WIND ENERGY

Principles of wind energy conversion :

Nature of wind : The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above a warm area expands, forced upwards by cool denser air which flows in from surrounding areas causing a wind. At night, process is reversed ∵ air cools down more rapidly over the land and the breeze ∴ blows off shore.

The direction of these air movements are affected by rotation of earth & net effect is a large countries - Clockwise circulation of air around low Pressure areas in the northern hemisphere, and clockwise circulation in the southern hemisphere. ~~...~~ wind speed inc. with ht.

Power in the wind : The Power in the wind can be computed by using the concept of kinetics. The wind mill works on the Principle of converting K.E. of the wind to the Mechanical energy. We know, Power = energy per unit time. The energy available = K.E. = $\frac{1}{2}mv^2$

$$K.E. = \frac{1}{2} m V^2$$

$$= \frac{1}{2} (\rho A V) V^2$$

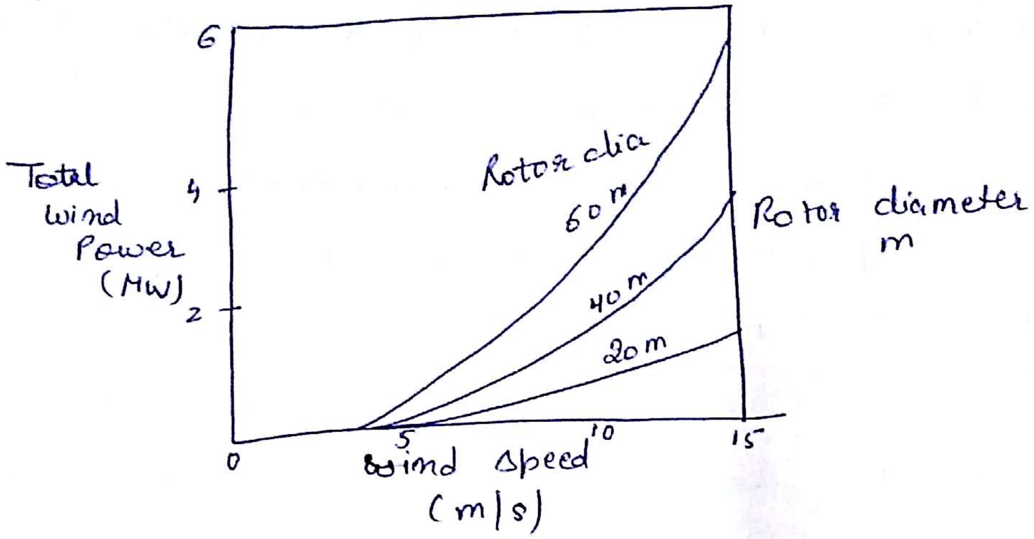
$$= \frac{1}{2} \rho A V^3$$

Amt. of air Passing in unit time through an Area A with Velocity V is A.V.
mass = density of air × AV

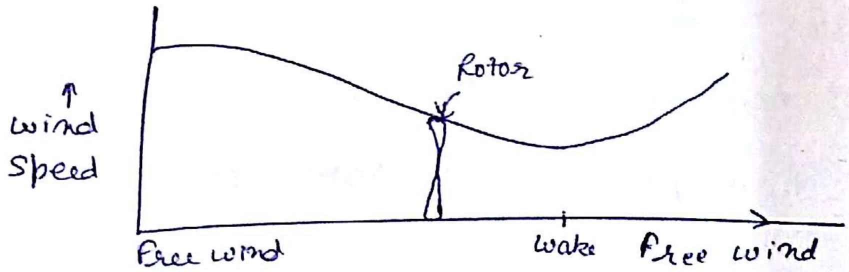
Power available $\propto$ Air density. ∴ small inc. in wind speed can have marked effect on the Power in the wind.

$$P_a = \frac{1}{2} \rho \frac{\pi}{4} D^2 V^3 = \frac{1}{8} \pi \rho D^2 V^3$$

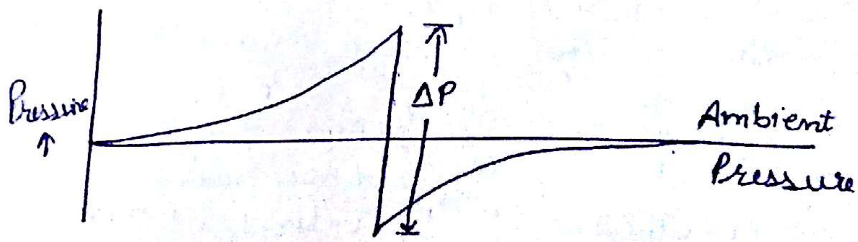
wind machines intended for generating substantial amounts of Power should have large rotors and be located in areas of high wind speeds.



Dependence of wind rotor Power on wind speed & rotor diameter



As free wind encounters and passes through rotor, wind X-fer some of its energy to the rotor & its speed dec. to min. in rotor wake.

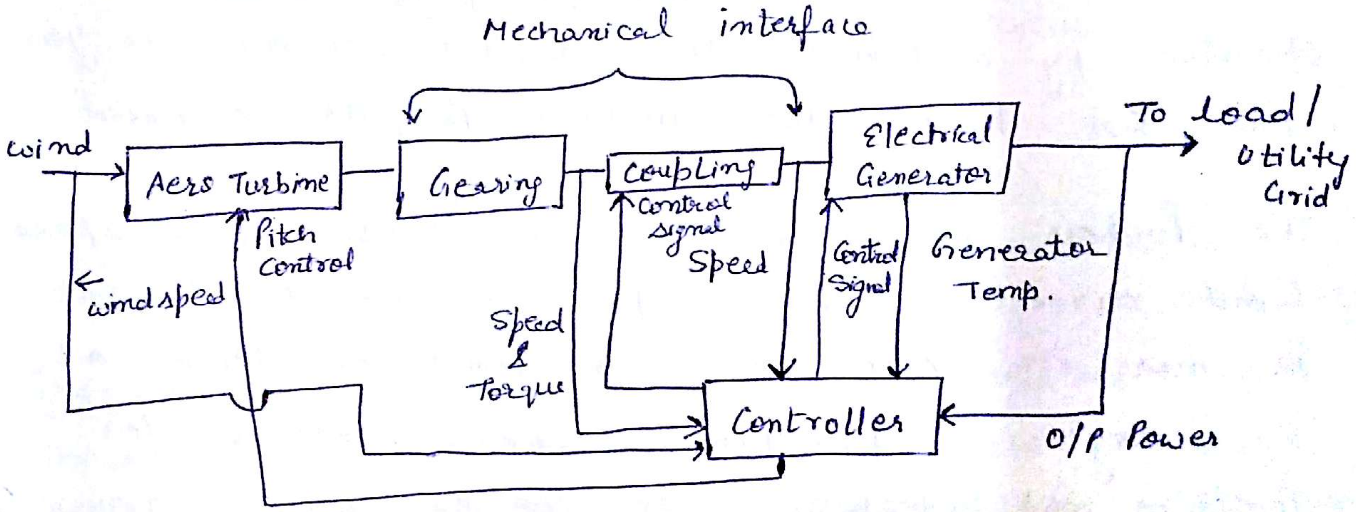


while the wind speed dec, air Pressure in windstream changes in a different manner. It 1st inc. as the wind approaches the rotor, then drops sharply by an amt. ΔP. Finally Pressure inc. to ambient atmospheric Pressure when wind stream regains energy.

The fraction of free flow wind Power that can be extracted by a rotor is called Power coefficient.

$$\text{Power coefficient} = \frac{\text{Power of wind rotor}}{\text{Power available in the wind}}$$

BASIC COMPONENTS OF WECS (Wind energy conversion System):



Aeroturbines Convert energy in moving air to rotary mechanical energy. In general, they require Pitch control & yaw control (only in the case of horizontal or wind axis machines) for Proper operation. A mechanical interface consisting of a step up gear and a suitable coupling x-mits the rotary mechanical energy to an electrical generator. The O/P of this generator is connected to the load or Power grid.

Yaw Control : when the rotor orientation is fixed with the swept area Perpendicular to the Predominant wind direction, such a machine is said to be yaw fixed. Most wind turbines are yaw active i.e. as the wind dir. changes, motor rotates the turbine slowly abt. vertical (yaw) axis so as to face the blades into the wind. The area of wind stream swept by the wind rotor is then max.

In small turbines, yaw action is controlled by a tail vane, similar to that in a typical pumping windmill. In larger machines, a servomechanism operated by a wind dir. sensor controls the yaw motor that keeps the turbine properly oriented.

The Purpose of controller is to sense wind speed, wind direction, shafts speed and torque at one or more Pts, O/P Power & generator temp. as necessary & appropriate control signals for matching the electrical O/P to the wind energy i/P & Protect the system from extreme condn. brought upon by strong winds electrical faults,

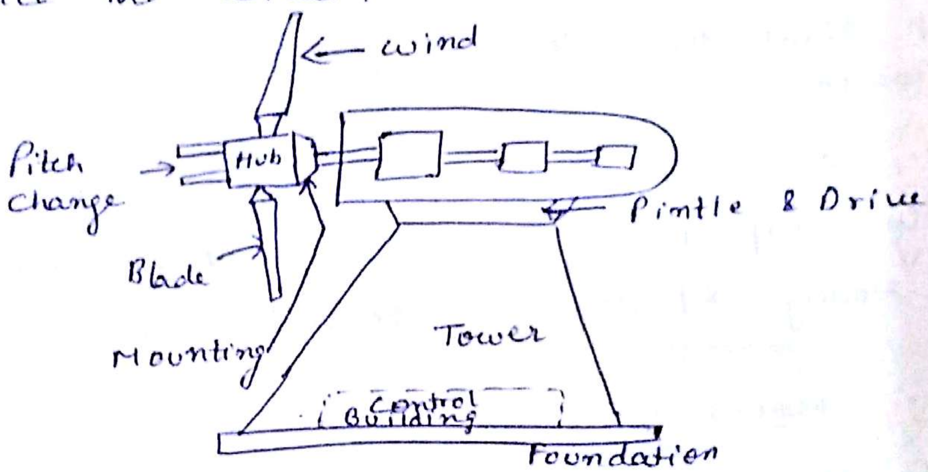
The sub - components of the windmill are:

→ wind turbine or rotor
→ wind mill head
→ X-mission & control
→ Supporting structure

Rotors : i) Horizontal Axis
ii) Vertical Axis

One advantage of vertical - axis machine is that they operate in all wind dir. no yaw adjustment needed.

Windmill head : It supports rotor, housing rotor bearings. It also houses any control mechanism incorporated like changing the pitch of blades for safety devices and tail vane to orient the rotor to face the wind.



Transmission : Among the x-mission options are mechanical systems involving fixed ratio gears, belts, chains, singly or in combination or hydraulic systems involving fluid pumps & motors. X-mission costs might be reduced by using large dia bearings with ring gears mounted on the hub to serve as a x-mission to inc. rotor speed (from 40 - 50 rpm to 1800 rpm) to generator speed.

Generator : Either a const. or variable speed generators are possible, but variable speed units are expensive and unproved. Among const. speed unit, synchronous, induction and permanent magnets type are used.

Controls : The modern large wind turbine generator requires a versatile & reliable control system to perform the foll. f^n

→ Orientation of rotor into the wind.
→ generator o/p monitoring
→ Protection for generator etc.

Towers :

→ Reinforced Concrete tower
→ Pole tower
→ built up shell tube tower
→ truss tower

Among these, truss tower is favoured ∵ it is Proved and widely adaptable, cost is low, Parts are readily available, readily x-ported, Potentially stiff.

Advantages of WECS :

1. Renewable source.
2. Non-Polluting.
3. Avoid fuel Provision and x-port.
4. Upto few kW (on small scale) less costly.

Disadvantages :

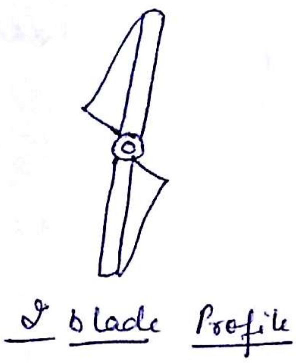
1. Fluctuating in nature.
2. Noisy in operation.
3. Large areas are needed.
4. High overall weight.

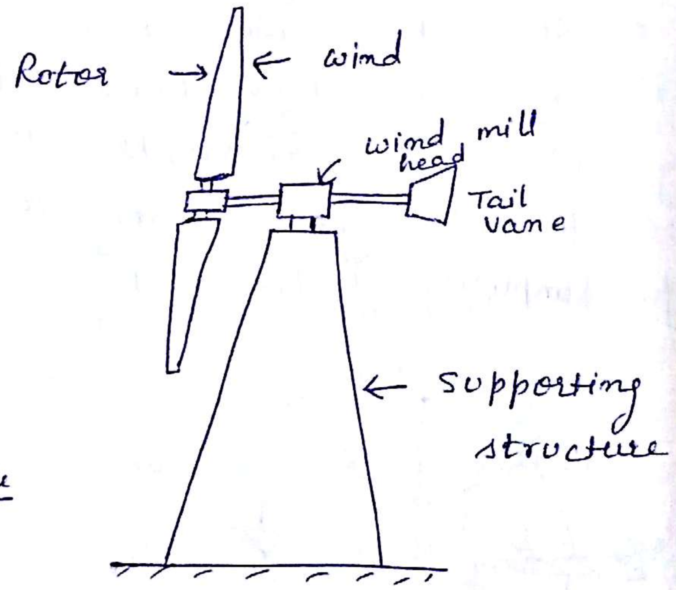
WIND ENERGY COLLECTORS :

wind aerogenerator of WECS are generally classified:

→ **Horizontal axis type :** These are further classified as single bladed, multibladed and by cycle multiblades type.

Horizontal axis using 2 aerodynamics blades : In this type of design, rotor drives a generator through step up gear box. The blade rotor is usually designed to be oriented downwind of the tower. The components are mounted on a bed plate which is attached on a pintle at the top of the tower. ∵ of high cost of blade rotor with more than 2 blades are not recommended.





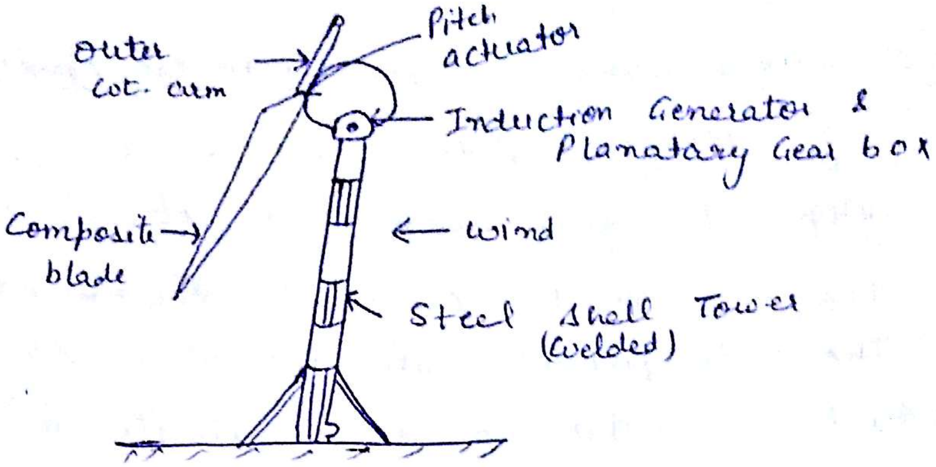
Horizontal axis Propeller type using single blade : A long blade is mounted on a rigid hub. If extremely long blade (60m or above) is mounted, large blade root bending moments may occur due to tower shadow, gravity & sudden shifts in wind direction.

Advantages :

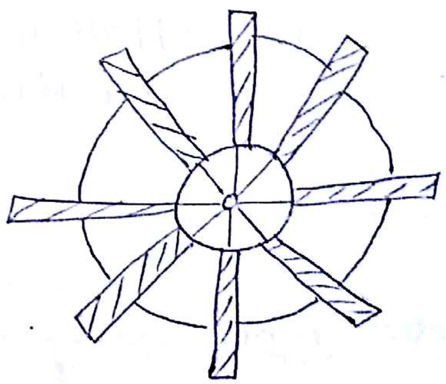
- simple blade control.
- counter wt. costs less than 2nd blade.
- Pitch bearing don't carry centrifugal force.

Disadvantages :

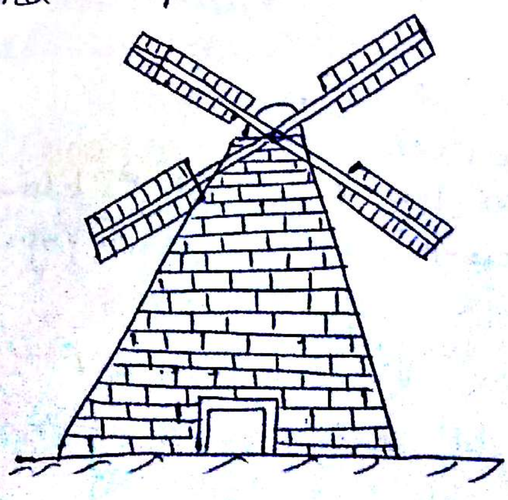
- Large blade root bending moment
- Vibration Produced due to aerodynamic torque.



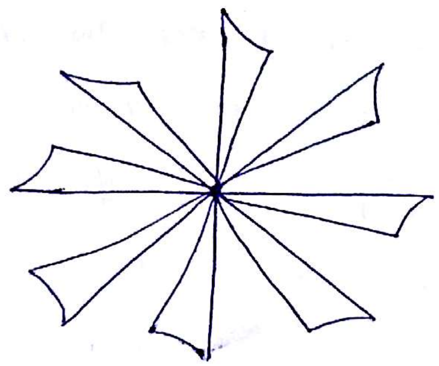
<u>Horizontal</u> <u>axis</u> <u>multibladed</u> <u>type</u>: This is made from sheet metal or Al. The rotors have high strength to wt. ratios and have been known to service hours of free wheeling operation in 60 km/hr winds. They have good Power coefficient, high starting torque & added advantage of simplicity & low cost.



<u>Horizontal</u> <u>axis</u> <u>wind</u> <u>mill</u> - <u>Dutch</u> <u>type</u>: It is one of the oldest designs. The blade surfaces are made from an array of wooden slats which 'feather' at high wind speeds.



Sail type : It is of recent origin. The blade surfaces is made from cloth, nylon, or Plastics arranged as Pole or sail wings.



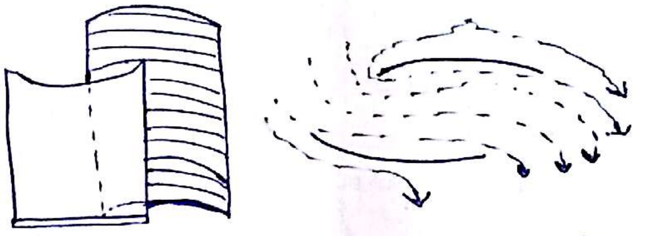
→ **Vertical axis type :** Advantages of vertical axis over horizontal axis are:

- React to wind from any dir. ∴ do not need yawing equipment to turn the rotor into the wind.
- Require less structural support ∵ heavy components (gear box & generator) can be located at ground level.
- ∵ blades do not turn end over end, rotor is not subjected to continuous cyclic gravity loads. (Fatigue induced by such action is a major consideration in the design of large horizontal axis machines).

The disadvantage of vertical axis machines is that far less is known abt. them than horizontal axis ones.

Savonius Rotor : This is invented by S. J. Savonius in 1920. It consists of 2 half cylinders facing opp. dir. in such a way as to have almost an S-shaped cross section.

These 2 semi circular drums are mounted on a vertical axis perpendicular to the wind dir. with a gap at the axis b/w the two drums. Irrespective of the wind dir. the rotor rotates such as to make the convex sides of buckets head into the wind. From the rotor shaft we can tape power for use like water pumping, battery charging, etc.



Savonius rotor   Stream flow

Characteristics : i) Self starting
ii) Low speed
iii) Low efficiency

Advantages : i) Low cut in speed (wind speed required for switching electric power into line)
ii) Simple structure
iii) Ground level monitoring

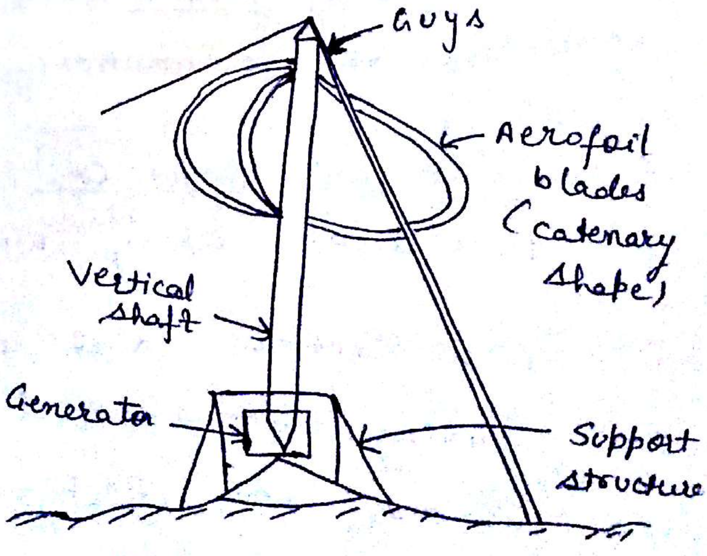
Disadvantages : i) Excessive weight
ii) Not useful for a very tall installation ∵ long drive shaft problems.

Darrieus type (High velocity wind) : Invented by G.J.M Darrieus in 1925. This has same advantage but additional advantage is that it supports its blades in a way that minimizes bending stresses in normal operation. It has 2 or 3 thin, curved blades with airfoil cross section and const. chord length. Both ends of blades are attached to a vertical shaft. Thus the force in the blade due to rotation is pure tension. This provides a stiffness to help withstand the wind forces it experiences. The blades can thus be made lighter than in the propeller type. When rotating, these airfoil blades provide a torque about the central shaft in response to a wind stream. This shaft torque is being x-mitted to a generator at the base of the central shaft for power generation.

Characteristics:
i) Note self starting
ii) High speed
iii) High efficiency
iv) Potentially low capital cost.

Advantages:
i) Machine can be mounted on the gnd.
ii) Yaw control not needed.

Disadvantages:
i) Requires external mechanical aid for start up.
ii) O/P efficiency is lower



Vertical axis wind mill

Site Selection Considerations:

1. **Availability of wind curve at the Proposed site:** This Curve determine the max. energy in the wind & hence is the principal initially controlling factor in Predicting the electrical o/p & hence revenue return of WECS.

2. **Availability of Anemometry data:** The Principal object is to measure the wind speed which basically determines the WECS o/p Power. The anemometer ht. above ground, accuracy, linearity, location on the support tower, shadowing etc. are a few of many difficulties encountered.

3. **Distance to Roads or Railways:** This is another factor the system engineer must consider for heavy machinery, structures, materials, blades etc. will have to be moved into any chosen WECS site.

4. **Nature of ground:** Ground condn. should be such that the foundations for a WECS are secured.

5. **Favourable land cost:** Land cost should be favourable along with other siting costs.

6. Other Problems such as icing, salt spray or blowing dust should not Present at the site as they may affect aeroturbine blades, or environmental is generally adverse to machinery & electrical apparatus.

Wind data and energy estimation :

The seasonal as well as instantaneous changes in winds both with regard to magnitude and direction need to be well understood to make the best use of them in windmill designs. Winds are known to fluctuate by a factor of 2 or more within sec. (thus causing power to fluctuate by a factor of 8 or more). This calls for a proper recording and analysis of the wind ch.

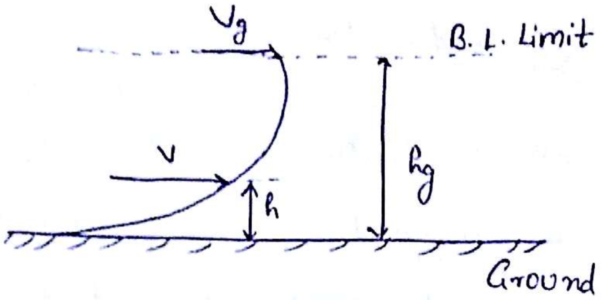
The factors which affect nature of wind close to the surface of earth are:

→ Latitude of place → altitude of place

→ topography of place → scale of hrs, month or year.

The basic data used in windmill designs is <u>hourly mean wind velocity</u> (averaged over day, month, year or years) as collected by meteorological observations. This provides the data for establishing the potential of the place for tapping wind energy.

The wind near the surface of earth are interpreted in terms of boundary layer concept. The wind velocity at a given ht., $\frac{V}{V_g} = \left(\frac{h}{h_g}\right)^n$ in terms of gradient ht. and velocity.



The values of V_g, h_g and n depends on the nature of terrain:

i) Open terrain with few obstacles (open land, lake, shore, deserts etc.)

ii) Terrain with uniformly covered obstacles (wood land, Small towns, suburbs, etc.)

iii) Terrain with large and irregular objects (large city centres, country with breaks of large trees etc).

In addition to the data on hourly mean velocity, 2 other informations required are:

→ Spells of Low wind speeds : Required for providing storage or alternatives.

→ gusts : Required for structural design of the windmill as well as to provide safety measures against damage.

Betz limit : According to Betz's law, no turbine can capture more than $\frac{16}{27}$ i.e. 59.3% of K.E. in wind. The factor $\frac{16}{27}$ (0.593) is known as Betz's coefficient.

Practical utility-scale wind turbines achieve at peak 75% to 80% of Betz limit. This is given by physicist Albert Betz in 1919.

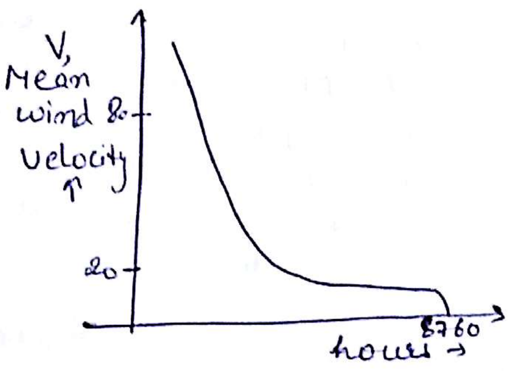
surface wind data on a national or regional basis is usually presented in the forms of:

i) Isovents or contours of constant avg. wind velocity (m/s or km/hr)

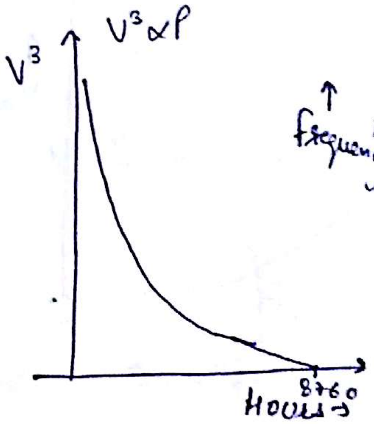
ii) Isodynes are contours of constant wind power (watts/m² of perpendicular to the wind flow).

<u>Energy</u> <u>Estimation</u> :

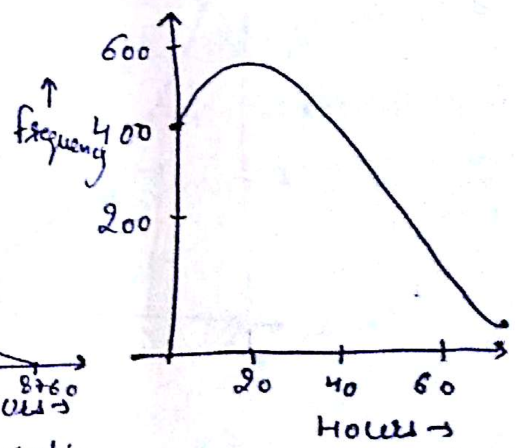
1st curve → velocity duration curve useful for establishing wind energy potential of a place and design wind speed.



<u>Velocity duration Curve</u>



<u>Power duration Curve</u>



<u>Frequency duration Curve</u>

2nd curve → Power duration curve also useful for the same purpose as 1st curve.

3rd curve → frequency duration curve useful in deciding the design wind speed for a given site and actual energy o/p of the plant.

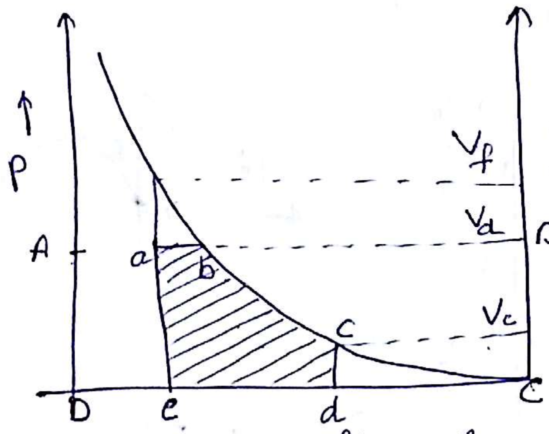
The three speeds associated with the design of a windmill are:

V_c – Cut in speed, speed below which wind mill does not operate.

V_d – design speed, speed for which rotor is designed.

V_f – furling speed, speed at which rotor is turned away from facing the wind or stopped otherwise with a view to protect the windmill.

Another reference speed is V_{rat} at which the plant o/p is max.



Ideal Plant o/p

Area abcde → represents annual energy o/p from ideal plant

ABCD Area → represents o/p obtainable from ideal plant, if windmill were to operate at the design speed all the time.

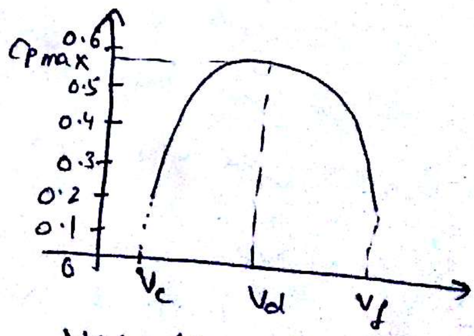
Ratio $\frac{abcde}{ABCD}$ = Annual load factor of the plant.

Actual o/p < Area abcde due to instability of the rotor to convert entire K.E. available in the wind. This is represented by C_p.

Annual o/p from a plant,

$$E = \int \eta_m C_p \rho A V^3 \delta_T$$

δ_T = time inc. ∵ data is usually in form of no. of hrs for which each mean wind velocity is available.



Variation of C_p as a f^n of V

Tip speed ratio - Solidity:

All horizontal - axis rotors depend mainly on lift (Lift type rotors use twisted blades to reduce the bending strains on the roots of the blades) to rotate them. Given that a rotor's tip travel faster than points nearer axis, the angle at which the wind meets the plane of rotation dec. in linear proportion to the radius. For this reason, an efficient wind rotor requires the blades to be twisted so that optimum ~~tip-speed ratio at~~ angle of incidence is obtained at all radii when the machine is running at its design speed. For the same reason, high speed machines have blades set at a finer pitch than low-speed ones.

The ratio of speed of the rotor blades tips to the speed of the wind is called tip-speed ratio. Every rotor has an optimum tip-speed ratio at which its max. efficiency is achieved, and which also characterizes the rotor

$$TSR = \frac{V_{tip}}{V}$$

V_{tip} = speed of rotor tip

V = free wind speed.

Scanned by CamScanner

As TSR inc., no. of blades dec. <u>Solidity</u> is normally defined as the fraction of the total circumferential (either at the tip or sometimes at 2/3 of tip radius) that contains blades.

$$S = NC/\pi D$$

N : no. of blades
C : avg. breadth of a blade
D : dia of circle described by a blade.

The faster a rotor runs w.r.t. wind speed, less solidity is required to intercept the entire stream tube of wind passing through the rotor disc. In other words, a rotor with a high TSR needs less material and can have relatively slender blades. However, ∵ it rotates at higher speeds and twist angles require only slight angles of attack at the tip ∴ needs good quality airfoils (similar to those used in aircrafts). They must also be made with a good surface finish and the structural integrity necessary to withstand high rotational speeds. ∴ cost/m² > low speed rotors, despite the reduced quantity of materials.

Torque on wind - wind thrust calculations:

There are 2 types of forces acting on the blades:

1. Circumferential force acting in the dir. of wheel rotation that provides torque, T.
2. Axial force acting in the dir. of wind stream that provides an axial thrust that must be counteracted by proper mechanical design.

Here blades of Propeller type wind turbine is Considered.

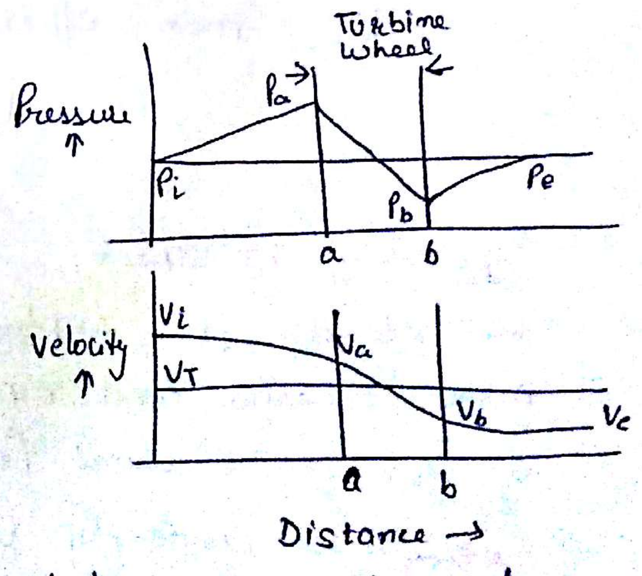
$$T = \frac{P}{\omega} = \frac{P}{\pi D N}$$

where, ω = angular velocity of turbine wheel, m/s
D = dia. of turbine wheel
N = wheel rev. per unit time, s^{-1}
P = Power.

P_i, V_i = wind pressure and velocity at upstream of turbine

P_e, V_e = Pressure and velocity at downstream of turbine.

$a-b$ = turbine wheel thickness



$V_e < V_i$ as. K.E is converted to mechanical work from a to b.

The general energy eq. for entry and exit region:

$$P_i + \rho \frac{V_i^2}{2g_c} = P_a + \rho \frac{V_a^2}{2g_c} \rightarrow (1)$$

$$P_e + \rho \frac{V_e^2}{2g_c} = P_b + \rho \frac{V_b^2}{2g_c} \rightarrow (2)$$

Combining eq. (1) & (2),

$$P_a - P_b = \left(P_i + \rho \frac{V_i^2 - V_a^2}{2g_c}\right) - \left(P_e + \rho \frac{V_e^2 - V_b^2}{2g_c}\right)$$

Assume, $P_e = P_i$ i.e. wind pressure at e is ambient

Assume, $V_a \simeq V_t \simeq V_b$, as blade width a-b is very thin to total distance considered.

$$\therefore P_a - P_b = \rho\left(\frac{V_i^2 - V_e^2}{2g_c}\right)$$

Axial force, $F_x = (P_a - P_b) A = \rho A \left(\frac{V_i^2 - V_e^2}{2g_c}\right)$

$$F_x = \frac{\pi}{8g_c} \rho D^2 (V_i^2 - V_e^2) \qquad \left\{\begin{matrix} A = \pi r^2 \\ A = \pi\left(\frac{D}{2}\right)^2 \end{matrix}\right\}$$

For max. efficiency, $V_e = \frac{1}{3} V_i$

$$F_{x,max} = \frac{\pi}{9g_c} \rho D^2 V_i^2$$

Repowering Concept:

It stands for replacement of old wind turbine with more powerful and modern turbines. This able to generate more wind Power from surface area. This Concept is commonly used in european markets, especially in Germany and Denmark.

Wind turbines that are over 15 years old cover a landscape that could easily be called 'Gulf of wind energy in India'. These turbines hardly do justice to the potential that this region houses. In Tamil Nadu, about 60% of small wind turbines (< 400 kW) installed before the year 2000 are operating with Plant load factor (PLF) ranging from 10-15%, whereas the new technology wind turbines can operate at PLF range of 27 - 32% in the same sites.