AIR-1 Notes

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Hydraulic Machine

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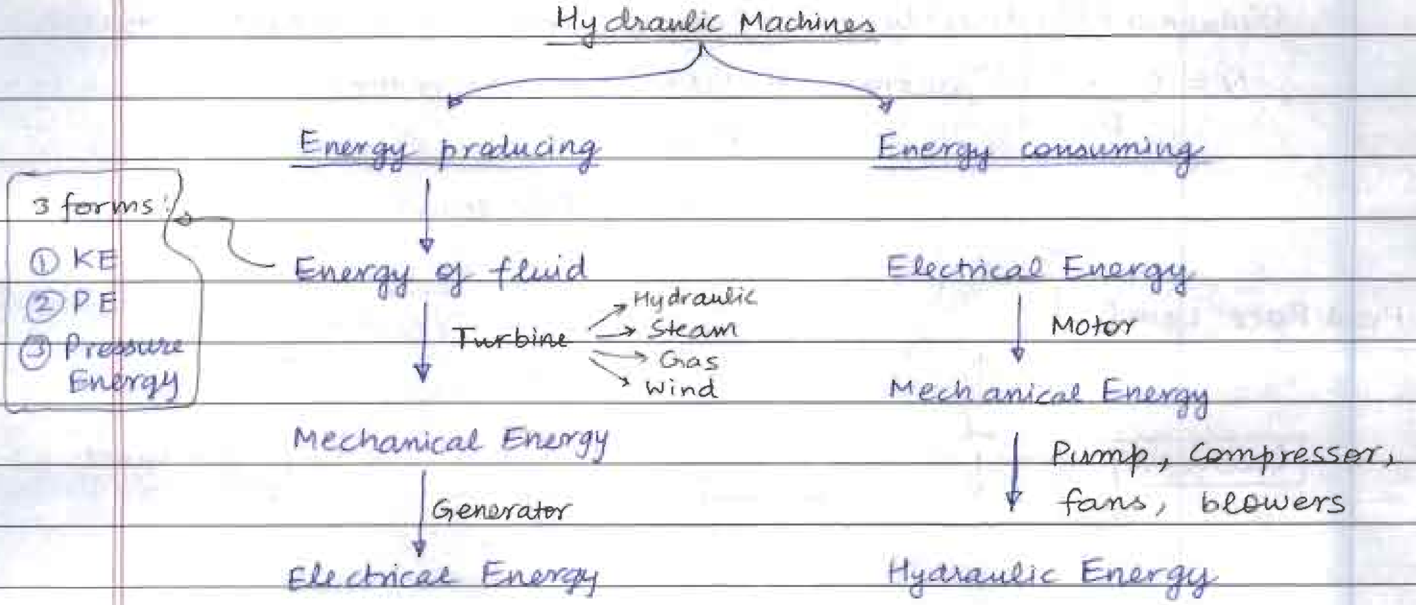
HYDRAULIC MACHINES

CONTENT

Hydraulic Machines

ESE(P) → 6 Ques
ESE (M) → 20-25 Marks

1) Overview of Hydro-electric Projects (HEP's)
2) Hydraulic Turbines { Impulse Turbines
   Reaction Turbines
3) Hydraulic Pumps { centrifugal pumps
   Reciprocating pumps

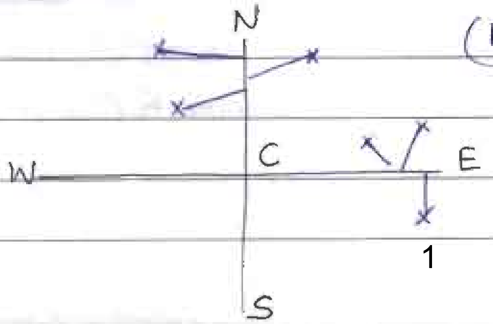


→ Pumps ~~as~~ increase the PE of fluid, compressors (generally used for gases) increase the pressure energy of fluid and fans and blowers increase the KE of fluid.

Chapter 1 - Overview of HEP

⇒ Basics of Electrical

1) Generation
2) Transmission (PGCIL)
3) Distribution (SEBs)



→ Generation plants supply electricity to grids and grids supply it to us.

	Supply	(Load) Demand
f=50Hz	500MW	500MW
f<50Hz	500MW	600MW
f>50Hz	500MW	400MW

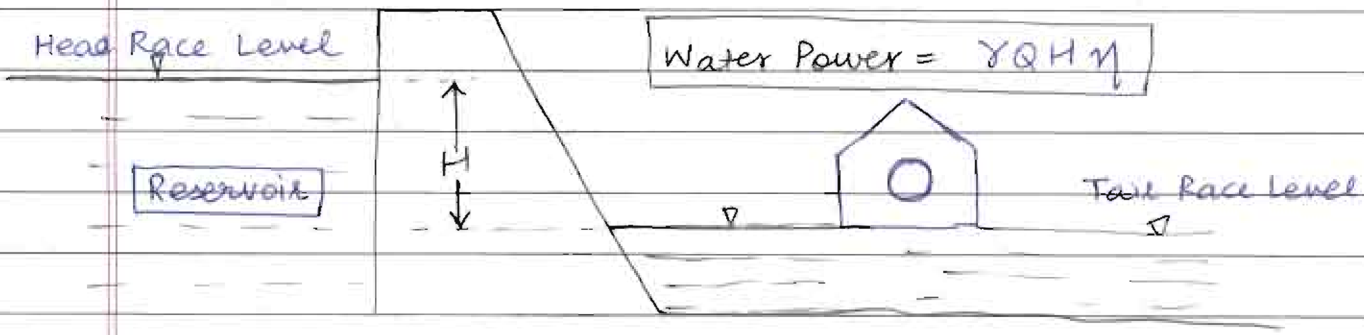
For generation companies,
if Demand is high, price ↑
if Demand is low, price ↓

→ Both of these situations are not desirable as appliances are set to work at 50Hz

→ frequency (f) directly relates to the speed of rotation of turbines.

$$N = \frac{60 \times f}{P}$$ where

N → Speed of generator
f → frequency
P → No of Pole pairs.



Water Power = $\gamma Q H \eta$

→ In HEPs, PE of water is utilized to drive a turbine which in turn runs the generator to produce electricity

→ Apart from producing electricity, these projects can also be used for irrigation, drinking water supply, flood moderation, fishing and recreational activities.

→ Such projects are known as Multi Purpose Projects.

⇒ Components of HEP

① Reservoir

→ Water available in the catchment area is stored in reservoir so as to meet requirement of plant throughout the year. Reservoirs can be natural as well as artificial

→ Natural reservoirs are lakes in mountains.

→ Artificial Reservoirs are made by constructing a dam across a river

② Trash Rack

It is used to obstruct debris from going into the intake.

③ Waterways

→ It is a passage through which water is carried from the storage reservoir to the power house

→ It consists of Head Race Tunnel (HRT) or Powerchannel, Forebay, Penstock, surge tank

Surge Tank ↓

Trash Rack → Intake → HRT → Forebay → Penstock → Turbin ↓ Tail Race ↓ River

(i) Forebay

→ It is an enlarged section at the end of power channel (HRT)

→ Its function is to store, temporarily, the water rejected by the plant when the load is reduced and to meet the instentan increased demand of water due to sudden increase in load.

→ It also helps in absorbing the sudden rise in pressure due to closure of valves when load on turbine decreases. Thus it prevents HRT from water hammer impact.

(ii) Penstock

→ Penstock is a closed conduit for supplying water under pressure from the forebay to the turbine.

→ It is subjected to water hammer pressure due to fluctuation in turbine load and to reduce this a surge tank is provided

(iii) Surge Tank

→ It is a small reservoir fitted at some opening in the penstock to receive the rejected flow when the load on the turbine decreases and thus prevents penstock from water hammer impact

④ Tail Race

→ It is a waterway to carry water discharged by the turbine to a suitable point where it can be safely disposed off or stored for pumping ~~bag~~ back into the original reservoir

NOTE:

1) Forebay and Surge Tank, both serve same purpose.
2) Surge Tank should be located close to the turbine

→ Classification of HEPs

① Based on availability of head

(a) High Head Plants → Head is more than 250 m
(eg - Tehri) (260m)
(b) Medium Head Plants → Head is b/w 30 m to 250m
(c) Low Head Plants → Head is less than 30m.

→ This classification is not based on any scientific criteria

② Based on Load capacity

(a) Base Load Plant → They supply constant power (Base Load)
eg - Thermal Power Plants, Hydro Power Plants with storage

(b) Peak Load Plants → They supply power during peak hours only
→ Storage type Hydroplant is ideally suited for this purpose as it can be started in few minutes

NOTE: Storage and Pondage

→ Storage and Pondage of water is required for regulation of flow of water so as to make it available in requisite quantity to meet the power demand at a given time.

→ Storage – Storage is impounding of considerable amount of excess runoff during seasons of surplus flow for use in dry seasons. This is accomplished by constructing a dam across a river.

→ Pondage – Pondage is simply a regulating body of water in the form of relatively small pond or reservoir provided at the plant. Pondage is used to regulate the variable water flow to meet power demand. eg – Forebay and Surge Tank

→ Storage and pondage can be obtained from Flow duration curve.

⑤ Based on Function

(a) Run-of-River (R-O-R) plants

→ No storage of water is done and whatever water is available in the river is utilized to run the turbine.
→ RoR plants are suitable for perennial rivers only.
→ RoR plants can be with or without pondage.
→ RoR plants without pondage are suitable for Base load applicat and RoR plants with pondage are suitable for peak load application
→ Plants with pondage is provided with a weir or Barrage to accommodate sufficient storage to take care of load fluctuations.

(b) Storage Plants

→ These plants have storage provided by constructing dams.
→ These plants can meet the peak load demands

(c) Pumped Storage Plants

→ This type of plant is provided when there is a shortage of water
→ These plants generate power during peak hours. During off peak

hours, water is pumped back from tail race channel to the Reservoir.

→ These plants use reversible turbines which functions as both as turbines as well as pump.

→ Such plants convert low value off peak energy into high value on peak energy and hence are economically viable.

→ suitable for peak load applications.

④ Based on source of Energy

(a) River based Power Plant

(b) Tidal Power Plant

→ These plants tap the energy of earth's rotation.

→ There is rise in level of sea water during high tide period and fall during low tide period.

→ Water rises and falls twice a day and hence head on the turbine varies with time cyclically

→ During high tide, when water level along the coast is rising, electricity can be produced.

→ Electricity can also be produced when water is retreating by changing the direction of rotation of turbine

→ Turbines used are Bulb Turbine and Tubular Turbine

Advantages	Limitations
1) Water → Renewable source	1) Setup cost is high
2) Running cost is low	2) Long gestation Period [Due to large scale rehabilitation and clearances from multiple stakeholders like Niti Aayog, MoEFCC, MoWR, MoTA]
3) Renewable source of energy	3) Far from load centre → high transmission cost
4) No GHG emission	4) ecology is disturbed downstream of the reservoir
5) Quick start and closure ↓ Hence suitable for peak load applications.	5) Rehabilitation and Resettlement issues

⇒ Terminologies in Power generation

① Load Factor $$= \frac{\text{Average load during a certain period}}{\text{Peak load during that period}}$$

② Utilisation Factor or Plant use Factor

$$= \frac{\text{Maximum Power utilized}}{\text{Maximum Power available (= Installed capacity)}}$$

③ Diversity Factor $$= \frac{\text{Sum of individual maximum demands}}{\text{Simultaneous maximum demand.}}$$

④ Demand Factor $$= \frac{\text{Simultaneous maximum demand}}{\text{Sum of individual maximum demand}}$$

$$= \frac{1}{\text{Diversity Factor}}$$

⑤ Primary Power (Firm Power)

→ It is the net amount of power that is available from a plant on a guaranteed basis.

⑥ Secondary Power

→ Excess power available over and above primary power

Q. Load on a Hydel Plant varies from a min of 10000 KW to a max. of 35000 KW. 2 turbogenerators of capacity 22000 KW each have been installed. Calculate

① Total installed capacity of the plant → 44000 KW
② Maximum demand → 35000 KW
③ Load factor → 9/14 → 64.28%
④ Utilization / Plant Use factor → 79.54%

Q. The peak on a power plant is ~~60000 kW~~ 60 MW. The loads having max^m demands of 30MW, 20MW, 10MW and 14MW are connected to the power plant. The capacity of the power plant is 80MW and annual load factor is 0.5

Estimate:

① Average load on the power plant → 30 MW

② Energy supplied per year in kWh → 262800000 kWh

③ Demand factor = 0.811

④ Diversity factor = $\frac{30+20+10+14}{60}$ = 1.233

Chapter-2 Hydraulic Turbine

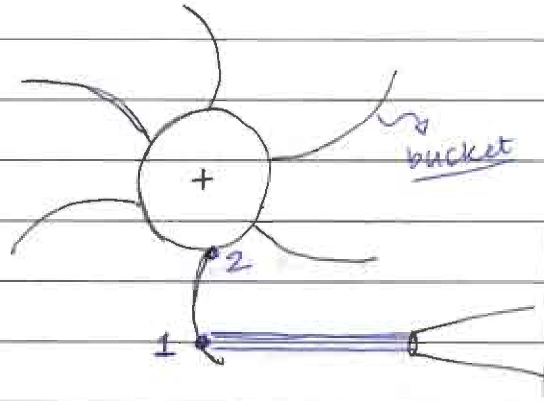
$$\begin{tikzcd}
\text{Hydraulic Energy} \arrow[r, "\text{Turbine}"] \arrow[d] & \text{Mechanical Energy} \arrow[r, "\text{Electrical}", "\text{Generator}"'] & \text{Electrical Energy} \\
\text{PE} & &
\end{tikzcd}$$

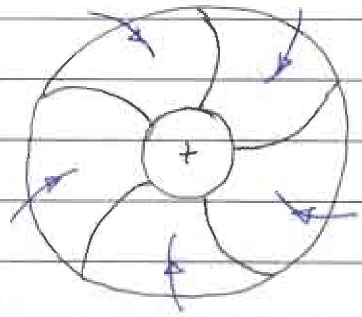
PE converted →

KE → Impulse effect

Pressure Energy → Reaction effect

Impulse effect	Reaction effect
↓	↓
Impulse Turbine	Reaction turbine





$$\frac{v_1^2}{2g} - \frac{v_2^2}{2g} = RP$$

→ Only KE is used

$$\frac{P_1-P_2}{\gamma} + \frac{v_1^2-v_2^2}{2g} = RP$$

→ Both KE and Pressure energy is used.

→ Hydraulic turbines are the devices which convert hydraulic energy into mechanical energy. This mechanical energy is further converted into electrical energy by a generator

→ Classification of hydraulic turbines

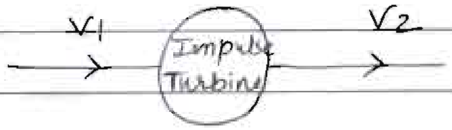
① According to the action of water on moving blade

(a) Impulse Turbine

→ In Impulse Turbine, the energy available at the entrance to the turbine is in the form of Kinetic Energy and water strikes the bucket with KE causing an impact or impulse action

→ Throughout the movement of water through the runner, pressure remains atmospheric and KE of water is extracted in the form of runner power

→ Pelton wheel is the most commonly used impulse turbine



$V_1 > V_2$

$P_1 = P_2 = P_{atm}$

$$\text{Runner Power} \equiv \frac{V_1^2 - V_2^2}{2g}$$

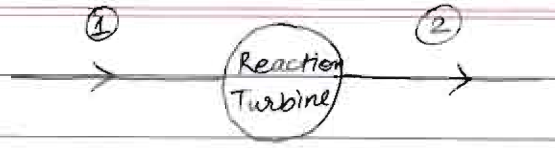
→ ~~In~~ (b) Reaction Turbine

→ In reaction turbines, runner blades are completely submerged in water and energy available at the entrance to turbine is in the form of both Pressure Energy and KE.

→ While flowing through the runner, both KE and pressure energy are extracted in the form of runner power and at exit both KE and pressure are low

→ Flow in reaction turbine is inside an air tight casing

→ Commonly used reaction turbines are Francis turbine, Kaplan turbine and Propeller turbine

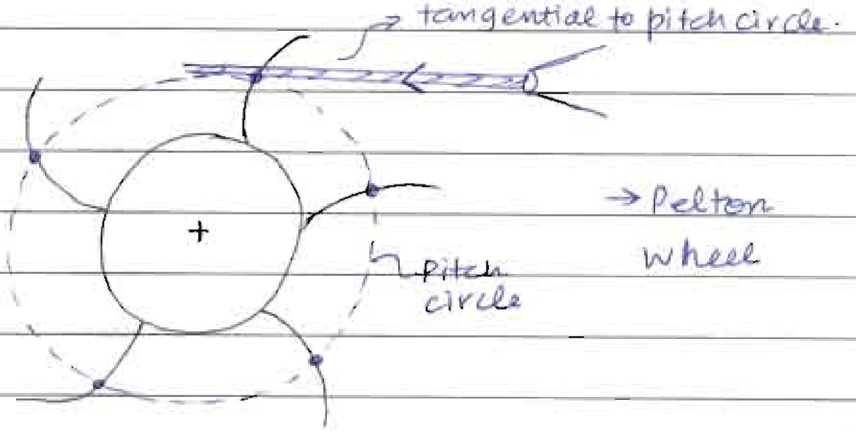


$V_1 >> V_2$
$P_1 >> P_2$

$$\Rightarrow \underset{\text{(Runner Power)}}{RP} = \frac{(P_1-P_2)}{\gamma} + \frac{V_1^2-V_2^2}{2g}$$

② According to the direction of flow of water

(a) Tangential flow Turbine



→ Pelton wheel

→ Water flows in a direction tangential to the path of rotation of runner

(b) Radial flow Turbine

→ water flows in a radial direction and remains mainly in a plane normal to the axis of rotation of runner.

→ It can be

(i) In ward Radial flow

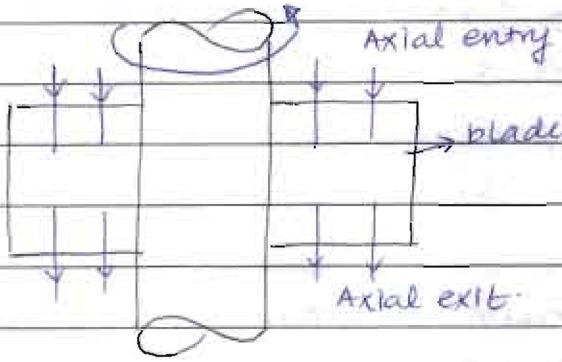
→ Water enters at outer circumference and flows radially inwards towards centre of runner. eg- Old Francis, Thomson turbine

(ii) Outward Radial flow

→ Water enters at centre and flows radially outwards, towards the outer periphery of runner. eg- Fourneyron Turbine

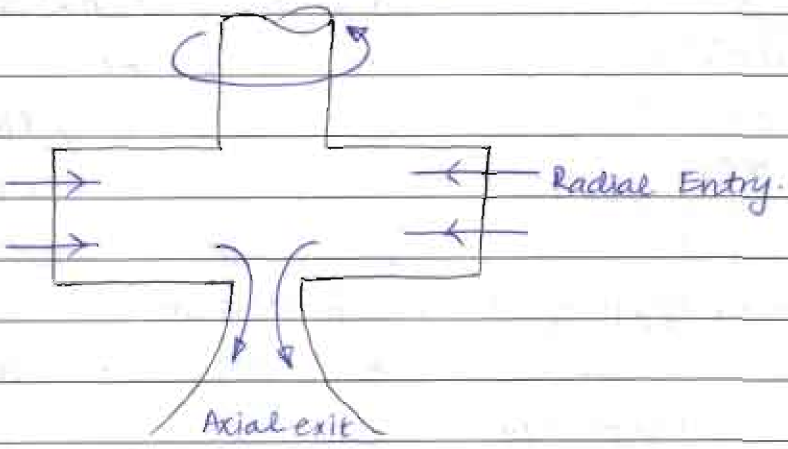
(c) Axial flow Turbine

→ In this turbine, flow of water through the runner is mainly along the direction parallel to the axis of rotation of runner eg- Kaplan turbine, Propeller turbine.



(d) Mixed flow Turbine

→ In this type of turbine, water enters the runner at outer periphery in radial direction and leaves it at centre in the direction parallel to axis of rotation of runner. eg- Modern Francis turbine



③ According to head and discharge

(a) Pelton wheel → Works under high head and hence requires low discharge [$\because P = \gamma Q\downarrow H\uparrow \eta$]

(b) Francis turbine → Works under medium head and hence requires medium discharge.

(c) Kaplan and Propellor Turbine - Works under low head and hence requires high discharge

④ According to specific speed

→ Specific Speed (N_s) → Speed of a geometrically similar turbine which while working under a head of 1 m produces 1 KW power

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

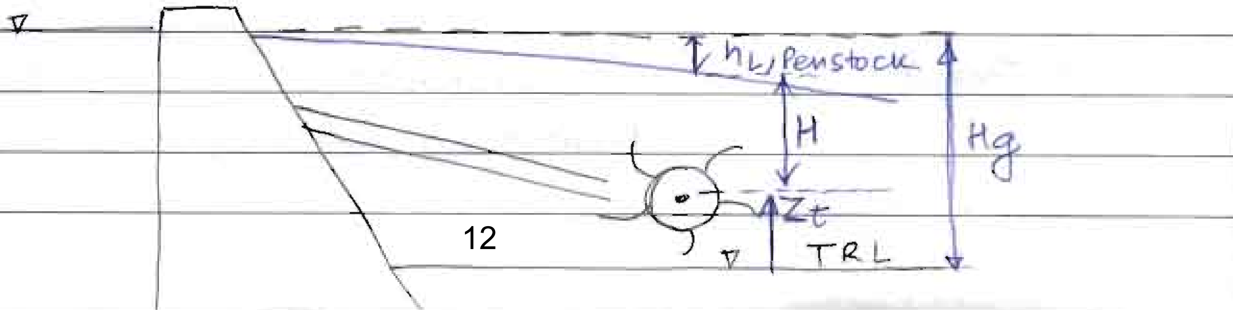
N : speed of runner (in rpm)
P : Power output (in KW)
H : Net Head.

N_s	Type of Turbines
10-35	Pelton wheel with single Jet
>35	Pelton wheel with multiple Jets
60-300	Francis Turbine
300-900	Kaplan Turbine / Propeller
>900	Special type of runners are used

NOTE: Calculation of specific speed is independant of size of turbine and hence this is the most scientific criteria for classification of turbine.

⇒ Head and efficiency of Turbine

① Gross Head (H_g) → It is the difference of Level b/w HRL and TRL



② Net Head

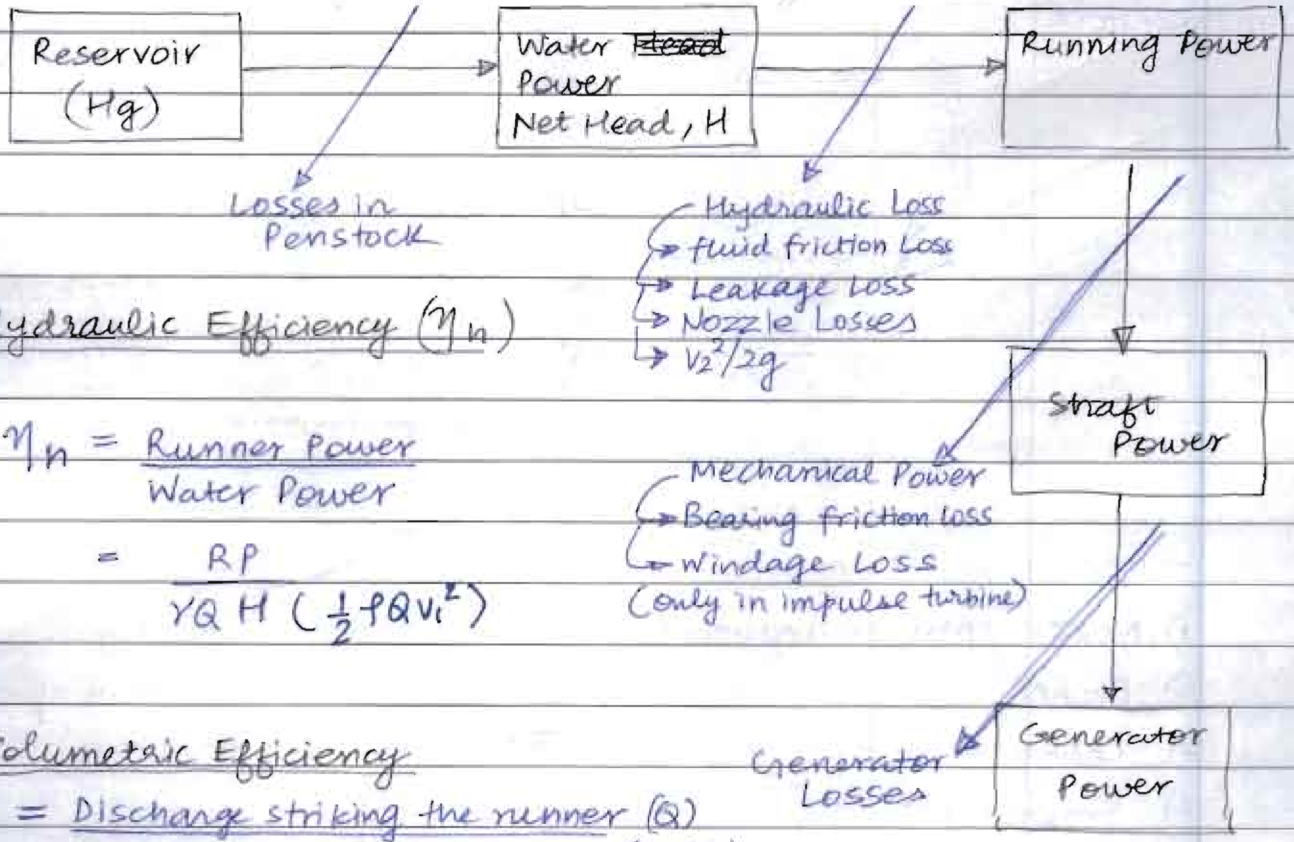
$$\boxed{\text{Net Head} = H_g - h_{L,\text{Penstock}} - Z_t}$$ → Impulse Turbine

Z_t → height of turbine above TRL

$$\boxed{\text{Net head} = H_g - h_{L,\text{Penstock}} - \frac{V_{dt}^2}{2g}}$$ → Reaction Turbine

V_{dt} → Velocity at the exit of draft Tube.

→ Efficiencies of hydraulic Turbine



① Hydraulic Efficiency (η_h)

$$\eta_h = \frac{\text{Runner Power}}{\text{Water Power}}$$

$$= \frac{RP}{\gamma Q H \left(\frac{1}{2}\rho Q V_1^2\right)}$$

② Volumetric Efficiency

$$= \frac{\text{Discharge striking the runner } (Q)}{\text{Discharge supplied to runner } (Q+\Delta Q)}$$

ΔQ → Leakage Losses (generally neglected)

③ Mechanical Efficiency (η_m)

$$\eta_m = \frac{\text{Shaft Power}}{\text{Runner Power}} = \frac{RP - \text{Mechanical Losses}}{WP - \text{Hydraulic Losses}}$$

④ Overall Efficiency (η_o) $= \dfrac{\text{Shaft Power}}{\text{Water Power}}$

Shaft Power → Brake horse Power (BHP)

Water Power → Water horse power (WHP)

$$\boxed{\eta_o = \eta_h \times \eta_m}$$ $$\boxed{1\,hp = 745.7\,W}$$