Unit-3
Wind Energy

Wind Energy : Wind Energy is an indirect source of Energy, can be used to run a wind mill which inturn drives a generator to produce electricity.

Introduction : The wind is a byproduct of solar Energy. Approximately 2% of suns energy reaching the Earth is converted into wind Energy.

→ The surface of the Earth heats and cools unevenly, creating atmospheric pressure zones that makes the air flow from high to low pressure areas.

Characteristics of wind :

The main characteristics of wind are :

→ Wind speed increases roughly as $\frac{1}{7}^{th}$ power of height. Typical tower heights are about 20 - 30 m.

→ Energy - pattern factor : It is the ratio of actual energy in varying wind to energy calculated from the cube of mean wind speed. This factor is always greater than unity, which means the energy estimates based on mean or hourly speed are pessimistic.

Advantages and Disadvantages of Wind Energy :-

Advantages :

1) It is a renewable energy source
2) Wind power systems being non-polluting have no adverse effect on the Environment
3) Fuel provision and transport are not required

4) Economically competitive

5) Ideal choice for rural and remote areas which lack other energy sources.

Dis advantages :

1) Availability of energy is fluctuating in nature

2) owing to its irregularity, the wind energy needs storage.

3) The overall weight of a wind power system is high.

4) wind energy conversion system are noisy in operation.

5) Large areas are required for installation / operation of wind energy system.

6) present systems are neither maintenance free nor practically reliable.

7) Low energy density

8) Favourable winds are available only in few geographical locations, away from cities and forests.

9) only in KW, and a few MW range ; it does not meet the energy needs of large cities and industry.

→ Environment Impacts of wind Energy :-

The possible environment impacts of wind energy are :

1) wind energy creates noise pollution because of mechanical (gearbox) aerodynamic noise.

2) The wind Turbine produces Electromagnetic interference when placed between radio, Television etc stations.

3) It produces visual shining because of reflection and refraction which depends upon Turbine size, no. of Turbines in wind farm, design etc.

4) Safety consideration for life because of accidental braking of blade.

5) Fatal collisions of birds caused by rotating Turbine blades.

→ **Sources (or) origins of wind :**

Following are the two sources or origins of wind :

1) local wind 2) planetary wind.

1) Local wind : These winds are caused by unequal heating and cooling of ground surfaces and ocean or lake surfaces during day and night.

2) Planetary winds: These winds are caused by daily rotation of Earth around its polar axis and unequal Temperature between polar regions and equitorial regions.

→ **Basic principles of wind Energy conversion :-**

(1) The Nature of wind :-

→ Despite the wind's intermittent nature, wind patterns at any particular site remain remarkably constant year by year.

→ Average winds speeds are greatly in hilly areas & Coastal areas.

→ wind speeds increases with height.

(2) wind power :-

→ The power in the wind can be computed by using the concept of Kinetics.

→ The windmill works on the principle of converting Kinetic energy of the wind to the mechanical energy.

Let V = velocity of wind
ρ = Density of air
A = Area, through which air flows.
m = mass of air

The amount of air passing in unit time through the area A, with velocity V is given by

$$m = \rho A V \longrightarrow (1)$$

$$\text{Kinetic energy (KE)} = \frac{1}{2} m V^2$$

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

KE (or) Total wind power available $= \frac{1}{2} \rho A V^3 \longrightarrow (2)$

Area (A) is normally circular of diameter D in horizontal axis aeroturbines, then $A = \frac{\pi}{4} D^2$

$$\text{Total Available wind power } P_{total} = \frac{1}{2} \rho A V^3$$

$$= \frac{1}{2} \rho \frac{\pi}{4} D^2 V^3 \text{ watts.}$$

$$= \frac{1}{8} \rho \pi D^2 V^3 \longrightarrow (3)$$

where D = Diameter in horizontal axis aeroturbines.

from above eq, it is obvious that, power output ~~of~~ wind mill Varies as cube of wind velocity. and square of diameter.

Maximum power:

Let ~~P_i and V_i~~ P = atmospheric wind pressure

Let P_{us} = wind pressure at upstream of wind turbine

V_{us} = velocity at upstream of wind Turbine.

V_{ds} = velocity at downstream of turbine

P_{ds} = wind pressure at downstream of turbine.

A_b = Area of blades

m = mass flow rate of wind

ρ = Density of air.

V_b = Velocity of blades.

The energy from wind is extracted by a wind turbine, by converting the Kinetic energy of wind to mechanical energy

Kinetic energy of wind stream passing through turbine rotor is given by :

$$KE = \frac{1}{2} m V_b^2 \longrightarrow (1)$$

$$\text{mass } m = \rho A_b V_b. \longrightarrow (2)$$

$$\therefore KE = \frac{1}{2} \rho A_b V_b \cdot V_b^2$$

$$= \frac{1}{2} \rho A_b V_b^3 \longrightarrow (3)$$

The force on the rotor disc,

$$F = (P_{us} - P_{ds}).A_b \longrightarrow (4)$$

$$\text{Also } F = m[V_{us} - V_{ds}] \longrightarrow (5)$$

momentum from upstream to downstream.

Applying Bernouli's Equation to upstream and downstream sides, we get,

$$P + \frac{1}{2}\rho V_{us}^2 = P_{us} + \frac{1}{2} V_b^2 \quad \text{and} \longrightarrow (6)$$

$$P_{ds} + \frac{1}{2}\rho V_b^2 = P + \frac{1}{2}\rho V_{ds}^2 \longrightarrow (7)$$

Solving the above two Equations, we obtain:

$$P_{us} - P_{ds} = \frac{1}{2}\rho\left[V_{us}^2 - V_{ds}^2\right] \longrightarrow (8)$$

Equating eq (4) and (5), we get

$$(P_{us} - P_{ds})A_b = m\left[V_{us} - V_{ds}\right]$$

$$(P_{us} - P_{ds})\cancel{A_b} = \rho \cancel{A_b} V_b\left[V_{us} - V_{ds}\right]$$

$$P_{us} - P_{ds} = \rho V_b\left[V_{us} - V_{ds}\right] \longrightarrow (9)$$

Solving eqs (8) and (9) we get,

$$\frac{1}{2}\cancel{\rho}\left[V_{us}^2 - V_{ds}^2\right] = \cancel{\rho} V_b\left[V_{us} - V_{ds}\right]$$

$$\frac{1}{2}\left[V_{us}^2 - V_{ds}^2\right] = V_b\left[V_{us} - V_{ds}\right]$$

$$\frac{1}{2} \cdot \frac{\left[V_{us}^2 - V_{ds}^2\right]}{\left[V_{us} - V_{ds}\right]} = V_b$$

$$\Rightarrow V_b = \frac{1}{2} \cdot \frac{(V_{us} - \cancel{V_{ds}})(V_{us} + V_{ds})}{(V_{us} - \cancel{V_{ds}})}$$

$$V_b = \frac{V_{us} + V_{ds}}{2} \longrightarrow (10)$$

In wind Turbine system, speed flow work W is the difference in KE between upstream & downstream of turbine for unit mass flow, $m = 1$.

$$W = KE_{us} - KE_{ds}$$

$$= \frac{1}{2} m V_{us}^2 - \frac{1}{2} m V_{ds}^2$$

$$= \frac{1}{2} V_{us}^2 - \frac{1}{2} V_{ds}^2 \quad (\text{since } m = 1)$$

$$W = \frac{1}{2} [V_{us}^2 - V_{ds}^2] \longrightarrow (11)$$

Power output P of wind turbine

$$P_o = \frac{1}{2} \dot{m} [V_{us}^2 - V_{ds}^2] \longrightarrow (12)$$

Here $\dot{m} = \rho A_b V_b = \rho A_b \left[\frac{V_{us} + V_{ds}}{2} \right]$

$$P_o = \frac{1}{2} \rho A_b \left[\frac{V_{us} + V_{ds}}{2} \right] [V_{us}^2 - V_{ds}^2]$$

$$P_o = \frac{1}{4} \rho A_b [V_{us} + V_{ds}] [V_{us}^2 - V_{ds}^2]. \longrightarrow (13)$$

To get maximum Turbine output P_{max}, the above eqn is differentiating w.r.to V_{us} and Equal to zero,

$$\frac{dP_o}{dV_{us}} = \frac{d}{dV_{us}} \left[\frac{1}{4} \rho A_b (V_{us} + V_{ds})(V_{us}^2 - V_{ds}^2) \right] = 0.$$

$$\Rightarrow 3 V_{ds}^2 + 2 V_{us} V_{ds} - V_{us}^2 = 0$$

The above quadratic Equation has the following two solutions,

$$V_{ds} = \frac{1}{3} V_{us} \quad \text{and} \quad V_{ds} = V_{us}.$$

for power generation $V_{ds} < V_{us}$, so we can have only

$$V_{ds} = \frac{1}{3} V_{us} \longrightarrow (14)$$

Substituting Eq (14) in Eq (13), we get

$$P_{max} = \frac{1}{4} \rho A_b \left[V_{us} + \frac{1}{3} V_{us} \right] \left[V_{us}^2 - \left(\frac{1}{3} V_{us}\right)^2 \right]$$

$$= \frac{1}{4} \rho A_b \left[\frac{4}{3} V_{us} \right] \left[\frac{8}{9} V_{us}^2 \right]$$

$$P_{max} = \frac{8}{27} \rho A_b \cdot V_{us}^3 \longrightarrow (15)$$

$$= \frac{16}{27} \left[\frac{1}{2} \rho A_b V_{us}^3 \right]$$

$$P_{max} = 0.593 \left[\frac{1}{2} \rho A_b V_{us}^3 \right]$$

Since, Total available power in the wind $P_{total} = \frac{1}{2} \rho A_b V_{us}^3$.

$$\Rightarrow \quad P_{max} = 0.593 \, P_{Total} \longrightarrow (16)$$

Now co-efficient of power $C_p = \frac{P_{max}}{P_{total}} = 0.593. \longrightarrow (17)$

The factor 0.593 is known as Betz limit.

Thus C_p cannot exceed 0.593 for a horizontal axis wind machine.

(3) Forces on the Blades and Thrust on Turbines :-

The axial force or thrust

$$F_x = \frac{\pi}{8} \rho D^2 (V_{us}^2 - V_{ds}^2)$$

for maximum output, $V_{ds} = \frac{1}{3} V_{us}$ in above eq.

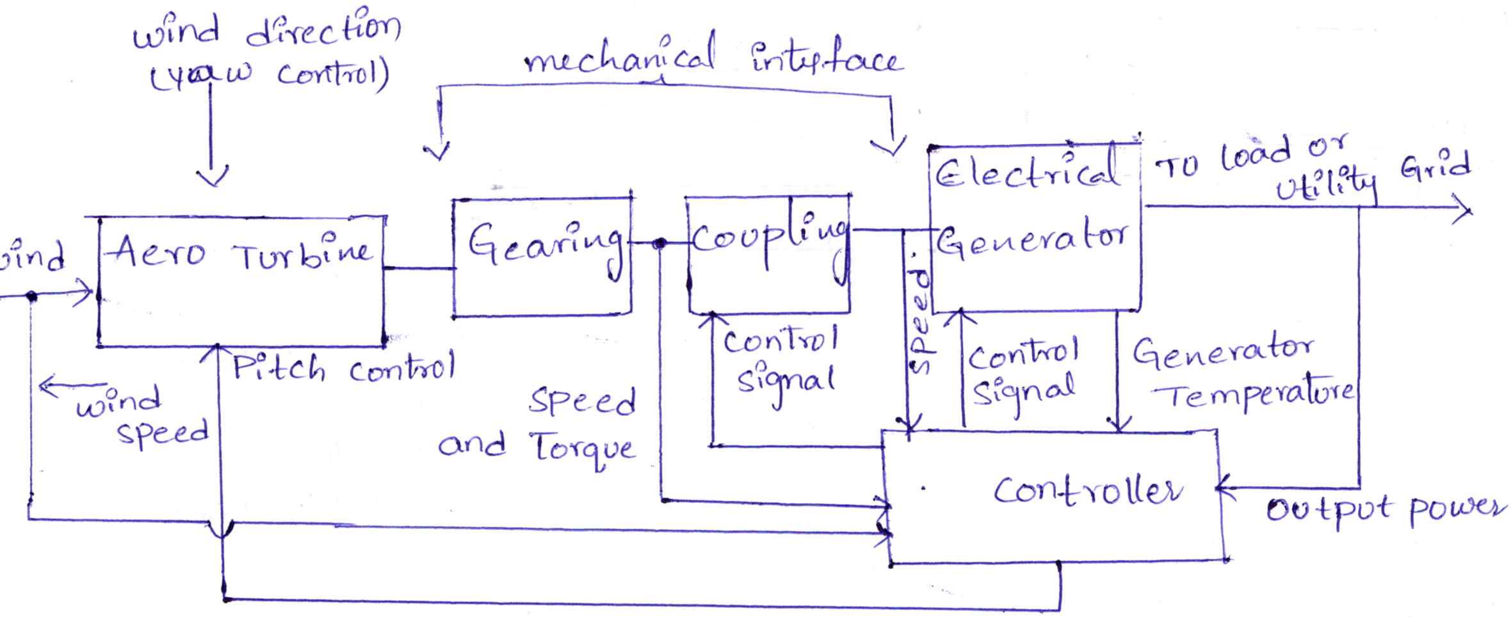
$$\therefore \quad F_{x,max} = \frac{\pi}{9} \rho D^2 V_{us}^2$$

→ Basic Components of Wind Energy conversion system (WECS) and Components of wind mill :-

~~Fig shows the~~

↳ Components of WECS :-

Fig(1) shows the block diagram of basic components of wind Energy Conversion system.



Fig(1) : ~~Compon~~ block diagram of basic components of WECS.

1) Wind Turbines (Aero Turbines): convert the Energy of moving air into rotary mechanical Energy.

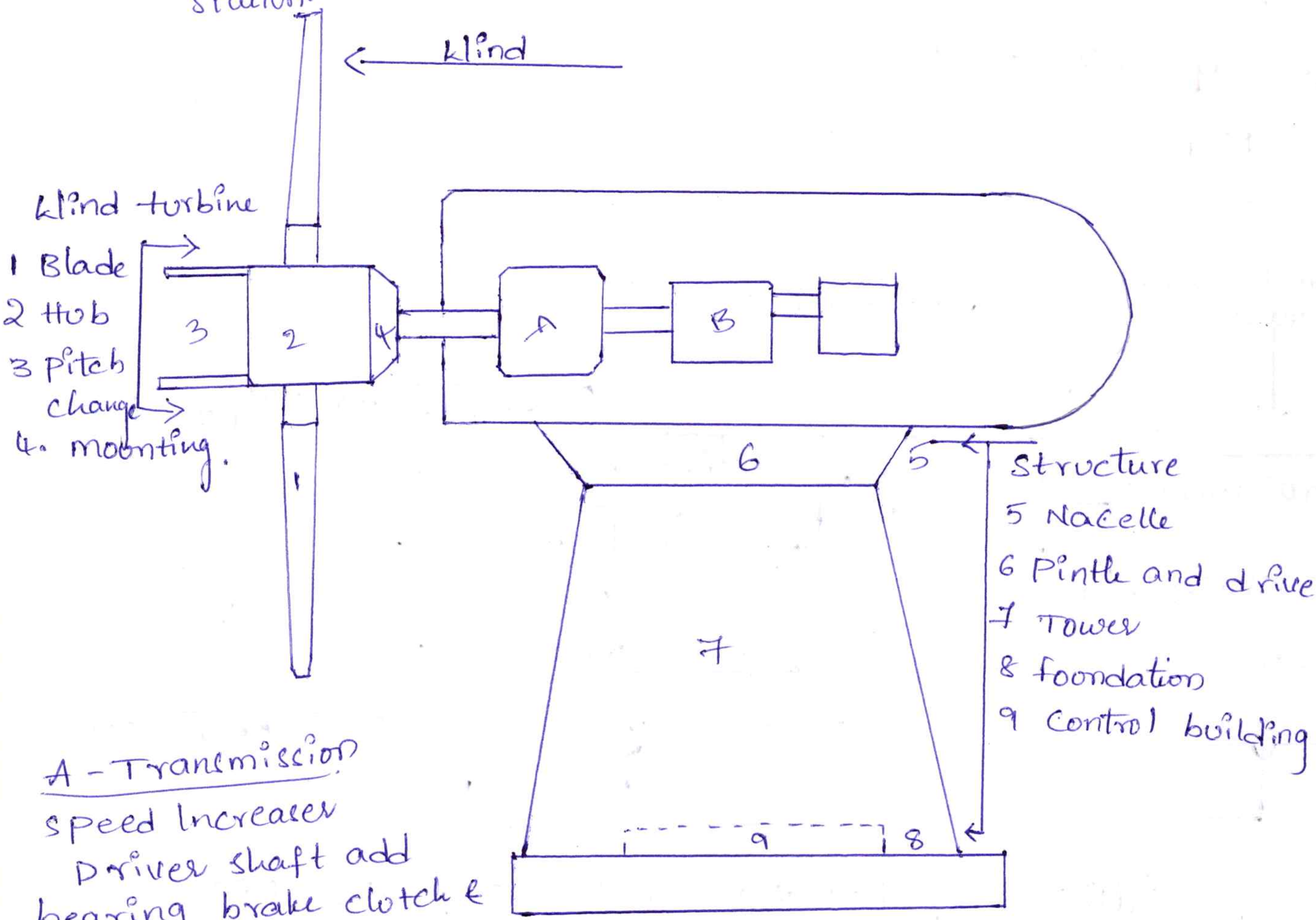
2) Mechanical Interface : consisting of a stepup gear and a suitable coupling that transmits the rotary mechanical energy to an electrical generator.

3) Controller : serves purposes of sensing i) the wind speed and ii) wind direction. (iii) output power and generator temperature (iv) appropriate control signals for matching the Electrical output to the wind energy input. (v) protect the system from ~~wind~~ Extreme Conditions.

4) Yaw control : It is the control for orienting the axis of wind Turbine in the direction of wind.

↳ Components of wind mill :-

fig (2) shows the physical embodiment of wind electric generating station.



A - Transmission
speed Increaser
Driver shaft add bearing brake clutch & coupling.

B - Electrical
Generator ⇒ control & indicators (at ground level)

The sub components of wind mill are :

1) Wind Turbine (or) rotor
2) Wind mill head
3) Transmission and control
4) Supporting structure.

Rotors : It is the primary part of wind turbine that Extracts Energy from wind. It constitutes the blade and hub assembly.

Rotors are mainly of two types :

(i) Horizontal axis rotor (ii) Vertical axis rotor.

Blades: ~~Most Turbine~~ An important part of wind turbine that extracts wind energy. Most turbines have Either Two or three blades.

Hub: Blades are fixed to the hubs which is a central solid part of the Turbine.

Pitch change or Pitch control: It is the control of pitch angle by turning the blades or blade tips.

pitch angle: It is angle between direction of wind and the direction perpendicular to the planes of blades.

mounting: The Orientation of rotor blades is facilitated by mounting it on the top of supporting structure on suitable bearings.

Nacelle: It is an assemblage comprising of the wind turbine, gears, generator, bearings, control gear etc, mounted in housing.

Brake: A disc brake which can be applied mechanically, Electrically. or hydraulically to stop the rotor in Emergencies.

Controllers: The controller starts up the machine at windspeeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph.

Gear box: Gear connect the low speed shaft to the high speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm.

Generator: Generator which converts mechanical Energy into Electrical energy. It produces alternating Current (AC).

Tower : Towers are made from the Tubular steel, concrete, or steel lattice. Because wind speed increases with height, so taller towers enable Turbines to capture more energy.

The minimum tower height for a small WECS is about 10 m and the maximum height is estimated about 60 m.

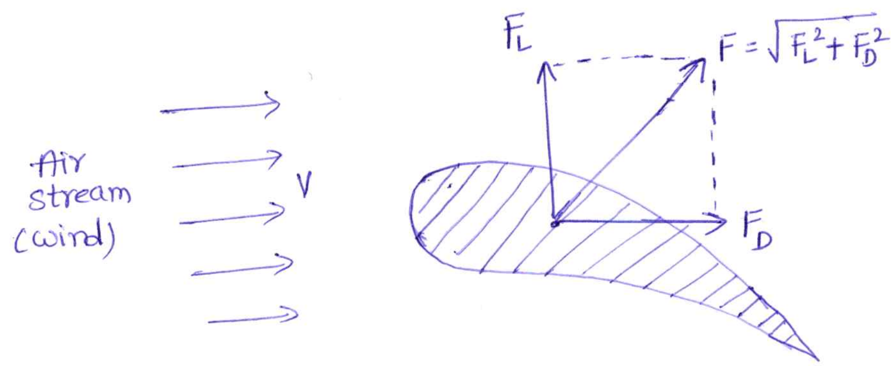
Wind ~~direction~~ Vane : Measures wind direction & communicates with yaw drive to orient the turbine properly with respect to wind.

yaw drive : Upwind turbines face into the wind, the yaw drive is used to keep the rotor facing into the wind ~~as~~ the wind direction changes.

Down wind turbines donot require yaw drive, the wind blows the rotor downwind.

yaw control : It is the control for orienting the axis of wind turbine in the direction of wind.

→ Lift and Drag - The basis for wind Energy conversion :-



F_L = Lift force, F_D = Drag force, F = Resultant force.

Fig : Lift and Drag force on an airfoil

→ The Extraction of power from wind depends on creating certain forces and applying them to rotate a mechanism.

Lift force (F_L) : The component of force right angles to the direction of airstream on the airfoil is called Lift force F_L.

Drag force (F_D) : The component of force in the direction of air stream is called drag force.

→ Various Types of windmill/machines :-

A) Based on the orientation of axis of rotor :

1) Horizontal axis machines
2) Vertical axis machines

B) Based on rotor :

1) Propeller type (Horizontal axis)
2) Multiblade type (Horizontal axis)
3) Savonius type (Vertical axis)
4) Darrieus type (Vertical axis).

C) According to size :

1) Small scale (up to 2 KW)
2) Medium size machines (2 - 100 KW)
3) Large size machines (100 KW and above)

D) Based on rotational speed of aeroturbines ;

1) Constant speed with variable pitch blades
2) Nearly constant speed with fixed pitch blades.
3) Variable speed with fixed pitch blades.

→ Constructional features of wind mills / wind machines :-

Horizontal axis wind machines :

1) Horizontal axis wind machine with Two blades :

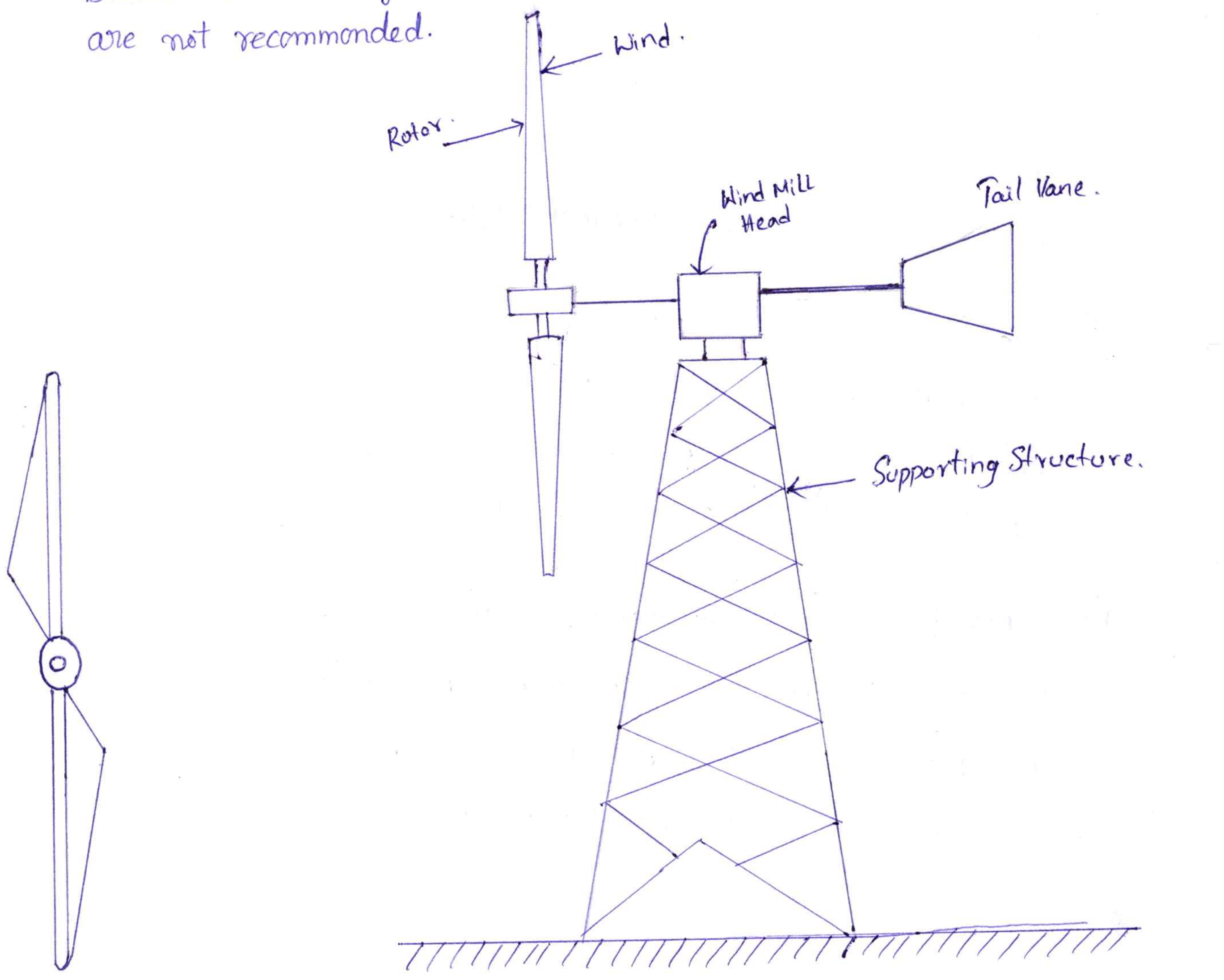
~~Fig (1)~~ Shows the ~~common~~ wind ~~Turbine~~ with

Fig (1) shows the schematic arrangement of a Horizontal axis wind machine.

→ In this design, rotor drives a generator through a step up gear box. The blade rotor is designed to be oriented downwind of the Tower.

→ The components are mounted on a bedplate which is attached on a pintle at the top of tower.

→ Because of the high cost of blade rotors with more than two blades are not recommended.



(a) TWO BLADE PROFILE

(b) Schematic of a Horizontal Axis Type Wind Mills

Fig (1) : HAWT with two blades.

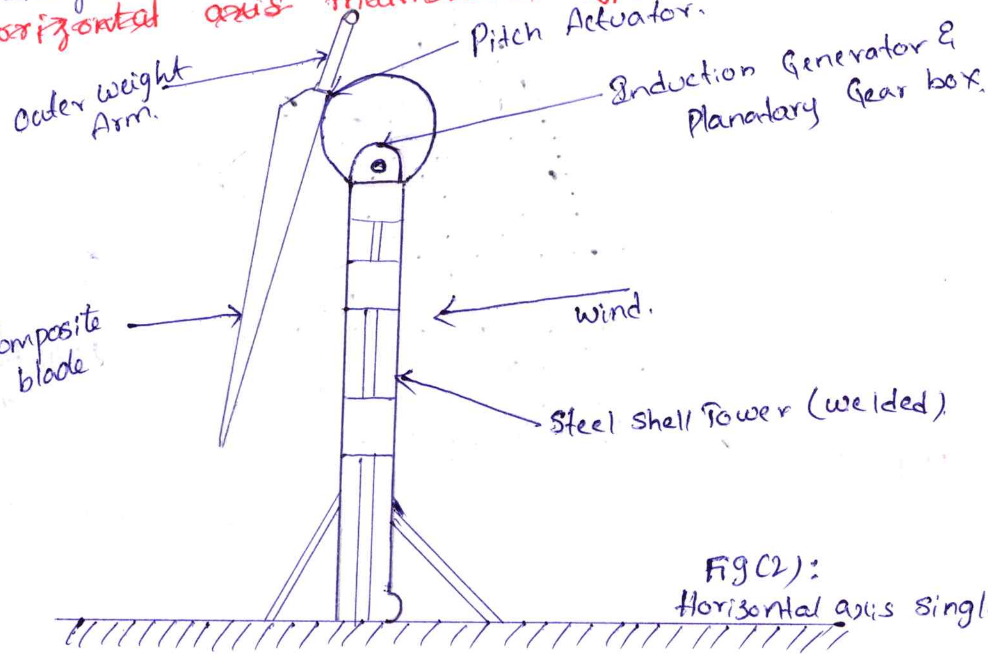
2) Horizontal axis propeller type using single blade :

→ In this arrangement, a long blade is mounted on a rigid hub.

→ To reduce rotor cost, use of low cost counter weight is recommended which balance long blade centrifugally.

→ Advantage of one bladed rotor are simple blade controls, low cost.

~~3) Horizontal axis multibladed type~~

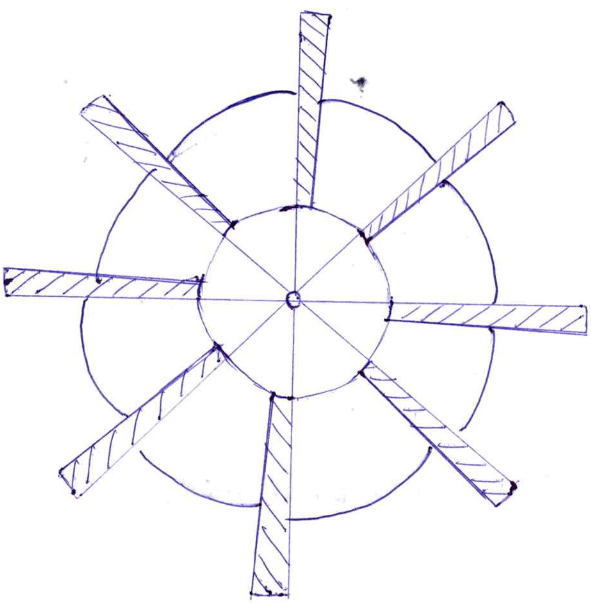


Fig(2): Horizontal axis single blade wind mill.

3) Horizontal axis Multibladed Type :

This type of design for multiblades made from sheet metal or aluminium. The rotors have high strength to weight ratios.

→ They have good power coefficient, good starting torque & low cost.



fig(3) Multiblade Propeller.

4) Horizontal axis wind mill Dutch type :

It is the oldest design. The blade surfaces are made from an array of wooden slats which feather at high wind speeds.

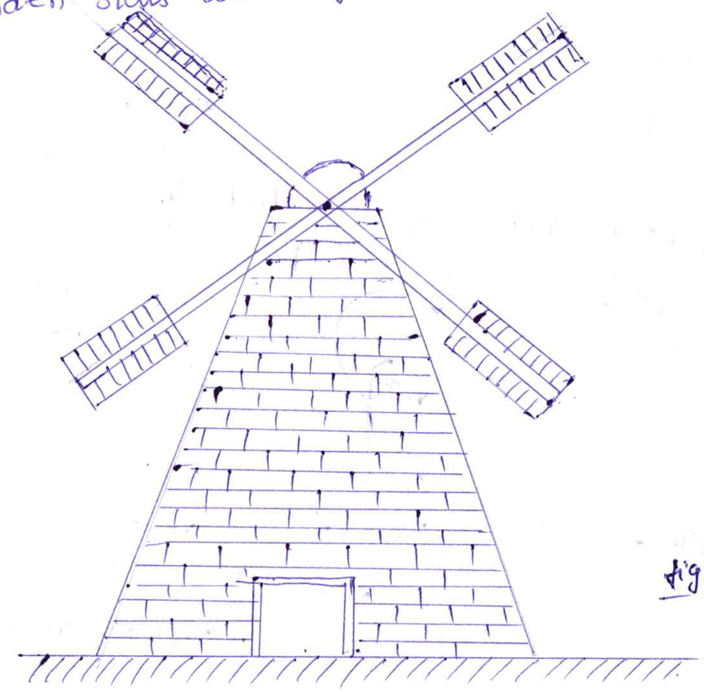


fig 4: Horizontal Axis, Dutch type Windm

5) Sail Type :

It is of recent origin. The blades surface is made from cloth, nylon or plastics arranged as mast and pole or sail wings.

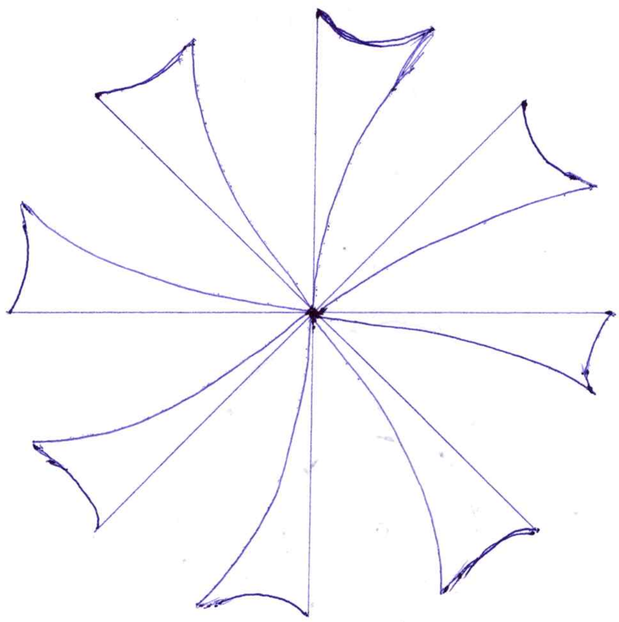


Fig 5: Blads of Sail Type wind mill.

→ Advantages of Horizontal axis wind machine (or) Turbine (HAWT) :-

1) The output power is high as compared to the Vertical axis wind Turbine.
2) The efficiency of HAWT is high
3) It is more consistent and its rotational speed is high
4) one variation in the wind shear, the tall tower captures wind power.
5) Reliable is high.
6) The blades of the Turbine can be bent using a gearbox to get best wind attack angle, which results in better performance under stormy conditions.
7) The rotor can be tilted by the blades during storms.

→ Dis advantages of Horizontal axis wind machines or Turbines (HAWT) :-

1) HAWT's are available only in large sizes.
2) Due to Heavy weight, transportation from one place to another is difficult.
3) The mounting of heavy generator and gearbox at top of tower requires a stronger structure, which increases the complexity & cost of structure.
4) Installation and maintenance of HAWT is difficult process.
5) Noise is High compared to other turbines.
6) To design & manufacture a HAWT, heavy machinery is required.

Design considerations of Horizontal Axis machines :-

Some of the main design considerationes are as follows :

1) Rotor : A wind turbine's rotor may have any no.of blades which may be made from wood, metal or composite materials.

→ Horizontal axis rotors can be either lift or drag devices.

→ Every rotor has an optimum tip-speed ratio, to achieve maximum efficiency and also characterizes the rotor.

$$\text{Tip Speed Ratio, TSR} = \frac{V_{tip}}{V}$$

where V_{tip} = Speed of rotor tip, V = free wind speed.

→ If TSR increases, the number of blades decreases.

Table : Tip speed ratio Versus Number of blades

Tip speed ratio	No. of blades
1	6 – 20
2	4 – 12
3	3 – 8
4	3 – 5
5–8	2 – 4
8–15	1 – 2.

2) Number of blades: wind turbines have been built with upto six propellers type blades but two and three propellers are most common. A one-bladed rotor has some advantages including lower weight and cost and simple control over multi blade type.

3) Blade design : wind turbine blades have an airfoil type cross section and a vairable pitch. They are slightly twisted from the outer tip to the root to reduce the tendency for the rotor to stall.

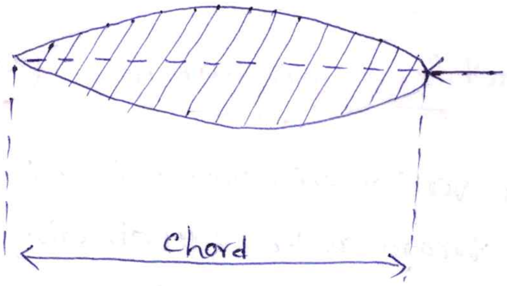


Fig (1) : Cross section of airfoil - type wind rotor blade

4) yaw Control : It is the control for orienting the axis of wind turbine in the direction of wind.

→ When wind direction changes, a motor rotates the turbine slowly about the vertical axis (or yaw) axis so as to face the blades into the wind.

→ In smaller turbines, yaw action is controlled by a tail vane and in larger machines, a servomechanism operated by a wind-direction sensor controls the yaw motor that keeps the turbine properly oriented.

5) wind stream variations : wind speed variability must be considered especially in the design of larger wind Energy conversion (WEC) machines.

(i) cut-in speed ; It is the minimum wind speed, at which wind turbine ~~allowed~~ starts delivering shaft power.

(ii) Rated speed : It is the velocity at which the wind-Turbine generator delivers rated power.

(iii) Cut-out speed (furling wind velocity) : It is the speed at which power conversion is cut out.

6) Turbine Tower System : The horizontal axis wind turbines are mounted on towers and there are wind forces on the tower.

→ Both upwind & downwind locations have been used so that tower design is an essential aspect of overall system design.

→ Vertical axis wind machines (or) Turbines (VAWT) :-

→ One of main advantages of vertical axis rotors is that they do not have to be turned into windstream as the wind direction changes, because their operation is independent of wind direction.

These vertical axis machines are called penemones.

Types of vertical axis wind machines are :

1) Darrieus rotor
2) Savonius rotor.

1) Darrieus rotor - VAWT :-

→ ~~It~~ This type of machine was invented by GJM Darrieus, a French engineer.

→ It has two or three thin curved (egg beater) blades with airfoil cross section and constant chord length.

→ Both ends of blades are attached to a vertical shaft.

→ Darrieus type rotors are lift devices, characterized by curved blades with airfoil cross sections.

→ Darrieus rotor configurations are ϕ- Darrieus, Δ- Darrieus, Y - Darrieus and $\Box$- Darrieus. Such darrieus rotors can be designed to operate with one ~~or~~, two, three or more blades.

Advantages of Darrieus rotor W.T. :-

1) The major advantage of this design is that rotor blades can accept the wind from any direction.

2) The generator, gear box etc are placed on the ground eliminating tower structure and lifting of huge weight machines

3) No need of yaw mechanism to turn the motor against the wind.

4) Air foil fabrication costs are expected to be reduced

5) The absence of pitch control requirements may yield additional cost savings.

Disadvantages of Darrieus rotor W.T :-

1) Although a Darrieus machine has many directional symmetry for wind energy capture, it requires mechanical aid for startup.

2) Rotor output efficiency is some what lower than Horizontal rotor.

3) Darrieus rotor is placed near ground, it may also experience lower velocity wind, which yields less Energy output.

4) Greater Vibratory stresses are encountered, that will affect rotor system life.

5) Special high torque braking system needs to be incorporated.

Characteristics of Darrieus rotor:

i) Not self starting

(ii) High speed

(iii) High efficiency

(iv) potentially low capital cost.

Working:

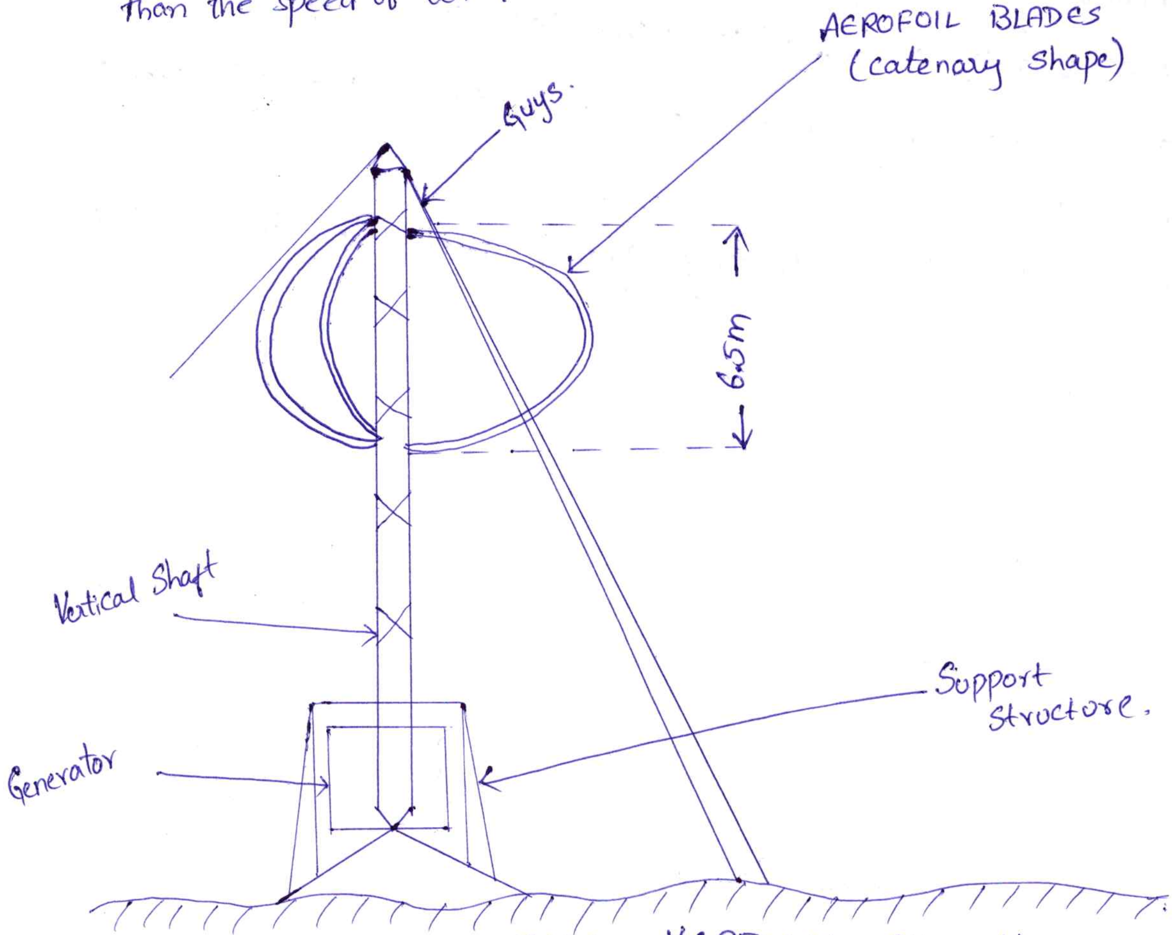
→ The Darrieus rotor principle is based on the principle by which a Bermuda-rigged sailing ship can sail across the wind at speeds greater than that of wind.

→ These type of wind turbines use the aerodynamic force of the lift to revolve.

→ By flowing around the construction, the wind will create a suction on the front face of wind turbine, to drive the wings to revolve.

→ These turbines do not experience as much as drag due to shape of wings.

→ once the revolution begins, these turbines will go faster to rotate faster than the speed of wind.



Fig(1): VERTICAL AXIS WIND MILL.

2) Savonius Rotor - VAWT :-

→ The simplest of the modern types of wind energy conversion system is the Savonius rotor which works like cup anemometer.

→ This type was invented by S.J. Savonius in 1920.

→ This machine has become popular since it requires relatively low velocity winds for operation.

→ It consists of two half cylinders facing opposite directions in such a way as to have almost an S-shaped cross section.

→ The halves are mounted on vertical shaft with a gap in between.

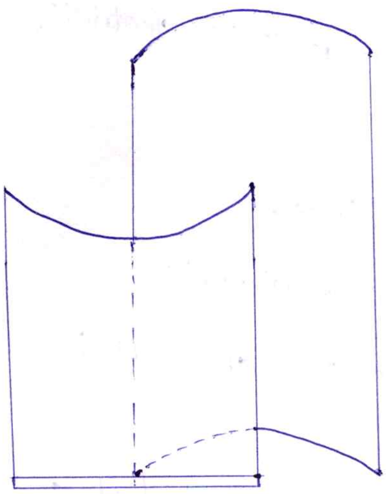
→ Torque is produced by pressure difference between the two sides of half facing the wind.

Characteristics of Savonius Rotor:

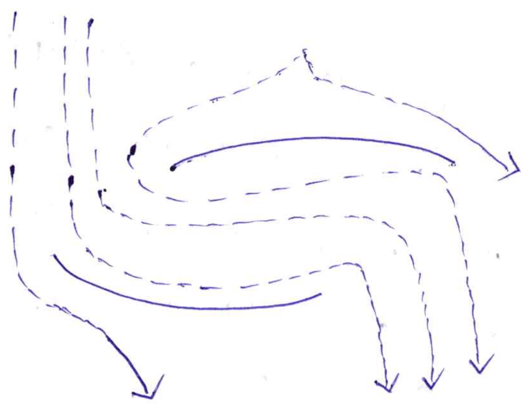
(i) Self starting

(ii) Low speed

(iii) Low efficiency



(a)



(b)

Fig(2): The Savonius rotor & its stream flow.

↳ Advantages of Savonius Rotor-VAWT :-

1) Low cost
2) operation at low wind Velocity
3) No need of yaw and pitch control
4) Generator can be mounted at the ground level.
5) Simple structure
6) overall weight of the Turbine less than that of Conventional system.

↳ Disadvantages of Savonius Rotor :

1) This type of machine is too solid, having so much metal or other material surface.
2) It is not useful for a very tall installation.

→ Advantages of Vertical axis wind machines or Turbines (VAWT) :-

1) Quieter and less Vibration than horizontal axis wind Turbines.
2) Does not need yaw control because it can produce electricity regardless of direction the wind is blowing.
3) Produces Electrical Energy at very low winds.
4) operation of VAWT is independent of wind direction
5) slower blade speeds because the blades are closer to the axis of rotation.
6) Can be installed in urban Environments and residential & Commercial areas because they operate at low noise levels.
7) The generator is placed near to ground, so a crane is not needed for servicing.
8) Vertical axis towers are much shorter than horizontal axis.

→ Disadvantages of Vertical axis wind machines or Turbines (VAWT) :-

1) Requires power and a starting motor to start Darrieus wind Turbine

2) Need guy wires to ensure the pole stays vertical, so blade rotation is smooth.

3) Not as efficient as horizontal axis wind turbines.

4) Since wind turbines are lower to ground, they do not harness the higher wind speeds.

→ Comparison between Horizontal axis and vertical axis wind machines:

S.NO	Aspects	H-AWT	VAWT
1.	Power captured	More	Less
2.	Noise problem	Less	more
3.	Complexity of design	More	Less
4.	space required	More	Less
5.	cost (per KWh)	More	less
6.	Efficiency	High	low
7.	yaw mechanism	yes	No
8.	operating mechanism	complex	Simple
9.	self starting	yes	NO
10.	Generator position	on Top of tower	on ground
11.	Tower inference	Large	small.
12.	Effect of birds	high	Low.

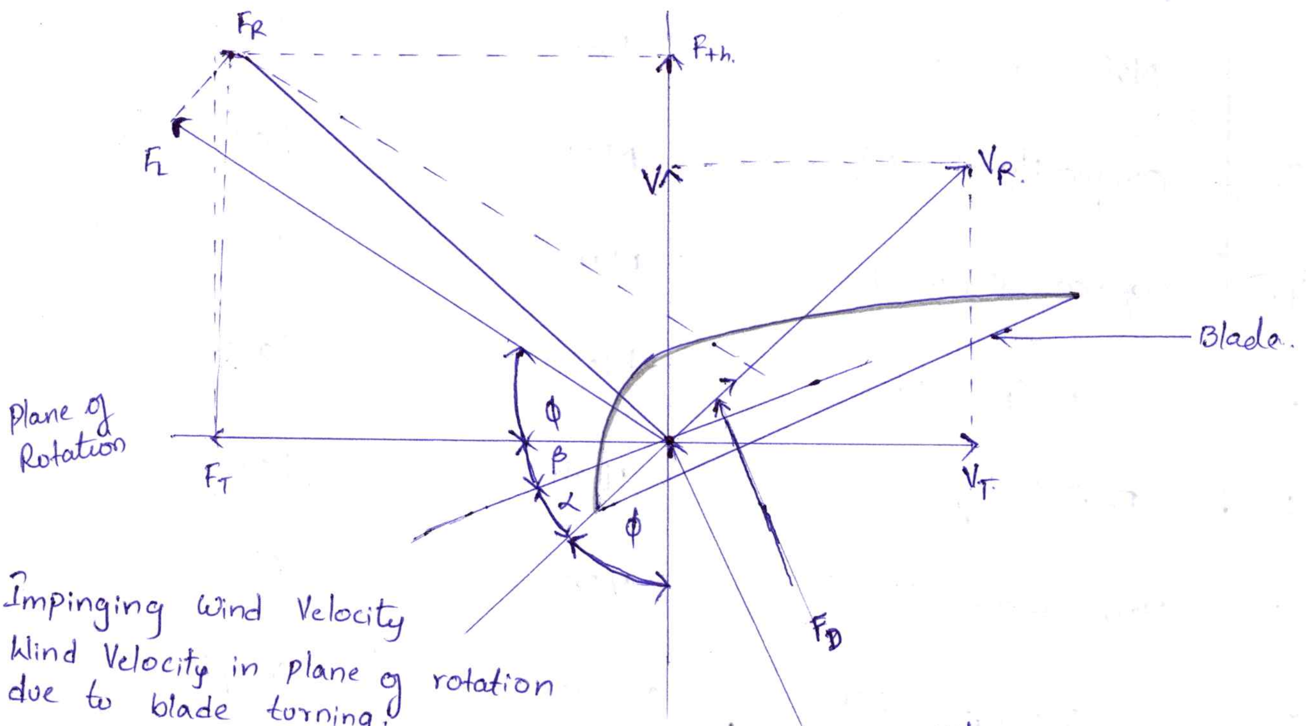
→ Analysis of Aerodynamics forces acting on the Blade :-

→ Aerodynamic forces acting on a blade element tending to make it rotate are important parameters for a system design.

→ This aerodynamic forces illustrate the basic principle of aeroturbine rotation.

→ Consider the aerodynamic blade as shown in Fig (1). below. The blade can be thought of as a typical cross sectional element of a two bladed aeroturbine.

Fig(1): Vector diagram of forces on a elemental blade section of aeroturbine.



V = Impinging wind Velocity
V_T = Wind Velocity in plane of rotation due to blade turning.
V_R = Resultant wind Velocity seen by Aeroturbine blade.
F_L = Lift force (Normal to V_R)
F_D = Drag force (Parallel to V_R)
F_R = Resultant force on blade.
F_T = Torque producing component of F_R making aeroturbine rotate.
F_{th} = Thrust force component of F_R.
α = Angle of attack of blade. β = Blade Pitch angle.

→ The element shown is at some radius r from the axis of rotation.

→ It is moving to the left. Because the blade is moving in the plane of rotation it sees a tangential wind velocity V_T, in the plane of rotation.

→ This V_T is added vertically to the Impinging wind velocity V, gives the resulting wind velocity V_R, seen by the blade element.

→ At right angles to the V_R, Lift force F_L is caused by the aerodynamic shape of the blade.

→ The drag force F_D is parallel to V_R.

→ The vector sum of F_L and F_D is F_R which has a torque producing component F_T and a thrust producing component F_{th}.

→ F_T drives the aeroturbine rotationally and F_{th} flex the blade and overturn the aerogenerator.

→ According to aircraft wing theory, one of the critical parameter is α, the angle of attack of blade.

→ α determines lift & drag forces and hence speed & torque output of aeroturbine.

→ These quantities can be varied by changing the blade pitch angle β, and this is the basic torque control method.

→ Since V_T increases linearly as we go out radically r, it is necessary to adjust β with r so as to have a positive α.

→ This means at larger r, β is made small, while at small r, β is large.

→ Thus the blade bites ~~the~~ air more in close ~~near~~ than near the tips.

→ These considerations result in aeroturbine blade with an apparent twist in it.

→ Wind Data and Energy Estimation :-

↳ Wind Data :

→ The Seasonal as well as instantaneous changes in winds both in magnitude and direction need to be well understood to make the best use of them in wind mill designs.

→ There are various ways the data on wind behaviour is collected depending on the use.

→ The hourly mean wind velocity as collected by meteorological observation is the basic data used in wind mill design.

→ The hourly mean is the one averaged over particular hour of the day, over the day, month, year and years.

→ ~~winds being~~ The factors which affect the nature of wind close to the surface of Earth, they are

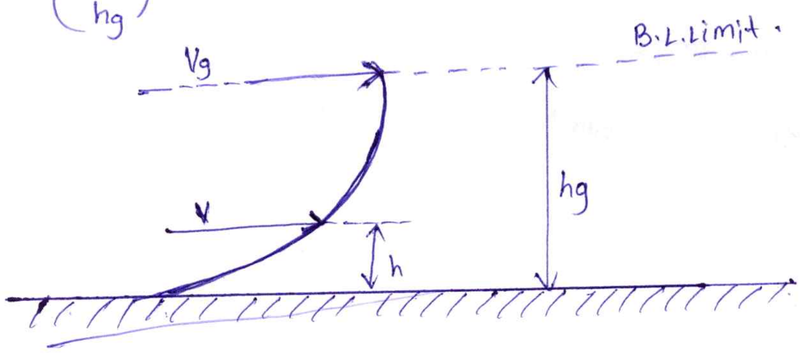
1) latitude of place
2) altitude of place
3) Topography of place
4) Scale of hours, months or year.

→ winds being an unsteady phenomenon, the scale of periods is considered as an important set of data required in the design.

→ The data based on scale of hour is useful for mechanical aspects of design.

→ The wind velocity at given height can be represented interms of gradient height & velocity.

$$\frac{V}{V_g} = \left(\frac{h}{h_g}\right)^n$$



Fig(1): Representation of gradient height & Velocity.

→ The replot of this on V^3 basis is called power duration curve.

→ These curves are useful for establishing wind energy potential of a place & the design wind speed.

Frequency duration curve is useful in deciding the design wind speed for a given site, and the data is also useful in Estimating the actual energy output of the plant.

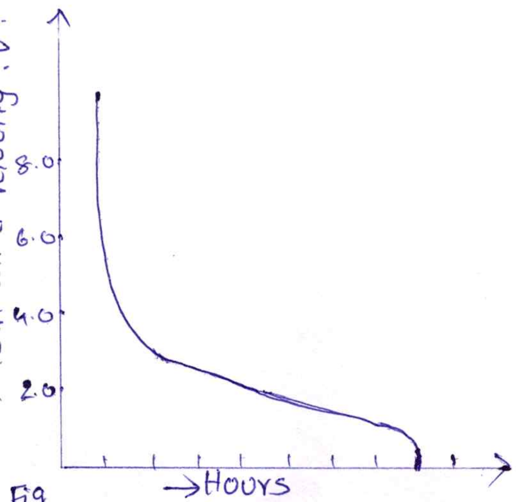


Fig (2) Velocity duration Curve

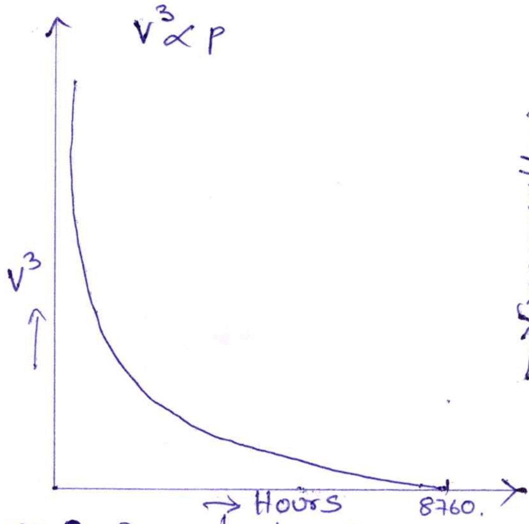
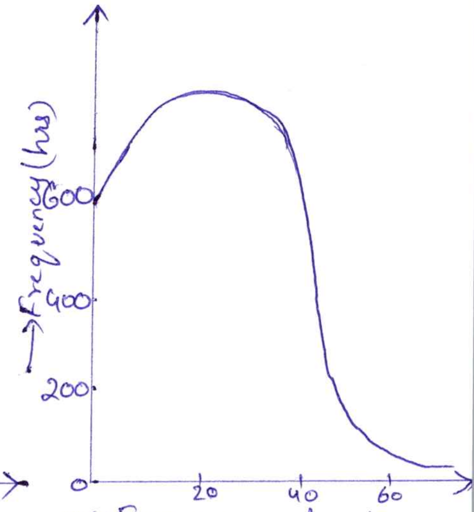


Fig. (3) Power duration Curve



Fig(4) Frequency - duration curve.

~~Fig~~:

The Three speeds associated with the design of windmill are :

V_c - cut in speed, the speed below which wind mill does not operate.

V_d - design speed, the speed for which rotor is designed

V_f - furling speed the speed at which rotor is turned away.

→ The three speeds are marked on fig (5). The hatched area a, b, c, d, e represents the annual Energy output ~~available~~ from an ideal plant

→ ABCD represents output obtainable from ideal plant.

→ The ratio of $\frac{abcde}{ABCD}$ is the annual load factor of plant

→ The values of V_g, h_g & n depends on the nature of Terrain.

→ Surface wind data on a national or regional basis is usually presented in the form of

(1) Isovents or contours of constant average wind velocity (m/sec or km/hr).

(2) Isodynes or contours of constant wind power (walt/m²)

↳ Wind Measurements (or) wind Surveys :-

Typical wind measurements at potential sites for wind machines usually require the following :

(1) Instrumentation : 3 cup anenometer & wind direction sensors
Height of instruments.

(2) Data recording systems :
- strip chart
- magnetic tap

(3) Type of data : wind speed and directional hourly averages

(4) Data reporting : wind frequency curves
Daily, weekly, monthly.

↳ Energy Estimation :

The basic wind data of hourly mean wind velocity is recost into no. of hours in the year for which speed equals or exceeds each particular value.

→ The first of these plotted amongst the hours in the year is called velocity-duration curve.

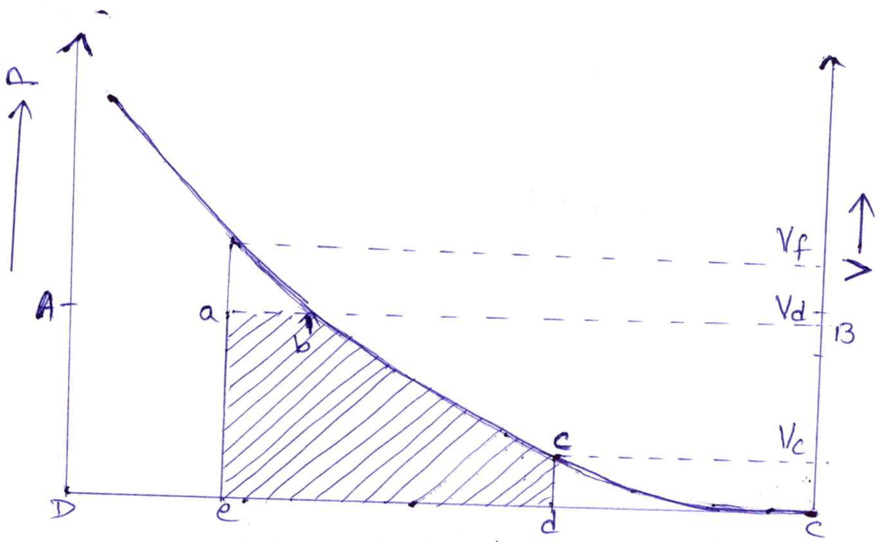


fig (5) Ideal Plant output.

→ In practice the actual output will be smaller than that represented by abcde, due to the inability of rotor to convert ~~the~~ kinetic energy available in the wind. This is represent by C_p, which varies as a function of velocity V. This is shown in fig (5).

Taking this in to consideration,

The annual output from a plant is given by,

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

where δ_T = Time increment

since the data is available in the form of no. of hours for which each mean wind velocity is available,

The expression is written as

$$E = \sum_{c}^{f} \eta_m C_p \rho A V_{c-f}^3 \delta_T$$

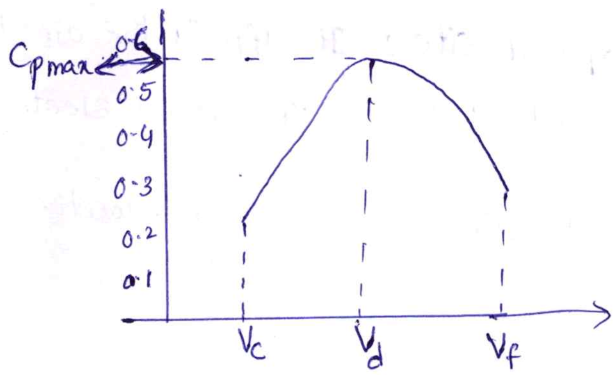


Fig: Variation of C_p as a function of V.

→ Site Selection consideration :-

Following factors should be given due considerations while selecting the site for WECS :

1) High annual average wind speed: A fundamental requirement of to successful use of WECS is adequate supply of wind.

The power in wind, $P_w = K V^3$.

where K = Constant
V = Velocity of wind.

Thus a high average wind velocity is principal fundamental parameter in WECS site.

2) Availability of anemometry data: The major aim is to measure the wind speed which determines the WECS output power. The anemometer data should be available over some time period at The precise spot where any WECS is to be built.

3) Availability of wind $V_{(t)}$ curve at the proposed site: This curve determines the maximum energy in the wind and hence is the major controlling factor in predicting the electrical output & hence revenue return of WECS machine.

4) wind structure at the proposed site: The Ideal case for WECS should be a site such that $V_{(t)}$ curves was Flat i.e, smooth steady wind that blows at all time, but a typical site is always less than ideal.

5) Altitude of the proposed site: It affects the air density and thus power in the wind & hence the useful electrical power output.
It is well Known that winds have higher velocities at higher altitude.

(6) Terrain and its aerodynamic : If the WECS is placed near the top, then it may be possible to obtain a 'speedup' of the wind velocity

→ It may be possible to make use of hills or mountains, to obtain higher wind power.

(7) Local Ecology : If the surface is bare rock it may mean lower hub heights hence lower structure cost.

→ If trees or grass or vegetation are present, the hub higher, resulting in larger system costs.

(8) Distance to Roads or Railways : This is another factor the system engineer must consider for heavy ~~structure~~ machinery, structures, materials, blades etc to moved into any chosen WECS site.

(9) Nearness of site to local centre/users : This criterion minimizes the transmission line length & hence losses & costs.

(10) Nature of ground : Ground surface should be stable. Erosion problem should not be there.

(11) Favourable land cost : Land cost should be favourable as this along with other siting costs, enters into Total WECS cost.

(12) other conditions such as icing problem, salt spray or blowing dust : All these conditions should not present at the site, as they may affect aeroturbine blades or environmental is generally adverse to machinery & electrical apparatus.

→ Applications of wind Energy :-

1) Generating Electricity
2) Pumping water
3) Milling grain
4) Reducing carbon footprint
5) sailing
6) wind surfing etc.