Chapter 6: Non-reactive energy sources

Types of non-reactive energy sources
1. Water power
2. Geothermal energy
3. Wind energy
4. Solar energy

<u>Utilization</u>

1. Direct electricity
2. Mechanical power
3. Thermal power
4. Heating

- largest utilization cost => Fixed or capital cost

- Advantages: Absence of waste and pollution (nuclear and fossil fuel)

Water power

<u>Hydroelectric power</u> ← needs turbines

Advantages:
1. Highly effective energy conversion system
2. No environmental pollution
3. More economical than fossil fuel system

Turbines
(depends on H & Q)

Reactive

- $H \downarrow$ & $Q \uparrow$
- Types: Radial (Francis) / Propeller (Kaplan) / Mixed flow
  - Propeller: runner blades can be adjusted
- It has a runner that functions within a completely water filled casing.
- Draft tube:
  - below runner
  - Discharges water

Impulse

$H \uparrow$ & $Q \downarrow$

Head $\xrightarrow{\text{Nozzle}}$ Kinetic $\rightarrow$ Blades

Turbine Selection

Based on available head & flow rate

Power analysis

$$\dot{W} = \dot{m}\,[\underbrace{g(z_1 - z_2)}_{P.E} - \underbrace{\frac{C_2^2}{2}}_{K.E} - \underbrace{g\,\Delta z_f}_{\text{Friction losses}}]$$

(C_2: Velocity)

$$\dot{W}_{max} = \dot{m}g(z_1 - z_2)$$

K.E = 0

Microhydro water power

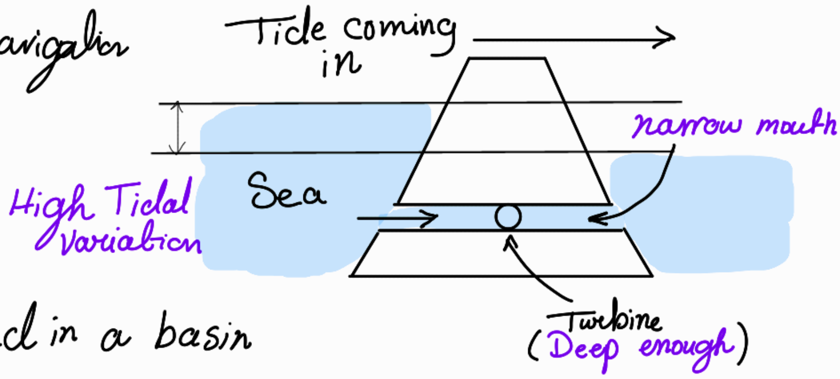
- Power less than 100kW
- Obtained from low heads or small flow rates
- Impulse turbine (Pelton) is used: higher η at partial loads and simple control arrangements

Tidal power

- Flood tide twice during each lunar day
- Variation in water level (Tidal range) depends on: the relative positions of moon & sun

Utilization:

- Enhanced through ~~water~~ ways, rivers and bays
- Bulb type and slant axis turbines are used ($H\downarrow$ & $Q\uparrow$)
- Problems of silting and adverse effects on ecology and navigation must be solved
- Disadvantage: Generation is only for 10 hours each day
- Gates open: Water is stored in a basin during high tide
  Gates are then closed and reopened at low tide



▶ Power analysis

$$\dot{m} = 2\rho\left(\frac{A\,\Delta z}{\tau}\right)$$

A: Area of basin; τ: 12.43 h

$$W_{max} = \dot{m} g \frac{\Delta z}{2} = \frac{\rho A g (\Delta z)^2}{\tau}$$

Two basin system

The high basin is filled at high tide while low basin emptied during low tide

Wave power

- Wave motion is up and down
- Wave height varies according to location and wind speed

Geothermal power

- Geothermal resource classified based on state
  1. Hydrothermal resources : hot water and steam T= 360°
  2. Geopressured reservoirs : dissolved natural gas (Saline fluids) ← T = 150 - 200
  3. Hot dry rock resources: Little or no fluid present ← T= 140-400

- Geothermal resource classified based on temperature:
  1. High temperature → Steam and electricity production
  2. Medium temperature } Heating & cooling applications
  3. Low temperature } Heating & cooling applications

Geothermal energy applications

1. Electricity production
2. Direct space and water heating
3. GHP for space heating and cooling

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GHP

Consists of:

1. Ground heat exchanger
2. Water/water or Water/air heat pump
3. Heat distribution system

Wind power

Wind turbine types

Shape: 1. Horizontal axis : Blades fixed at horizontal shaft
2. Vertical axis: Blades rotate in a plane normal to the wind velocity direction

Modes: 1. Stand alone systems
2. Grid connected systems
3. Hybrid : wind + diesel /PV

Size : 1. Small: 0.3 – 50 kW
2. Intermediate : 10 – 100 kW
3. Large: 500kW – over 2 MW

Wind speed measuring devices

1. Cup aneomometer
2. Turbine aneomometer
3. Ultra sound aneomometer

▶ Power analysis

For a horizontal axis wind turbine:

$$\dot{W}_{wind} = \dot{m}\frac{V^2}{2} = 0.5(\rho A V)V^2 = 0.5\rho\pi R^2 V^3$$

Wind power ($\dot{W}_{wind}$); ρ: Air density; R: Rotating blade radius; V: Wind speed

Theoretical maximum power:

Betz limit ⟶ $W_{Turb} = 0.593\,(\underbrace{0.5\rho\pi R^2 V^3}_{W_{wind}})$

Coefficient of preformanc

$$C_p = \frac{W_{act}}{W_{wind}} = 0.593 \; \eta_{overall}$$

↳ $\eta_c \, \eta_m \, \eta_g$ (if for turbine)

or η_c (if for Rotor)

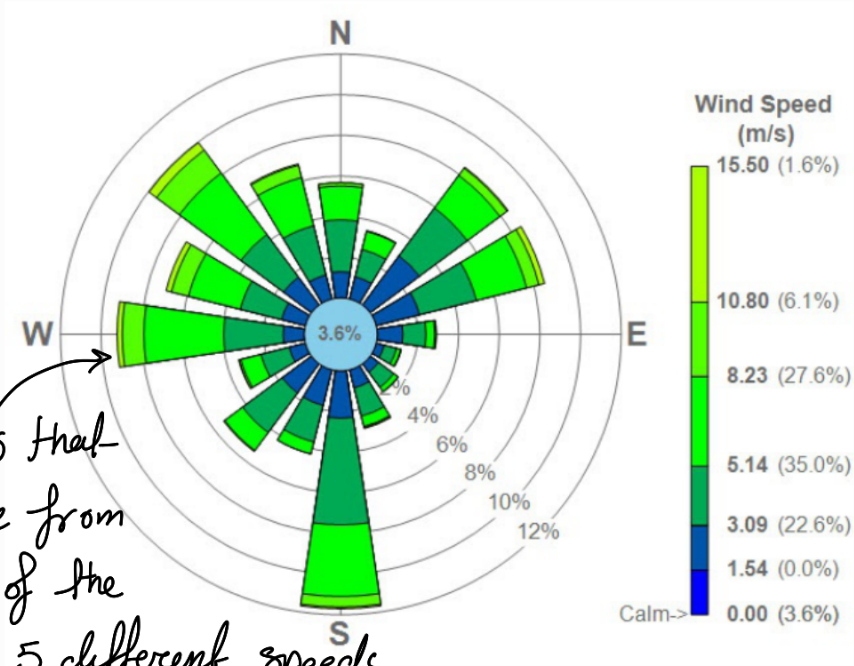
Overall C.P

$$W_{act} = \eta_c \, \eta_m \, \eta_g \, \dot{W}_{wind} \, 0.593$$

Rotor C.P

$$W_{act} = (\eta_c \, \dot{W}_{wind} (0.593))$$

Wind rose



This means that wind came from west 9% of the time with 5 different speeds

Wind Speed probability

$$\Phi(V_i) = \frac{f_i}{\Sigma f_i}$$

$\Phi(V_i)$ ← Probability of V_i

f_i ← frequancy of V_i

Σf_i ← Total frequency for all speeds

- Area under $\Phi(V) = 1$

$$V_{avg} = \Sigma(\Phi(V_i) \, V_i)$$

Probability functions

1. Rayleigh distribution (Simple)

$$\Phi(V) = \pi \frac{V}{2 V_m^2} e^{\left(-\frac{\pi V^2}{4 V_m^2}\right)}$$

V_m ← mean velocity

2. Weibull

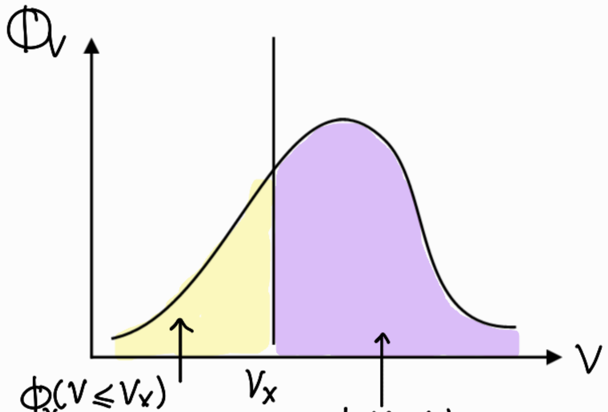
$$\Phi(V) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)^k}$$

Constants → k: shape factor (1.8 to 2.3)

c: scale factor (around mean wind speed)

- For Rayleigh:

Assuming $V = V_x$



$\Phi(V \leq V_x)$

$= \int_0^{V_x} \Phi(V)\, dv$

$= 1 - e^{\frac{-\pi V_x^2}{4 V_m^2}}$

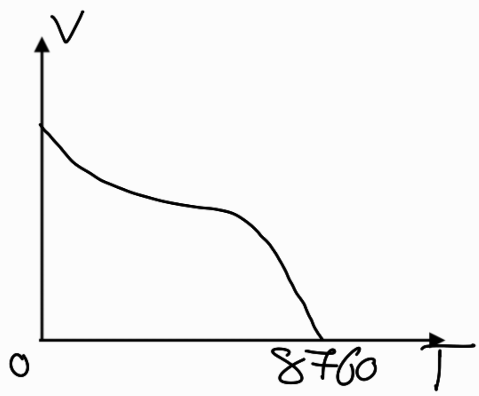
$\Phi(V \geq V_x)$

$= 1 - \Phi(V \leq V_x) = e^{\frac{-\pi V_x^2}{4 V_m^2}}$

Velocity duration curve

A plot of velocity V vs T where $V \geq V_x$

$0 \leq T \leq 8760$



Generated wind energy

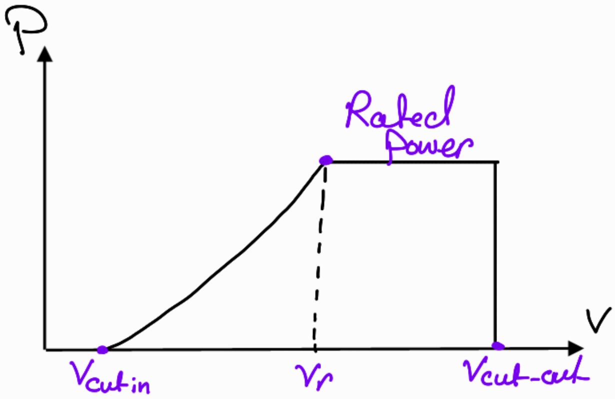
$$E_T = \int_{\text{cut-in}}^{\text{cut-out}} \Phi(V) \cdot T \cdot P_T(V)\, dv$$

T: time period in hrs

P_T: Turbine output power function

Turbine output power

$$P(V) = \begin{cases} 0 & , V < V_{cut\text{-}in} \\ CV^3 & , V_{cut\text{-}in} < V < V_r \\ cvr & , V_r < V < V_{cut\text{-}out} \\ 0 & , V > V_{cut\text{-}out} \end{cases}$$



$$\text{Annual plant factor} = \frac{\text{Actual energy output annually } [kWh/year]}{\text{Rated power } (kW) \times 8760 \frac{hr}{yr} \; [kWh/year]}$$

for $\frac{KJ}{year}$ → multiply by $3600 \frac{s}{hr}$

Wind water pumping

High inertial torque → High solidarity, multi blade turbines + cylinder-piston pump (simple)