE 8. A typical storage-type hydroelectric station with a power house build at the toe of the dam

3. Pumped-Storage schemes

Hydropower schemes of the pumped-storage type are those which utilize the flow of water from a reservoir at higher potential to one at lower potential (Figure 6d). A typical schematic view of such a plant is shown in Figure 9. The upper reservoir (also called the head-water pond) and the lower reservoir (called the tail-water pond) may both be constructed by providing suitable structure across a river (Figure 10). During times of peak load, water is drawn from the head-water pond to run the reversible turbine-pump units in the turbine mode. The water released gets collected in the tail-water pond. During off-peak hours, the reversible units are supplied with the excess electricity available in the power grid which then pumps part of the water of the tail-water pond back into the head-water reservoir. The excess electricity in the grid is usually the generation of the thermal power plants which are in continuous running mode. However, during night, since the demand of electricity becomes drastically low and the thermal power plants can not switch off or start immediately, there a large amount of excess power is available at that time.

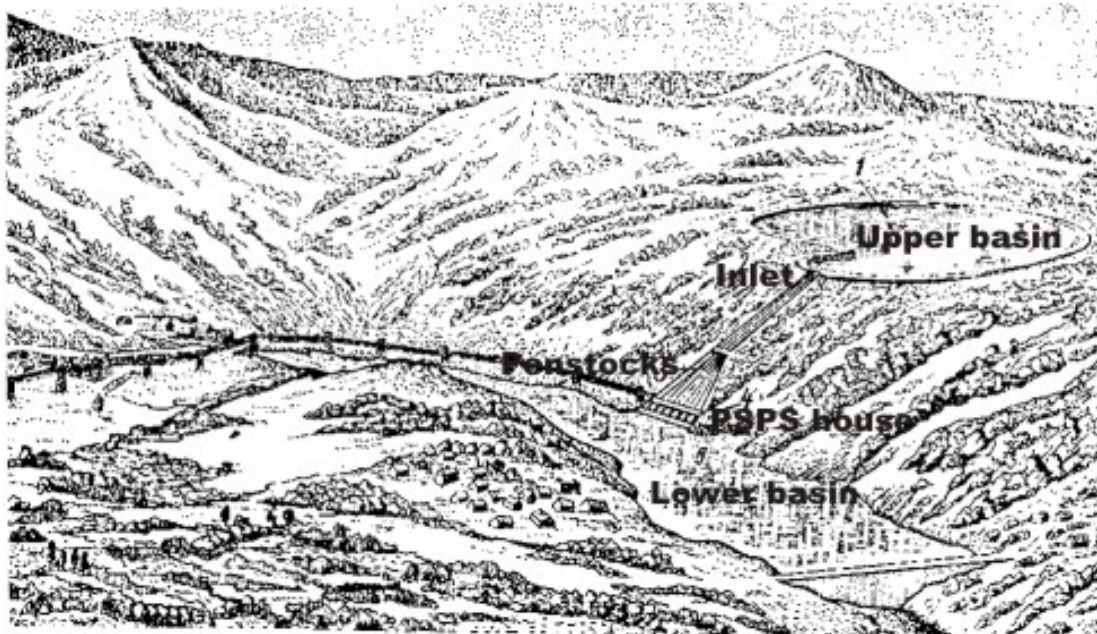


FIGURE 9. General view of pumped storage power station

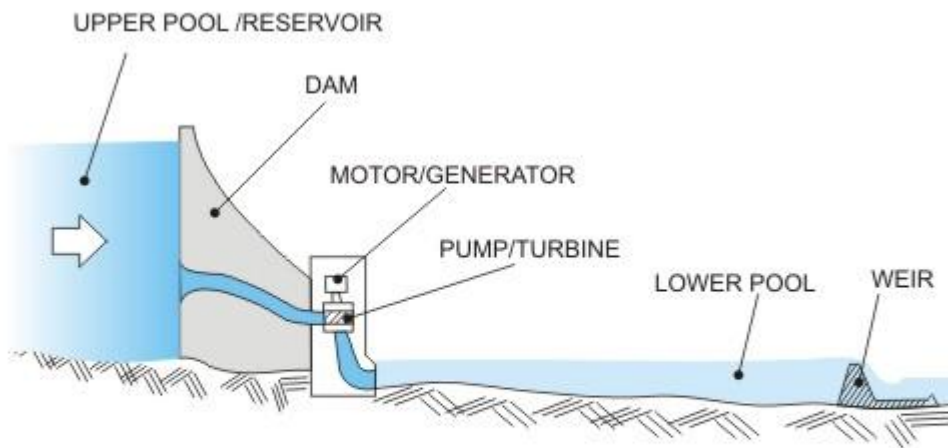


Figure 10. Pump-storage scheme development with upper and lower pools in the same river

4. Tidal power development schemes

These are hydropower plants which utilize the rise in water level of the sea due to a tide, as shown in Figure 11. During high tide, the water from the sea-side starts rising, and the turbines start generating power as the water flows into the bay. As the sea water starts falling during low tide the water from the basin flows back to the sea which can also be used to generate power provided another set of turbines in the opposite direction are installed. Turbines which generate electricity for either direction of flow may be installed to take advantage of the flows in both directions.

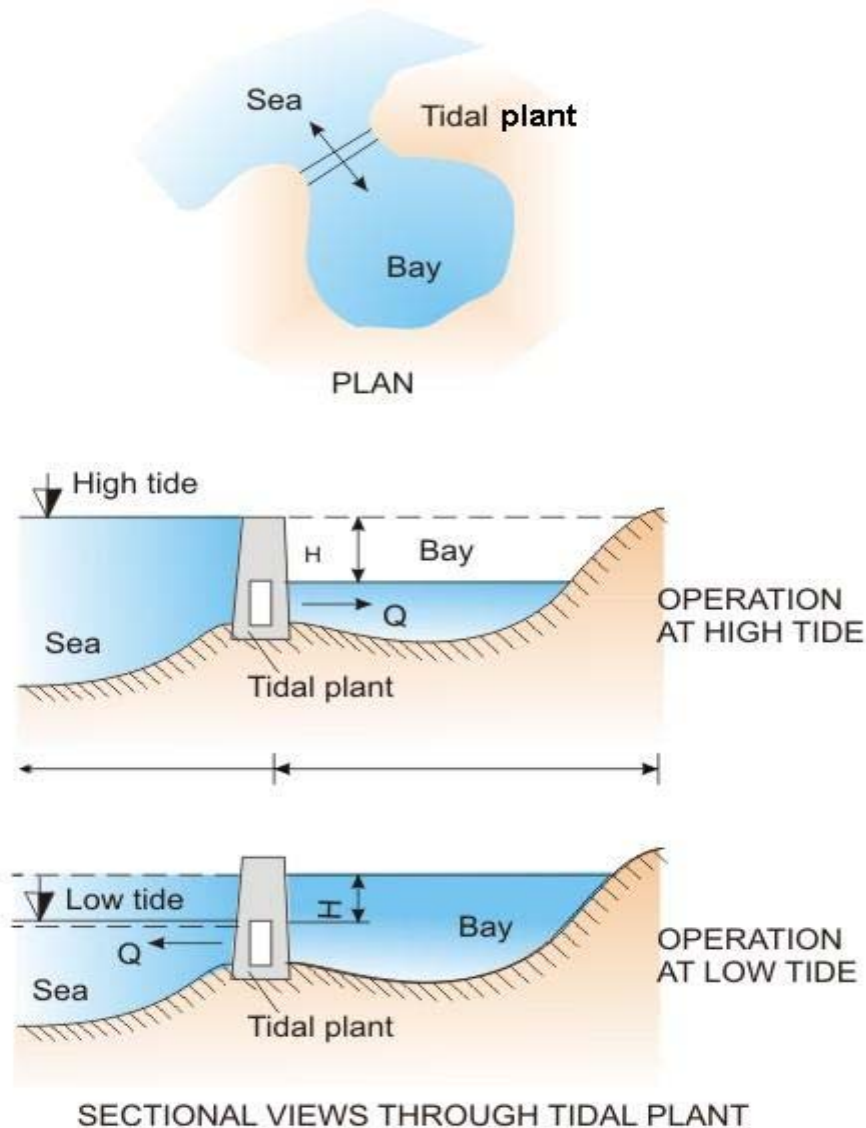


FIGURE 11. Concept of a tidal power development scheme

According to the National Oceanographic and Atmospheric Administration, USA, the potential energy of tides (often referred to as Blue Oil) is estimated at 3×10^6 MW, of which one-third is dissipated in shallow seas. This implies that the exploitable energy available on sea coasts is of the order of 10^6 MW. Power can be generated where sufficiently large tides are available. According to experts it may be techno-economically possible to eventually develop 170,000MW at 30 sites worldwide. Globally, so far around 265 MW has been developed, although around 120,000MW are in the planning stage.

Hydroelectric power plants are also sometimes classified according to the head of water causing the turbines to rotate. The Bureau of Indian Standards code IS: 4410(Part10)-1998 "Glossary of terms relating to river valley projects: Hydroelectric power station including water conductor system," the following types of power plants may be defined:

1. **Low head power plant:** A power station that is operating under heads less than 30m (Figure12).

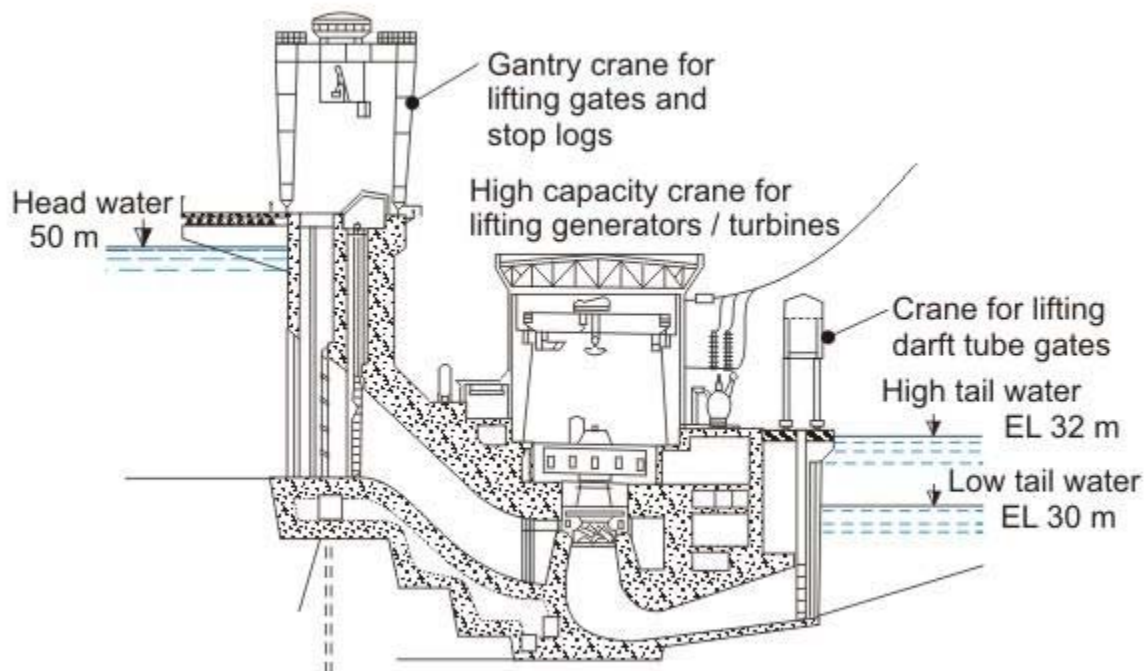


FIGURE 12. Sectional view of a typical low head hydro power station

2. **Medium head power plant:** A power station operating under heads from 30m to 300m. Of course, the limits are not exactly defined and sometimes the upper limit for medium head power station may be taken as 200 to 250m. (Figure 13)

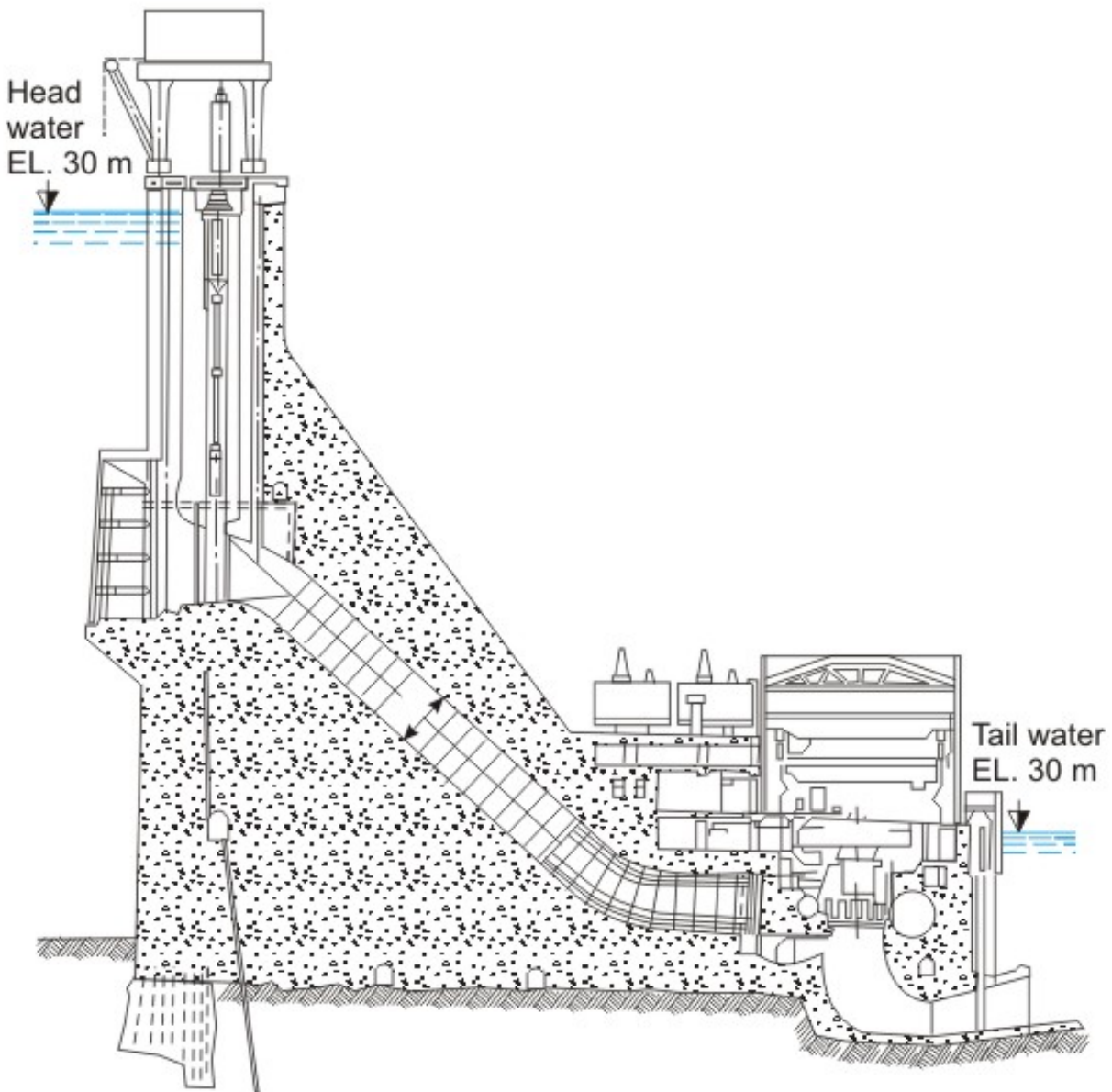


FIGURE 13. Sectional view of a typical medium head hydropower station.

- 3. High head power station:** A power station operating under heads above about 300m. A head of 200m/250m is considered as the limit between medium and high head power stations. (Figure 14).

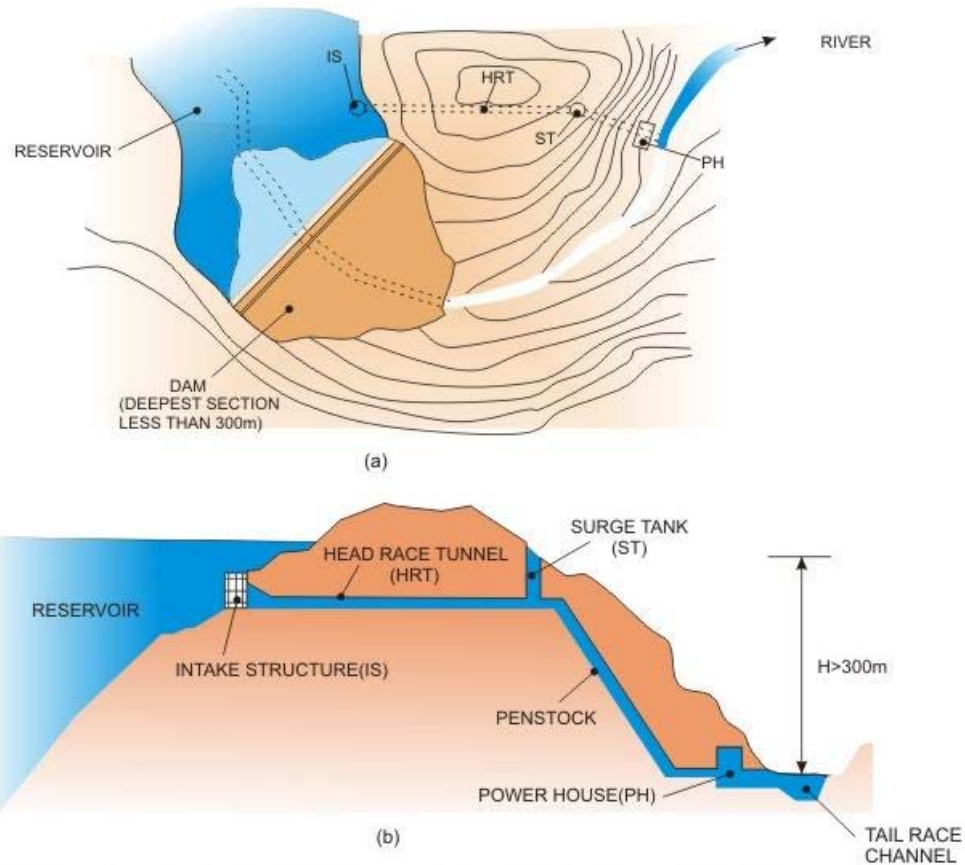


FIGURE 14. (a) Layout of the project showing an embankment dam creating a reservoir with a high head
(b) Sectional view through the water conducting system for hydropower

IS: 4410(part10)-1998 also classifies hydropower plants according to their operating functions as follows:

1. Base load power plant: A power station operating continuously at a constant or nearly constant power and which operates at relating high load factors. It caters to power demand at base of the load curve.
2. Peak load power plant: A power station that is primarily designed for the purpose of operating to supply the peak load of a power system. This type of power station is also, therefore, termed as 'Peaking station'.

According to Mosonyi (1991), hydropower plants can also be classified according to plant capacity as follows:

- | | |
|--------------------------|----------------|
| 1. Midget plant: | up to 100KW |
| 2. Low-capacity plant | up to 1,000KW |
| 3. Medium capacity plant | up to 10,000KW |
| 4. High capacity plant | > 10,000KW |

In India, Micro-hydel plants with capacity less than 5000KW are being encouraged to tap small streams and canal falls. Of the larger hydropower stations in India, the following are at the top of the list:

Sl. No	Project	Number of units × Capacity	Total capacity (MW)
1.	Bhakra	5*108(MW)+5*132(MW)	1200
2.	Dehar	6*165(MW)	990
3.	Koyna	4*165(MW)+4*75(MW)+4*80(MW)	880
4.	Nagarjuna sagar	1*110(MW)+7*100(MW)	891
5.	Srisailam	7*110(MW)	770
6.	Sharavathy	10*89.1(MW)	891
7.	Kalinadi	6*135(MW)	810
8.	Idukki	6*130(MW)	780

A map showing the major hydroelectric power station in India as given in CBIP (1987) is shown in Figure 15.

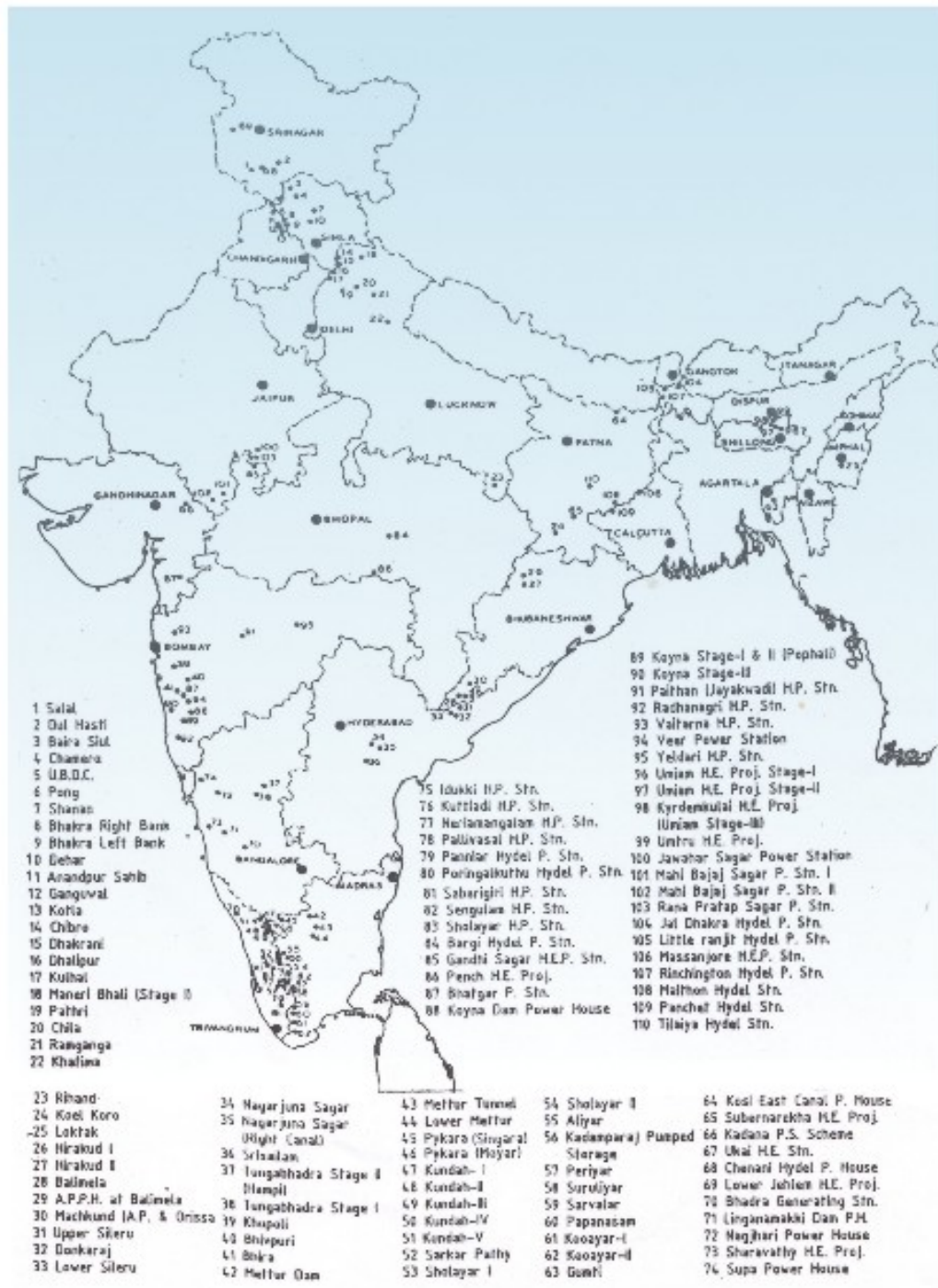


FIGURE 15. Hydro electric power stations in India

World-wide, there are a few hydropower plants with capacity greater than 10,000MW. These are given in the following list.

Sl.no	project	Country	Total Capacity
1.	Turukhnok	C.I.S.	20,000MW
2.	Three Gorges	China	13,400MW
3.	Itaipu	Brazil	12,000MW
4.	Grand Coulee	U.S.A	10,830MW
5.	Guri	Venezuela	10,300MW

On the other hand, China has over 88,000 small hydropower stations with a total installed capacity of 6929MW generating one-third of all the electricity consumed in rural areas. Hence, emphasis on micro-hydel development cannot be overlooked and similar developments can be done in the hilly regions of India where streams and small rivers may be tapped to provide power locally to the neighbouring rural community.

Though there has been a study growth of hydropower development in India over the years (Figure16), the proportional contribution of hydropower to the country's total energy production is rather small (Figure17).

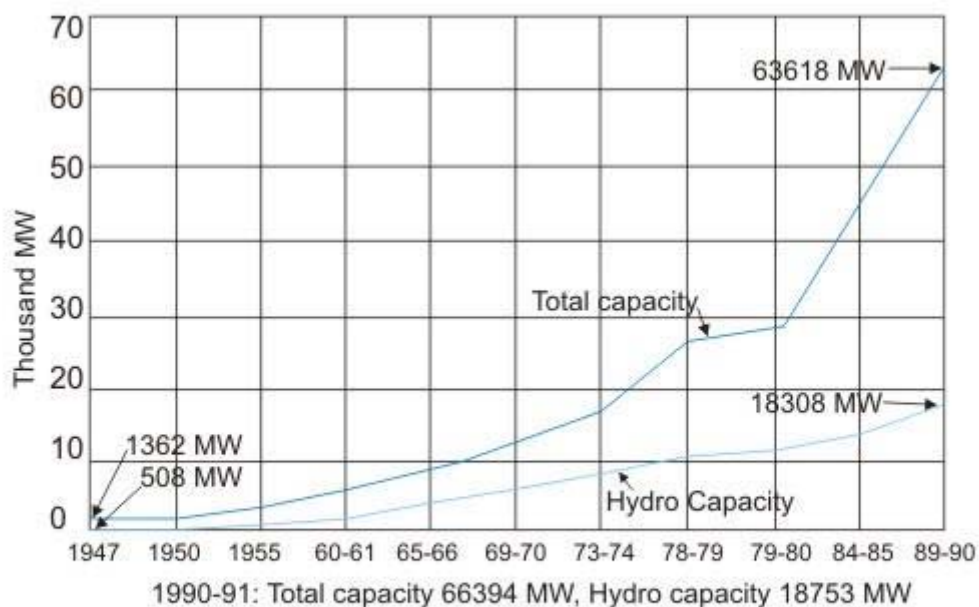


FIGURE 16. Total energy production and hydro power contribution for india

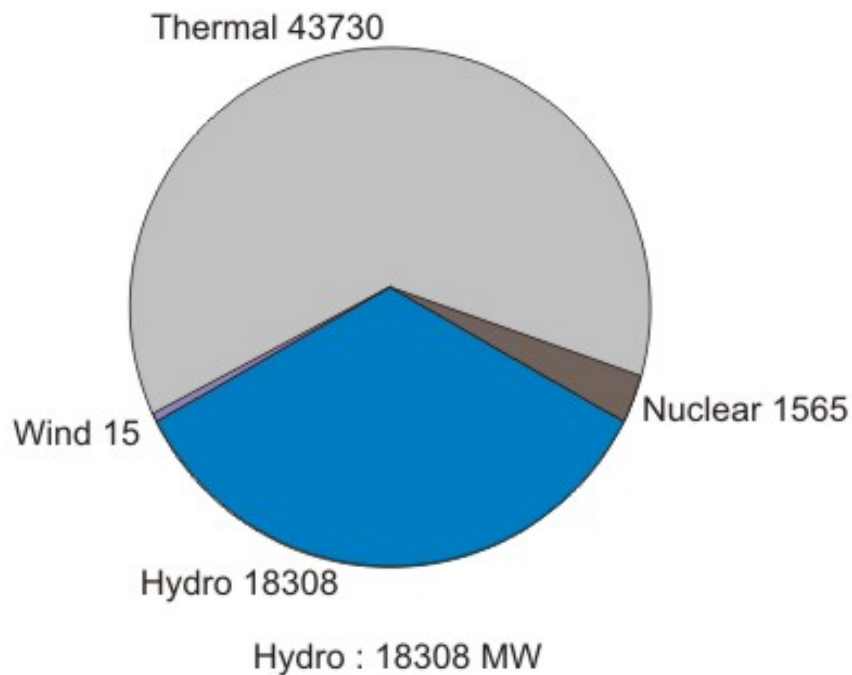


Figure 17. Installed capacity of india's energy producing units. This shows a hydro thermal mixratio of 29:71 approximately

In comparison, there are countries where hydropower production is the major source of electricity as given in the following table:

Rank	Country	Hydro production	Share of electricity
1.	Norway	83.5	99.4
2.	Zambia	8.8	98.9
3.	Zaire	4.3	98.6
4.	Ghana	4.7	98.5
5.	Mozambique	13.6	97.1
6.	Brazil	127.0	92.7
7.	Zimbabwe	4.0	88.9
8.	Sri Lanka	1.5	88.6
9.	New Zealand	16.3	74.1
10.	Nepal	0.2	73.6
11.	Switzerland	33.6	69.7
12.	Austria	29.1	69.3
13.	Canada	251.0	68.4
14.	Colombia	13.8	67.0
15.	North Korea	22.5	64.3
16.	Sweden	61.8	64.1

Ideally, for India, the Hydro: Thermal mix of around 40:60 has been considered to be the optimum.

5.1.3 Hydropower plant scheme layout

Typical components of a hydroelectric plant consist of the following:

1. Structure for water storage and/or diversion, like a dam or a barrage.
2. A head-race water conveying system like a conduit (penstock) or an open channel to transport water from the reservoir or head-water pool up to the turbines.
3. Turbines, coupled to generators
4. A tail race flow discharging conduit of open channel that conveys the water out of the turbine up to the river.

Although the above components are common for all hydropower development schemes the general arrangement for high and medium head power houses are more or less similar. The low head power plants, which are usually of run-of-river type schemes, have a slightly different arrangement as mentioned in the paragraphs below.

High and medium head development

Usually, there could be two types of power scheme layout:

- Concentrated fall schemes
- Diversion schemes

In the concentrated fall type projects, the powerhouse would be built at the toe of a concrete gravity dam, shown as a schematic view in Figure 7 and sectional view in Figure 12. This type of project development is suitable for medium head projects since a high head project would require an enormous concrete gravity dam, which is generally not adopted. A medium or high head project with an earthfill or rockfill dam may have an isolated or off-stream power house as shown in Figure 13. Here, the water is conveyed to the turbines via penstocks laid under, or by-passing, the dam. Spillways are provided separately to take care of floods. A distinction of such projects is that it consists of a long system of water conduits. Surge tanks are sometimes provided at the end of the conduits to relieve them of water hammer, which is the very high pressure developed by causing the stoppage of flow too suddenly at the turbine end.

In the diversion type of layout, the diversion could be using a canal and a penstock (Figure 18) or a tunnel and a penstock (Figure 19). The former is usually called the Open-Flow Diversion System and the latter Pressure Diversion System.

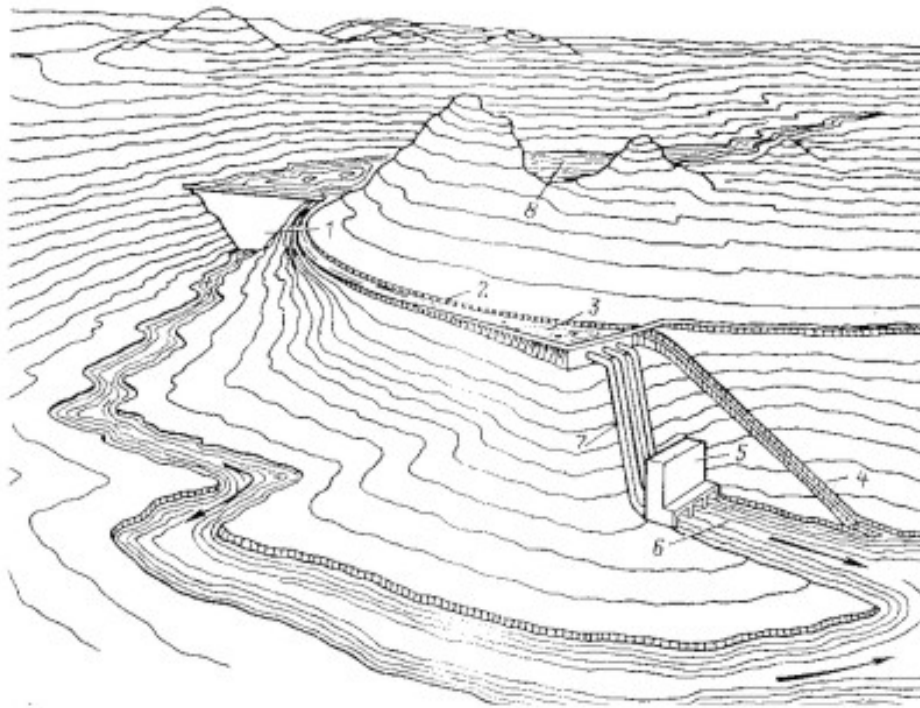


FIGURE 18 HYDROELECTRIC PROJECT BASED ON OPEN FLOW DIVERSION SCHEME
 1-DAM .2-INTAKE DIVERSION CONDUIT. 3-HEAD POND. 4- SPILLWAY . 5- POWER HOUSE.
 6- TAILVACE. 7-PENSTOCKS. 8-RESERVAIR

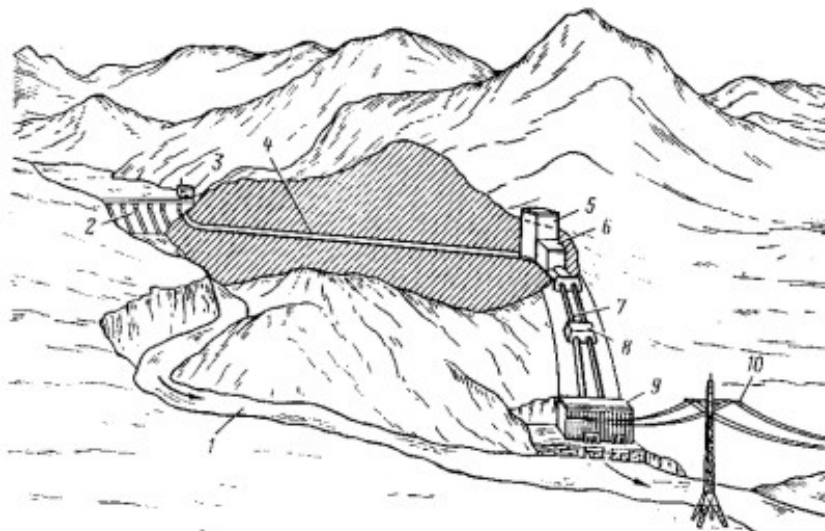


FIGURE 19. HYDROELECTRIC PROJECT USING A PRESSURE DIVERSION SYSTEM
 1-WATERCOURSE. 2-DAM. 3- INTAKE STRUCTURES. 4-DIVERSION TUNNEL. 5- SURGE TANK. 6-PENSTOCK FORK HOUSE
 7-PENSTOCKS.8- PENSTOCKS SUPPORT.9- POWER HOUSE. 10- POWER LINE

In fact, the combination of open channel and pressure conduit and penstock may be done in a variety of ways shown in Figure 20.

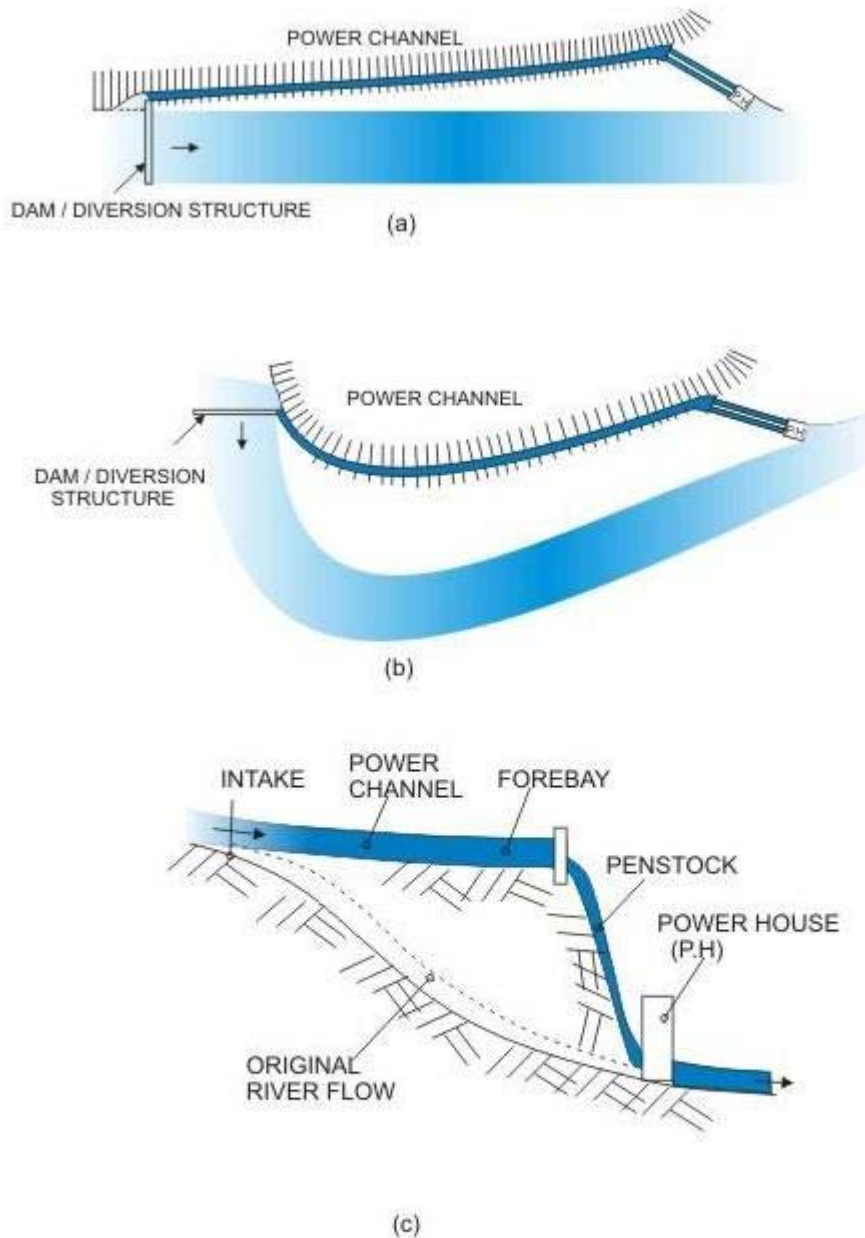


FIGURE 20. DIVERSION HYDRO POWER PROJECT BASED ON OPEN CHANNEL AND PRESSURE FLOW SYSTEMS
 (a) LONG CANAL AND SHORT SURFACE PENSTOCK ALONG STRAIGHT RIVER REACH
 (b) SAME AS (a) BUT IN A CURVED RIVER REACH
 (c) SECTIONAL VIEW ALONG WATER CONDUCTING SYSTEM FOR (a) AND (b)

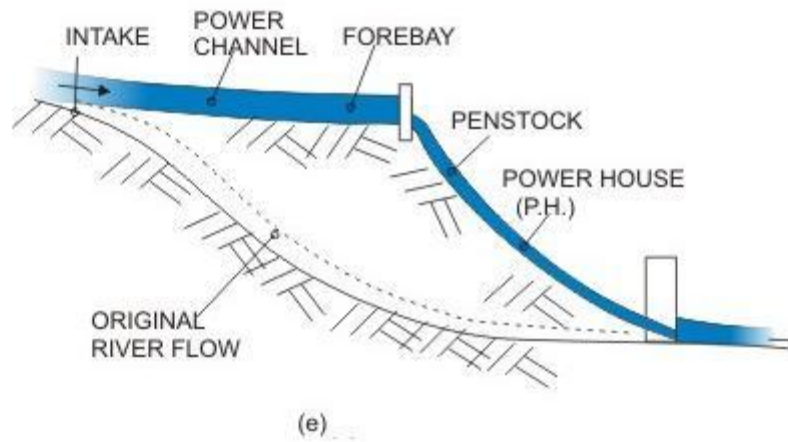
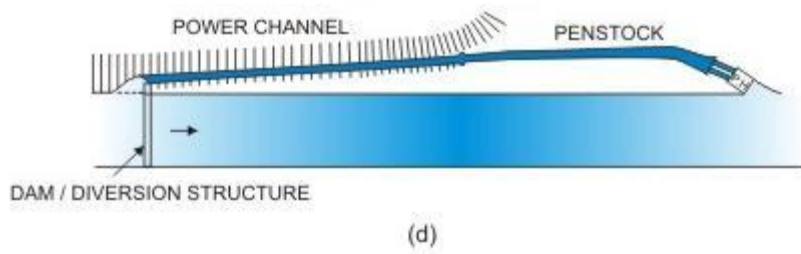


FIGURE 20. DIVERSION HYDRO POWER PROJECT BASED ON OPEN CHANNEL AND PRESSURE FLOW SYSTEMS
 (d) SHORT CANAL AND LONG SURFACE PENSTOCK
 (e) SECTIONAL VIEW FOR (d)

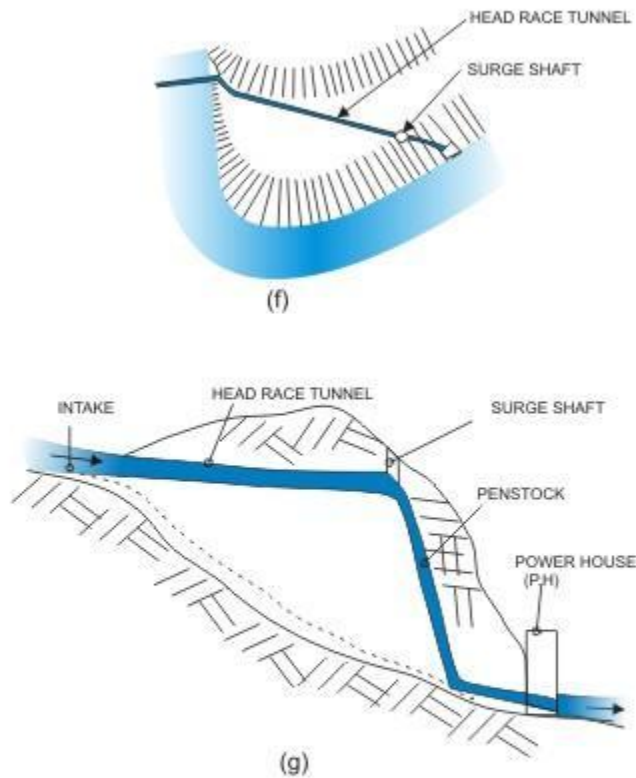


FIGURE 20. DIVERSION HYDRO POWER PROJECT BASED ON OPEN CHANNEL AND PRESSURE FLOW SYSTEMS
 (f) HEAD RACE TUNNEL AND PENSTOCK IN A CURVED RIVER REACH
 (g) SECTIONAL VIEW FOR (f)

There could be totally underground projects which consist of only pressure system of water conveyance. A variety of such projects are shown in Figure 21. This type of project layout may be termed as underground diversion schemes where even the power house is built underground.

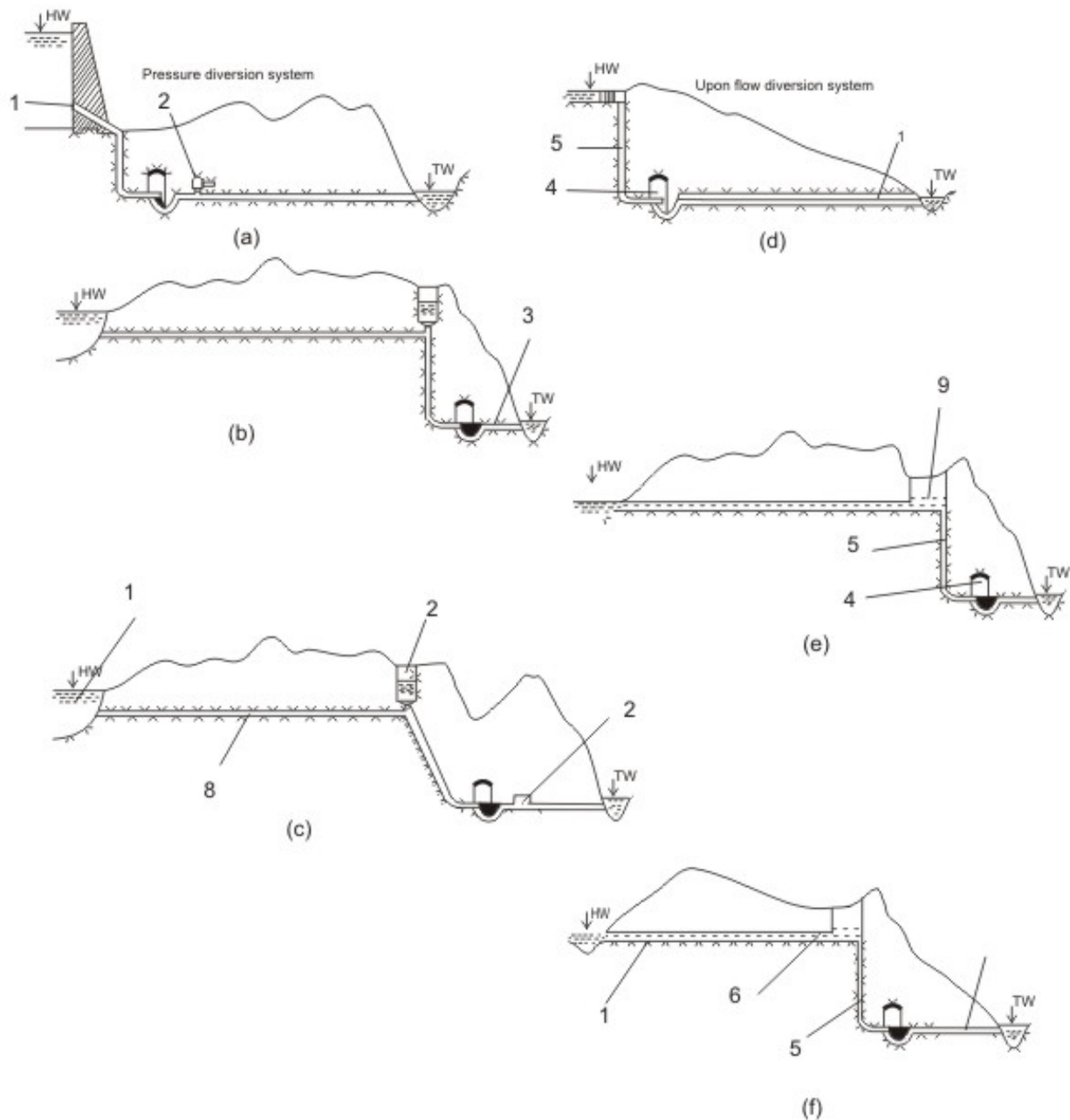


FIGURE 21. Underground project with (a),(b) and (c) pressure diversion system, and (d),(e) and (f) open flow diversion system; 1-intake structure; 2- surge tank; 3-tailrace pressure tunnel; 4- power house; 5-penstock 6-intake open flow tunnel; 7-tailrace open flow tunnel ;8-intake pressure tunnel; 9--head pond

Low head development

Here too, two types of layouts may be possible:

- In-stream scheme
- Diversion scheme

In the in-stream type of project, the powerhouse would be built as a part of the diversion structure, as shown in Figure 2(a) or a general detailed view in Figure 6. A typical layout of such a power house and its cross section is shown in Figure 22.

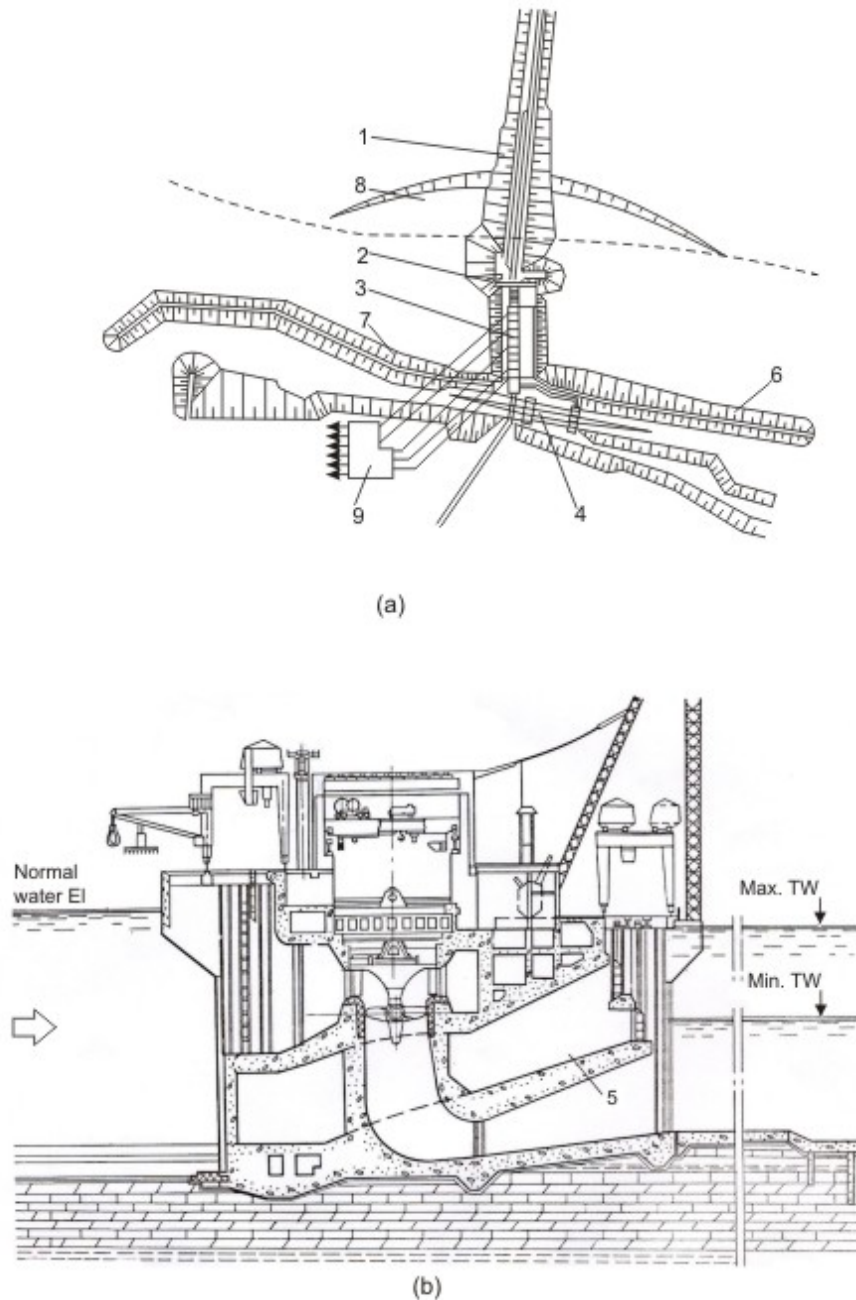


FIGURE 22. A TYPICAL LOW-HEAD IN STREAM POWER HOUSE
 (a) plane ;(b) sectional elevation of the power house; 1-earth dam.2-over flow dam
 3- power house; 4-lock;5-spillways in power house; 6- navigable canal dike downstream of dam;
 7-output dike; 8- left bank clearing; 9- electrical switch yard

In the diversion type of scheme, there has to be a diversion structure as well as a diversion canal, as shown in Figure 2(b). The power house may be located at some convenient point of the canal, that is, at its upstream end, middle, or at the downstream end. The location of the power house depends upon conditions such as hydrological, topographical, geological, environmental economic conditions. The ground water table has to be taken into account.

Position of power houses

As might have been noticed from the layouts, there could be a variety of position for the power house with respect to natural ground level.

IS: 4410(Part10)-1988 differentiates between the following types of power stations, which may be constructed as per site conditions:

1. Surface power station or over ground power station: A power station which is constructed over the ground with necessary open excavation for foundations. Typical examples may be seen from Figs. 7, 11 or 12.
2. Underground power station: A power station located in a cavity in the ground with no part of the structure exposed to outside. A typical example of this type is shown in Figure 23.

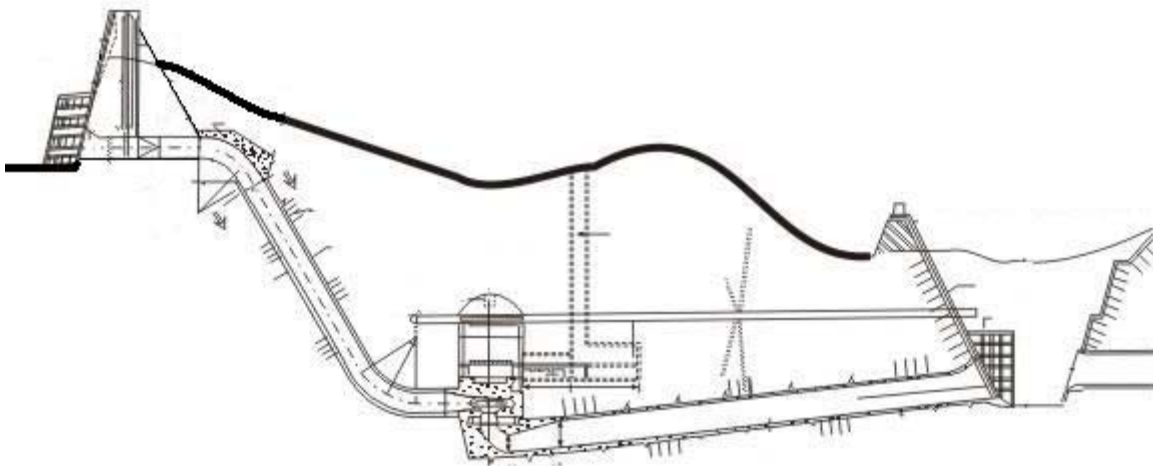


FIGURE 23 Underground power house of Sardar Sarovar Dam project

3. Semi-underground power station: A power station located partly below the ground level and followed by a tail race.

5.1.4 Electrical terms associated with hydropower engineering

Electrical power generated or consumed by any source is usually measured in units of Kilowatt-hour (kWh). The power generated by hydropower plants are normally connected to the national power grid from which the various withdrawals are made at different places, for different purposes. The national power grid also obtains power generated by the non-hydropower generating units like thermal, nuclear, etc. The power consumed at various points from the grid is usually termed as electrical load expressed in Kilo-Watt (KW) or Mega-Watt (MW). The load of a city varies throughout the day and at certain time reaches the highest value (usually in the evening for most Indian cities), called the Peak load or Peak demand. The load for a day at a point of the national power grid may be plotted with time to represent what is known as Daily Load Curve. Some other terms associated with hydropower engineering are as follows:

Load factor

This is the ratio of average load over a certain time period and the maximum load during that time. The period of time could be a day, a week, a month or a year. For example, the daily load factor is the ratio of the average load may be obtained by calculating the total energy consumed during 24 hours (finding the area below the load vs. time graph) and then divided by 24. Load factor is usually expressed as a percentage

Installed capacity

For a hydro electric plant, this is the total capacity of all the generating units installed in the power station. However all the units may not run together for all the time.

Capacity factor

This is the ratio of the average output of the hydroelectric plant for a given period of time to the plant installed capacity. The average output of a plant may be obtained for any time period, like a day, a week, a month or a year. The daily average output may be obtained by calculating the total energy produced during 24hours divided by 24. For a hydroelectric plant, the capacity factor normally varies between 0.25 and 0.75.

Utilization factor

Throughout the day or any given time period, a hydroelectric plant power production goes on varying, depending upon the demand in the power grid and the power necessary to be produced to balance it. The maximum production during the time divided by the installed capacity gives the utilization factor for the plant during that time. The value of utilization factor usually varies from 0.4 to 0.9 for a hydroelectric plant depending upon the plant installed capacity, load factor and storage.

Firm (primary) power

This is the amount of power that is the minimum produced by a hydro-power plant during a certain period of time. It depends upon whether storage is available or not for the plant since a plant without storage like run-of-river plants would produce power as per the minimum stream flow. For a plant with storage, the minimum power produced is

likely to be more since some of the stored water would also be used for power generation when there is low flow in the river.

Secondary Power

This is the power produced by a hydropower plant over and above the firm power.

References

Mosonyi, Emil (1991) "Water power development", Akademia Budapest.