Salahaddin University – Erbil
College of Engineering
Electrical Engineering Department
2022-2023

Power Generation

Hydro-Electric Power Plants

Class: 3rd Year (**P/ E**)
B.SC Degree in Power Engineering

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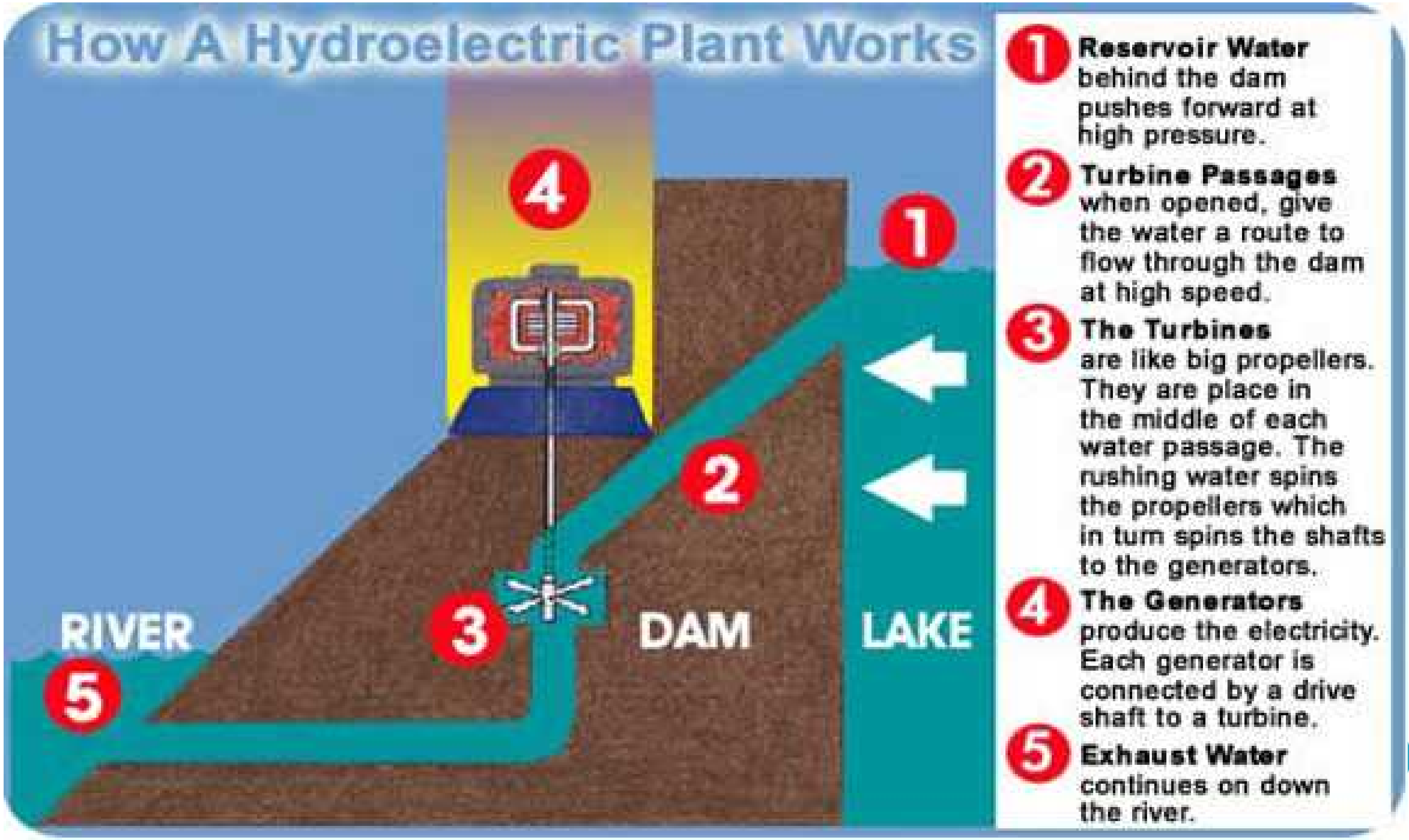
Hydro-Electric Power Plants

Hydropower, hydraulic power or water power is power that is derived from the force or energy of moving water, which may be harnessed for useful purposes.

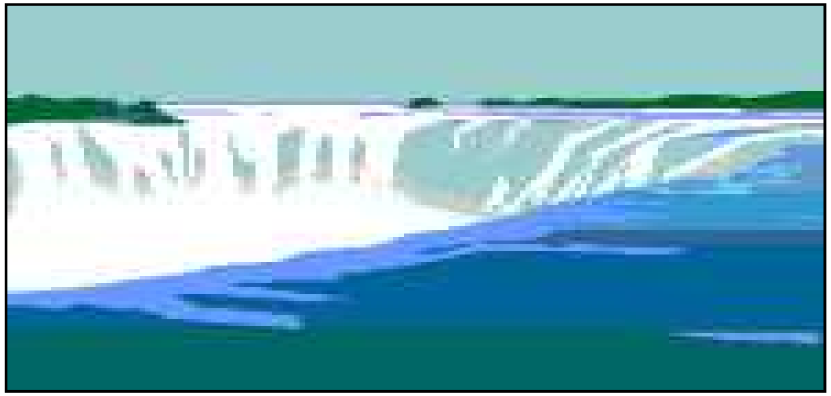
Hydropower was used for **irrigation** and **operation** of various machines, such as **watermills**, **textile machines** and **sawmills** etc.

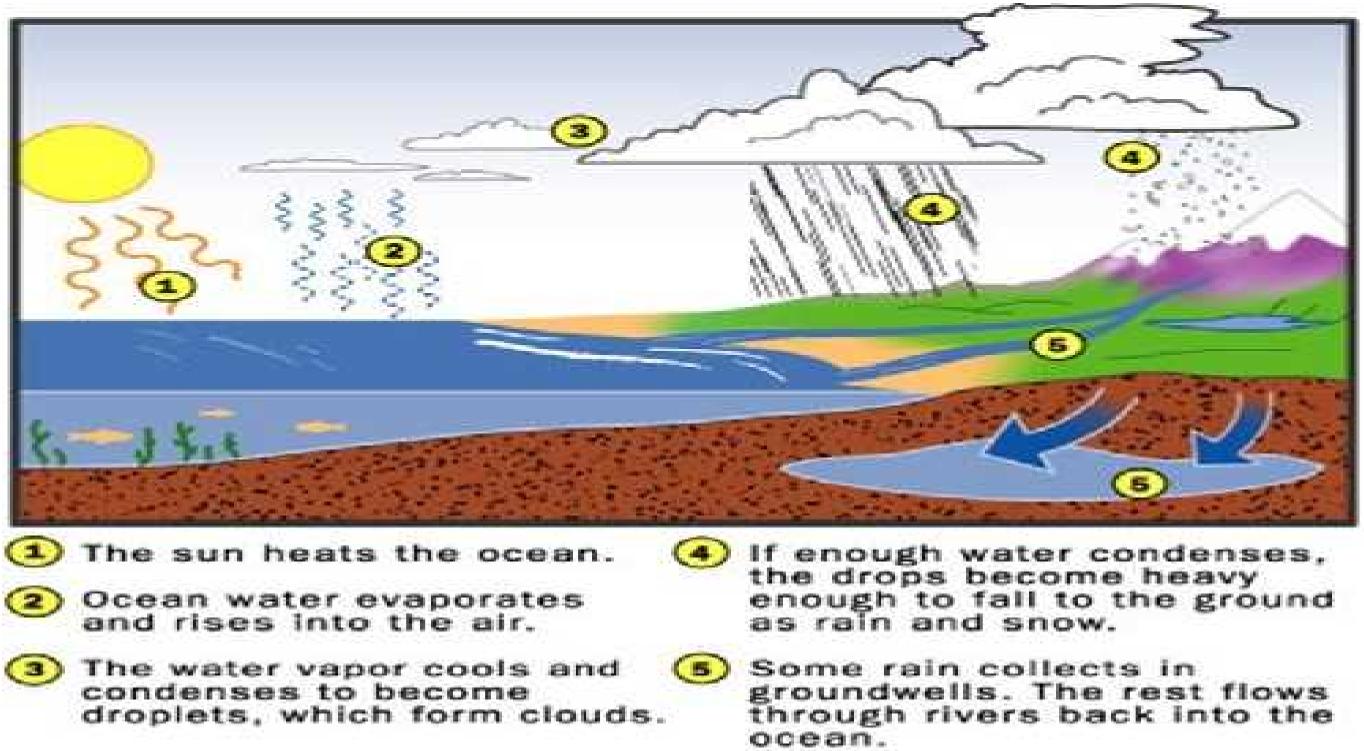
By using water for power generation, people have worked with nature to achieve a better lifestyle. The mechanical power of falling water is an age-old tool.

The figure below shows a cross sectional view of a Hydroelectric power plant



- When rain water falls over the earth's surface, it possesses potential energy relative to sea or ocean towards which it flows. As the water falls through **a certain height, its potential energy is converted into kinetic energy and this kinetic energy is converted to the mechanical energy by allowing the water to flow through the hydraulic turbine runner**. This mechanical energy is utilized to run an electric generator which is coupled to the turbine shaft.





- **The generation** of electric energy from falling water is only a small process in the mighty heat power cycle known as **<u>“Hydrological cycle”</u>** or **<u>rain evaporation cycle”.</u>** It is the process by which the moisture from the surface of water bodies covering the earth’s surface is transferred to the land and back to the water bodies again. This cycle is shown in Figure above. The input to this cycle is the **<u>solar energy.</u>**

General Formula:

➔ Density=mass/volume

➔ W=m x g

➔ Density of water =1000Kg/m^3

➔ g- acceleration due to gravity

➔ hydraulic efficiency x electrical efficiency= overall efficiency

Available Hydro Power

- The power that can be extracted from a waterfall depends upon its height and rate of flow.
- The available hydro power can be calculated by the following equation:

Power = W.q.h.η watts

- P=available water power[kW]
- q=water rate of flow [m^3/s]
- h= head of water [m]

- Determination of the head for a proposed hydropower plant is a surveying problem that identifies elevations of water surfaces as they are expected to exist during operation of the hydropower plant.

- Because the headwater elevation and tail water elevations of the impoundment can vary with stream flow, it is frequently necessary to develop headwater and tail water curves that show variation with time, river discharge, or operational features of the hydropower project

<u>Hydro projects are developed for the following purposes:</u>

1. To control the floods in the rivers.
2. Generation of power.
3. Storage of irrigation water.
4. Storage of the drinking water supply.

Before a water power site is considered for development, the following factors must be thoroughly analyzed:

1. **The capital cost** of the total plant.
2. The capital cost of **<u>maintaining</u>** the transmission lines and the annual power loss due to transformation and transmission of electric power since the water power plants are usually situated in hilly areas away from the load center.
3. **The cost of electric generation** compared with steam, oil or gas plants which can be conveniently set up near the load center.

The main advantage and disadvantage of hydro power plant:

Advantage:

1. No fuel charges.
2. An-hydro –electric plant is **highly reliable**.
3. **Maintenance and operation** charges are very low.
4. **Running cost** of the plant is low.
5. The plant has no stand by losses.
6. The plant **efficiency** does not change with age.
7. It takes a few minutes to **run and synchronies** the plant.
8. No fuel **transportation** problem.
9. The number of operations required is considerably small compared with thermal power plant.
10. The load can be varied quickly and the rapidly changing load demands can be met without any difficulty.

However, the hydro-electric power plants have the following disadvantages also:

1. The initial cost of the plant is very high.

2. Such plants are usually located in hilly areas for away from the load center and as such they require long transmission lines to deliver power, subsequently the cost of transmission lines and losses in them will be more.

3. Power generation by the hydro-electric plant is only dependent on the quantity of water available which in turn depends on the natural phenomenon of rain. So if the rainfall is in time and proper and the required amount of water can be collected, the plant will functions satisfactorily otherwise not.

Selection of site for a hydro- power plant:

The following factors should be considered while selecting the site for hydro power plant:

1. Availability of water.
2. Water storage.
3. Water head.
4. Accessibility of the site.
5. Distance from load center.
6. Type of the land of site.

1. **<u>Availability of water:</u>** the most important aspect of hydro electric plant is the availability of water at the site since all other designs are based on it.

- To know the available energy from a given stream or river, the **discharge flowing and its variation with time over a number of years must be known.**
- The average quantity of water available should be prepared on the basis of: **actual measurements of stream or river flow**.
- The recorded observation should be taken over a number of years to know within reasonable, **limits the maximum and minimum variations from the average discharge.**
- The river flow data should be based on **daily, weekly, monthly and yearly flow** ever a number of years. Then the curves or graphs can be plotted between tile river flow and time. These are known as **<u>hygrographs and flow duration curves.</u>**

- The plant capacity and the estimated output as well as the need for storage will be governed by the average flow. The primary or dependable power which is available at all times when energy is needed will depend upon the minimum flow. Such conditions may also fix the capacity of the standby plant. The, maximum of flood flow governs the size of the headwords and dam to be built with adequate **spillway.**

2-Water storage:

Since there is a wide variation in rainfall during the year, therefore, it is always necessary to store the water for continuous generation of power. To have a uniform power output, water storage is needed so that excess flow at certain times may be stored to make it available at the times of low flow. To select the site of the dam ; careful study should be made of the geology and topography of the catchment area to see if the natural foundations could be found and put to the best use.

3- <u>Water head:</u>

In order to generate a requisite quantity of power it is necessary that a large quantity of water at a sufficient head should be available. An increase in effective head, for a given output, **reduces the quantity of water required to be supplied to the turbine.**

4-Accebility of the site:

The site where hydro electric power plant is to be constructed should be easily accessible. This is important if the electric power to be utilized at or near the plant site.

5-Distance from the load center:

It is of paramount importance that the power plant should be set up near the load center, this will reduce the cost of erection and maintenance of transmission line.

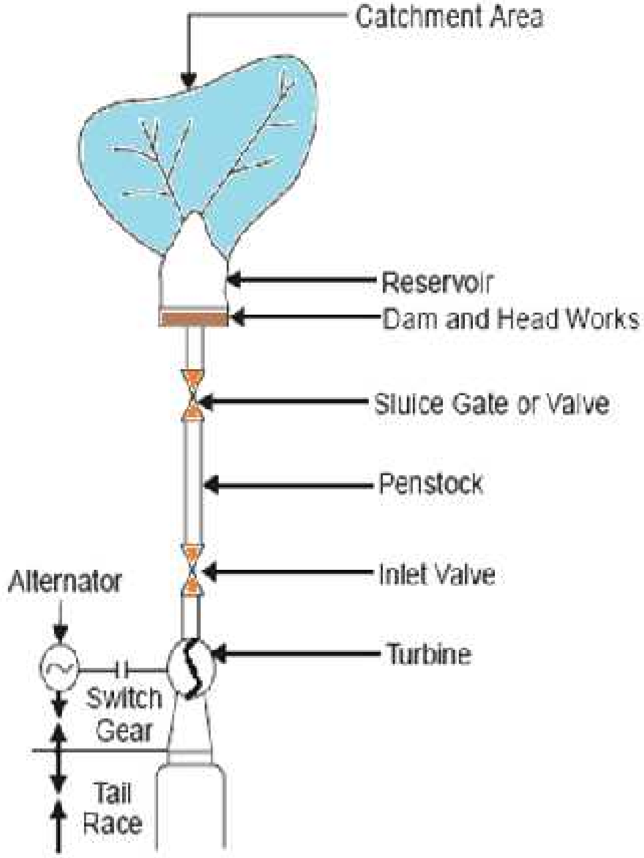
6-Type of the land of the site:

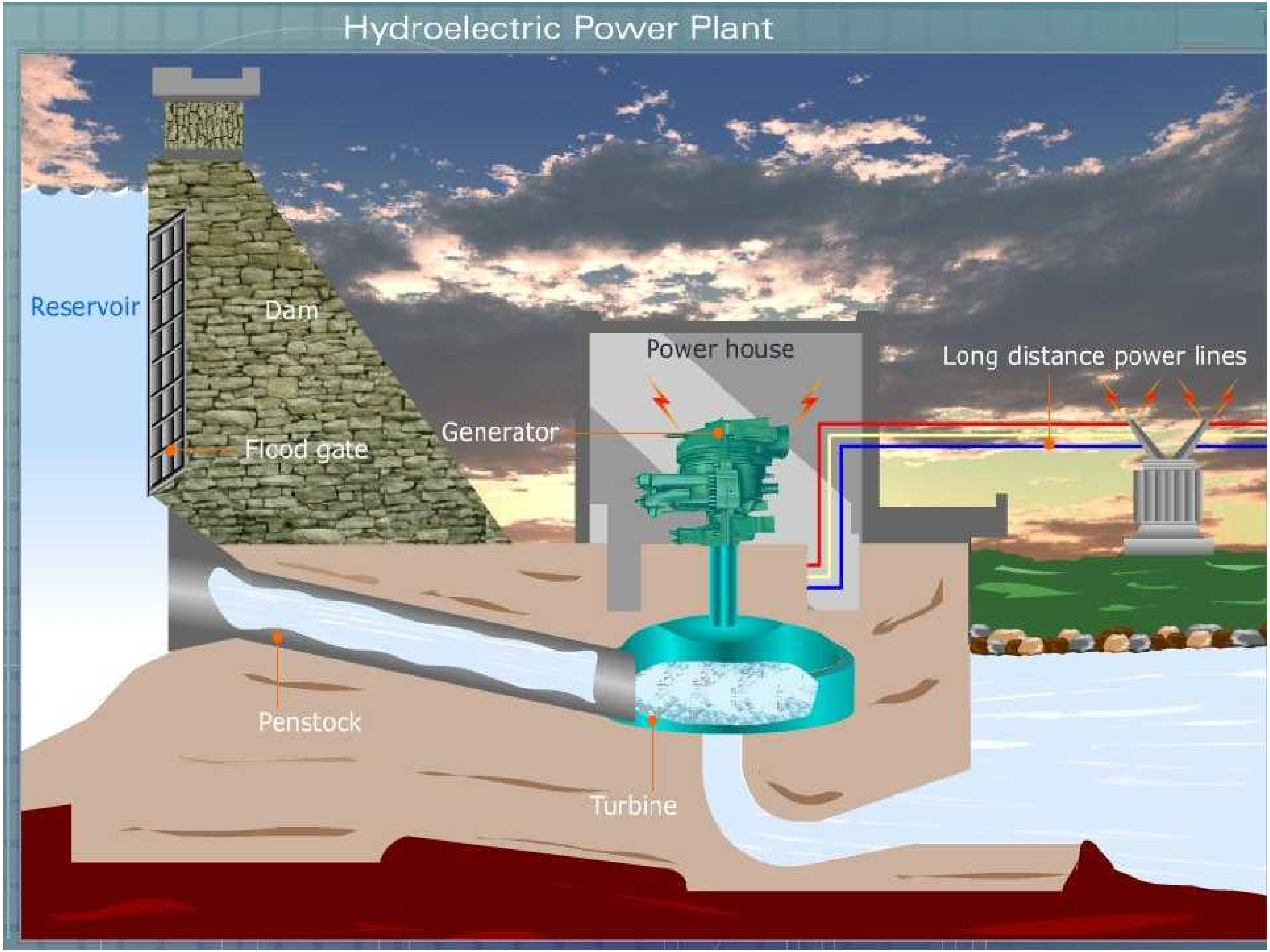
The land to be selected for the site should be cheap and rocky. The ideal site will be one where the dam will have largest catchment area to store water at high head and will be economical in construction.

Essential features elements of hydro- electric power plant:

The following are essential elements of hydro- electric power plant:

1. Catchment area.
2. Reservoir.
3. Dam.
4. Spillways.
5. Penstocks.
6. Surge tanks.
7. Draft tubes.
8. Primemovers.
9. Powerhouse and equipment.




Hydroelectric Power Plant
Reservoir
Dam
Flood gate
Power house
Generator
Long distance power lines
Penstock
Turbine

1. **Catchment Area.** The catchment area of a hydro plant is the whole area behind the dam, draining into a stream or river across which the dam has been built at a suitable place.

2. **Reservoir.** Whole of the water available from the catchment area is collected in a **reservoir behind the dam**.

The purpose of the storing of water in the reservoir is :

To get a uniform power output throughout the year. A reservoir can be either **natural** or **artificial** . A natural reservoir is a lake in high mountains and an artificial reservoir is made by constructing a dam across the river.

3. **Dam and Intake House.** A dam is built across a river for two functions:

1.to impound the river water for storage and

2.to create the **head** of water.

Dams may be classified according to their structural materials such as:

Timber, steel, earth, rock filled and masonary.

Timber and steel are used for dams of height 6 m to 12 m only. Earth dams are built for larger heights, up to about 100 m. **To protect the** dam from the wave erosion, a protecting coat of rock, concrete or planking must be laid at the water line. The other exposed surfaces should be covered with grass or vegetation **to protect the dam from rainfall erosion.**

4. **<u>Spillways.</u>** There are times when the river flow exceeds the storage capacity of the reservoir. Such a situation arises during heavy rainfall in the catchment area.

In order to discharge the surplus water from the storage reservoir into the river on the downstream side of the dam **spillways are used**. These are generally constructed of concrete and provide with water discharge opening shut off by metal control gates. Surplus water is discharged over the crest of the dam by opening gates.

5. **<u>Penstocks.</u>** Penstocks are open or closed conduits which carry water to the turbines.

<u>In case of medium head power plants</u>, each unit is usually provided with its own penstock.

<u>In case of high head plants,</u> a single penstock is frequently used and branch connections are provided at the lower end to supply two or more units. **The steel penstocks can be designed for any head.**

6. <u>Surge tanks.</u> (or surge drum) is a standpipe or storage reservoir at the downstream end of a closed aqueduct, feeder, dam, barrage pipe to absorb sudden rises of pressure, as well as to quickly provide extra water during a brief drop in pressure.

- For hydroelectric power uses, a surge tank is an additional storage space or reservoir fitted between **<u>the main storage reservoir</u>** and **<u>the power house</u>** (as close to the power house as possible).

- Surge tanks are usually provided in <u>high</u> or <u>medium-head</u> plants when there is a **considerable distance between the water source and the power unit, necessitating a long penstock**.

7.**Draft tubes.** In power turbines like **reaction turbines**, **Kaplan turbines**, or **impulse turbines**, a diffuser tube is installed at the exit of the runner, known as draft tube.

- A draft tube at the end of the turbine increases the pressure of the exiting fluid at the expense of its velocity. This means that the turbine can reduce pressure to a higher extent without fear of back flow from tail race.
- The Draft tube gives an advantage of placing the turbine above the tail race so that any required inspections can be made easily. Moreover, it also converts the wasteful kinetic energy at the exit of the runner into the useful pressure energy.

The draft tube serves the following two purposes:

1.It allows the turbines to be set above tail-water level, **without loss** of **head**, to facilitate inspection and maintenance.

2.It regains, by diffuser action, the major portion of the kinetic energy delivered to it from the runner.

Classification of hydro-electric power plants

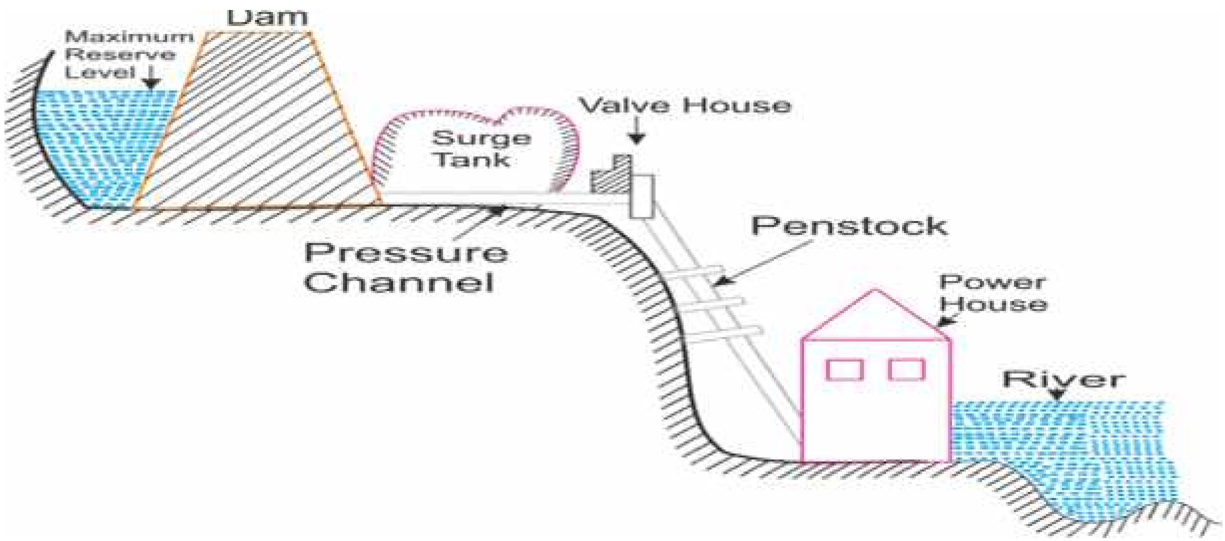
Hydro-electric power stations may be classified as follows:

A. **According to availability of head:**

1. High head power plants. 100 m and above
2. Medium head power plants. 30 to 100 m
3. Low head power plants. Less than 30m

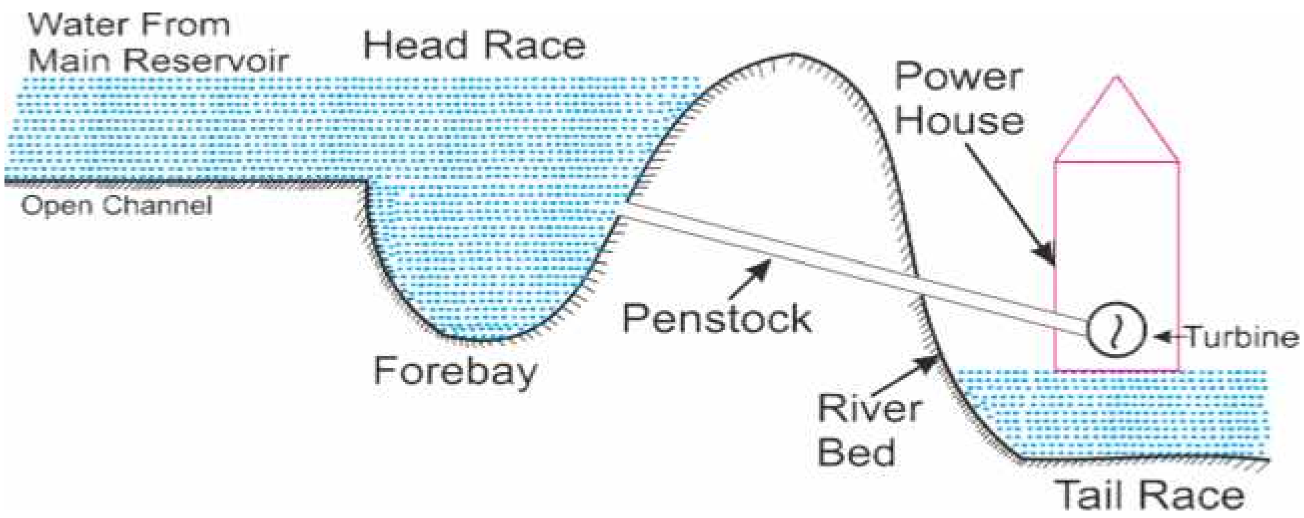
<u>1.High head power plants</u>

- These types of plants work under heads ranging from **<u>100 to 200</u>** meters. Water is usually stored up in lakes on high mountains during the rainy season or during when the snow melts. The rate of flow should be such that water can last throughout the year.
- Surplus water discharged by the **spillway** can not endanger the stability of the main dam by erosion because they are separated. The tunnel through the mountain has a surge chamber excavated near the exit. **<u>Flow is controlled</u>** by head gates at the tunnel intake, butterfly valves at the top of the penstocks, and gate valves at the turbines. This type of site might also be suitable for an underground station.
- The **Pelton wheel** is the common prime mover used in high head power plants.



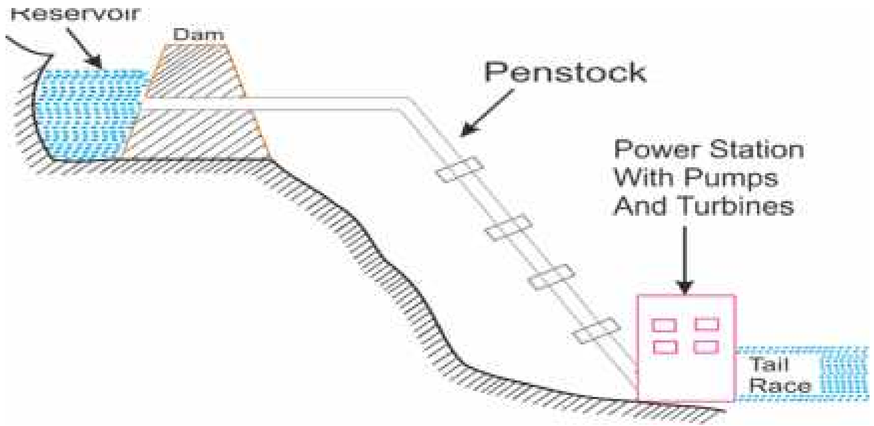
2. **Medium head power plants**

- When the operating head of water lies between 30 to 100 meters, the power plant is known as medium head power plant. This type of plant commonly uses **Francis turbines.**
- The forebay provided at the beginning of the penstock serves as water reservoir. In such plants, the water is generally carried in open canals from main reservoir to the forebay and then to the power house through the penstock. The forebay itself works as a surge tank in this plant.



3.Low head power plants.

These plants usually consist of a dam across a river. A sideway stream diverges from the river at the dam. Over this stream the power house is constructed, later this channel joins the river further downstream. This type of plant uses vertical shaft **Francis** turbine or **Kaplan turbine.**



B. According to the nature of load:

1. Base load plants.
2. Peak load plants.

1. Base load plants

The plants which cater to the base load of the system are called base load plants. These plants are required to supply a constant power when connected to the grid. Thus they **run without stop** and are often remote-controlled with which least staff is required for such plants. But the firm capacity in such cases will be **much less**.

2. Peak load plants

The plants which can supply the power during peak loads are known as peak load plants. Some of such plants supply the power during average load but also supply peak load as and when it is there, whereas other peak load plants are required to work during peak load hours only. **The run of river plants may be made for the peak load by providing pondage.**

C. According to the quantity of water available:

1. Run-of river plant without pondage.
2. Run-of river plant with pondage.
3. Storage type plants.
4. Pump storage plants.
5. Mini and micro-hydro plants.

1. **Run-of-river plants without pondage**

- **Does not store** water and uses the water as it comes.
- There is **no control** on flow of water so that during high floods or low loads water is wasted while during low run-off the plant capacity is considerably reduced.
- Due to **non-uniformity** of supply and lock assistance from a firm capacity:
  - the utility of these plants is **much less** than those of other types.
  - The load on which these plants work varies considerably.
- Such a plant can be made a great deal more useful by providing sufficient storage at the plant to take care of the hourly fluctuations in load. This lends some firm capacity the plant.
- **During good flow conditions** these plants may cater to **base load** of the system, when flow reduces they may supply the peak demands.
- **Head water elevation** for plant fluctuates with the flow conditions. These plants without storage may sometimes be made to **supply the base load but the firm capacity depends on the minimum flow of river.**
- The run-of-river plant may be made for load service with pondage, though storage is **usually seasonal.**

2. Run-of-river plants with pondage

- Pondage usually refers to **the collection of water behind a dam at the plant and increases the stream capacity for a short period, say a week**.
- Storage means collection of water in upstream reservoirs and these increases the capacity of the stream over an extended period of several months. **Storage plants may work satisfactorily as base load and peak load plants.**
- This type of plant as compared to the without pondage:

- is more reliable.
- Its generating capacity is less dependent on the flow rates of water available.

3. Storage type plants

- A storage type plant is one with a reservoir of sufficiently **large size** to permit carry-over storage from the **wet season to the dry season**, and thus to supply firm flow substantially more than the minimum natural flow.
- This plant can be used **as base load plant** as well as **peak load** plant as water is available **with control** as required. Thus **majority of hydro-electric plants are of this type.**

4. Pumped storage plants.

- Pumped storage plants are employed **at the places where the quantity of water available for power generation is inadequate**.
- Here the water passing through the **turbines is stored in tail race** pond.
- **During low load periods** this water is pumped back to the head reservoir using the extra energy available. **This water can be again used for generating power during peak load periods.**

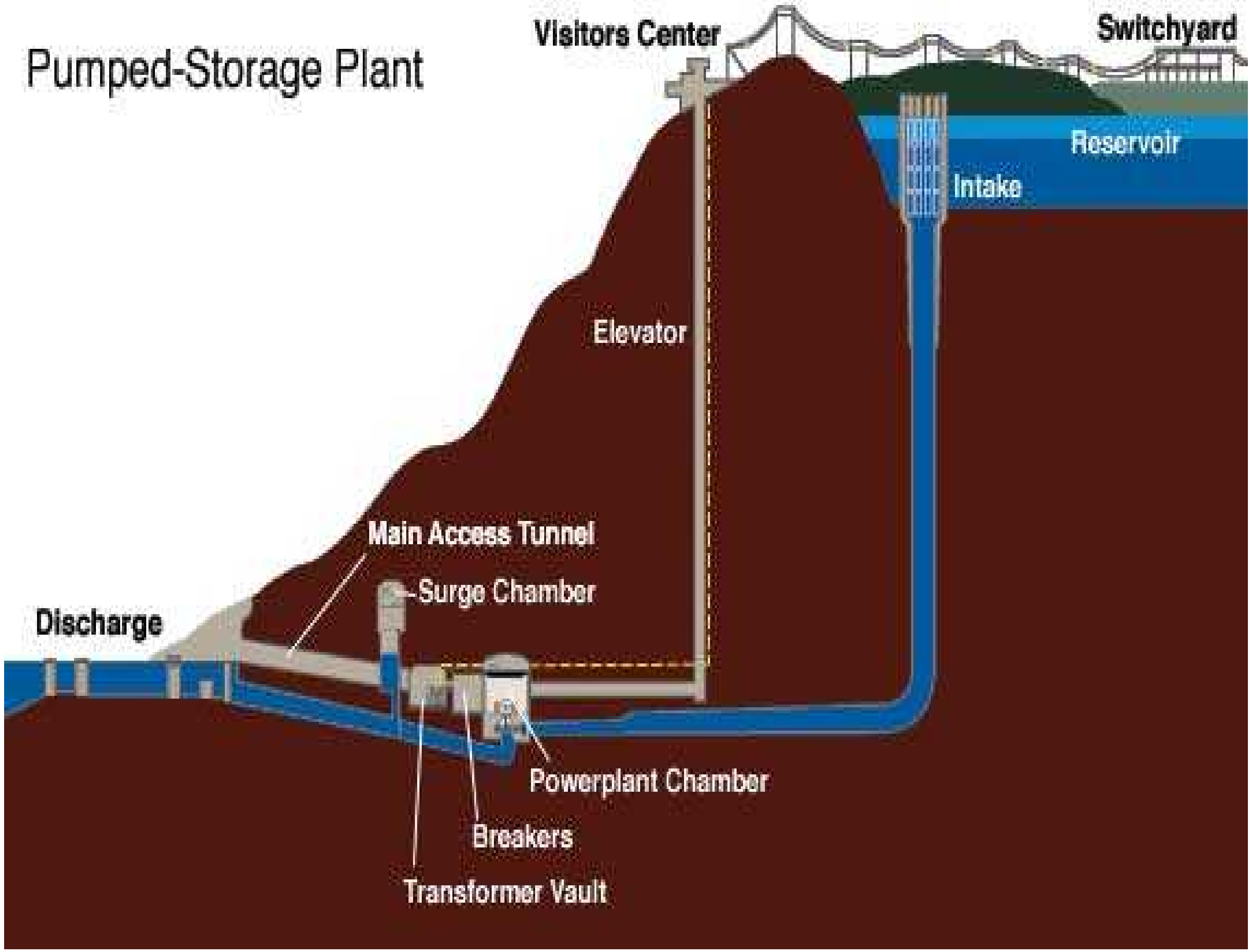
- Pumping of water may be done **seasonally** or **daily** depending upon the:
  - **Conditions of the site**
  - **The nature of the load on the plant.**

- Such plants are usually interconnected **with steam** or **diesel engine** plants so that off peak capacity of interconnecting stations is used in pumping water and the same is used during peak load periods.

- The energy available from the quantity of water pumped by the plant <u>**is less than the energy input during pumped operation.**</u>

- Again while using pumped water the **power available is reduced on account of losses occurring in prime movers.**

PUMPED STORAGE



Powerhouse:

A powerhouse should have a stable structure and its layout should be such that adequate space is provided around the equipment for convenient dismantling and repair. The equipment provided in the powerhouse includes the following:

1. Hydraulic turbine.
2. Electric generators.
3. Governors.
4. Gate valves.
5. Relief valves.
6. Water circulation pumps.
7. Air duct.
8. Switch board and instruments.
9. Storage batteries.
10. Cranes.

5. **Mini and Micro-hydro plants.**

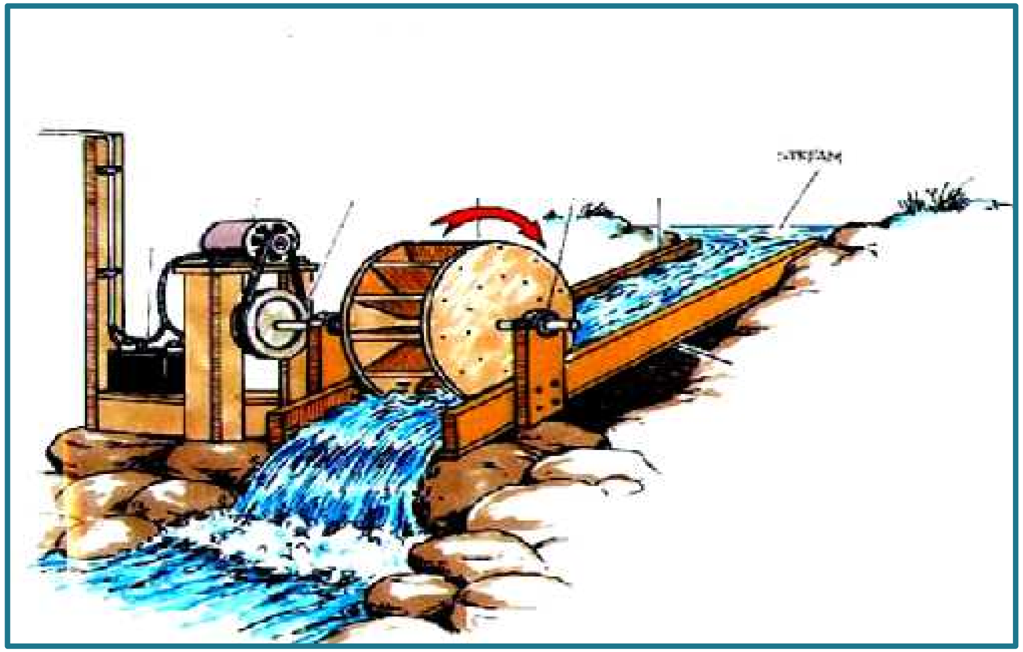
- **Mini (5m to 20m head).**
- **Micro (less than 5m head).**

To reduce the cost of micro-hydro stations than of the cost of conventional installation the following considerations are kept in view:

1. **The civil engineering** work needs to be kept to a minimum and designed to fit in with already existing structures e.g, irrigation, channels, locks, small dams etc.
2. **The machines** need to be manufactured in a small range of sizes of simplified design, allowing the use of unified tools and aimed at reducing the cost of manufacture.
3. These installations must be automatically controlled to reduce attending personnel.
4. **The equipment** must be simple and robust, with easy accessibility to essential parts for maintenance.

5. The units must be light and adequately sub assembled for ease of handing and transport and to keep down erection and dismantling costs.

- Micro-hydro plants (micro-stations) make use of standardized **bulb** sets with unit output ranging from **100 to 1000 KW** working under heads between **1.5 to 5 meters**



Hydraulic Turbines

A hydraulic turbine converts the potential energy of water into mechanical energy which in turn is utilized to run an electric **generator** to get electric energy.

Classification of hydraulic turbines

The hydraulic turbines are classified as follows:

1. According to the **head and quantity** of water available.
2. According to the **name of the originator**.
3. According to the **action of water on the moving blades**.
4. According to the **direction of flow of water in the runner**.
5. According to the **disposition of the turbine shaft.**
6. According to the **specific speed N_s.**

According to the head and quantity of water available:

1. **Impulse turbine-**requires **high head and small quantity of flow**.

2. **Reaction turbine** –requires **low head and high rate of flow**.

Actually there are two types of reaction turbines:

- One for medium head and medium flow.
- The other for low head and large flow.

According to action of water on the moving blades:

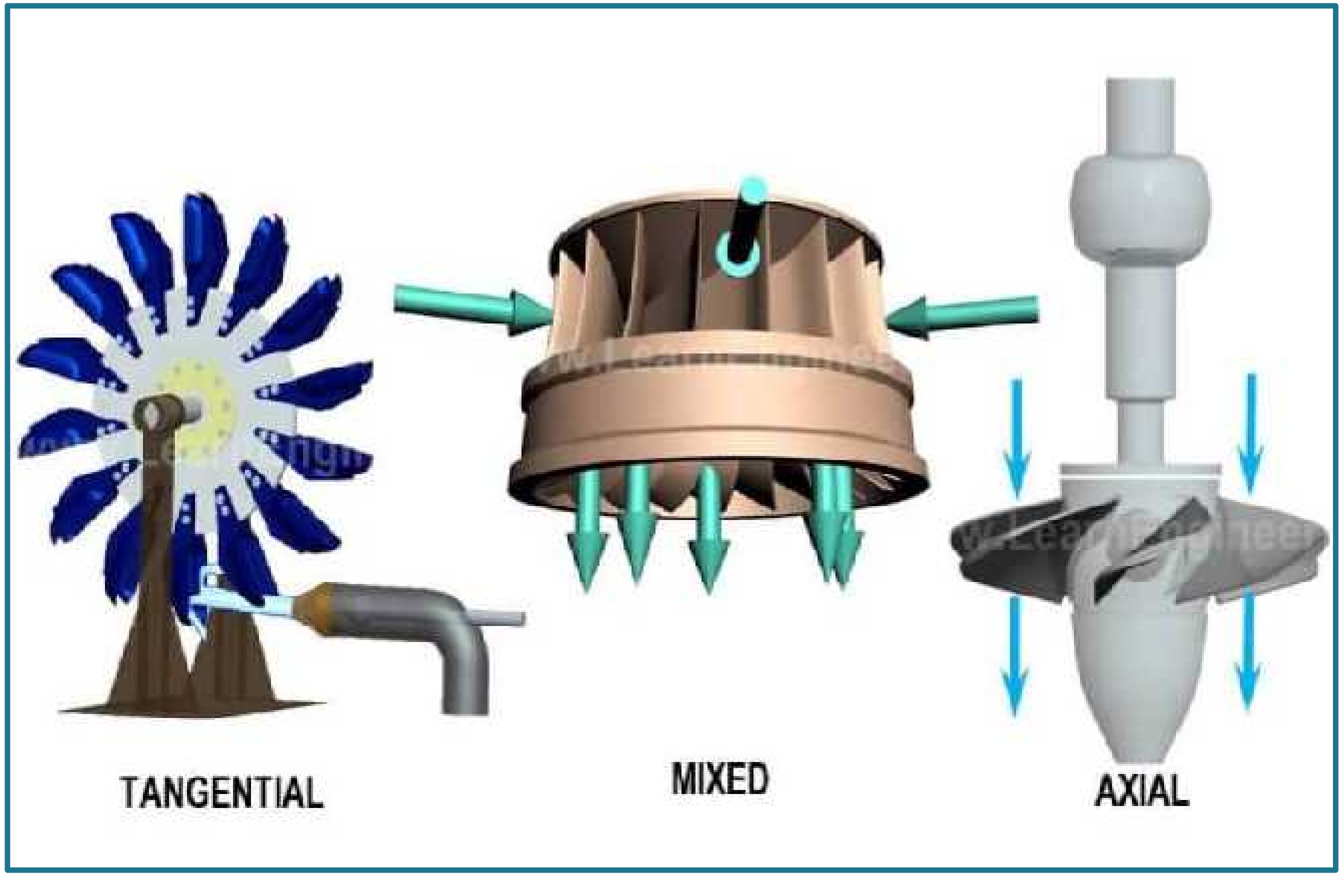
- **Turbines**
  - **Impulse turbine – Pelton turbine**
  - **Reaction turbines**
    - **Francis turbine**
    - **Kaplan and Propeller turbines**

According to direction of flow of water in the runner:

1. **Tangential flow** turbine (Pelton turbine)
2. **Radial flow turbine** (no more used)
3. **Axial (radial and axial)** flow turbine (Francis turbine)

According to the disposition of the turbine shaft:

Turbine shaft may be either **vertical** or **horizontal.** In modern turbine practice, Pelton turbines usually have horizontal shafts whereas the rest, especially the large units, have vertical shafts.


TANGENTIAL
MIXED
AXIAL

According to specific speed:

The specific speed of a turbine is defined as the speed of a geometrically similar turbine that would develop one brake horsepower under the head of one meter. All geometrically similar turbines (irrespective of their sizes) will have the same specific speed when operating under the same conditions of head and flow.

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

The table below shows the specific speed s for the various types of runners

Type of turbine	Type of runner	Specific speed (N_s)
Pelton	Slow Normal Fast	10 to 20 20 to 28 28 to 35
Francis	Slow Normal Fast	60 to 120 120 to 180 180 to 300
Kaplan	______	300 to 1000

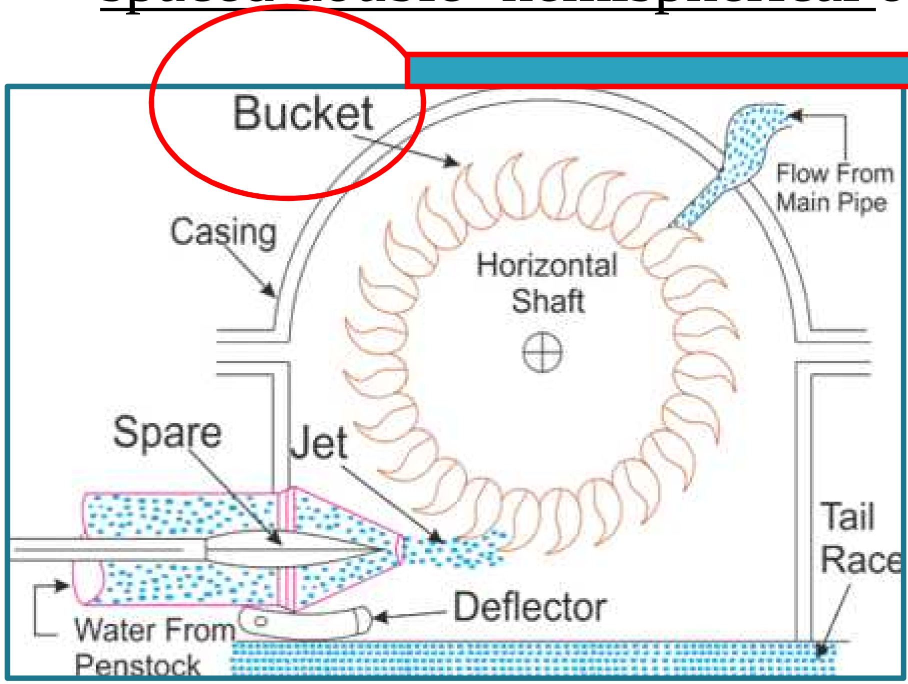
Note: Turbines with low specific speeds works under a high head and low discharge condition, while high specific speed turbines work under low and high discharge conditions.

Pelton wheel

Pelton wheel, among the various impulse turbines that have been designed and utilized, is by far the important.

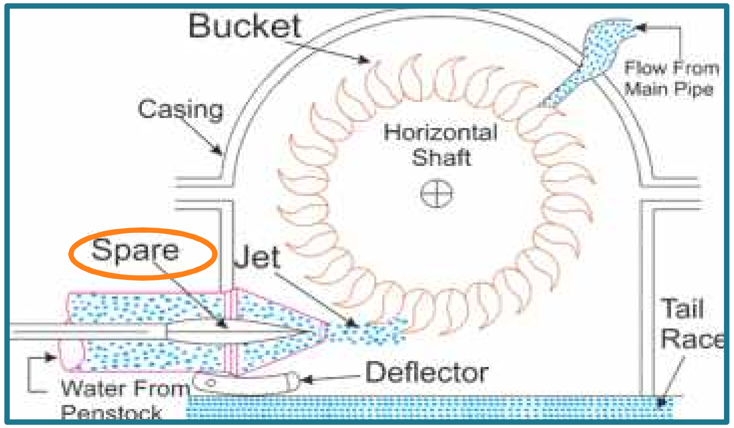
- The Pelton turbine is a **tangential flow impulse turbine.**

- It consists of **a rotor** at the periphery of which is mounted equally spaced double- hemispherical or double ellipsoidal buckets.



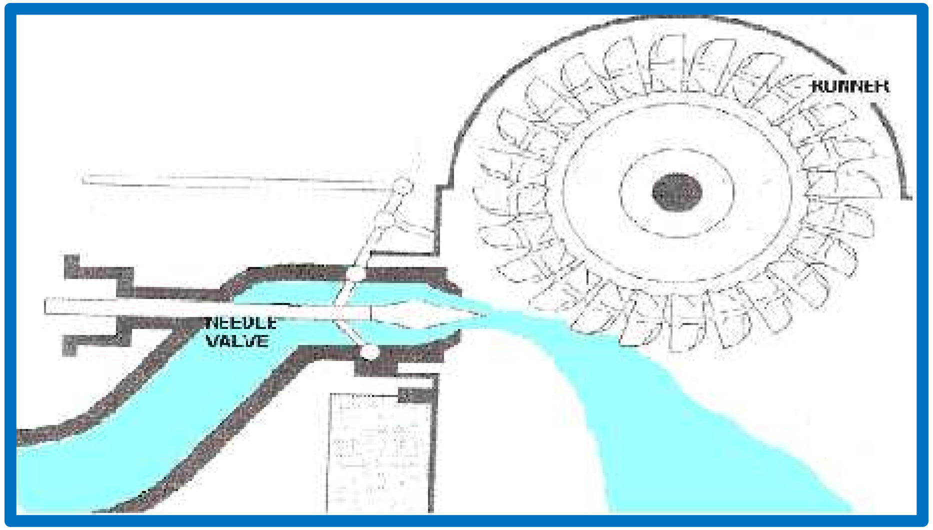
- Water is transferred from a **high head source** through penstock pipes. A branch pipe from each penstock pipe ends in **a nozzle**, through which the water flows out as a high speed jet.

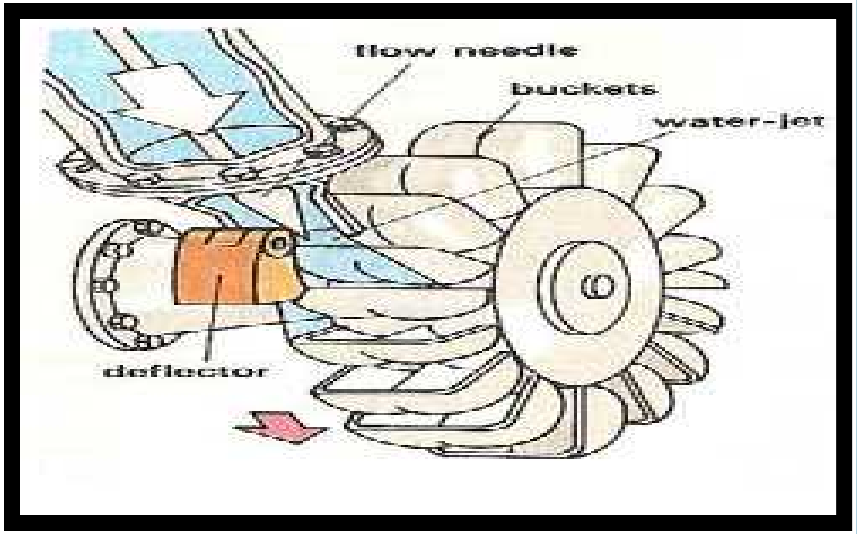
- **A needle or spare moving inside the nozzle:**
  - **controls the water flow through the nozzle**
  - **At the same time provides a smooth flow with negligible energy loss.**



- All the available potential energy is thus converted into kinetic energy before the jet strikes the buckets. **The pressure all over the wheel is constant and equal to atmosphere,** so that energy transfer occurs due to purely impulse action.

- The jet emerging from the nozzle hits the splitter symmetrically and is equally distributed into the two halves of hemispherical bucket.

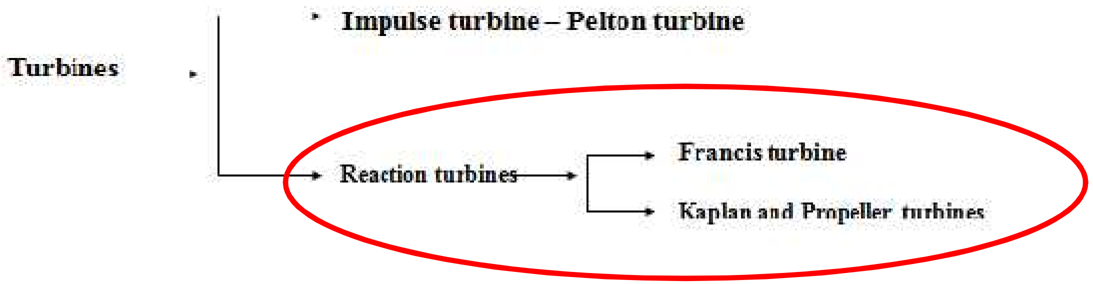




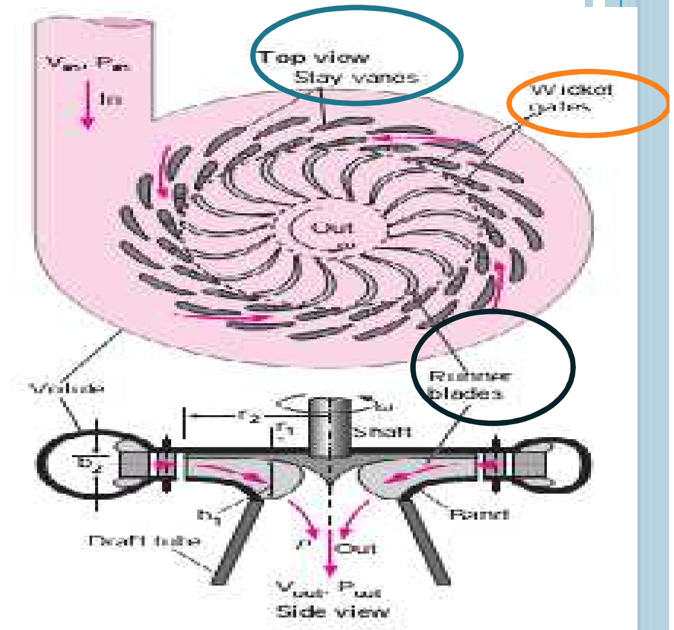
- The bucket center line cannot be made exactly like a mathematical cusp, partly because **of manufacturing difficulties and partly because the jet striking the cusp invariable carries particles of sand** and other abrasive materials which tend to wear it down.
- The **inlet angle of the jet** is therefore between **1^o and 3^o**, but it is always assumed to be zero in all calculations.
- Theoretically, if the bucket were exactly hemispherical, it would deflect the jet through **180^o.**

How Pelton Wheel turbines work?

REACTION TURBINES



- The other main type of energy-producing hydroturbine is the reaction turbine, which consists of
  - Fixed guide vanes called **stay vanes,**
  - Adjustable guide vanes called **wicket gates,**
  - and rotating blades called **runner blades**

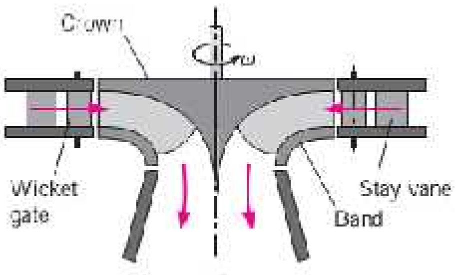


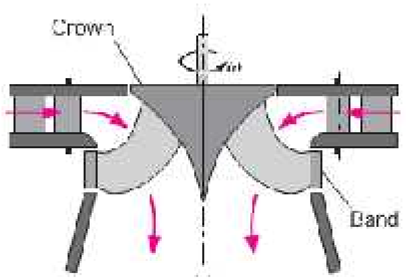
Classification of Reaction Turbines

We classify reaction turbines according to the angle that the flow enters the runner.

1) If the flow enters the runner radially **Francis radial-flow turbine**
   - **Inward flow turbines:** The water enters the runner at the outer periphery and the flows inwards (towards the center of the runner)
   - **Outward flow turbines:** The water enters at the center of the runner and then flows outwards (towards the outer periphery of the runner)
2) If the flow enters the runner at some angle between radial and axial, the turbine is called a **Francis mixed-flow turbine**.
3) If the flow is turned completely axially before entering the runner, the turbine is called an **axial-flow turbine**.

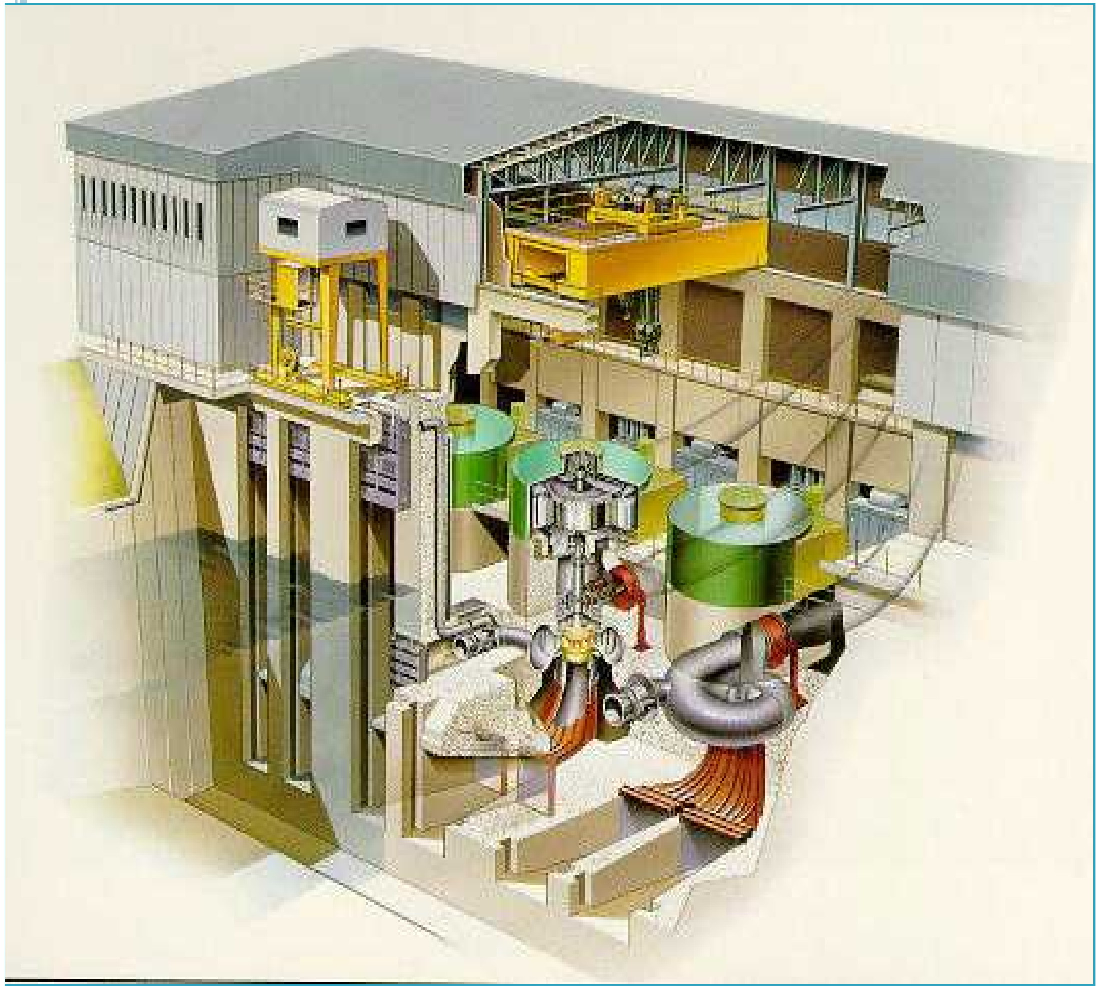
Francis radial-flow turbine





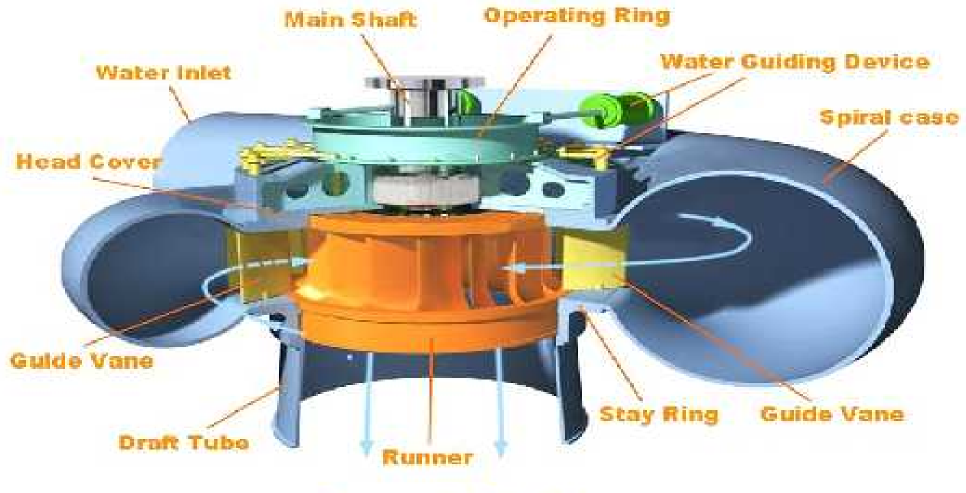
Francis mixed-flow turbine

FRANCIS TURBINES



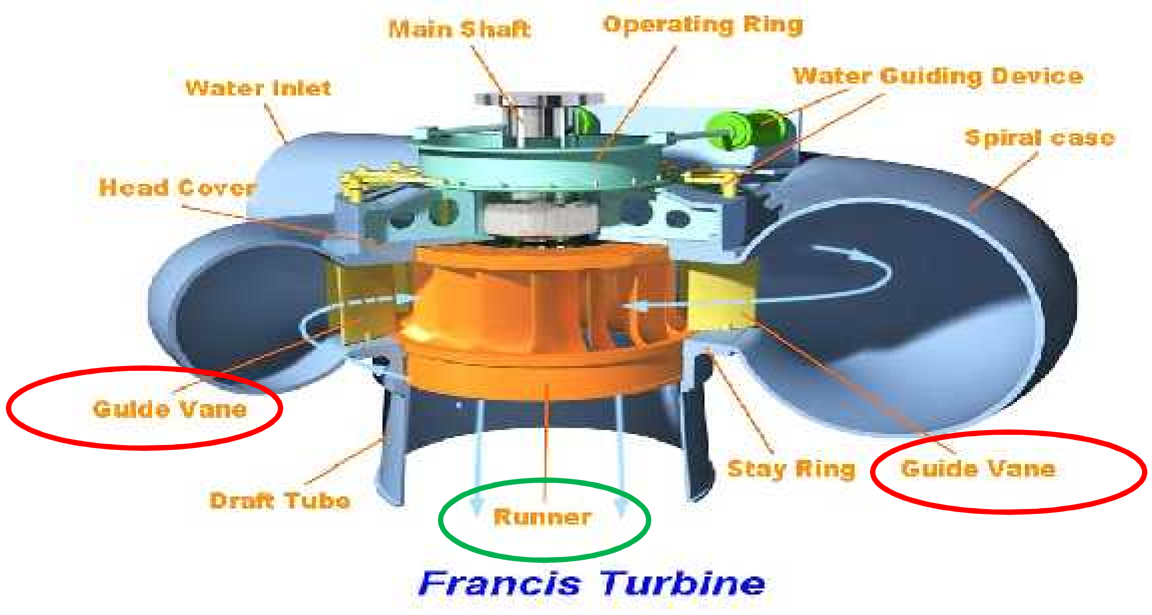
Francis turbines

- The modern Francis water turbine is an **inward mixed flow reaction turbine.**
- The water under pressure, enters the runner from the guide vanes towards the **center in radial direction and discharges out of the runner axially**.
- The Francis turbine operates under medium heads and also requires medium quantity of water.
- It is employed in the **medium head power plants**. This type of turbine covers a wide range of heads.

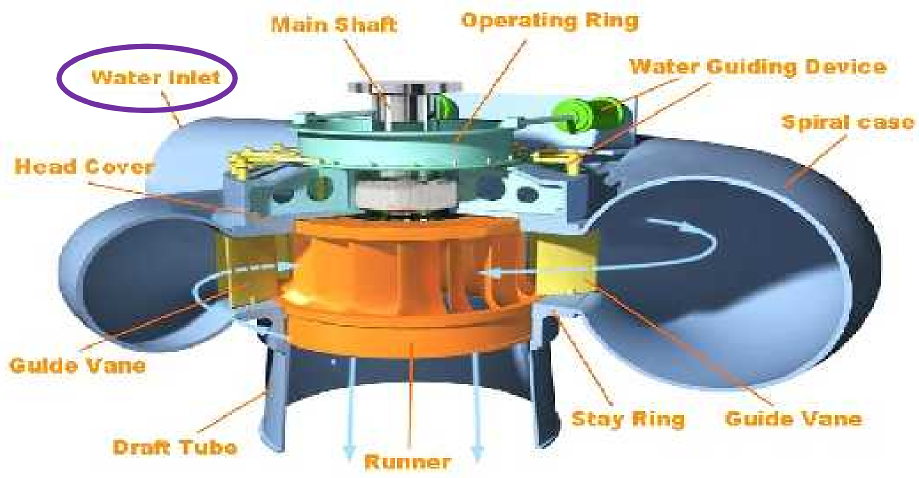


Francis Turbine

- **The head** acting on the turbine is partly transformed into kinetic energy and the rest remains as pressure head. **There is a difference of pressure between the guide vanes and the runner which is called the reaction pressure and is responsible for the motion of the runner**. That is why a Francis turbine is also known as reaction turbine.



- **In Francis turbine the pressure the inlet is more than that at the outlet.** This means that the water in the turbine must flow in a closed conduit. Unlike the Pelton type, where the water strikes only a few of the runner buckets at a time.



Francis Turbine

- **The Francis turbine the runner is always full of water**. The movement of the runner is affected by the change of both the potential and the kinetic energies of water. After doing is work the water is discharged to the tail race through a closed tube of gradually enlarging section. This tube is known as draft tube.
- It does not allow water **to fall freely to tail race level** as in the Pelton turbine. The free and of the draft tube is submerged deep in the tail water making, thus, the entire water passage, right from the head race up to the tail race, totally enclosed.

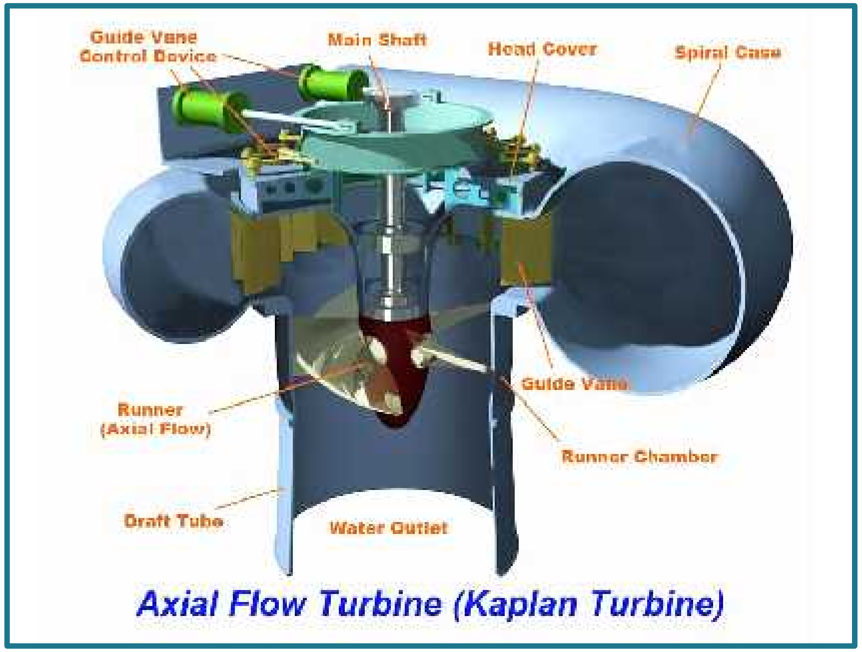
Propeller and Kaplan turbines

- The need **to utilize low heads where large volumes of water are available** makes it, essential to provide a larger flow area and to run the machine at very low speeds.
- The propeller turbine is a reaction turbine used for heads less than 30m, and has **a specific speed ranging from 300 to 1000**. It is **purely axial-flow** device providing the largest possible flow area that will utilize a larger volume of water and still obtain flow velocities which are not too large.
- **The propeller turbine consists of:**

- **an axial-flow runner with four to six or at most ten blades of air-foil shape**. The **spiral casing** and c blades are similar to those in Francis turbines. In the propeller turbine as in Francis turbines the runner blades **are fixed and non-adjustable**.

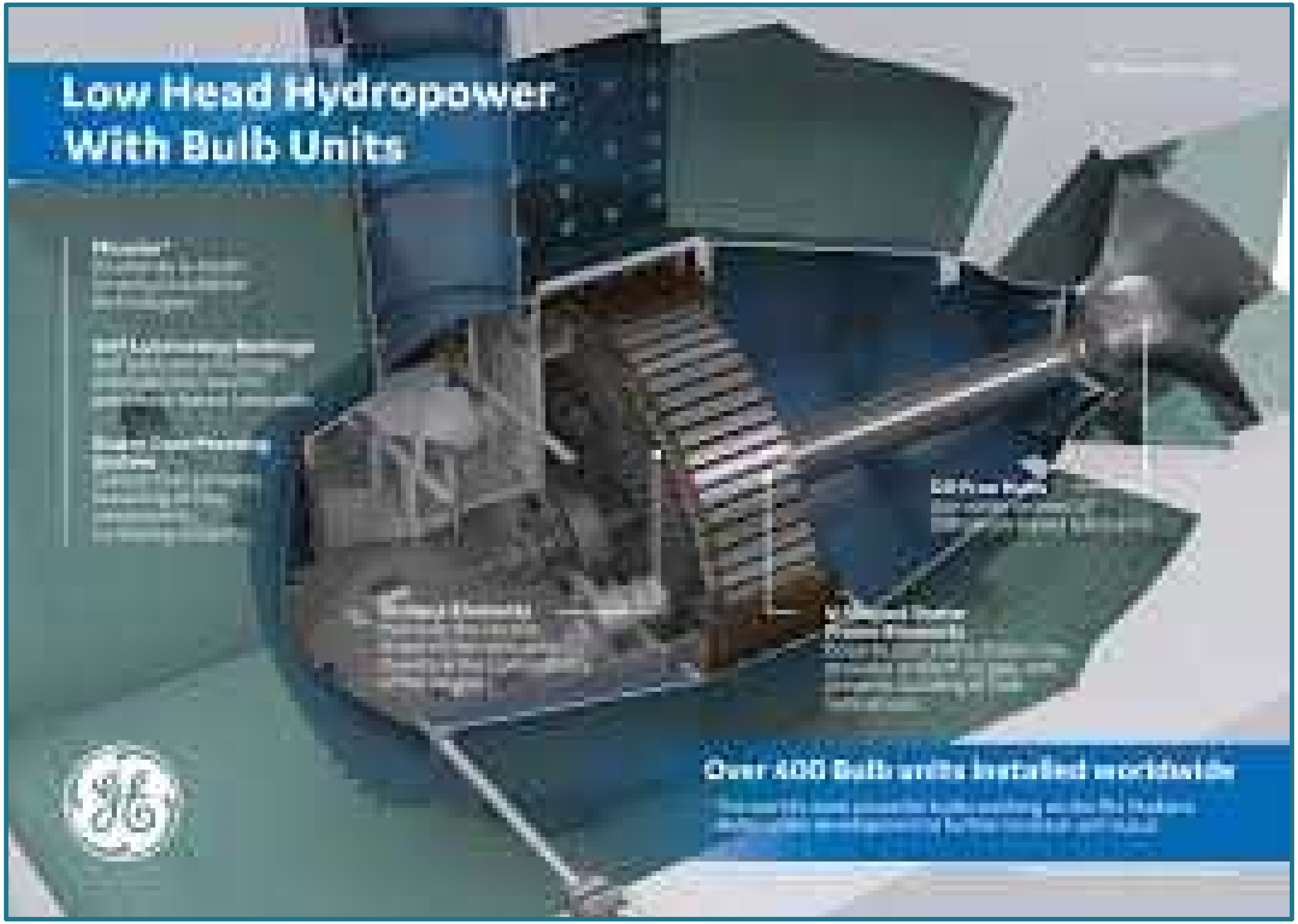
However in a Kaplan turbine. Which is modification of propeller turbine the runner blades are adjustable and can be rotated about pivots fixed to the boss of the runner. **The blades are adjusted automatically by servomechanism** so that at all loads the flow enters them without shock.

Kaplan turbine has taken the place of Francis turbines for certain **medium head** installations. Kaplan turbines with **sloping guide vanes** to reduce the overall dimensions are being used.


Guide Vane
Control Device
Main Shaft
Head Cover
Spiral Case
Runner
(Axial Flow)
Guide Vane
Runner Chamber
Draft Tube
Water Outlet
Axial Flow Turbine (Kaplan Turbine)

Tubular (or Bulb) turbines

- Kaplan turbine when employed for:
- **very low head.**
- has to be installed **below the tail race level**, thus requiring a deep excavation.
- For Kaplan turbine installation there are a number of heads at inlet casing and the **draft tube of elbow type** through which the water flows describing 'Z' path giving rise to continuous losses at the bends.
- Whenever the turbines is **repaired or dismantled**, the generator has to be removed first, the cost of turbine and that of civil engineering works using conventional Kaplan turbine with deep excavation is very high.
- The efficiency of such plants working under low head is less due to **excessive losses at the bends**..


Low Head Hydropower
With Bulb Units
Over 400 Bulb units installed worldwide

Comparison of common turbines

	Pelton wheel	Francis turbine	Kaplan /propeller turbine
Flow	Tangential, single stage, impulse	Inward radial flow, single stage, reaction	Axial flow, single stage reaction
Maximum capacity	250 MW	720 MW	225 MW
Number of jets/ kind of blades	1 to 6 maximum 2 for horizontal and 6 for vertical shaft	Fixed blades	Propeller turbine have fixed blades, while Kaplan turbines have adjustable blades
Head	100-1750 m	30-550 m	1.3-77.5 m
RPM	75-1000	93.8-1000	72-600
Hydraulic efficiency	Single jet (85-90)%	(90-94)%	(85-93)%
Specific speed	6-60	50-400	280-1100
Regulation mechanism	Spear nozzle and deflector plate	Guide vanes	Blade stagger

This table can be used for selecting the turbine for a specific application

Specific speed of a turbine

The specific speed of a turbine is defined as the speed of a turbine which is identical in shape, geometrical dimensions, blade angles, gate opening etc, with the actual turbine but of such a size that it will develop unit horse power when working under unit head.

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

- Specific speed plays an important role for **selecting the type of the turbine.** Also the performance of a turbine can be predicted by knowing the specific speed of the turbine.

To compare the characteristics of machines of different types, it is necessary to know a characteristic of an imaginary machine identical in shape. **The imaginary turbine is called a specific turbine**; the specific speed provides a means of comparing the speed of all types of hydraulic turbines on the basis of head and horse power capacity.

- **The runner of too high specific speed** with available head increases the cost of turbine on account of high mechanical strength required.
- **The runner of too low specific speed** with low available head increases the cost of generator due to the low turbine speed.

Efficiencies of a turbine

The important efficiencies of a turbine are as under:

1. Hydraulic efficiency, η_h
2. Mechanical efficiency, η_m
3. Volumetric efficiency, η_v
4. Overall efficiency, η_o

1- **Hydraulic efficiency, (η_h)** it is defined as the ratio of power developed by the runner of a turbine to the power supplied by the water at the inlet of the turbine.

$$\eta_h = \frac{\text{power developed by runner}}{\text{power developed at inlet}}$$

2- **Mechanical efficiency, (η_m)** it is defined as the ratio of power available at the shaft of the turbine (known as S.H.P) to the power developed by runner

$$\eta_m = \frac{\text{power available at the shaft ot the turbine}}{\text{power developed by the runner}}$$

3- **Volumetric efficiency** (η_v) the ratio of the volume of the water actually striking the runner to the volume of water supplied to the turbine is called volumetric efficiency.

$$\eta_v = \frac{\text{Volume of water actually striking the runner}}{\text{Volume of water supplied to the turbine}}$$

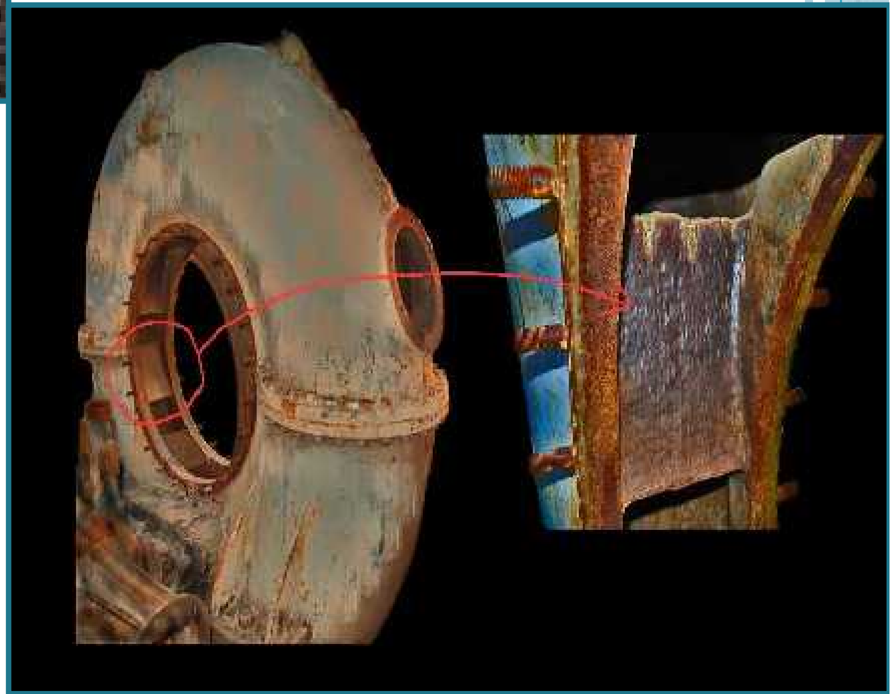
4- **Overall efficiency** (η_o) it is defined as the ratio of power available at the shaft of the turbine the power supplied by the water at the inlet of the turbine.

$$\eta_v = \frac{\text{Power available at the shaft of the turbine}}{\text{Power supplied at the inlet of the turbine}} = \frac{\text{Shaft power}}{\text{Water power}} = \frac{P}{wQH}$$

If η_g is the efficiency of a generator, then power output of a hydro-unit $= (w\ Q\ H) \times \eta_o \times \eta_g$

Cavitations

- It is known that when velocity of flow increases, the pressure falls.
- In liquids, the pressure cannot fall below vapor pressure which depends upon **the temperature** and **height above mean sea level of the site.**
- In any turbine part **if the pressure drops below the evaporation pressure**, the liquid boils and a large number of small bubbles of vapor are formed. These bubbles mainly formed on account of low pressure are carried by the stream to higher pressure zones where the vapors condense and the bubbles suddenly collapse, as the vapors are condensed to liquid again.



Methods to avoid cavitations:

The following methods may be used to avoid cavitations:

1. **Runner/turbine** may be kept under water. But it is not advisable as the inspection and repair of the turbine is difficult. The other method to avoid cavitations zone without keeping the runner under water is to use the runner of **low specific speed**.
2. It is possible to reduce the cavitations effect by selecting materials which can resist better the cavitations effect. The **cast steel** is better than **cast iron** and **stainless steel** or **alloy steel** is still better than cast steel.
3. The cavitations effect can be reduced by polishing the surfaces. That is why the **cast steel runner** and **blades are coated with stainless steel.**
4. The cavitations may be avoided by selecting a runner of power specific speed for gives head.

Selection of turbine

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

1- **Specific speed:** high specific speed is essential where head is low and output is large, because otherwise the rotational speed will be low which means cost of turbo-generator and power house for high head installations, because even with low specific speed, high rotational speed can be attained with medium capacity plants.

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

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

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

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

5- **Cavitations:** The installation of water turbines of reaction type over the tailrace level is effected by cavitations. **The critical value of Cavitations factor must be obtained to see that the turbine works in safe zone**.

- Such a value of cavitations factor also effects the design of turbine, especially of Kaplan, propeller and bulb types.

6- **Disposition of turbine shaft:** Experience has shown that the **vertical shaft arrangement is better for large-sized reaction turbines**, therefore it is almost universally adopted. In case of large size impulse turbine, horizontal shaft arrangement is mostly employed.

7- **Head:**

(i) **Very high heads** (350m and above). For heads greater than 200m, Pelton turbine is generally employed and there is practically no choice except in very special cases.

(ii) **High heads (above**100m to 350m). In this range either **Pelton or Francis** turbine may be employed. For higher specific speeds Francis turbine is more compact and economical than the Pelton turbine.

(iii) **Medium heads** (30m to 100m). A **Francis** turbine is usually employed in this range. Whether a high or low specific speed unit would be used depends on the selection of speed.

(iv) **Low heads** (below 30m), both **Propeller** and **Kaplan** turbine may be used.

(v) **Very low heads.** For very low heads bulb turbines are employed these days.

Example: A large hydropower station has a head of 324m and an average flow of 1370m^3/s. The reservoir of water covers an area of 6400Km^2. Calculate:

1. The available hydraulic power
2. the number of days this power could be sustained if the level of the impounded water were allowed to drop by 1m.

Solution:

1. The available hydropower can be found using the equation

P=9.8qh

P=9.8 x 1370 x 324=4350MW

2. we have to find the number of days ?

Using the 1 m drop we find the corresponding volume of water

Volume = area x height =$6400 \times 10^6 m^2 \times 1m = 6400 \times 10^6 m^3$

Rate of flow= $1370m^3/s$

By looking at the units of rate of flow we can deduce that time in seconds would be volume divide by rate of flow

$t=6400x10^6/1370 = 4.67x10^6$ s = 1298h =54 days

Example:

A hydro electric generating station is supplied from a reservoir of capacity $5x10^6$ cubic meters at a head of 200 meters. Find the total energy available in kWh if the overall efficiency is 75%.

Solution:

Given data:

- $V= 5x10^6 m^3$
- h =200m

Q can be calculated as $5x10^6 m^3/s$

P=9.8qh =$9.8x5x10^6$x200 =9800000000 x 0.75(efficiency) kW

E=PT

E=$(98x10^8$ x 10^3)W x 1s x0.75(efficiency)

We need to find out the energy in kWh so we divide the above value by (3600 x1000) and get the answer which is 2.0416 x 10^6 kWh

Example:

A hydroelectric project is at a side having a catchment area at 500 m^2. The annual rainfall is 125 cm available head in the reservoir is 300 m. Calculate the available power, assuming plan efficiency at 85% and average runoff of 70%.

Solution:

Water stored = 500 * 1000^2 *1.25*0.7

= 436* 10^6 m^3

$$\text{Discharge} = \frac{\times}{\times \quad \times \quad \times} = 13.86 \text{ m } /\text{sec}$$

Available power = 9.8*13.8*300*0.85 = 35 MW

Example:

A turbine develops 1800 hp working under a head of 250 m, when running at 400 r.p.m calculate specific speed of turbine specify the type of turbine to be used.

Solution:

H= 520 m, P= 1800 hp, N= 400 r.p.m

$$= \frac{\sqrt{\ }}{-}$$

$$= \frac{\sqrt{\ }}{(\quad)^{-}} = 21.4$$ for this specific Pelton turbine is used

Example:

Calculate the specific speed of a turbine and suggest the type of turbine required for a river having a discharge of 250 liter / second with an available head of 50 m. Assume efficiency of turbine as 80% and speed 450 r.p.m.

Solution:

W= 1 kg/liter, H= 50 m, N= 450 r.p.m, efficiency = 80%

$= \frac{\quad}{\quad}$ hours power

$= \frac{\cdot \times \times \quad \times}{\quad} = 133 \cdot 3\, h$

$= \frac{\sqrt{\;}}{-}$

$= \frac{\sqrt{\quad \cdot}}{(\quad)^{-}} = 39 \cdot 9$

For the specific speed Pelton wheel turbine is suitable

Example:

It is desired to belt a hydro power station a cross a river having a discharge at 30000 liters/sec at a head of 10 m a summing turbine efficiency turbine efficiency 80% and speed ratio ku as 0.83, determine:

Is it possible to use two turbines with a speed not less than 120 r.p.m and specific speed not more than 350.

Specify the type of runner that can be used also calculate the dimeter of runner.

Note: ku: speed ratio, D: Diameter of runner

Solution:

$= \frac{}{} \text{ h.p}$

$= \frac{\cdot \times \times \times}{} = 3200 \text{ h.p}$

$= \frac{\sqrt{}}{}$

$= \frac{\sqrt{}}{(\ )} = 267$

$V = Ku\sqrt{2} = \frac{}{60}$

$= \frac{60 \times Ku\sqrt{2}}{\times 120}$

D = 1.85 m