Hydro Plants

Hydroelectric power, also called **hydropower**, electricity produced from generators driven by turbines that convert the potential energy of falling or fast-flowing water into mechanical energy. There are three types of hydropower facilities: impoundment, diversion, and pumped storage. Some hydropower plants use dams and some do not.

IMPOUNDMENT*:* The most common type of hydroelectric power plant is an impoundment facility. An impoundment facility, typically a large hydropower system, uses a dam to store river water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. The water may be released to meet changing electricity needs or other needs, such as flood control, recreation, fish passage, and other environmental and water quality needs.

DIVERSION*:* A diversion, sometimes called a "run-of-river" facility, channels a portion of a river through a canal and/or a penstock to utilize the natural decline of the river bed elevation to produce energy. A penstock is a closed conduit that channels the flow of water to turbines with water flow regulated by gates, valves, and turbines. A diversion may not require the use of a dam.

PUMPED STORAGE*:* Another type of hydropower, called pumped storage hydropower, or PSH, works like a giant battery. A PSH facility is able to store the electricity generated by other power sources, like solar, wind, and nuclear, for later use. These facilities store energy by pumping water from a reservoir at a lower elevation to a reservoir at a higher elevation.

When the demand for electricity is low, PSH facility stores energy by pumping water from the lower reservoir to an upper reservoir. During periods of high electrical demand, the water is released back to the lower reservoir and turns a turbine, generating electricity.

Merits of Hydroelectric Plants

- No fuel is required, so operating cost is low and no problems of handling and storage of fuel.
- Highly reliable, cheapest in operation and maintenance.
- Plant can be synchronized and run up in few minutes.
- Load variation demand can be met without and difficulty.
- Accurate governing is possible.
- Longer life time and efficiency does not fall with age.
- Other purpose i.e irrigation, navigation and tourism also possible.
- Renewable source.

Demerits

- Required large areas.
- High in construction cost and time.
- Long transmission line is required as plant is located in areas which may far from load center.
- Dependence on rate of flow of water so affected by season.
- Submerges huge areas, uproot large population and create social and other problems.

Classification / Types Of Hydro-Power Plants

1. **According mode of operation**

    Run of river plant

    Storage plant

    Pumped storage plant

Run of River plants: No dam is constructed and, hence, reservoir is absent. A portion of river is diverted through a penstock or canal to the turbine. Thus, only the water flowing from the river is available for the generation. And due to absence of reservoir, any oversupply of water is passed unused

Storage plants: Hydropower plants with storage are supplied with water from large storage reservoir that have been developed by constructing dams and reservoirs 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.

Pumped storage plant: In pumped storage plant, a second reservoir is constructed near the water outflow from the turbine. When the demand of electricity is low, the water from lower reservoir is pumped into the upper (main) reservoir. This is to ensure sufficient amount of water available in the main reservoir to fulfill the peak loads.

2. **According to the head of water causing the turbines to rotate**
   Low head power plant: A power station that is operating under heads less than 30m.
   Medium head power plant: A power station operating under heads from 30m to 300m.
   High head power station: A power station operating under heads above about 300m.

3. **According to their operating functions**
   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
   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'.
   Pumped storage plants for peak load:

4. **According to installed capacity**
   - Large hydro plant: > 100MW
   - Medium hydro plant: 15-100MW
   - Small hydro plant: 1-15MW
   - Mini hydro plant: 100KW-1MW
   - Micro hydro plant: 5KW-100KW
   - Pico hydro plant: up to 5 KW

5. **Based on Interconnection**
   Isolated plants: If a power station works independently it is referred as an isolated plant. Generally installed in industries (i.e. Captive power plant)
   Interconnected plants: If a power station is connected with grid, it is called interconnected plant.

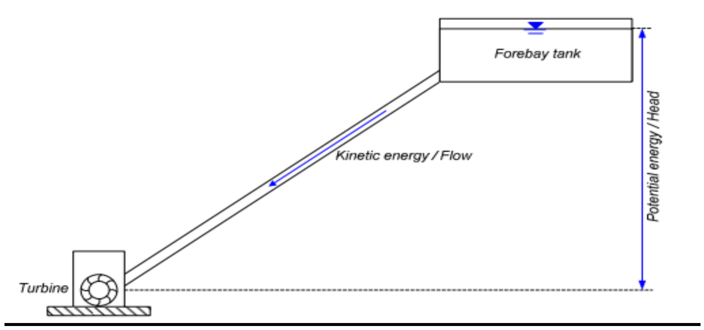
Working principle and power calculation

Working Principle: The potential energy of stored water is converted into kinetic energy and is utilized to rotate a turbine and thus produce electricity through generator. The amount of energy so produced depends upon the storage height of water and the quantity (mass) of water striking the turbine blades per second, also called as mass flow rate of water.

Power calculation

Water can be piped from a certain level to lower level; the resulting water pressure can be used to move mechanical components that convert potential energy into mechanical energy.

$$K.E = P.E = m.g.H$$



The mass of water is due to the volume V and the water density ρ i.e. mass = volume*density

$= \rho.V.g.H$ where

m= mass

g = acceleration due to gravity

H = vertical difference of level,head

Energy per unit time, power= energy/time

$= \rho.(V/t).g.H$

The amount of water added to the turbine is measured in volume per time unit and is called flow rate Q. As released energy per time unit equals to the capacity in watts

$$P = \rho.Q.g.H \quad \text{Watt}$$

Because of different losses, the energy generated by the turbine is less than the calculated gross output, so considering efficiency

$$P = \eta . \rho.Q.g.H \quad \text{Watt}$$

- The water density is assumed to be approximately 1000kg/ m3 ,

$$P = \eta.Q.g.H \quad \text{kW}$$

Site selection of Hydroelectric power plant

- Availability of water
- Water storage
- Water head
- Distance from load center
- Geological investigation
- Water pollution
- Sedimentation Environmental effect
- Access to site
- Large catchment area/cost and type of land

Essential element of hydro power plant

- Catchment area
- Reservoir
- Dam
- Safety devices (Spillway , surge tank and trash rack)
- Powerhouse and equipment
- Water conduits
- Prime movers

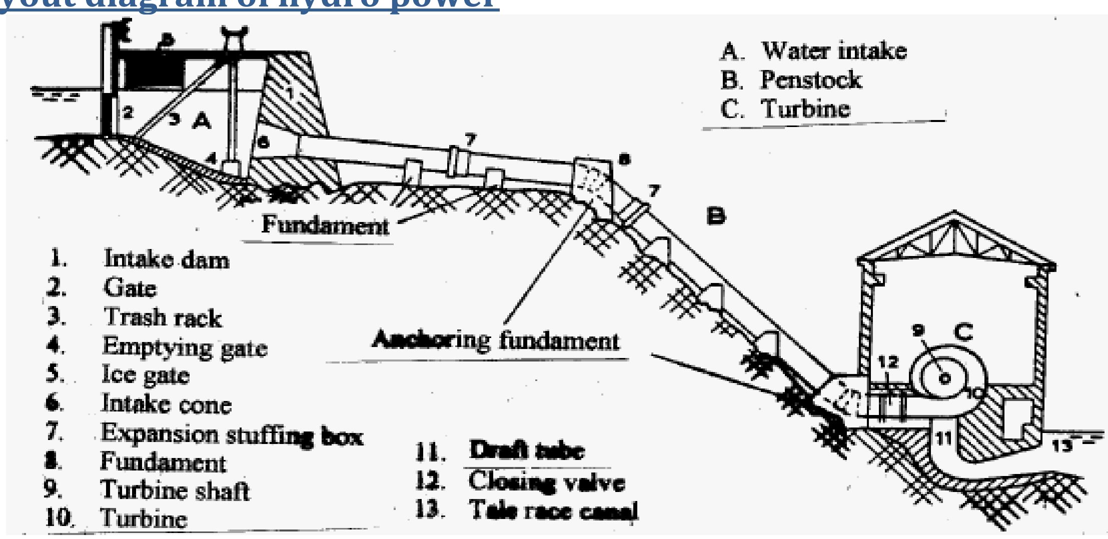
Problems being faced in execution of HYDRO PROJECTS

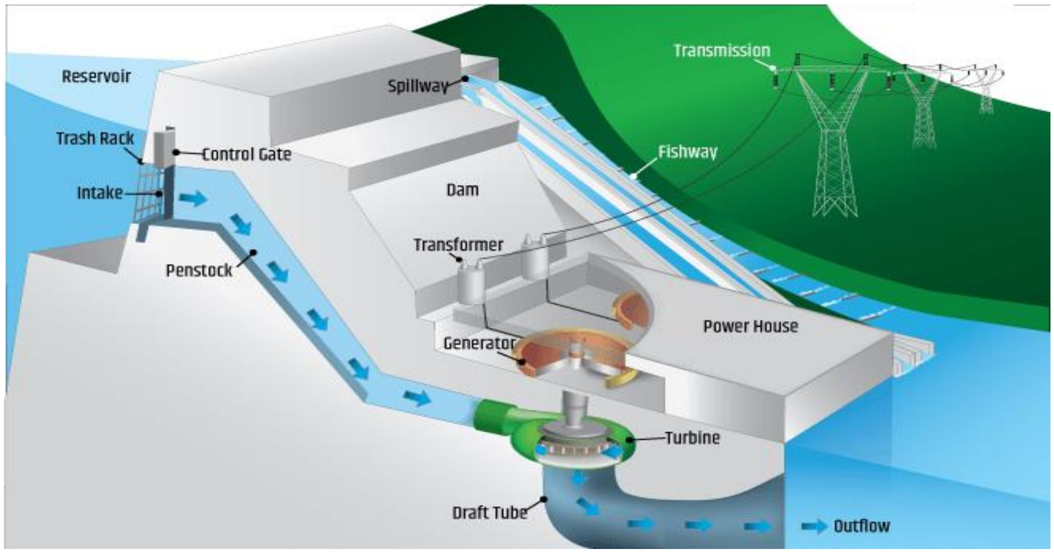
- Competition
- Lack of cooperation from local population/ Lack of involvement of local people
- R&R issue
- Environment & Forest clearances
- Political (change of parties) and • Political insurances
- Delay in issuing licensee like blasting, stone crushers, quarrying of river
- Lack of liaison & coordination (with multiple cooperation)
- Delay in design drawings
- Insurance for replacement values
- Labour laws
- Shortage of local labour, local contractors, quality assurance, manpower

Risk in Hydropower and its mitigation measures

Risk	Mitigation
Hydrological Risk	Long term data Good quality rainfall- run off modeling Sustainable Water shed management Good availability of resource data, maps
Geological Risk	Detailed investigations Catchments treatment Good design
Constructions Risk	Insurance Tern key contract Performance guarantees Liquid damages on non-performance Due diligence process Good engineering design Good supervision
Performance Risk	Insurance Warrantees Out sourcing of O&M Trained manpower Availability of spares and others
Power evacuation risk	Disciplined grid Stable grid
Financial Risk Delayed disbursement Delayed receipts from sale Delayed receipt of insurance Short duration PPAs Market fluctuation	Long term financing To have better understanding by FIs

Layout diagram of hydro power





Component of hydro plants

- Dams
- Trash rack
- Water reservoirs
- Intake or control gates/headrace
- Spillway
- Settlings basin
- Fore bay
- Penstock pipes
- Surge tank
- Anchor block
- Power house
- Turbine
- Tailrace

Dams

The dam is the most important component of hydroelectric power plant. The dam is built on a large river that has abundant quantity of water throughout the year. It should be built at a location where the height of the river is sufficient to get the maximum possible potential energy from water.

Water reservoirs

The water reservoir is the place behind the dam where water is stored. The water in the reservoir is located higher than the rest of the dam structure. The height of water in the reservoir decides how much potential energy the water possesses. The higher the height of water, the more is its potential energy. The high position of water in the reservoir also enables it to move downwards effortlessly. The height of water in the reservoir is higher than the natural height of water flowing in the river, so it is considered to have an altered equilibrium.

Trash Racks:

These are built up from long, flat bars set vertically or nearly so and spaced in accordance with the minimum width of water passage through the turbine. The clear space between the bars varies from 25 mm or 40 mm to 150 or 200 mm on very large installations. These are to prevent the ingress of floating and other material to the turbine. In some cases where large diameter turbines are employed, the racks are omitted, but provision is usually made for skimmer walls or booms to prevent ice and other material from entering the unit.

Intake or control gates

These are the gates built on the inside of the dam. The water from reservoir is released and controlled through these gates. These are called inlet gates because water enters the power generation unit through these gates. When the control gates are opened the water flows due to gravity through the penstock and towards the turbines. The water flowing through the gates possesses potential as well as kinetic energy

Spillway

Spillways are structures constructed to provide safe release of flood waters from a dam to a downstream are, normally the river on which the dam has been constructed. Every reservoir has a certain capacity to store water. If the reservoir is full and flood waters enter the same, the reservoir level will go up and may eventually result in over-topping of the dam. To avoid this situation, the flood has to be passed to the downstream and this is done by providing a spillway which draws water from the top of the reservoir. A spillway can be a part of the dam or separate from it

Settling basin

The water drawn from the river and fed to the turbine will usually carry a suspension of small particles. This sediment will be composed of hard abrasive materials such as sand which can cause expensive damage and rapid wear to turbine runners. To remove this material the water flow must be slowed down in settling basins so that the silt particles will settle on the basin floor. The deposit formed is then periodically flushed away.

From the size of the smallest particle allowed into the penstock the maximum speed of the water in the settling basin can be calculated as the slower the water flows the lower the carrying capacity of the water for particles. The water speed in the settling basin can be slowed down by increasing the cross section area of the channel. For each maximum size of the particles the optimum size of the settling tank can be calculated.

Forebay

The forebay tank forms the connection between the channel and the penstock. The main purpose is to allow the last particles to settle down before the water enters the penstock. Depending on its size it can also serve as a reservoir to store water.

A sluice will make it possible to close the entrance to the penstock. In front of the penstock a trash rash need to be installed to prevent floating large particles to enter the penstock.

A spillway completes the forebay tank.

Penstock

The penstock is the long pipe or the shaft that carries the water flowing from the reservoir towards the power generation unit, comprised of the turbines and generator. The water in the penstock possesses kinetic energy due to its motion and potential energy due to its height.

The total amount of power generated in the hydroelectric power plant depends on the height of the water reservoir and the amount of water flowing through the penstock. The amount of water flowing through the penstock is controlled by the control gates.

Surge tank/surge chamber

A surge tank is a cylindrical tank which is open at the top to control the pressure in penstock. It is connected to the penstock and as close as possible to the power house.

Whenever the power house rejected the water load coming from penstock the water level in the surge tank rises and controls the pressure in penstock.

Similarly, when the huge demand is needed in power house surge tank accelerates the water flow into the power house and then water level reduces. When the discharge is steady in the power house, water level in the surge tank becomes constant.

The change in water pressure in penstock pipes due to change in load condition result in water hammer effects, which surge tank can provide safety from damage of penstock.

A surge tank is a water storage device used as a pressure neutralizer in a hydropower water conveyance system to resists excess pressure rise and pressure drop conditions.

Water Hammer Effect in penstock

Water hammer effects in the penstock are **created by any changes in discharge through the turbine, caused by changes in the connected power network, by the operators, or by breakdowns**.
When the water flowing in a long pipe is suddenly brought to rest by closing the valve, the momentum of the flowing water will be destroyed and consequently, a wave of high pressure will be set up. The kinetic energy of flowing liquid will be converted into the internal pressure energy with the rising of pressure.
This wave of high pressure will be transmitted along the pipe with a velocity equal to the velocity to the velocity of sound and may create a noise called knocking. This phenomenon of a sudden rise in pressure in the pipe is known as a water hammer or water blow.
When load on generator is reduced suddenly, governor closes the turbine gates and thus creates a increase in water pressure on the penstock, due to the movement of the moving water being dest raged. This cause a wave of high pressure to be transmitted along the pipe which creates noise called knocking. This phenomenon of suddenly rise in pressure in pipe is called water hammer/water blow. This pressure ia called positive water hammer effect. To avoid this, a surge tank is introduced in the penstock to absorb excess pressure.
When turbine gets suddenly opens due to requirement of more water due to increase in load demand on the generator, water has to rush through pipe and there is tendency to cause vacuum air in the pipe supplying the water. This will create negative water hammer effect.
In such case water level in surge tank reduces to supply additional water through penstock in order to neutralize negative pressure so water flow smooth in penstock.

Causes of Water Hammer Effect

The water hammer effect is originated due to changes in velocity which are driven by:
✔ Due to the sudden closing of the valve
✔ Due to Power failure
✔ Beginning or closing down of pumps (hydro turbines)
✔ Changes in power demand in turbines
✔ Fracture of the line etc.
✔Mechanical collapse of the managing devices like the valve

Effects of Water Hammer Effect

✔ High-pressure fluctuations in pipelines
✔ Rupture of pipe or valve if beyond the safety limit
✔ Higher pressure requirements for the design of pipelines and penstocks etc.

Solutions for Water Hammer

Due to the decrease in the chance of the water hammer effect, following factors are considered:
✔ Steam lines should continuously be established with a slight slope (gradient) in direction of flow.
✔ installing steam traps at regular intervals and also at the low points. This ensures the removal of condensate from the steam system as soon as it is formed.
✔ Hanging pipes should be neglected by equipping suitable support. Sagging pipes can initiate a pool of condensate in the pipework, advancing the possibilities of a water hammer.
✔ Workers should be instructed to open the isolation valve gradually during the start-up modes.
✔ Drain pockets should be adequately sized to make sure that condensate just does not jump over them. Rather, the drain pockets should be sized sufficiently so that all the condensate comes into the trap.
✔ Eccentric reducers can be carried out against concentric reducers.

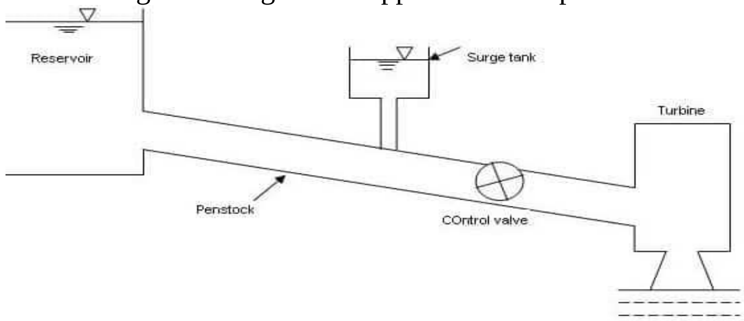
Types of Surge Tanks

Various types of surge tanks used in the hydropower water conveyance system are as follows.

- Simple surge tank
- Gallery type surge tank
- Inclined surge tank
- The restricted orifice surge tank
- Differential surge tank

Simple Surge Tank

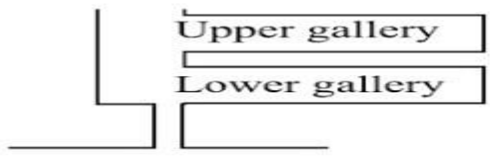
A simple surge tank is like vertical pipe which is connected in between penstock and turbine generator. These are constructed with greater height and supports are also provided to hold the tank.



Gallery Type Surge Tank

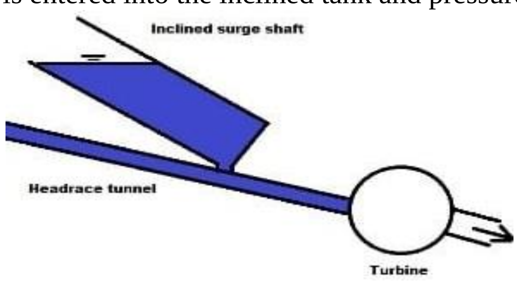
Gallery type surge tank consists of extra storage galleries in it. These storage galleries are also called as expansion chambers. So, gallery-type surge tanks can also be called expansion chamber-type surge tanks.

These expansion chambers are generally provided below & above the surge levels. Below surge level chambers are used to store excess water in them and released when it is required or there is a brief drop in pressure. Upper surge level chambers are used to absorb the excess pressure.



Inclined Surge Tank

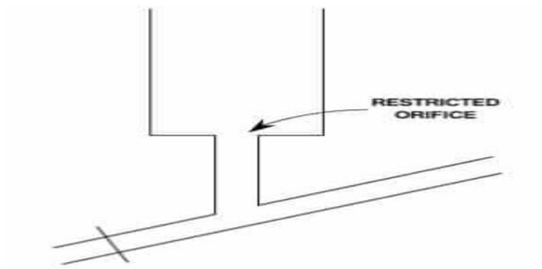
In the case of an inclined surge tank, the surge tank is provided with some inclination. It is provided when there is a limit in height of the tank. By providing an inclined surge tank the overflowed water under excess pressure is entered into the inclined tank and pressure destroyed.



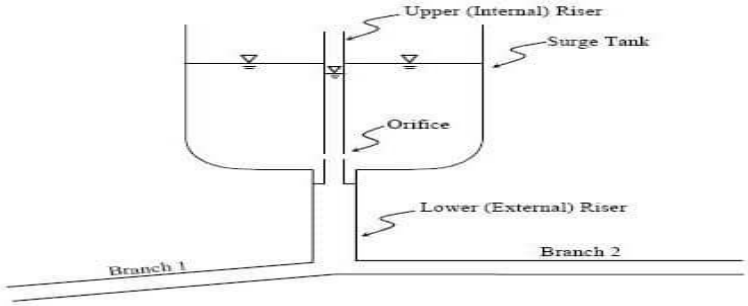
Restricted Orifice Surge Tank

Restricted orifice consists an orifice between pipeline and surge tank. This orifice is also called as throttle so; it is also called as throttled surge tank. This throttle or orifice have very small diameter.

If the water overflows it should enter into the surge tank through this orifice. Because of small diameter frictional losses will developed and excess pressure in main pipe line is destroyed. This will creates quickly a retarding or accelerating head in the conduit. To reduce the water hammer effect, diameter of orifice should be well designed for full rejection of load by the turbine.



Differential Surge Tank
Here, an internal riser is fixed in the tank. This riser have very small diameter through which water enters into the riser when it overflows. The riser also contains annular ports at its lower end.



These ports help the flow into or out of the tank. So, the excess pressure is destroyed by the internal riser of the surge tank and storage of water is done by the outer tank. So, it is called a differential surge tank.

Anchors blocks and Supporting piers
The function of the anchor block is to fix the penstock and do not allow the pipe with any direction of movement. The installation site of the anchor block is usually at the connection of forebay pool and pressure pipe, connection between pressure pipe and power house, and when pressure pipe changes its direction. The change of direction can be vertical or horizontal. In either cases anchor blocks should be provided. They are designed to ensure the thrust restraint of water. The penstocks between the anchors are supported by rocker supports/supporting piers.

Power house
The purpose of the power house is to support and house the hydraulic and electrical equipment

Hydraulic turbine
Hydraulic turbine is a device which can convert the hydraulic energy into the mechanical energy which again converted into the electrical energy by coupling the shaft of turbine to the generator.
Whenever the water coming from penstock strikes the circular blades or runner with high pressure it will rotate the shaft provided at the center and it causes generator to produce electrical power.
Generally hydraulic turbines are of two types namely

Impulse turbine/ velocity turbine/Pelton wheel turbine

Reaction turbine/ pressure turbine: Kaplan turbine and Francis turbine

Draft tube
If reaction turbines are used, then draft tube is a necessary component which connects turbine outlet to the tailrace. The draft tube contains gradually increasing diameter so that the water discharged into the tailrace with safe velocity. At the end of draft tube, outlet gates are provided which can be closed during repair works. The principal purpose of the draft tube is to convert water kinetic energy into pressure energy. To decrease the velocity of the water and to raise the pressure of the water before joining the tailrace, the pipe is used to steadily increase the cross-sectional area. The draft tube raises the water

pressure to the atmospheric pressure. To tolerate the high pressure and speed of the water, the tube must be strong enough.

The **Draft Tube** is a connecting pipe that is normally installed at the turbine's outlet or exhaust, and it transfers the water's kinetic energy to static pressure at the turbine's output. This prevents the kinetic energy of the water flowing through the turbines' output from dissipating.

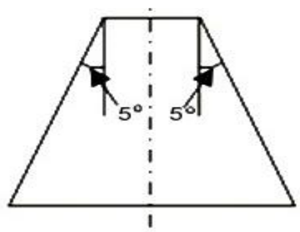
Types of Draft Tube

Various forms of draft tubes are available. There are mainly 4 types of draft tube

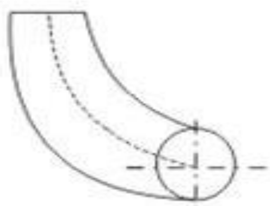
1. **Conical diffuser or straight divergent tube-**This type of draft tube consists of a conical diffuser with half angle generally less than equal to 10° to prevent flow separation. It is usually employed for low specific speed, vertical shaft Francis turbine. Efficiency of this type of draft tube is 90%

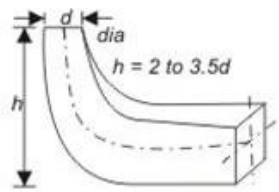
2. **Simple elbow type draft Tube-**It consists of an extended elbow type tube. Generally, used when turbine has to be placed close to the tail-race. It helps to cut down the cost of excavation and the exit diameter should be as large as possible to recover kinetic energy at the outlet of runner. Efficiency of this kind of draft tube is less almost 60%

3. **Elbow with varying cross section-**It is similar to the Bent Draft tube except the bent part is of varying cross section with rectangular outlet. The horizontal portion of draft tube is generally inclined upwards to prevent entry of air from the exit end.



Conical Diffuser


Simple elbow type



Elbow type with varying cross-section

DAM

- Dam is a barrier built across a river to hold Back River water for safe retention and storage of water or control the water flow.
- Dams allow to divert the river flow into a pipeline, a canal or channel. Dam's results in substantially raising water levels in the river over a large area thus create a storage space.
- Dams are built of concrete or stone masonry, earth or rock fill.

Purpose of dam

Dams and reservoirs are built to raise water level for storage and safe retention of large quantity of water. Water is subsequently released to achieve various purposes. Dams may be constructed to meet one or more purposes as:

- Irrigation
- Hydropower development
- Flood control
- Recreation (picnic, camping, fishing, swimming water rafting)
- Fish and wildlife protection and development, and improvement of river ecology
- River water quality / pollution control and management
- Stream flow regulation for various purposes
- Navigation

Site Selection Criteria for Dam

- Suitable foundation must be available.
- For economy, the length of the dam should be as small as possible and for given height it should store maximum amount of water.
- A suitable site for the spillway should be available in or nearby vicinity.

- The bed level at the dam site should preferably be higher than that of the river basin. This will reduce the height of the dam and will facilitate the drainage problem.
- The reservoir basin should be reasonably water-tight.
- Material required for the construction of the dam should be easily available locally.
- The value of the land and property submerged by the proposed dam should be as low as possible.
- Dam site should be easily accessible, such that it can be economically connected to important towns.
- Site for establishing labour colonies and healthy environment should be available nearby vicinity.

Types of dam

1. Masonary dams: usually built in a narrow canon. It can be further classified into three types:

a) Gravity dam
b) Arch dam
c) Buttress dam

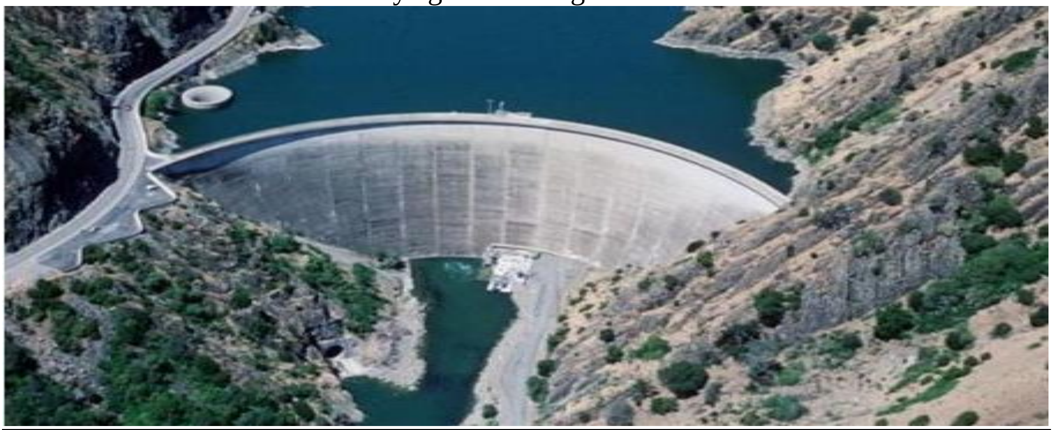
Gravity dams:

- A dam constructed of concrete and/or masonry, which relies on its weight and internal strength for stability. The gravity dams are the ones which are supported completely on the bed of the rock. In these types of dams, since there is huge quantity of water in the dams, it exerts excessively high hydraulic pressures on bed of the dam.
- Thus gravity dams can be constructed only in the places where there is strong structure of the rock so that it can sustain all the forces. Further, this rock structure should be able to prevent the seepage of water. This structure should be earthquake proof so that even in case of occurrence of natural disaster the rock structure remains intact.

Arch dams

- The arch dams comprise of the convex arch which is supported by the lateral rock walls. While in case of the gravity dams the maximum forces are exerted on the bed of the dam, in case of the arch the maximum forces are exerted on the lateral walls of the dam i.e. transmits a major portion of its water pressure horizontally to the abutments by arch action.
- The walls should be solid and strong enough to sustain all the visible and invisible forces of water so that the dam remains intact and no untoward incident occurs in the future. To ensure long-term safety of the wall, it is important to keep on inspecting the walls of arch dam regularly.

- The arch dams are constructed in the narrow canyons with steep sidewalls. In such cases the width of dam does not exceed six times its height.
- This dam has the inherent stability against sliding.



Buttress Dam

- A buttress dam or hollow dam is a dam with a solid, water-tight upstream side face that is supported at intervals on the downstream side by a series of buttresses or supports.
- The dam wall may be straight or curved. Most buttress dams are made of reinforced concrete and are heavy, pushing the dam into the ground. Water pushes against the dam, but the buttresses are inflexible and prevent the dam from falling over.
- More suitable for weak foundation and earth quake prone sites.

2. Earth dams

- Usually best suited for a wide valley.
- Has wide base as compared to its height.
- They are cheaper than masonary and best fit in natural surroundings.
- But they are subjected to erosion by water

Factors affecting selection of Dam type

- Topographical situation of the dam site
- Foundation and geological structure
- Location and type of suitable material to be used in dam construction:

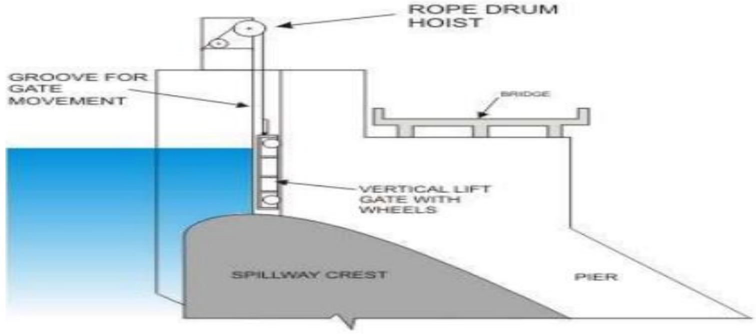
- Transportation facilities :
- Full spillway capacity and location
- Earthquake/ Landslide:
- Climatic conditions and duration of construction
- Economic situation of the country
- Machine park area availability, types and capacities of machines

Control Gates

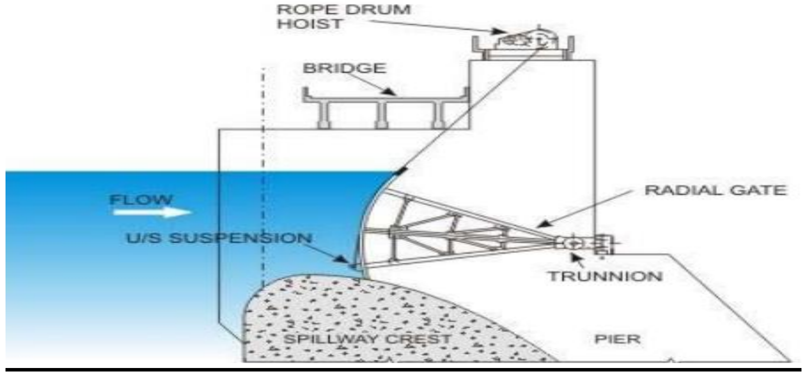
Different types of gates used which are intended to close over the flowing water are categories as

a) Vertical lift gates
b) Radial gates
c) Ring gates
d) Sector gates

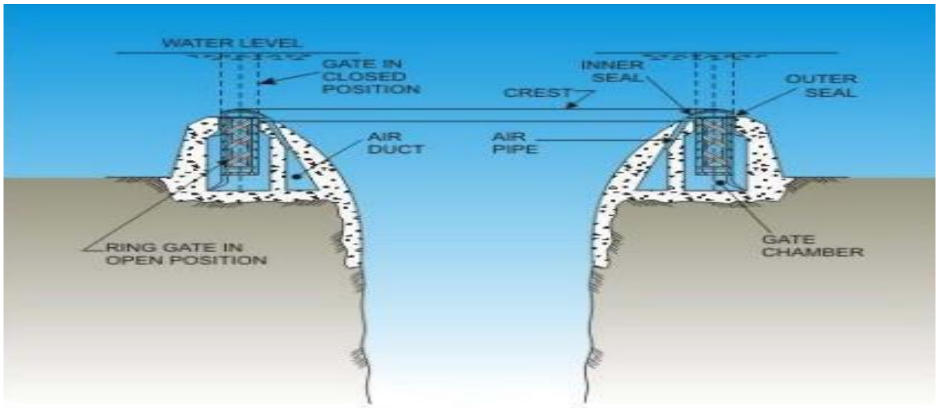
Vertical lift gates: These are gates that moves within a vertical groove incised between two piers. The vertical lift gates used for controlling flow over the crest of a hydraulic structure are usually equipped with wheels; this type of gate is commonly used for barrages but is nowadays rarely used for dam spillways. Instead, the radial gate is used for dams. This is mostly due to the fact that in barrage spillways, the downstream tail water is usually quite high during floods that may submerge the trunnion of a radial gate.



Radial gates: These are hinged gates, with the leaf (or skin) in the form of a circular arc with the center of curvature at the hinge or trunnion. The hoisting mechanism shown is that using a cable that is winched up by a motor placed on a bridge situated above the piers.



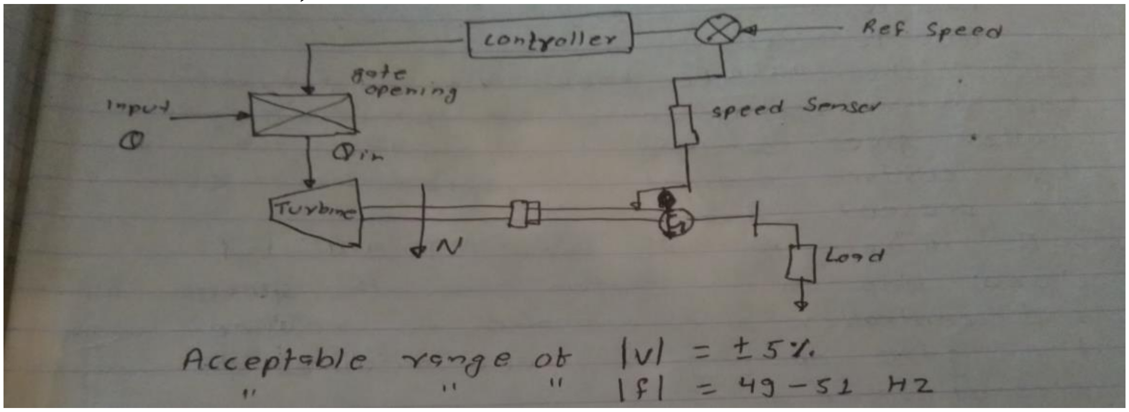
Ring gates: A cylindrical drum which moves vertically in an annular hydraulic chamber so as to control the peripheral flow of water from reservoir through a vertical shaft.



Steady state operation

- Deals with Stable operation condition
- In steady state system is able to maintain stability during gradual change in input output parameters.
- Voltage and frequency shall be controlled with in acceptable range by some control mechanism.
- For steady state operation, Pm=Pe i.e mechanical input power= electrical output power

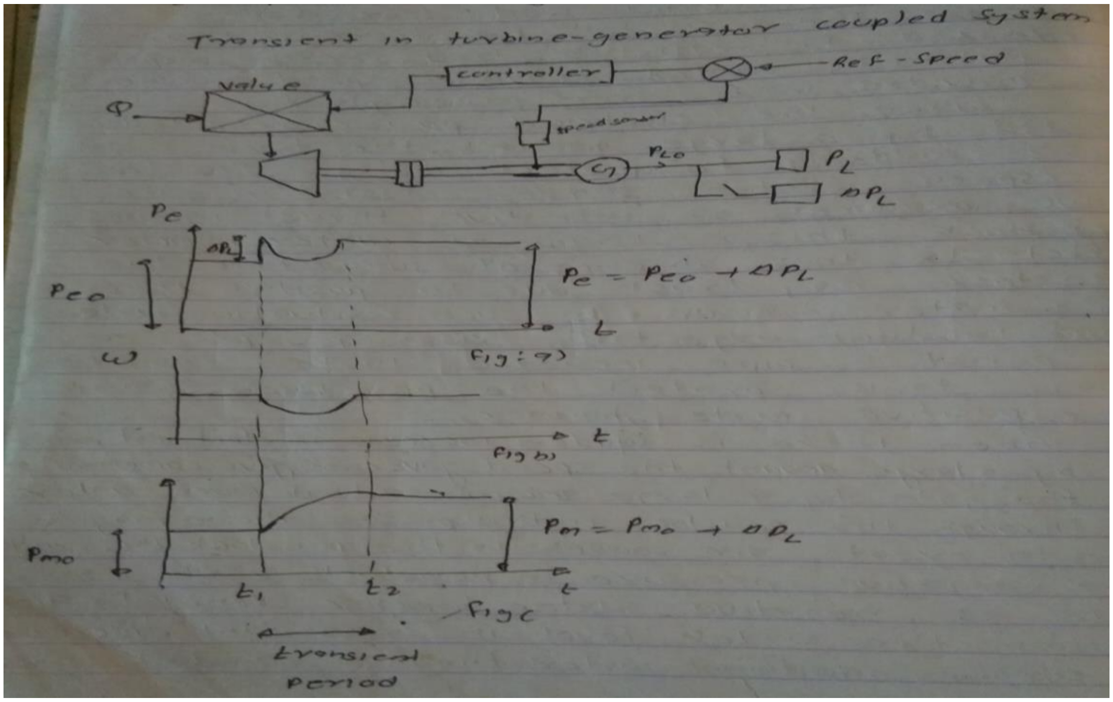
  or, Pm= Pe + losses



Case I: when Pm< Pe, then speed and frequency decreases , close loop control system sense the speed and controller gives command to open the gate by certain amount and speed increases to present value.
Case II: when Pm> Pe, then speed and frequency increases , close loop control system sense the speed and controller gives command to reduce the gate opening by certain amount and speed decreases to present value.

Transient, control of water delivary

- Transient refers to sudden change of some parameters of system by a large amount in very short time, which may destroy steady state behaviors of the system.
- Under such case speed, frequency, magnitude of voltage, mechanical power output may be deviated.
- Closed loop control system comebacks to the stable condition with new operating area as shown in fig a), b) and c) for response of electrical power output, speed and mechanical power output due to sudden increase in electrical system.



- At t=t1, a large load ΔPL is switched on . This will cause decrease in speed and hence magnitude of generated voltage.
- The closed loop control system senses speed and compare with reference speed. The error signal drives controller and give command to increase valve so increase amount of water flowing into turbine.
- So speed increases at t=t2 and remains constant with increase in new electrical power to match mechanical increased power.

Pumped Storage Power Plant

Pumped-storage hydroelectricity (**PSH**), or **pumped hydroelectric energy storage** (**PHES**), is a type of hydroelectric energy storage used by electric power systems for load balancing.

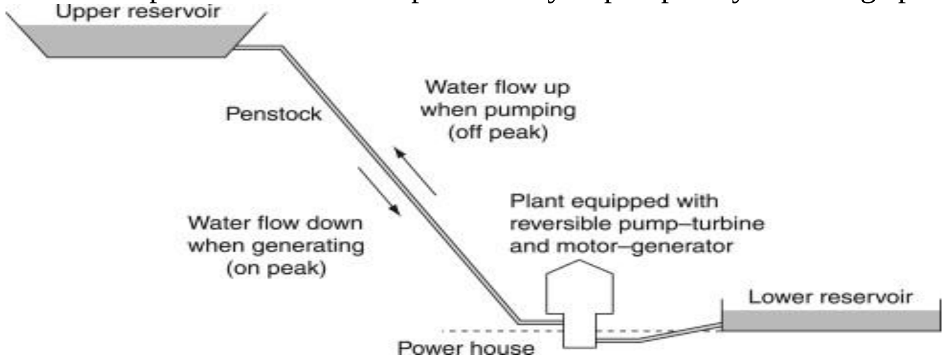
The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost surplus off-peak electric power is typically used to run the pumps.

During periods of high electrical demand, the stored water is released through turbines to produce electric power. Although the losses of the pumping process make the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest. If the upper lake collects significant rainfall or is fed by a river then the plant may be a net energy producer in the manner of a traditional hydroelectric plant.

Pumped storage hydro plants can also provide ancillary services to help balance the power system, such as inertia from spinning turbines, which ensures the system runs at the right frequency and reduces the risk of power cuts

Basic principle

At times of low electrical demand, excess generation capacity is used to pump water into the upper reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine, generating electricity. Reversible turbine/generator assemblies act as a combined pump and turbine generator unit (usually a Francis turbine design).Variable speed operation further optimize the round trip efficiency in pumped hydro storage plants.



Pumped storage hydro facilities act as vast 'water batteries'. They are a flexible way of storing excess energy generated by renewables, cost-effectively and at scale.

<u>Advantages:</u>

The pump storage plants entail the following advantages:

1. There is substantial increase in peak load capacity of a plant at comparatively low capital cost.
2. Due to load comparable to rated load on the plant, the operating efficiency of the plant is high.
3. There is an improvement in the load factor of the plant.
4. The energy available during peak load periods is higher than that of during off peak periods so that inspite of losses incurred in pumping there is over-all gain.
5. Load on the hydro-electric plant remains uniform.
6. The hydro-electric plant becomes partly independent of the stream flow conditions.

<u>Disadvantages</u>

The major issues associated with pumped storage hydropower plants lie in the scarcity of suitable sites for two reservoirs and a pumping station to be built with considerable elevation difference. This fundamental issue along with others gives rise to the series of problems that are:

- ✓ High cost relative to other technology
- ✓ Energy Losses
- ✓ Possibility of Affecting Aquatic Life
- ✓ Impact on Water Quality in the Vicinity
- ✓ Climate Dependent
- ✓ A threat to Habitats and Sites Entailing Sentiment
- ✓ Cavitation problem

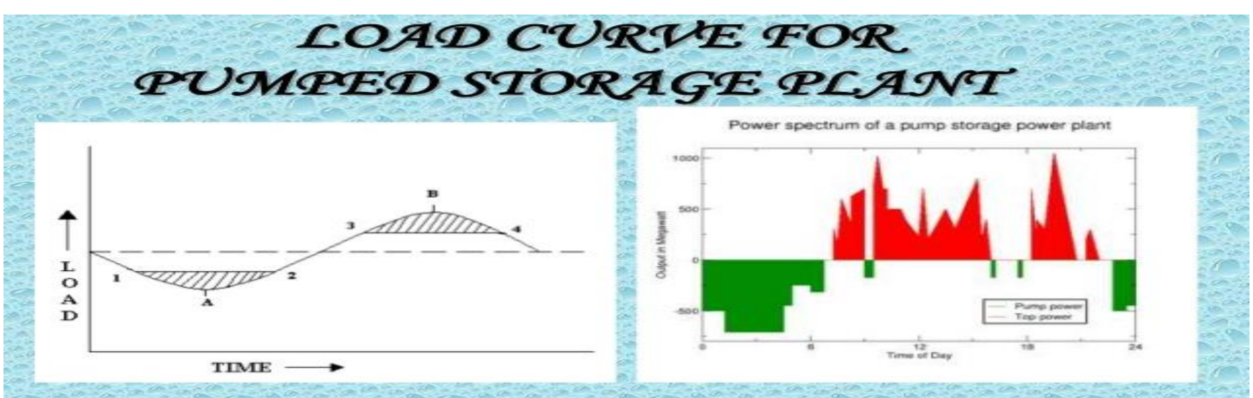


Figure:1 Hypothetical Load Curve Figure: 2 Actual Load Curve

Ancillaries and Auxiliaries of hydro plant

Auxiliaries: A auxiliaries helps in offering or providing helps in the service like startup, shutdown operation and given by power generated by power house itself. Examples:

- Cooling water system
- Compressed oil and hydraulic oil system
- Compressed air system
- Braking system for shutdown
- High pressure pump for startup
- Governor system
- Lubricating system
- DC distribution supply for control, field flashing etc

Ancillaries: Ancillaries provides something additional to main parts or functions and in service like scheduling and dispatch, reactive power and voltage control, loss compensation system protection, energy imbalance. Examples

- Ventilation system
- Air conditioning system
- Fire alarm system
- Lightning and power distribution
- Overhead crane system
- Telephone and communication system
- Diesel generator
- Elevator

Short circuit ratio (SCR) and its effects

- The ratio of the field current required to generate rated voltage on open circuit required to circulate rated armature current during short circuit is termed as short circuit ratio (SCR).
- Based on open circuit characteristics (OCC) and Short circuit characteristics (SCC), the ratio is determined as

The short-circuit ratio is also the reciprocal of the per unit value of the saturated synchronous reactance.

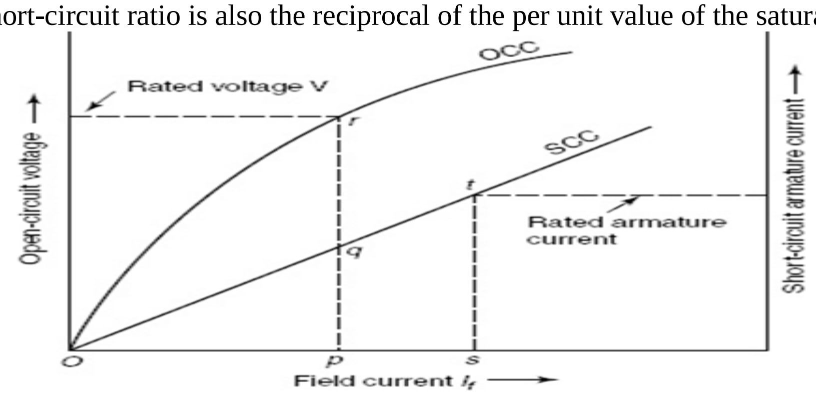


Figure- OCC and SCC of an alternator

Significance

- The SCR has a direct impact on the static stability and on the leading (absorbed) reactive power capability of the SG. A larger SCR means a smaller xd(sat) and a larger air gap.
- In turn, this requires more ampere-turns (magneto motive force [mmf]) in the field winding to produce the same apparent power.
- More excitation mmf means a larger rotor volume and, thus, a larger SG.
- The SCR has an impact on SG efficiency. An increase of SCR from 0.4 to 0.5 tends to produce a 0.02 to 0.04% reduction in efficiency, while it increases the machine volume by 5 to 10%

Governor and speed adjustment

- Governing system or governor is the main controller of the hydraulic turbine. The governor varies the water flow through the turbine to control its speed or power output. Generating units speed and system frequency may be adjusted by the governor. Governing system includes following.
  a) Speed sensing elements
  b) Governor control actuators
  c) Hydraulic pressure supply system
  d) Turbine control servomotors-these are normally supplied as part of turbine

Principle uses of elements

- Speed responsive element-usually flyball mechanism or speed/centrifugal governor.
- Control valve or relay valve to supply fluid under pressure to the power cylinder (servomotor) in order to actuate the turbine control mechanism. The use of control valve and servomotor is to amplify the force created by the flyballs.
- The restoring mechanism or follow-up linkage to hold the servomotor in required fixed position when the turbine output and load demand are equalized.
- The fluid pressure supply required for the action of servomotor.

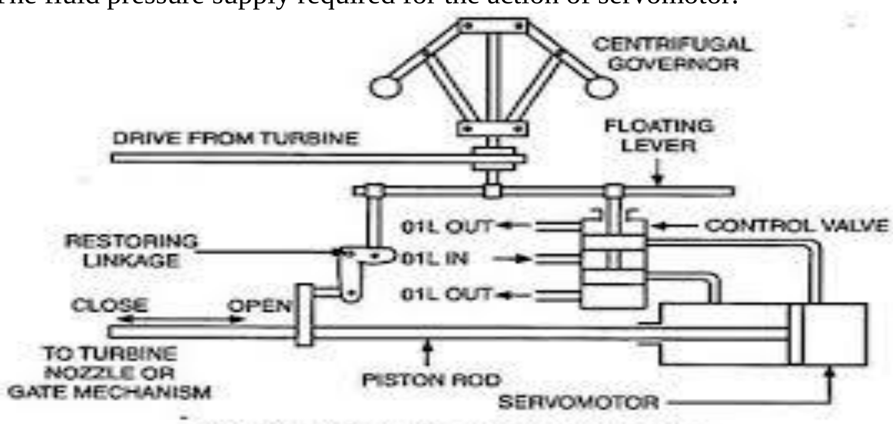


Fig. 2.22. ***Governing of Water Turbines***

Primary functions of the hydraulic turbine governor

- To start, maintain and adjust unit speed for synchronizing with the running units/grid.
- To maintain system frequency after synchronization by adjusting turbine output to load changes.
- To share load changes with other units in a planned manner in response to system frequency error.
- To adjust output of the unit in response to operator or other supervisory commands.
- To perform normal shut down or emergency over speed shut down for protection.

The Oil Pressure Governor

The main components of the governor are the following:
(i) The Servomotor or Relay cylinder
(ii) The distribution valve or control valve
(iii) Actuator or pendulum,
(iv) Oil pump
(v) Gear pump which runs by tapping power from the power shaft by belt drive,
(vi) A pipe system communicating with the control valve servomotor and the pump

Choice of size and number of generating units

The engineers concern, draw the probable load curves, determine from it other characteristics of the load. The use of this data is made to determine size and number of units of generating plant. In order to calculate the size of the units, the station auxiliary load and line losses should also be taken into account. The line losses & station auxiliary load may be taken as approximately 20% of the consumer load.

- The unit and size of generating plants should be capable to meet the maximum demand as load in power system is never constant.
- Each generating units should be selected so that running generating units should be operated at near full load so its operation gives maximum efficiency.
- For isolated station, in order to maintain reliability and continuity of supply, another units of equal capacity are required.
- Sized of generating units can be chosen so as to fit the load curve.
- If large number of units is selected than area & cost of building increases, which requires more frequent starting, stopping, parallel operation of equipment, operating cost & maintenance cost increases.
- The future demand and expansion should be considered.
- There should be a reserve unit of capacity equal to largest capacity of the units in the plant.
- Thus, compromise is to be made in selection of size and number of generating units.
- So we should not go large rating of neither single units nor small sizes with a number of generating units.

Turbine for hydro power

A **water turbine** is a rotary machine that converts kinetic energy and potential energy of water into mechanical work and the accompanying generator converts mechanical work into electrical output. These turbines rotate or spin as a response to water being introduced to their blades. These turbines are essential in the area of hydropower - the process of generating power from water.

Classification of Turbine

Based on head

a) **High head turbines**

High head turbines works under heads more than 70 m. The quantity of water needed in case of high head turbines is usually small. The Pelton turbines are the usual choice for high heads.

b) **Medium head turbines**

The turbines that work under a head of 16m to 70m are called medium head turbines. It requires medium flow of water. Francis turbines are used for medium heads.

c) **Low head turbines**

Turbines which work under a head of 2- 15m are called low head turbines. Owing to low head, large quantity of water is required. Kaplan turbines are used for low heads.

Based on hydraulic action of water/pressure change

a) Impulse turbines

If the runner of a turbine rotates by the impact or impulse action of water, it is an impulse turbine.eg Pelton, cross flow. Impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure.

b) Reaction turbines

These turbines work due to reaction of the pressure difference between the inlet and the outlet of the runner.eg Francis, propeller, Kaplan. A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually.

Based on Direction of flow of water in the runner

a) Tangential flow turbines

- When the flow is tangential to the wheel circle, it is a tangential flow turbine. A Pelton turbine is a Tangential flow turbine.

b) Radial flow turbines

- In a radial flow, the path of the flow of water remains in the radial direction and in a plane normal to the runner shaft. No pure radial flow turbine is in use these days but Francis can be considered.

c) Axial flow turbines

- When the path of flow water remains parallel to the axis of the shaft, it is an axial flow turbine. The Kaplan/propeller turbine is axial flow turbine

d) Mixed flow turbines

- When there is gradual change of flow from radial to axial in the runner, the flow is called mixed flow. The Francis turbine is a mixed flow turbine.

Based on discharge

- Low discharge: Pelton
- Medium discharge: Francis
- High discharge: Kaplan

Based on Specific Speed

The specific speed of a turbine (denoted by N_s) is defined as the speed of a turbine with a geometric similarity that can generate a unit of power under a head unit. The specific speed of a turbine is given by the manufacturer (along with other ratings) and will always refer to the point of maximum efficiency. This allows accurate calculations to be made of the turbine's performance for a range of heads.

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

where: Ns= Wheel speed (rpm), P = Power (kW), H = Water head (m)

Well-designed efficient machines typically use the following values: Impulse turbines have the lowest n_s values, typically ranging from 1 to 10, a Pelton wheel is typically around 4, Francis turbines fall in the range of 10 to 100, while Kaplan turbines are at least 100 or more, all in imperial units

Based on this parameter, water turbines are classified into three classes:

Low Specific Speed Turbine

The values between 1 and 10 are low specific speeds. Impulse turbines operate in this range. For example, the Pelton turbine usually operates at a specific speed of about 4.

Medium Specific Speed Turbine

Turbines that operate in the specific speed range of 10 to 100, such as Francis turbine

High Specific Speed Turbine

Specific speeds above 100 are considered high values. Kaplan turbine

Specific speed for different turbine

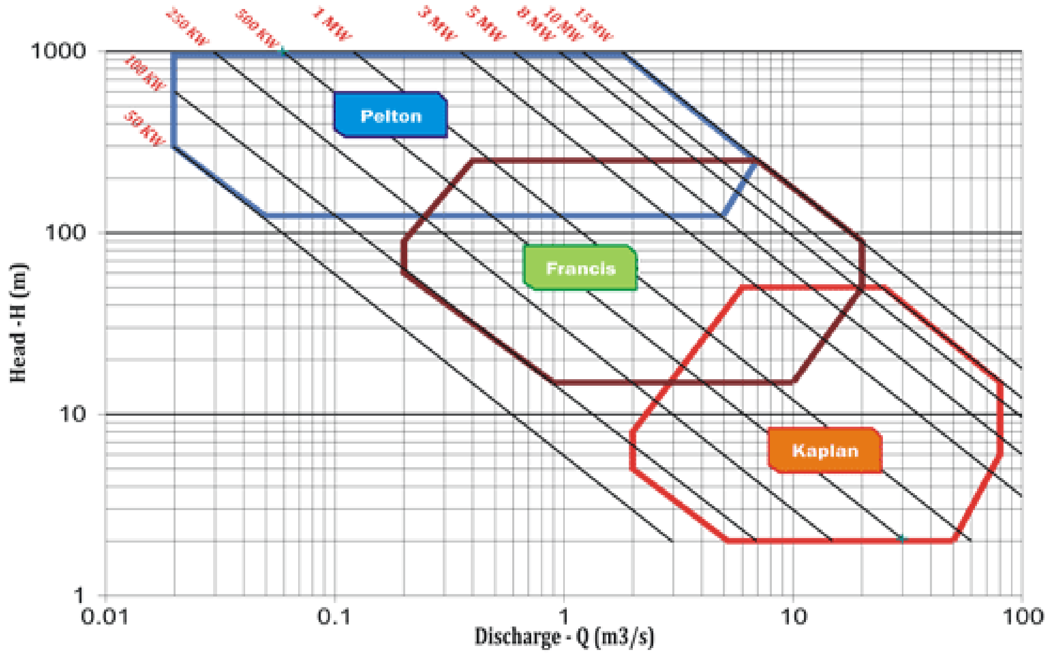
For Francis Ns=2400/(H)^0.5

Single jet Pelton = Ns=260(n)^0.5/(D/d)

Based on disposition of shaft of runner

- Pelton turbines are setup with horizontal shafts
- other types have vertical shafts.

Selection of Hydro Turbine Chart



Hydro Turbine Selection Chart

Performance of Turbines under unit quantities

The unit quantities give the speed, discharge and power for a particular turbine under a head of 1m assuming the same efficiency. Unit quantities are used to predict the performance of turbine.

1. Unit speed (N_u) - Speed of the turbine, working under unit head

$$Nu = \frac{N}{\sqrt{H}}$$

2. Unit power (P_u) - Power developed by a turbine, working under a unit head

$$Qu = \frac{Q}{\sqrt{H}}$$

3. Unit discharge (Q_u) - The discharge of the turbine working under a unit head

$$Pu = \frac{P}{H^{3/2}}$$

Unit Speed, Unit discharge and Unit Power is definite characteristics of a turbine.

If for a given turbine under heads $H_1, H_2, H_3, \ldots$ the corresponding speeds are $N_1, N_2, N_3, \ldots$, the corresponding discharges are $Q_1, Q_2, Q_3, \ldots$ and the powers developed are $P_1, P_2, P_3, \ldots$. Then

Unit speed $= N_u = \dfrac{N_1}{\sqrt{H_1}} = \dfrac{N_2}{\sqrt{H_2}} = \dfrac{N_3}{\sqrt{H_3}}$

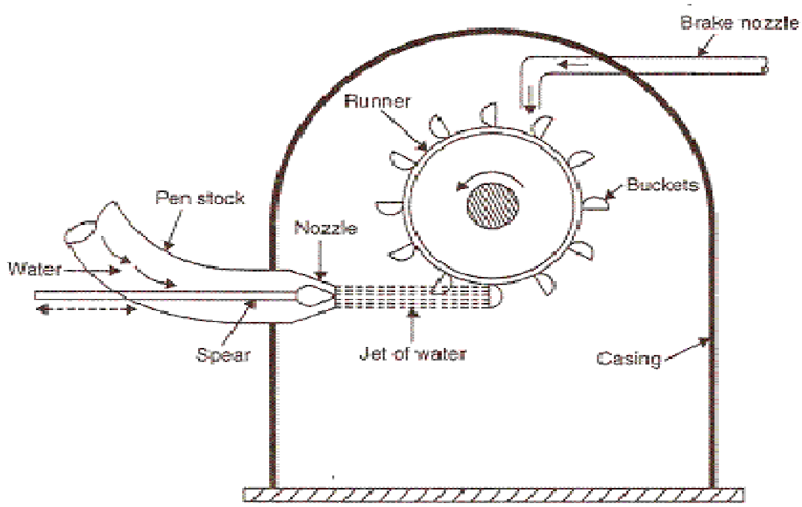
Unit Discharge $= Q_u = \dfrac{Q_1}{\sqrt{H_1}} = \dfrac{Q_2}{\sqrt{H_2}} = \dfrac{Q_3}{\sqrt{H_3}}$

Unit Power $= P_u = \dfrac{P_1}{H\sqrt{H_1}} = \dfrac{P_2}{H\sqrt{H_2}} = \dfrac{P_3}{H\sqrt{H_3}}$ or $P_u = \dfrac{P_1}{H_1^{3/2}} = \dfrac{P_2}{H_2^{3/2}} = \dfrac{P_3}{H_3^{3/2}}$

Thus if speed, discharge and power developed by a turbine under a certain head are known, the corresponding quantities for any other head can be determined.

Pelton Turbine

Working of Pelton Turbine

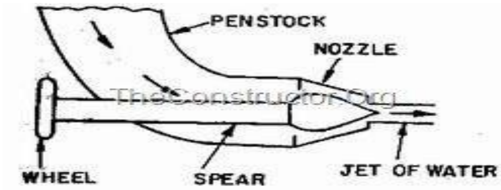


- The water is transferred from the high head source through a long conduit called Penstock.
- Nozzle arrangement at the end of penstock helps the water to accelerate and it flows out as a high speed jet with high velocity and discharge at atmospheric pressure.
- The jet will hit the splitter of the buckets which will distribute the jet into two halves of bucket and the wheel starts revolving.
- The kinetic energy of the jet is reduced when it hits the bucket and also due to spherical shape of buckets the directed jet will change its direction and takes U-turn and falls into tail race.
- In general, the inlet angle of jet is in between 1^o to 3^o and water enters tangentially in the middle and after hitting the buckets discharge backward and flow again tangentially in both direction to avoid thrust on the wheel, the deflected jet angle is in between 160^o to 170^o.
- The water collected in tail race should not submerge the Pelton wheel in any case.
- To generate more power, two Pelton wheels can be arranged to a single shaft or two water jets can be directed at a time to a single Pelton wheel

Components and their function

1. **Nozzle and Flow Regulating Arrangement (Spear)**

- Nozzle is used to increase the kinetic energy of the water that is going to strike the buckets or vanes attached to the runner.
- The quantity of water that strikes the buckets is controlled by spear. The spear is installed inside the nozzle and regulates the flow of water that is going to strike on the vanes of the runner. A nozzle containing spear is shown in the figure given below.
- The spear is a conical needle present in the nozzle. It is operated by a hand wheel or automatically in an axial direction.
- When the spear is move backward the rate of flow of water increases and when it is pushed forward the rate of flow of water decreases.



2. **Runner and Buckets**

- Runner is a rotating part of the turbine. It is a circular disc on the periphery of which a number of buckets evenly spaced are fixed.
- The buckets are made by two hemispherical bowl joined together. Each buckets have a wall in between two hemispherical bowl called splitter.

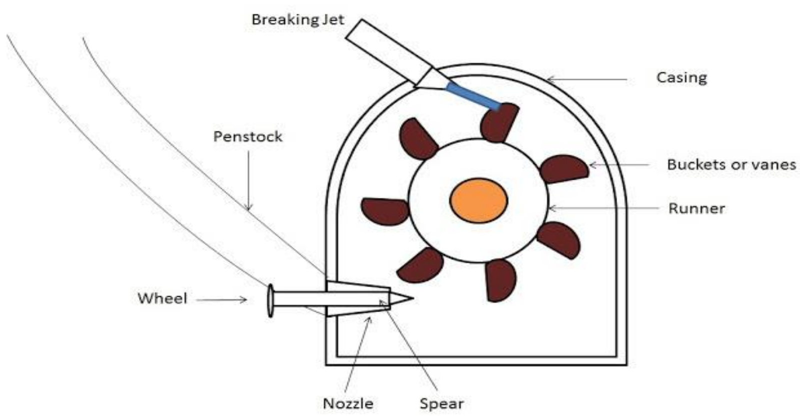
- The splitter splits the jet of water striking the buckets into two equal parts and the jet of water comes out at the outer edge of the bucket.
- The buckets are designed in such a way that the jet of water strikes the buckets, deflected through 160 degree to 170 degree.
- The buckets of the Pelton turbine are made up of cast iron, cast steel bronze or stainless steel.

3. **Casing**

- The outer covering of the turbine is called casing. The Pelton turbine with the casing is shown in the figure given below.
- It prevents the splashing of the water and helps to discharge the water to the trail race. It also acts as a safeguard in the case of any accident occurs.
- Cast iron or fabricated steel plates are used to make the casing of the Pelton Turbine.

4. Breaking jet

- When the jet of water is completely closed by pushing the spear in forward direction than the amount of water striking the runner becomes zero. But still the runner keeps moving due to the inertia of the runner.
- In order to stop the runner in the shortest possible time a small nozzle is provided which directs the jet of water at the back of the vanes. This jet of water used to stop the runner of the turbine is called breaking jet.



Design aspects of Pelton Turbine

1. Velocity of Jet

The velocity of the jet at inlet is given by V1 = Cv $\sqrt{2\ g\ H}$

Where, Cv = co-efficient of velocity =0.98 or 0.99 H= Net head

2. Velocity of Wheel

The velocity of wheel (u) is given by, u = $\phi\sqrt{2\ g\ H}$

Where, ϕ = speed ratio = 0.43 to 0.48

3. Angle of Deflection of Jet

The angle of deflection of jet after striking the buckets is taken as 165^o if no deflection angle is given.

6. Mean Diameter of The Wheel

The mean diameter or the pitch diameter D of the Pelton turbine is given by

U = $\frac{\pi\ D\ N}{60}$ or, D = $\frac{60\ U}{\pi\ N}$

7. Jet Ratio

It is defined as the ratio of the pitch diameter (D) of the Pelton turbine to the diameter of the jet (d). It is denoted by m and is given as

m = D/d

Jet ratio(m) is lies between 11 to 16 for maximum hydraulic efficiency. However, in most of the cases it is taken as 12.

8. Bucket Dimensions

Buckets dimensions are designed in such a way that its breadth = 3 to 4 times of diameter of jet,
length = 2 to 3 times of diameter of jet and
thickness = 0.8 to 1.2 times the diameter of jet.

9. Number of Jets

It is obtained by dividing the total rate of flow through the turbine by the rate of flow of water through a single jet.

In general, Number of jets are limited to two in case of vertical runner and six in case of horizontal runner.

8.Number of Buckets

The number of buckets (z) on a runner is given by

$$Z = 15+\frac{D}{2d} = 15+ 0.5\ m$$

Where, D = Pitch diameter, d = Diameter of Jet, m = jet ratio

Bucket spacing = s = πD/z

Working of Francis Turbine

Francis turbine blades are designed in such a way that one portion of the blade design creates the pressure difference between the opposite faces of the blade when water flows through it, and the remaining portion's blade design use the impulse force of water hitting it and this combined action of pressure difference and impulse force generates enough power to get turbine moving at a required speed. Thus there would be a decrease in both kinetic energy and potential energy of water at exit, then what it has when it enters the turbine.

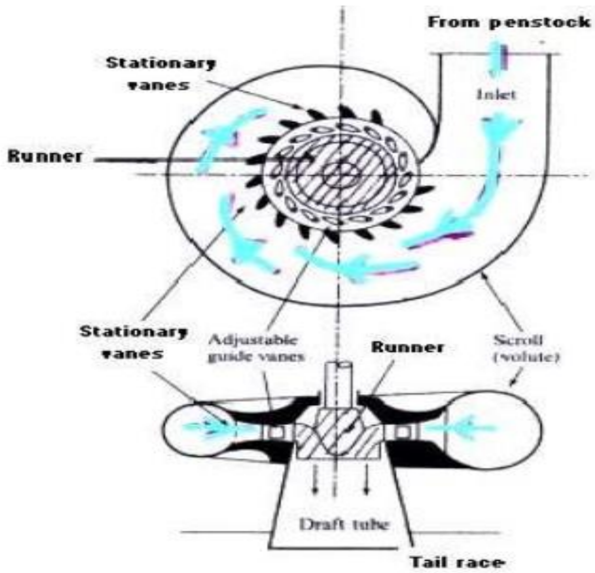
It is a clever design which uses both the reaction and impulse force to generate power output better than individual impulse turbine or reaction turbines could produce at same water head conditions.

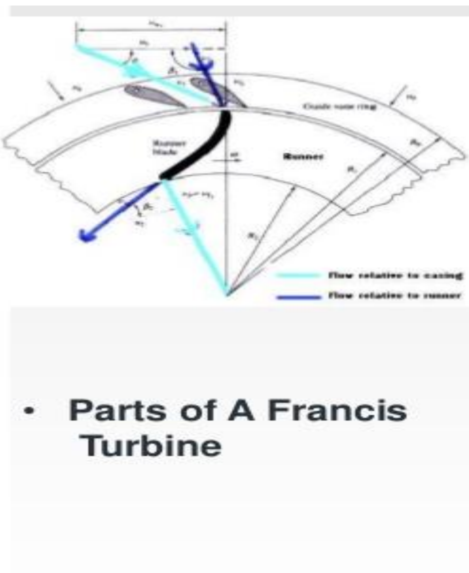
What is Cavitation?

Difference in the pressure of water entering the turbine and that exists after striking the runner blades is too high, due to this pressure difference the air molecules which are relatively at high pressure then water coming out, enters the turbine casing in the form of bubbles. These bubble keeps on exploding near the surface of the runner blades continuously causing a shock wave, which produces a kind of defect at runners surface called cavitation, thus causing a serious problem for turbines efficiency.

So what can we do is to prevent blades from cavitation?

One solution is to use a really hard surface material like stainless steel or we can also go with surface Hardening of the runner blades, to prevent them from cavitation





Components of Francis Turbine

1. <u>Spiral casing</u>

It is a spiral casing, with uniformly decreasing cross- section area, along the circumference. Its decreasing cross-section area makes sure that we have a uniform velocity of the water striking the runner blades, as we have openings for water flow in-to the runner blades from the very starting of the casing, so flow rate would decrease as it travels along the casing. So we reduce its cross-section area along its circumference to make pressure uniform, thus uniform momentum or velocity striking the runner blades.

2. <u>Stay vanes</u>

Stay vanes and guide vanes guides the water to the runner blades. Stay vanes remain stationary at their position and reduces the swirling of water due to radial flow, as it enters the runner blades. Thus making turbine more efficient

3. <u>Guide vanes</u>

Water after passing through stay vanes, glides through guide vanes to enter the runner blades. Guide vanes can change their angle thus can control the angle of attack of water to the runner blades, making them work more efficiently. Moreover they also regulate the flow rate of water into the runner blades thus controlling the power output of a turbine according to the load on the turbine.

4. <u>Runner Blades</u>

The performance and efficiency of the turbine is dependent on the design of the runner blades. In a Francis turbine, runner blades are divided into 2 parts. The lower half is made in the shape of small bucket so that it uses the impulse action of water to rotate the turbine.

The upper part of the blades use the reaction force of water flowing through it. These two forces together makes the runner to rotate.

5. <u>Draft Tube</u>

The pressure at the exit of the runner of Reaction Turbine is generally less than atmospheric pressure. The water at exit cannot be directly discharged to the tail race. A tube or pipe of gradually increasing area is used for discharging water from the exit of turbine to the tail race.

This tube of increasing area is called Draft Tube. One end of the tube is connected to the outlet of runner while the other end is sub-merged below the level of water in the tail-race.

<u>Design of fransis turbine</u>

- The ratio of width to diameter of wheel, n=Bi/Di where, n varies from 0.1.to 0.40

- The flow ratio is given by, Cm=Vi/(2gh)^0.5

  where, Vi is flow velocity at inlet tip and it varies from 0.15 to 0.30

- The speed ratio, φ=Vp/(2gh)^0.5

  where Vp= peripheral velocity of flow and varies from 0.6 to 0.9

- Diameter of turbine, D=84.6φ(H)^0.5/N

  where, φ=0.0197Ns^2/3+0.009

The design discharge through turbine,

Q= π*Binlet*Dinlet*Vinlet

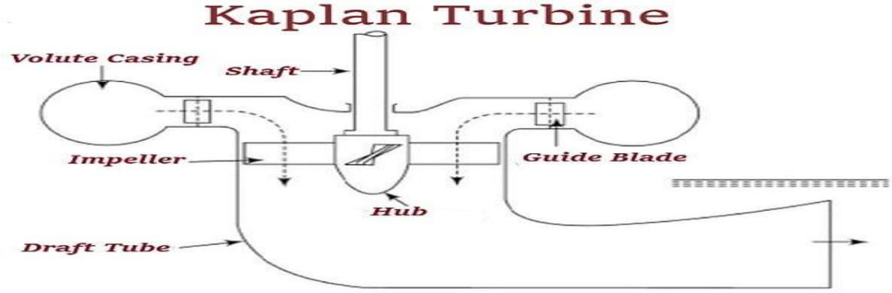
Or Q= π*Boutlet*Doutlet*Voutlet

Vinlet=Voutlet

Initially, Binlet*Dinlet=Boutlet*Doutlet

<u>Kaplan Turbine</u>

- A Kaplan turbine is basically a propeller with adjustable blades inside a tube. It is an axial-flow turbine, which means that the flow direction does not change as it crosses the rotor.



- In axial flow turbines, the water flows through the runner along the direction parallel to the axis of rotation of the runner. The water at the inlet of the turbine possesses both kinetic energy as well as pressure energy for effective rotation the blades in a hydro-power station.

- Kaplan turbine combined automatically adjusted propeller blades with automatically adjusted wicket gates to achieve efficiency over a wide range of flow and water level. It is also called as propeller turbine and evolved from the Francis Turbine. It is capable of working at low head and high flow rates very efficiently which is impossible with Francis turbine.

Main Parts of a Kaplan Turbine

The main components of a Kaplan turbine as listed below.

- **Scroll casing,**
- **Guide vane mechanism,**
- **Hub**
- **Draft tube, and**
- **Runner blades/impeller**

Scroll Casing:

The scroll casing is a spiral specimen of a casing that decreases the cross-section area. At first, the water from the penstocks goes into the scroll casing and then goes to the guide vanes. The water turns through 90° From the guide vanes and flows axially over the runner. The scroll casing shields the runner, runner blades, guide vanes, and other interior parts of the turbine from external damage over the turbine.

Guide Vanes Mechanism:

Guide Vanes Mechanism is the unique, controlling part of the whole turbine, which opens and closes based on the power demand. When more power output is required, it opens more to let more water hit the rotor's blades. And when the output required power is low, it closes to stop the flow of water. When the guide vanes are missing, then the turbine cannot work effectively; as a result, the efficiency of the turbine reduces.

Hub

Hub includes in the essential components of the Kaplan turbine. The blades mountain on the hub of the turbine. It controls the rotation of blades. And blades follow it for their movement. It connects with the central turbine shaft.

Draft Tube:

At the outlet of the reaction turbine's runner, the available pressure is generally smaller than the atmospheric pressure. So, the outlet water cannot be straight discharged to the tailrace.

A tube or pipe can gradually increase the area, and this is employed in water discharging from the turbine to the tailrace.

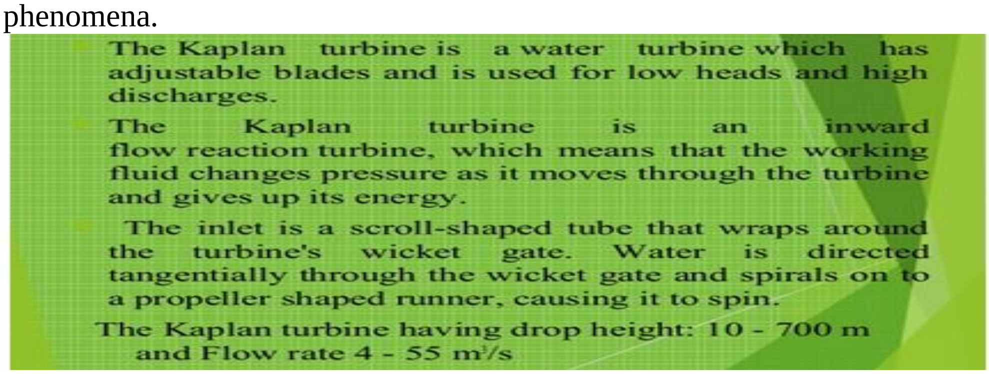
Thus, the expanding area of the tube or pipe is named a Draft tube. One end of this draft tube is attached to the runner outlet, and the opposite end is submerged beneath the level of water in the tail-race.

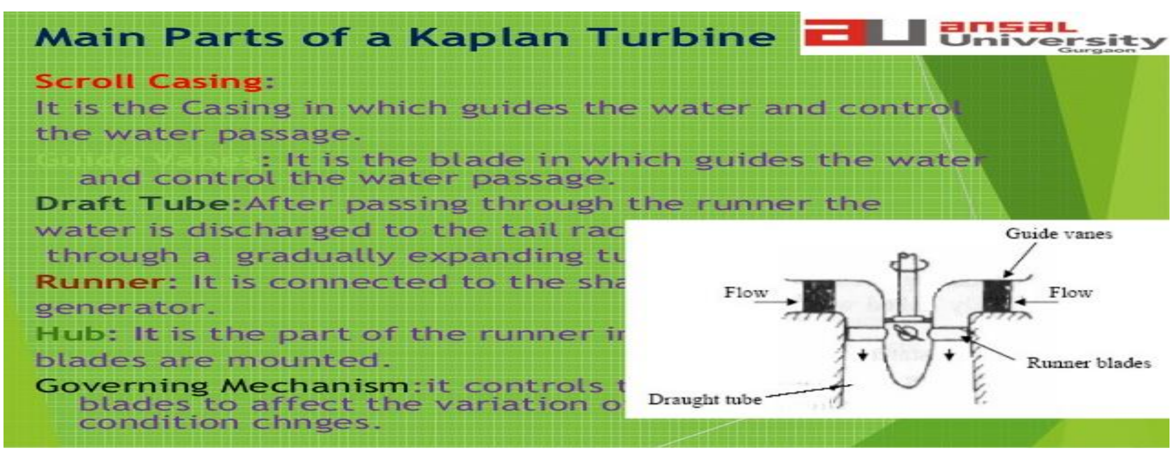
A significant point about this component is that the Draft tube is used only in the Reaction turbine.

Operation

- First of all, the water introduces into the volute/scroll casing from the pen-stock.

- As water flows inside the volute casing, guide blades direct the water from the casing toward the impeller blades. These blades are flexible and may change their position based on flow requirements.
- As the water enters into the impeller area, it takes a turn of 90^o so that it can strike the impeller blades in an axial direction.
- When the water strikes the impeller blades, these blades start revolving because of the water reaction force.
- These blades convert K.E of the water into speed and increase the speed of the water.
- After passing through the impeller blades, the water reaches the draft tube, where the kinetic and pressure energies of the water reduce.
- This draft tube converts the kinetic energy or speed into pressure energy and increases the pressure of water.
- When the water pressure increases according to the requirements, the water delivers into the tailrace.
- The increased pressure of the water rotates the turbine. A generator is coupled with the turbine shaft. The rotation of the turbine further rotates the generator coil. According to **Faraday's** 1st law, "when a conductor rotates in a magnetic field then electricity produces," and in hydroelectric powerplants, electricity produces by using the same phenomena.





Important Points for Kaplan turbine:

1. The velocity at inlet and outlet is equal i.e

$u_1 = u_2 = \frac{\pi D_0 N}{60}$;where D_0 = Outer dia. Of runner

2. Velocity of flow at inlet and outlet are equal i.e.

$$V_{f1} = V_{f2}$$

3. Area of flow at inlet = Area of flow at outlet

$$= \pi/4\,(D_0^2 - D_b^2).$$

Velocity triangles and work done per second:

1.work done per second;

$=\rho Q[V_{w1}U_1]$ $\{\because V_{w2}=0\}$

2.work done per second per unit weight of water striking$=V_{w1}U_1/g$

3.Hydraulic eff.$(\eta_h)=V_{w1}U_1/gH$

4.Mechanical eff.$(\eta_m)=SP/RP$

5.Overall eff.$(\eta_o)=SP/WP$

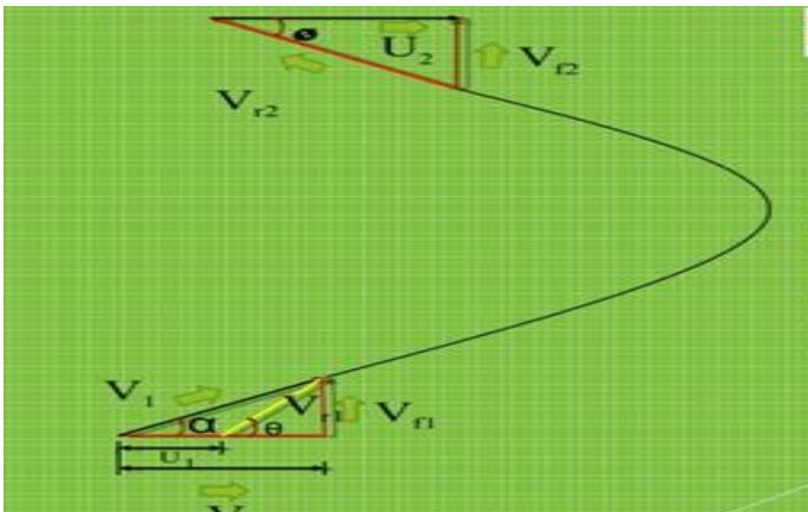


Fig: Velocity Diagram

For Kaplan turbine $U_1 = U_2$

$V_{f1} = V_{f2}$

Also β =90° **because of radial flow at outlet.**

$V_{f2}=V_2$ & $V_{w2}=0$

Design of Kaplan Turbine

Guidelines:

1. Velocity of Wheel, $u_1 = u_2 = \frac{\pi D_m \times N}{60}$ where Mean diameter, $D_m = \frac{D_o + D_b}{2}$
2. Work done per second $= \rho a V_1[V_{w_1} + V_{w_2}] \times u = \rho Q[V_{w_1} + V_{w_2}] \times u$
3. Velocity of Flow at Inlet and Outlet are equal $V_{f_1} = V_{f_2}$
4. Discharge, $Q = \frac{\pi}{4}(D_o^2 - D_b^2) \times V_{f_1}$
5. Flow Ratio $= \frac{V_{f_1}}{\sqrt{2gH}}$

Characteristics Curves of Turbine

These are curves which are characteristic of a particular turbine which helps in studying the performance of the turbine under various conditions. These curves pertaining to any turbine are supplied by its manufacturers based on actual tests.

The characteristic curves obtained are the following:

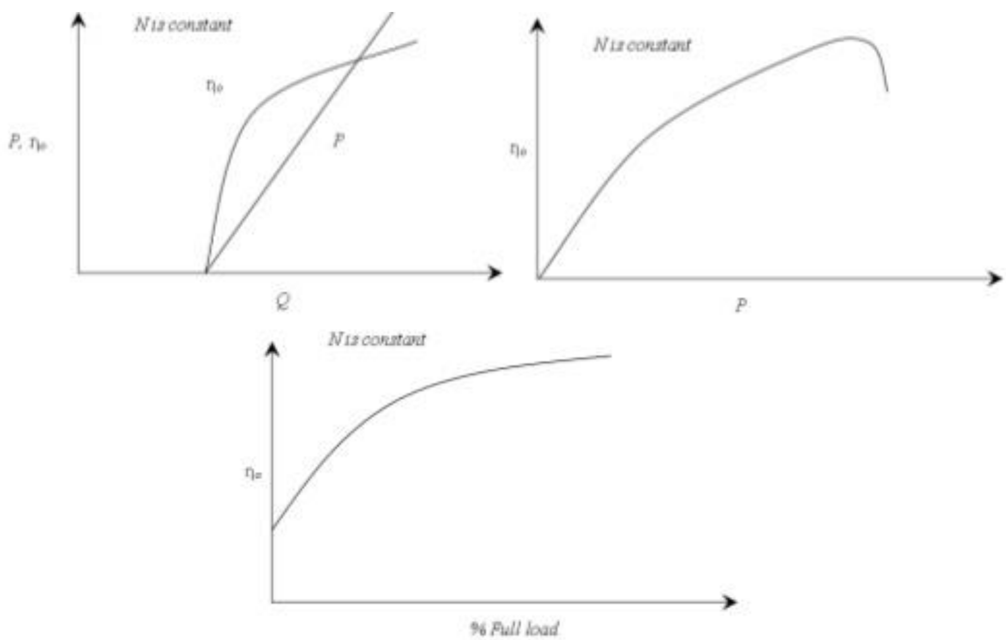
a) Constant head curves or main characteristic curves
b) Constant speed curves or operating characteristic curves
c) Constant efficiency curves or Muschel curves

Constant head curves or main characteristic curves

Constant head curves:
Maintaining a constant head, the speed of the turbine is varied by admitting different rates of flow by adjusting the percentage of gate opening. The power P developed is measured mechanically. From each test the unit power Pu, the unit speed Nu, the unit discharge Qu and the overall efficiency are determined.

The characteristic curves drawn are

a) Unit discharge vs unit speed
b) Unit power vs unit speed
c) Overall efficiency vs unit speed

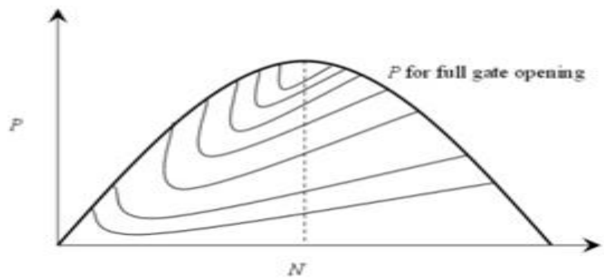


Operating Characteristic curves of a turbine

Constant efficiency curves or Muschel curves

Constant efficiency curves:
These curves are plotted from data which can be obtained from the constant head and constant speed curves. The object of obtaining this curve is to determine the zone of constant efficiency so that we can always run the turbine with maximum efficiency.

This curve also gives a good idea about the performance of the turbine at various efficiencies.



Constant Efficiency curves for Reaction turbine

Similitude of Turbines

Dimensionless Numbers:

$$\frac{Q}{ND^3}, \frac{gH}{N^2D^2}, \frac{P}{\rho N^3 D^5}$$

Where

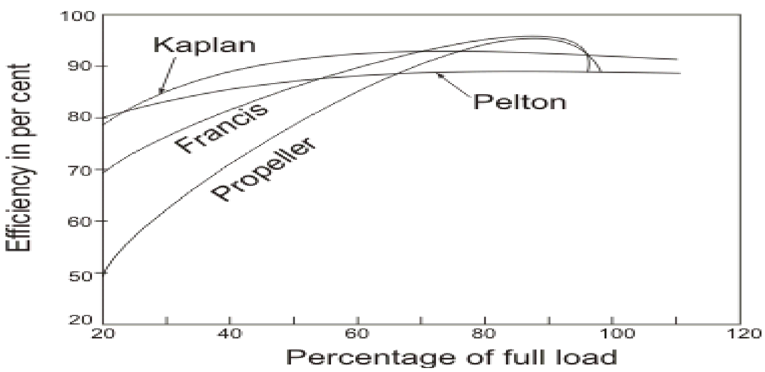
Q = Discharge

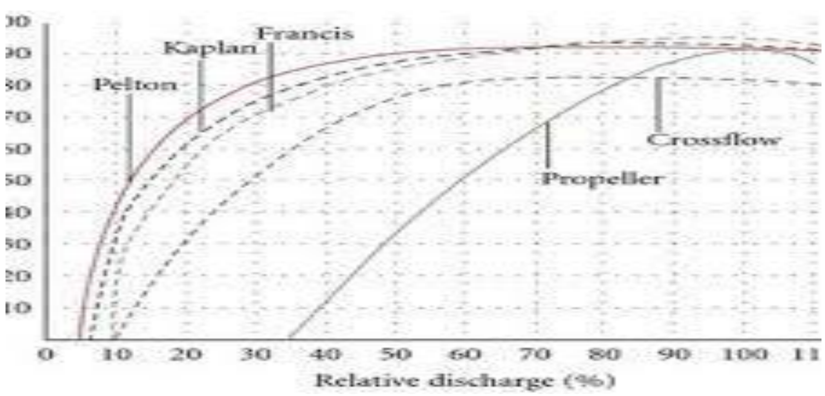
N = Speed of Wheel

D = Dia. of Wheel

H = Head

P = Shaft Power





Constant Speed Curves

In hydroelectric power plants, the turbines operate at constant speed and, therefore, variables are operating head H and discharge Q. As the discharge and head vary so as to keep the speed constant, the turbine output P_t is measured by brake arrangement. The turbine efficiency η is then calculated for various values of Q and H. Now the output discharge (P_t– Q), efficiency-discharge (η – Q) curves, as shown in Fig. and efficiency-percentage full load curves are drawn. From the curves drawn, it can be concluded that the Kaplan and Pelton turbines perform well at part loads but Francis and Propeller turbines do not.

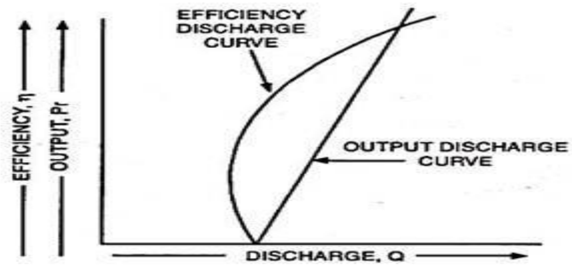


Fig. 2.19. ***Efficiency-Discharge Curve***

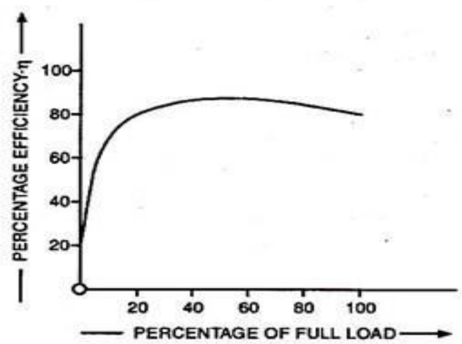


Fig. 2.20. ***Efficiency Curve of Impulse Turbine***

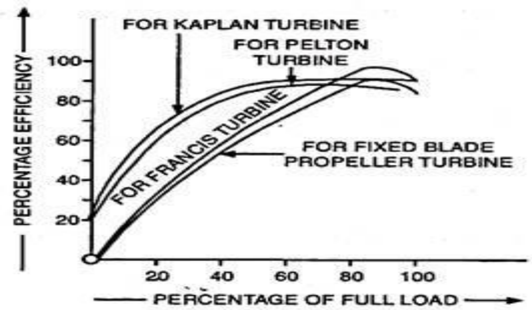


Fig. 2.21. ***Efficiency Curve of Reaction Turbines***

Factors affecting the Selection of Hydraulic Turbines

1. Head
2. Specific speed
3. Rotational speed
4. Efficiency of the turbine
5. Cavitation
6. Disposition of turbine shaft
7. Part load operation

Features of Hydro Generator

- Alternator is larger in diameter and smaller in axial length.
- Salient pole type rotor is used in the Hydro generator.
- Typically number of salient poles is between 4 to 60.
- They are generally having lower speed electrical machines, say 100 RPM to 1500 RPM.
- For large hydro generator, Vertical shaft generators are generally used. There are three types of vertical shaft hydro generators distinguished by design speed and the bearing arrangements. i.e. Umbrella type generators, Semi Umbrella, Conventional Standard Type Generators.
- Some medium size low flow turbine and most of the small hydro units upto 5 MW and tube turbine generators are horizontal shaft. Direct driven bulb turbine generators are also horizontal shaft generators located in the bulb.

Nepalese Power Plants, their types, salient features and locations

1. **Upper Tamakoshi Hydroelectric Project**
   456 MW peaking run-of-the-river hydroelectric project
   largest hydroelectric project in Nepal, operating since July 2021
   Location: Gaurishankar Conservation Area, Dolakha District

NEA has 41% stake, NTC has 6% and CIT & RBS each has 2% stake in the Company. Similarly, general public and residents of Dolakha District will have 15% and 10% share respectively. The remaining 24% share will be taken over by contributors in Employees Provident Fund (EPF), NEA & Companys staffs and staffs of financial institutions providing loans.

Hydraulic head 822 m
Turbines 6×Pelton wheels
Installed capacity 456 MW @ maximum flow 66 m3/s
Annual generation 2,281 GWh

2. MARSYAGNDI HPS
Type Peaking-run-of-river Location AanbuKhaireni Rural Municipality, Tanahun
Installed capacity 69 MW
Design annual generation 462.5 GWh
Catchment area 3850 Sq. km
Average annual discharge 210m3/s
Live storage volume 1.5 million m3
Rated net head 90.5m
Weir 102m long,
Concrete Head race tunnel 7199m, Ø 6.4m, concrete lined
Penstock 75m long, Ø 5m, steel lined
Turbine
Number and Type 3, Vertical Francis
Rated discharge 30.5m3/s
Rated output 26 MW
Rated speed 300 rpm
Generator
Capacity 30 MVA
Rated voltage 11 kV
Rated Frequency 50 Hz
Power factor 0.85
Excitation Thyristor Self Excitation
Power transformer 10 MVA, 11/132 kV, 9 (+1 Spare) Single phase
Transmission line 132kV, Total 108 km (Balaju 83km + Bharatpur 25km) S

3. KULEKHANI-I HYDROPOWER STATION
located at Dhorsing, Makwanpur is only reservoir type Hydro-electric Power Station in Nepal
Installed Capacity is 60 MW with two units of 30 MW each
This station was designed as a peaking power station but it is often operated to the system requirements for voltage improvement & system stability.
The Power Station is designed to generate 165 GWh as primary energy and 46 GWh as Secondary energy.
Rated Head 550m
Catchments Area 126km2
Design Discharge 12.1 m3/sec
Turbine:
No. and Type Speed Two, Vertical Shaft Pelton
Rated Output 31 MW
Rated Speed 600rpm
Generator:
Rated Capacity 35 MVA
Generating Voltage 11kV
Frequency 50 Hz

Penstock Ø 2.0-1.5m, 1324m length
Main Transformer Two, 35 MVA, 11/66 kV

4. Kulekhani-II Hydropower Station,
located at Bhimphedi Rural Municipality-4, Nibuwatar, Makawanpur district
cascade of Kulekhani-I HPS with installed capacity of 32 MW and annual design generation of 104.6 GWH
Maximum Gross/Net Head 310/284.1m
Turbine
    Number and Type 2, Vertical Francis Turbine
    Rated Discharge 16.65 m3/s
    Rated Output 16500kW
    Rated Speed 750 rpm
Generator
    Rated Output 18.8 MVA
    Rated Voltage 6.6kV
    Rated Frequency 50hz
    Power Factor 0.85lag
    Excitation Brushless 3 phase rotating armature
Transmission Line 132 kV, Hetauda Line-7.9 km, Siuchatar Line-33.4 km

5. Chameliya Hydropower Station
installed capacity of 30 MW and designed annual generation of 184.21 GWh.
daily pondage run off river hydropower with daily peaking capacity of 6 hrs at minimum discharge.
Located: Darchula and Dam site is located between Marma Gaupalika, Bitule, Darchula
installed Capacity 30 MW
Maximum Gross Head 103.70 m
Rated Net Head 94 m
Designed Flow 36 m3/sec
Turbine 2 Vertical shaft, Francis, rated output 2X15.6 MW, rated speed 428.6 rpm
Generator 2/3-phase synchronous, rated output 2x16.2 kVA
Transmission Line Length 131 km, 132 kV single circuits from Balanch to Attariya Sub-station

6. Trishuli Hydropower Station
Trishuli River at Trishuli Bazar, Nuwakot
24 MW with 6 units each 3.5 MW and one unit 3 MW.
It is a peaking run-of-river plant with peaking capacity of 21 MWh and annual design generation of 163 GWh.
Maximum gross head / Net head 51.4 m
Turbine
    Number and Type 7 Francsis
    Rated discharge 7.8m3/s
    Rated output 3620kW
    Rated speed 500rpm
Generator
    Rated output 3889kVA
Rated voltage 6.6kV
Rated frequency 50Hz
Power factor0.9
Transmission line 66 kV, 27.36 km, Double circuit

7. Devighat Hydropower Station

cascade hydropower Plant of Trishuli power Plant.
It is located at Battar, Nuwakot
installed capacity of 14.1 MW Installed capacity 15MW (after rehabilitation
and annual design generation of 114 GWh.
Turbine
Number and Type 3, vertical francsis
Generator
Rated output 5MW
Rated voltage 6.6kV
Rated frequency 50Hz
Power factor 0.8
Transmission line 66kV, 37km (Devighat -Chabel), 28km (Devighat - Balaju), Double circuit

8. GANDAK HYDROPOWER STATION
Installed capacity 15 MW
Turbine
Type Adjustable Blade Tubular Turbine
Number of units, Type 3, Kaplan