WRO-101
Notes

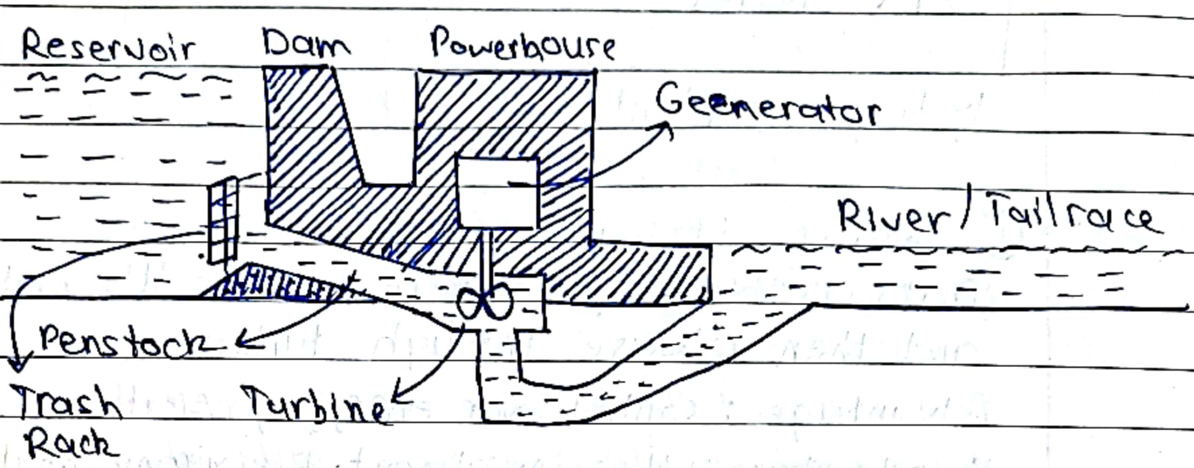
Hydropower Plant Types

1. Storage (Reservoir Based)
Dam is built upon rivers to store it's water and then release through turbines.
Advantage : Control over energy generation.
Disadvantage : High investment $ environmental impact

2. Run-of-River
A stream from river is diverted to pass through turbines and generate power.
Advantage : low cost and least environmental impact.
Disadvantge : less control over energy generation.

3. Pump-storage
Two reservoirs are used, during energy surplus hours, grid energy is used to pump the water upstream and during peak hours, water is released via turbines downstream.
Advantage : Helps regulate energy supply "battery"
Disadvantage : High initial investment $ net energy consumer.

Components of Storage Hydrostation

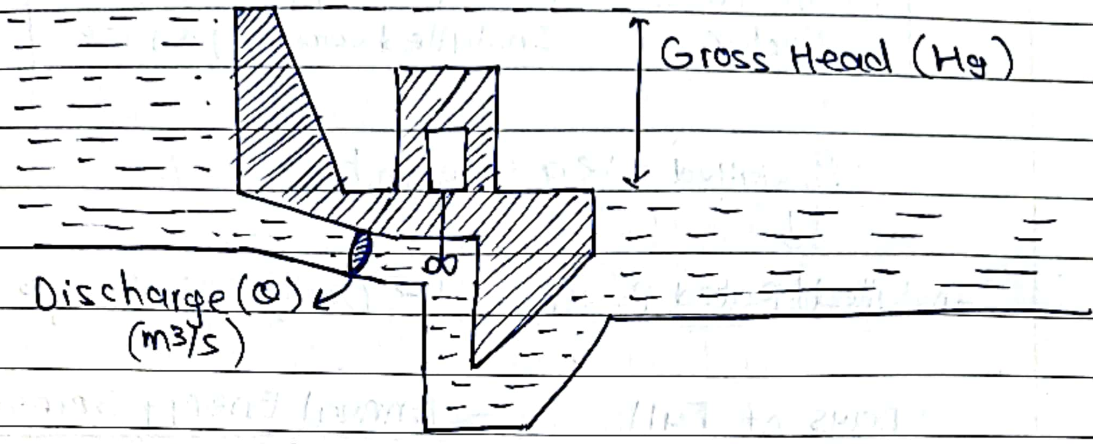


Dam blocks the water to build the reservoir, water is passed through turbine via the Penstock with rotates turbine to generate electricity and then the water is passed into the river.

Penstock has intake gates which when opened convert the potential energy of water into kinetic as it moves through the penstock, trash racks prevent debris from entering into the penstock

A spillway is created to divert extra water and avoid dam overflow during floods.

Hydropower Equations



Head loss (h_L) occurs due to friction and other losses in penstock & turbine.

Effective Head: $H = H_g - h_L$

$$\eta = \eta_h \cdot \eta_m \cdot \eta_g \longrightarrow \text{Generator Efficiency}$$

η → Net Efficiency

η_h → Hydraulic Efficiency

η_m → Mechanical Efficiency

$\boxed{P = \rho g Q H \eta}$ $\boxed{E = P \times t}$

$P(kW) = 9.81 \times Q(m^3/s) \times H(m) \times \eta$

$E(kWh) = P(kW) \times t(hrs)$

$$\boxed{\text{Plant Load Factor} = \frac{\text{Actual Energy Generated}}{\text{Installed Capacity} \times \text{Time}}}$$

$$P_{installed} = \rho g Q_{design} H \eta$$

$P_{installed}$ → Installed / Rated Power

Q_{design} → Design Discharge

$$\text{Days of Full Capacity Generation} = \frac{\text{Annual Energy Generated}}{\text{Installed Capacity} \times 24\text{hrs}}$$

$$P_{total} = n \times P_{unit}$$

P_{unit} is chosen such that it runs with good efficiency with least discharge in dry period.
P_{total} is calculated considering the design discharge.

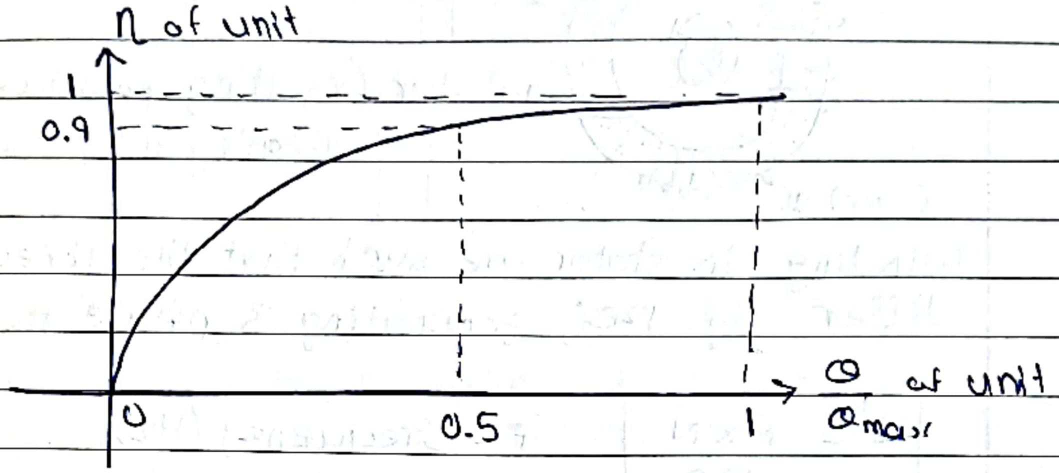
→ Base Load Stations: Operate continuosly to meet minimum demand, typically large and efficient economical plants (coal, hydro). Operates at high plant load factor.

→ Peak Load Stations: Operates only during peak hours, frequent start/stop. Less efficient but fast-start units.

Load Sharing: Load is shared equally among all units as far as possible.

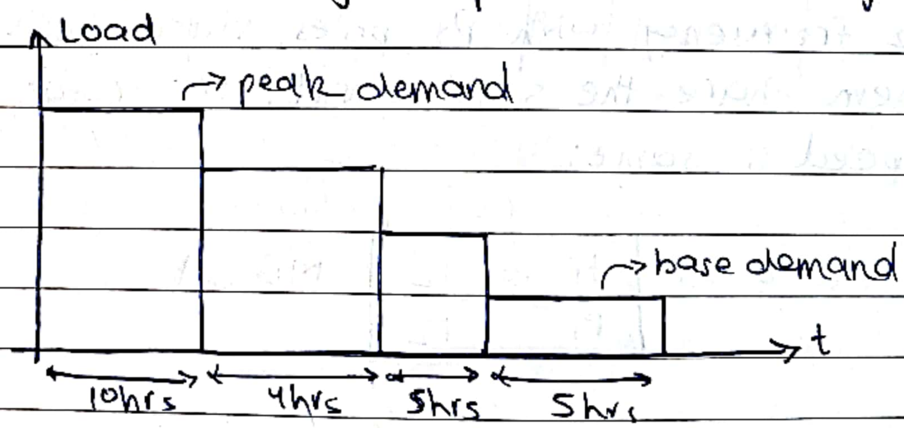
$$\text{Load Factor} = \frac{\text{Energy Consumed in Period (KWh)}}{\text{Maximum demand (KW)} \times \text{Time (hrs)}}$$

Reserve Capacity = Installed Capacity − Max Demand



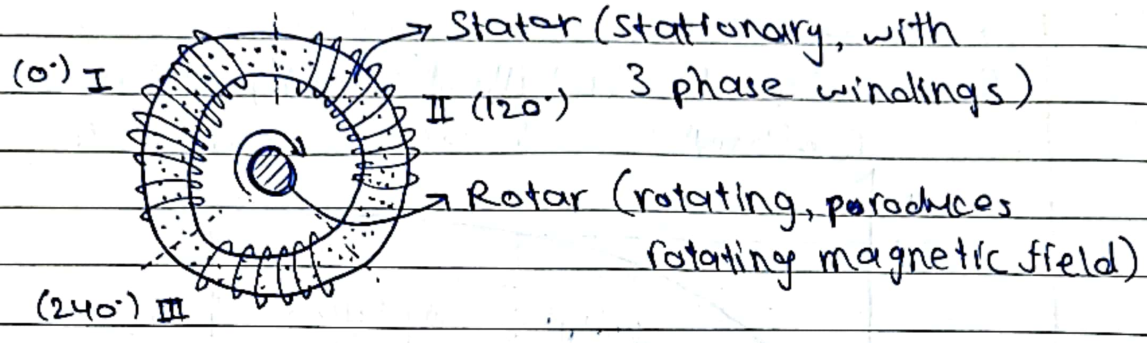
Hence, a unit can operate at good efficiency even at half the designed discharge of the unit.

Load Duration Curve: Loads are arranged in descending manner against time in hours or days during a period of a day or year.



Replacing load with flow of water gives us Flow Duration Curve in Hydropower stations.

Three Phase AC generator



Windings in stator are such that the three differ by 120°, generating 3 phase AC.

$$\boxed{f = \frac{P \times N}{120}}$$

f = frequency (Hz)
P = no. of poles (even always)
N = speed of rotor (rpm)

To convert ac from one frequency to another, a Motor-Generator set (MG set) is used in which a motor with f_1 frequency and P_1 poles is connected to a generator producing f_2 frequency with P_2 poles, since both of them share the same shaft, the rotor speed is same:

$$N_1 = N_2 \Rightarrow \boxed{\frac{f_1}{P_1} = \frac{f_2}{P_2}}$$ MG set

Generator $ Motor Parameters

Armature Resistance in the stator windings lead to copper losses (I^2R), this resistance Is calculated by passing a DC value: $R_a = \frac{V_{DC}}{I_{DC}}$

Synchronous Reactance (X_s) represents the opposition to the AC flow caused by the inductance of windings: $X_s = \frac{V_{oc}}{I_{sc}} - R_a$

Internal Impedance: $\boxed{Z_s = R_a + jX_s}$

Droop Characteristic

Designed relationship between generator load (power output) and frequency

$$Droop = \left(1 - \frac{f_{full\text{-}load}}{f_{no\text{-}load}}\right) \times 100\%$$

Typical droop settings of 3–5% prevent hunting $ instability by allowing frequency to change slightly with load.

$$\boxed{\Delta P = \frac{\Delta f}{R}}$$

ΔP: change in power needed
Δf : change in frequency
R: Speed regulation constant.

As the frequency droops, the Governer adjusts the power generation by changing water flow rate.

Date
Page

Steady-State stability reflects the stability after small disturbances whereas Transient stability is for large quick disturbances

Availability Factor = 100% − (Forced outage + Planned outage)

<u>Pumped Storage</u>

Fixed Speed: Pump operates at constant synchronous speed fixed by grid frequency, pumping flow and power fixed. Generation also fixed.

Variable Speed: Pump speed adjustable through power convertors.