Wind energy

Winds are caused because of two factors.

(1) The absorption of solar energy on the earth’s surface and in the atmosphere.

(2) The rotation of the earth about its axis and its motion around the sun.

Because of these factors, alternate heating and cooling cycles occur, differences in pressure are obtained, and the air is caused to move. The potential of Wind energy as a source of power is large. This can be judged from the fact that energy available in the wind over the earth’s surface is estimated to be $1.6x10_7$ K.W Besides the energy available is free and clean.

The problems associated with Utilizing wind energy are that:

(i) The energy is available in dilute form, because of this conversion machines have to be necessarily large.

(ii) The availability of the energy varies considerably over a day and with the seasons.

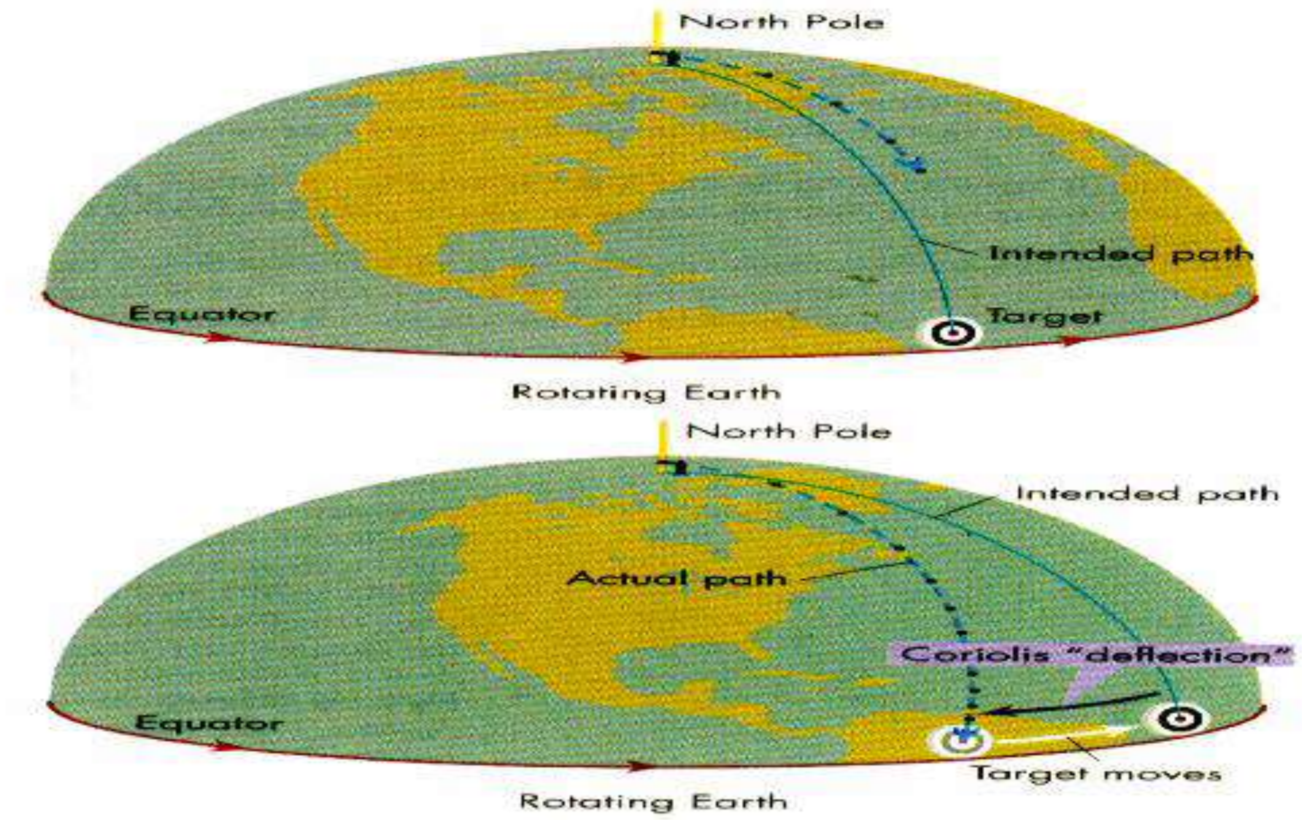
For this reason some Means of storage have to be devised if a continuous supply of power is required.

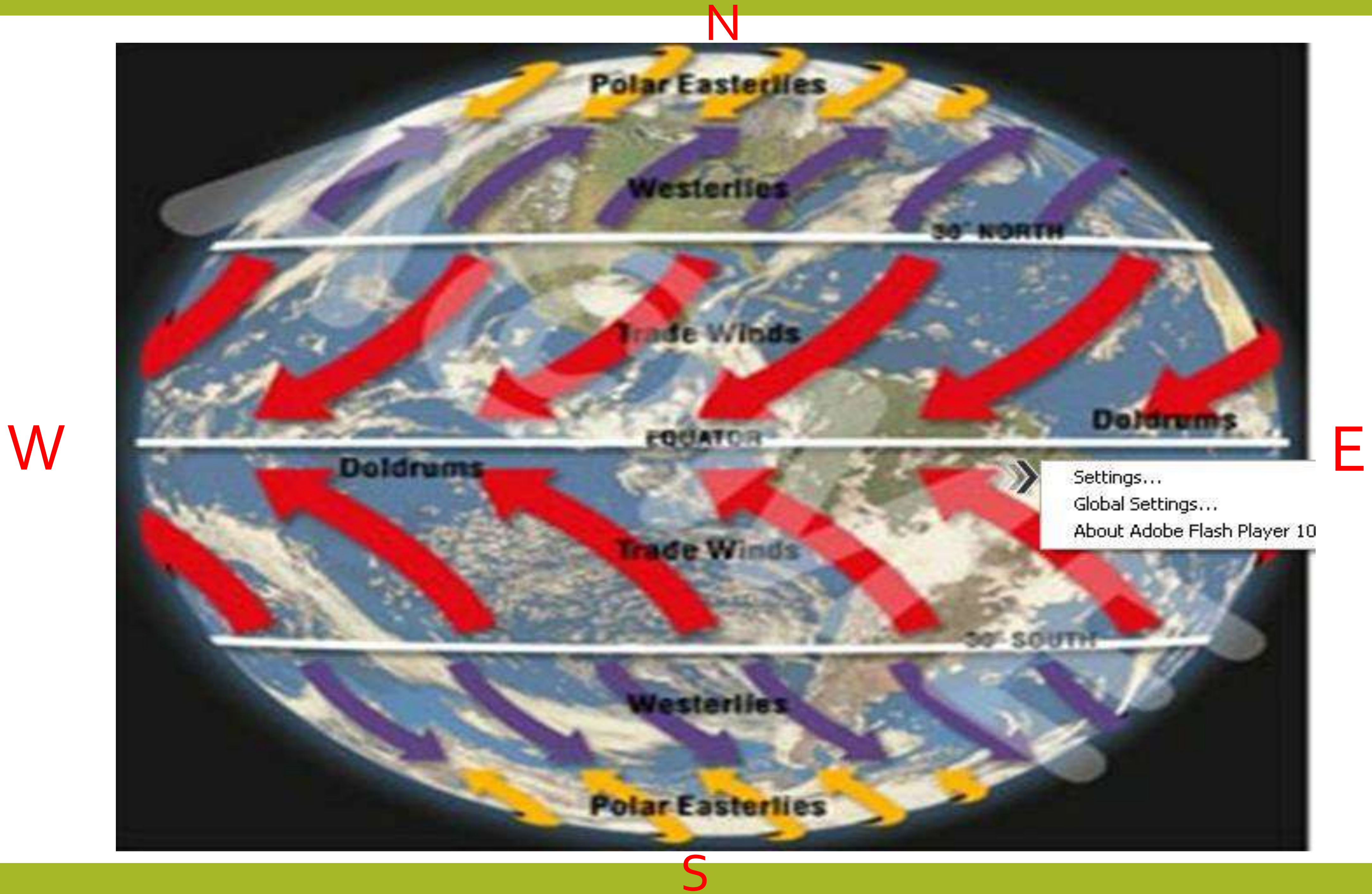
Wind is slowed by the surface roughness and obstacles. When dealing with wind energy, we are concerned with surface winds. A wind turbine obtains its power input by converting the force of the wind into a torque (turning force) acting on the rotor blades. The amount of energy which the wind transfers to the rotor depends on the density of the air, the rotor area, and the wind speed. The kinetic energy of a moving body is proportional to its mass (or weight). The kinetic energy in the wind thus depends on the density of the air, i.e. its mass per unit of volume. In other words, the "heavier" the air, the more energy is received by the turbine at 15° Celsius air weighs about 1.225 kg per cubic meter, but the density decreases slightly with increasing humidity.

Types of winds:

(1) Planetory winds:

- Differential solar heating of locations at the equator and poles
- Coriolis force due to earth's rotation

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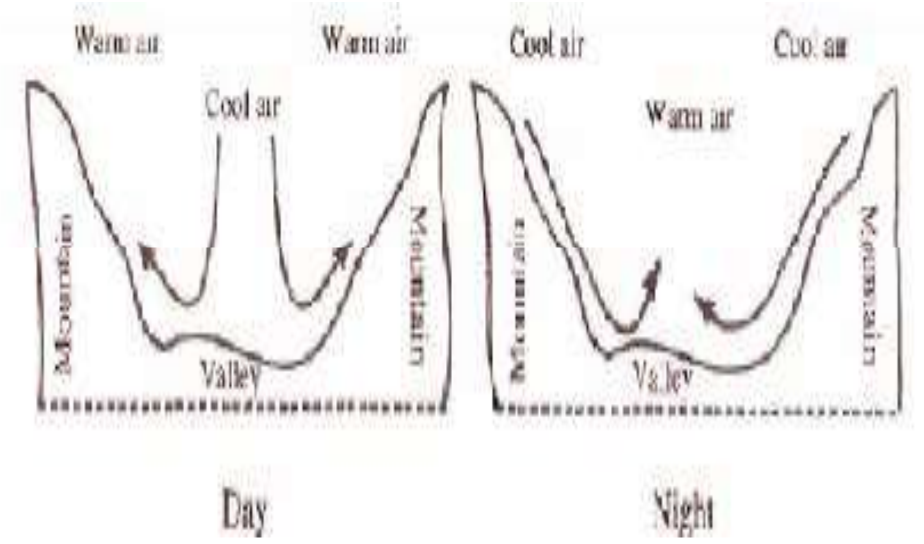
(2) Local winds:

- differential heating of the land mass and nearby sea surface water creates local winds
- During day land heats up faster rapidly compared with nearby sea water. Hence there tends to be surface wind flow from the water to the land
- During night wind reverses because land surface cools faster than the water
- Second mechanism of local winds is caused by hills and mountain sides. The air above the slopes heats up during the day and cools down at night, more rapidly than the air above the low lands. This causes heated air in the day to raise along the slopes and relatively heavy air to flow down at night.



Wind turbine:

A wind turbine is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a wind generator or wind charger. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump.

Types of Wind turbines:

Classification of wind mills

Wind mills

- (a) Horizontal Windmills
  - Single Bladed
  - Double bladed
  - Multi bladed
- (b) Vertical Windmills
  - Darrieus rotor
  - Savonius rotor.

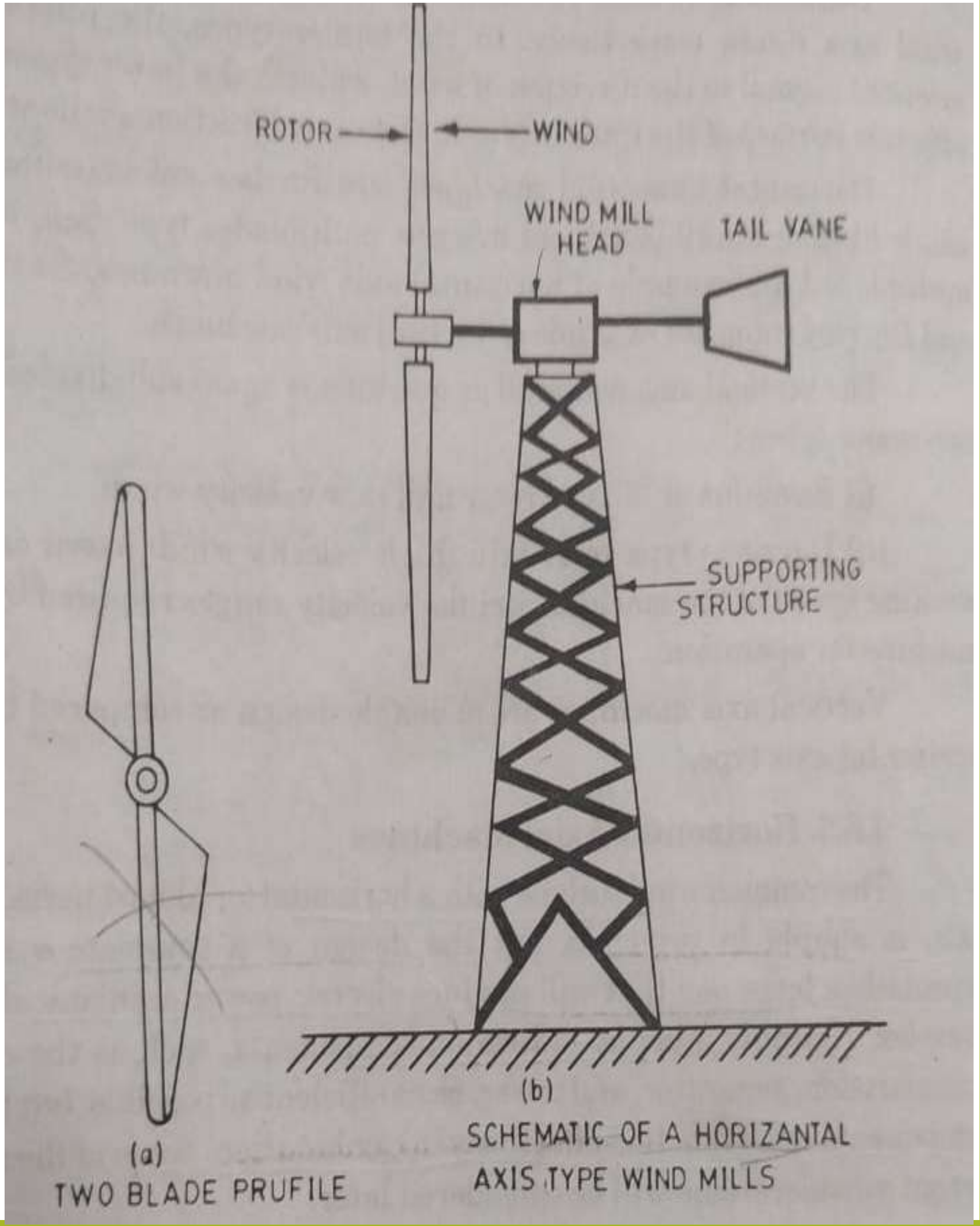
Horizontal-Axial Machines

The common wind turbine with a horizontal (or almost horizontal) axis, is simple in principle, but the design of a complete system, especially a large one that will produce electric power economically, is complex. Not only must be individual components, such as the rotor, transmission, generator, and tower, be as efficient as possible, but these components must function effectively in combination. Some of the horizontal axis type wind machines are briefly described below:

The horizontal axis types generally have better performance, They have been used for various applications, but the two major areas of interest are electric power generation, and pumping water. The latter introduces some complexity into the design as the mechanical energy has to be transmitted over a distance. Also in some cases the rotor motion has to be converted to reciprocating motion. The common wind turbine with a horizontal (or almost horizontal) axis is simple in principle, but the design of a complete system, especially a large one that will produce electric power economically, is complex.

1. **Horizontal axis using two aerodynamic blades**.

In this type of design, rotor drives a generator through a step up gear box. The design, rotor drives a generator through a 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. This arrangement is shown schematically in Fig. The rotor blades are continuously flexed by unsteady aerodynamic, gravitational and inertia loads, when the machine is in operation. If the blades are made of metal, flexing reduces their fatigue life with rotor the tower is also subjected to above loads, which may cause serious damage. If the vibrational modes of the rotor happen to coincide with one of the natural mode of the vibration of the tower, the system may shake itself to pieces. Because of the high cost of the blade rotors with more than two blades are not recommended.



2. Horizontal axis propeller type using single blade.

In this arrangement, a long blade is mounted on a rigid hub (Fig. 6.8.2). Induction generator and gear box are also shown. If extremely long blades (above say 60 m) are mounted on rigid hub, large blade root bending moment may occur due to tower shadow, gravity and sudden shifts in wind directions. To reduce rotor cost, use of low cost counter weight is recommended which balance long blade centrifugally.

Advantages of one bladed rotor:
Simple blade controls-lower blade weight and cost- lower gear box cost
Counter weight costs less than a second blade.
Counter weight can be inclined to reduce blade coning.
Pitch bearings do not carry centrifugal force.
Blade root spar can be large diameter i.e. more rugged.

Disadvantages:
(i) Vibration produced, due to aerodynamic torque.
(ii) Unconventional appearance.
(iii) Large blade root bending moment.
(iv) Starting-torque reduced by ground boundary layer.

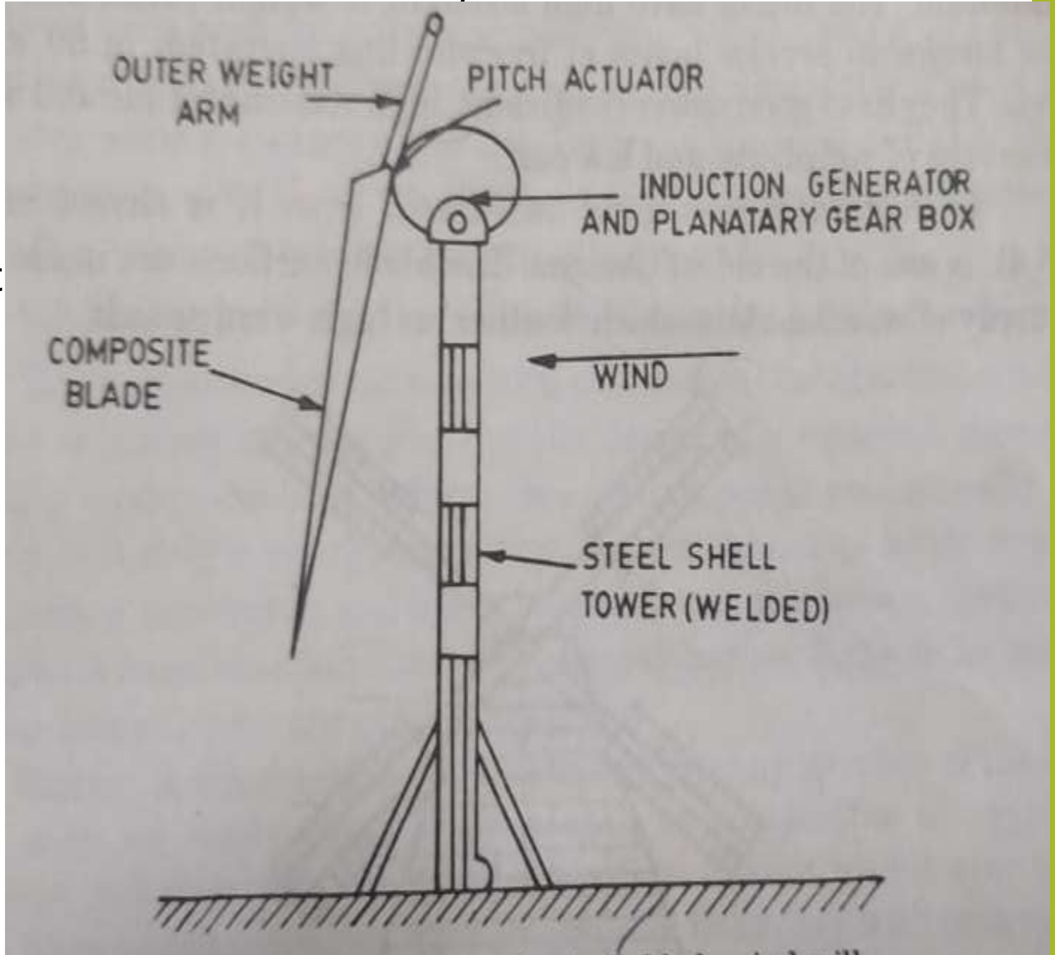


Fig. 6.8.2. Horizontal axis single blade wind mill.

3. Horizontal axis multi bladed type.

This type of design for multiblades as shown in Fig. (6.8.3), made from sheet metal or aluminium. The rotors have high strength to weight ratios and have been known to service hours of freewheeling operation in 60 km/hrwinds. They have good power coefficient, high starting torque and added advantage of simplicity and low cost.

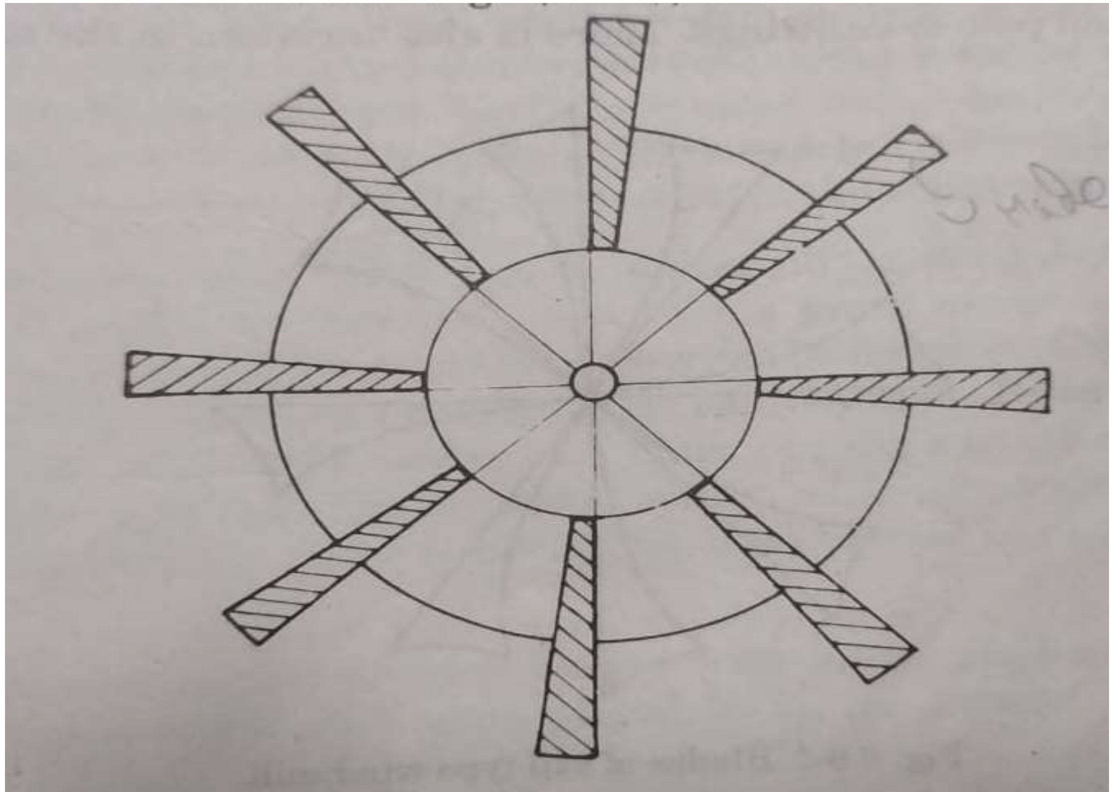


Fig. 6.8.3. Multiblade propeller.

4. Horizontal axis wind mill-Dutch type.

It is shown in Fig. (6.8.4), is one of the oldest designs. The blade surfaces are made from an array of wooden slats which 'feather' at high wind speeds.

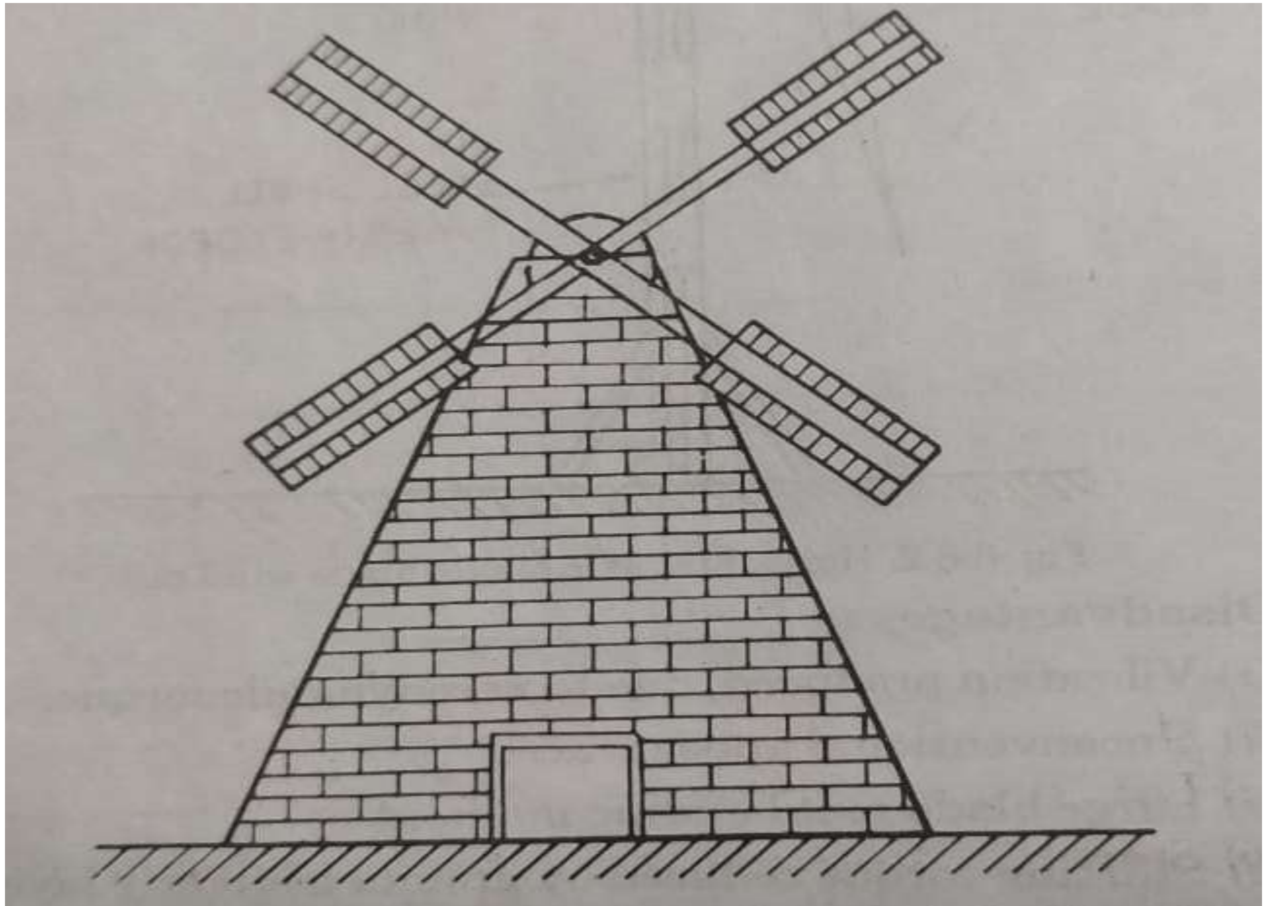


Fig. 6.8.4. Horizontal axis, Dutch type wind mill.

5. Sail type.

It's blade are shown in Fig. (6.8.5). It is of recent origin. The blade surfaces is made from cloth, nylon or plastic arranged as mast and pole or sail wings. There is also variation in the number of sails used.

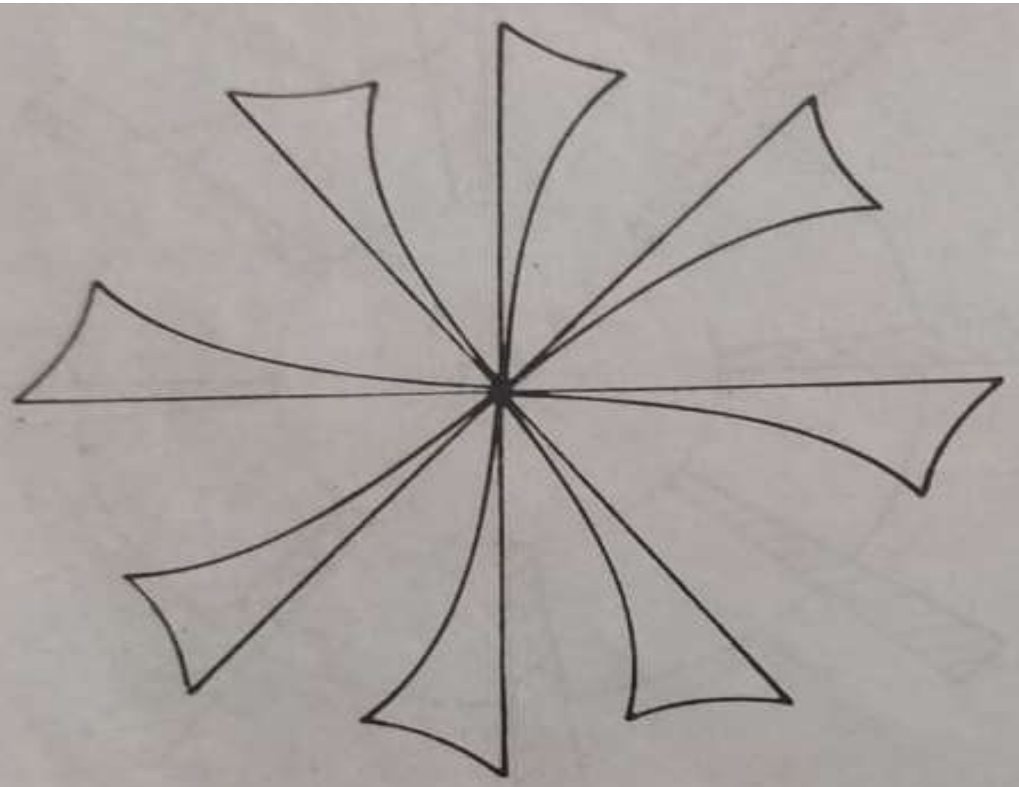
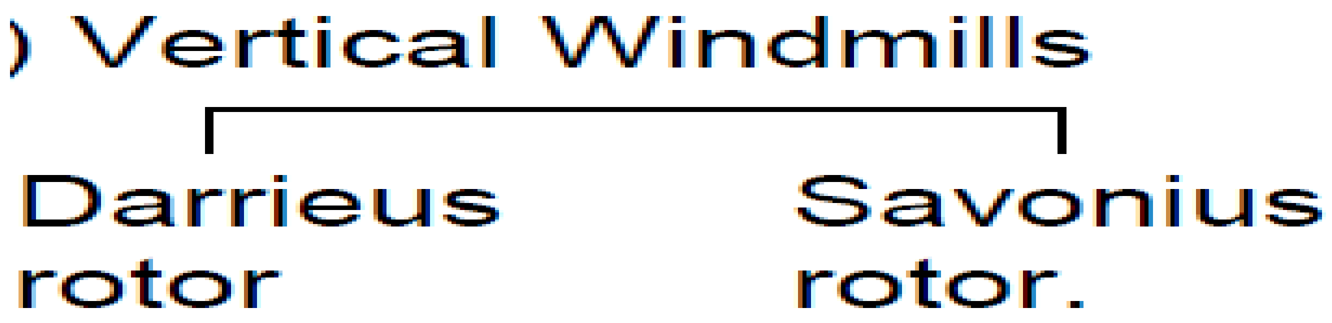


Fig. 6.8.5. Blades of sail type wind mill.

Vertical axis (or VAWTs)

They have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable, for example when integrated into buildings.



The Savonius Rotor:

Perhaps the simplest of the modern types of wind energy conversion systems is the Savonius rotor which works like a cup anemometer. This type was invented by S.J. Savonius in the year 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.

These two-semi circular drums are mounted on a vertical axis perpendicular to the wind direction with a gap at the axis between the two drums. Irrespective of the wind direction the rotor rotates such as to make the convex sides of the bucket head into the wind. From the rotor shaft we can tape power for use like water-pumping, battery charging, grain winnowing etc. However, instead of having two edges together to make an S-shaped they overlap to leave a wide space between the two inner edges,

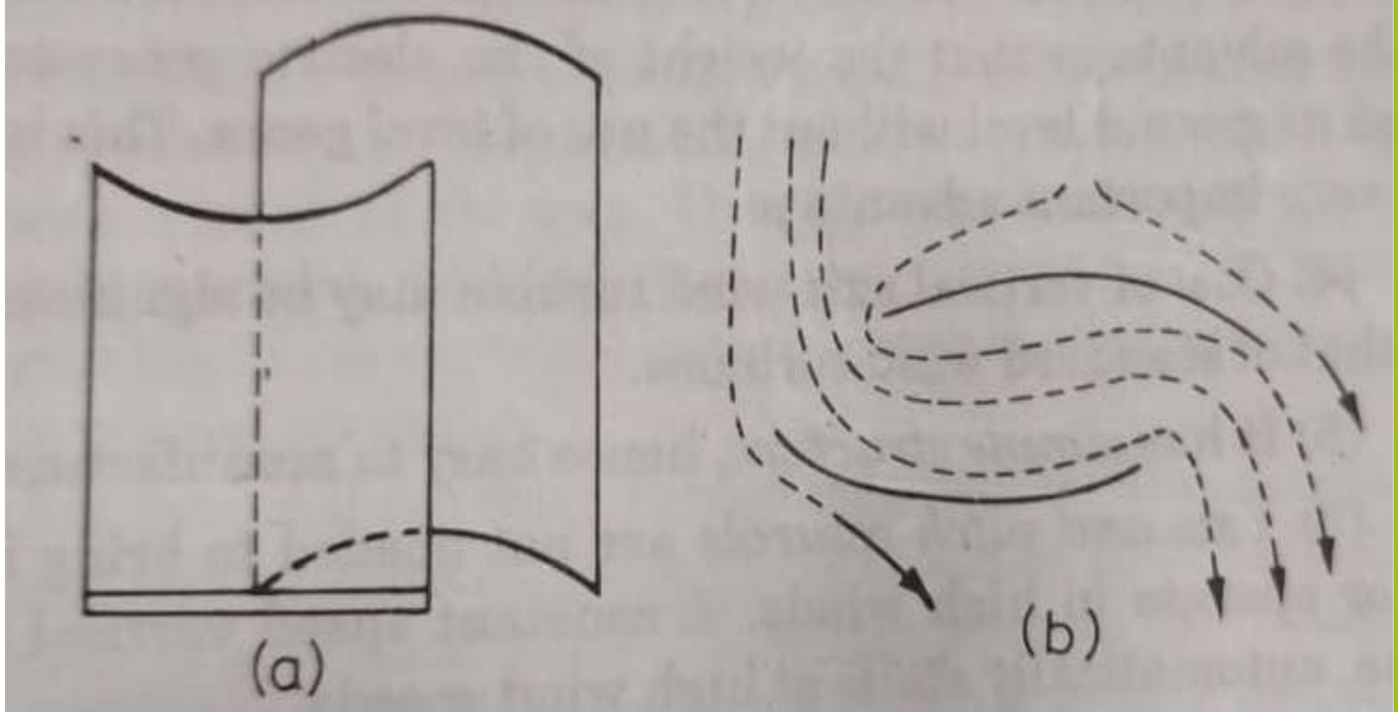


Fig. 6.8.8. The Savonius rotor and its stream flow.

so that each of these edges is near the central axis of the opposite half cylinder, as shown in the figure. The main action of the wind is very simple ; the force of the wind is greater on the cupped face than on the rounded face. In detail it is a bit more complicated. The wind curving around the back side of the cupped face exerts a reduced pressure much as the wind does over the top of an air-foil and this helps to drive the rotation. The wide slot between the two inner edges of the half cylinders, lets the air whip around inside the forward-moving cupped face, thus pushing both in the direction of the rotation.

Characteristics of Savonius Rotor

- Self starting
- Low speed
- Low efficiency.

Advantages of Savonius Rotor

(1) A Savonius wind energy conversion system has a vertical axis which eliminates the expensive power transmission system from the rotor to the axis. Since it is a vertical axis machine it does not matter much about the wind direction. The machine performs even at low-wind velocity ranges.

2) It has its low cut in speed it produces power effectively in winds as slow as 8 km/hour. This means that it is useful more of the time and is thus less dependent on storage of supplementary power.

(3) In common with all vertical-axis machines, the Savonius rotor has the advantage that the weight of the electric generator may be carried at ground level without the use of level gears. This is, however not a very important advantage.

(4) Cost of vertical axis wind turbine may be significantly lower than that of standard wind turbines.

(5) It has simple structure, hence easy to manufacture.

(6) Yaw and pitch controls are not needed to bring it into the wind or operate in high winds. A constant speed vertical axis wind turbine, automatically stalls at high wind speeds.

Disadvantages:

(i) This type of machine is too solid, having so much metal or other material surface compared with the amount of wind intercepted. This not only leads to excessive weight for a large installation but also leaves the machine of the mercy of severe storm, since there is no way to reduce the effective area.

(ii) It is not useful for a very tall installation because a long driveshaft problems and also the bracing of the topmost bearing above the rotor of a very tall vertical-axis machine is awkward, requiring very long guy wires. In a conventional horizontal-axis wind electric machine with the generator a loft, the strength of the structure required to carry the added weight of the generator is small compared with that needed to servive a severe storm and the generator housing adds little to the area presented to the storm.

b) **The Darrieus type machine** (High velocity wind). This machine was invented originally and patented in 1925 by G.J.M. Darrieus, a French engineer. In India at BHEL, Hyderabad and NAL Bangalore research and development of the Darrieus wind energy conversion systems are in progress. An additional advantage is that it supports its blades in a way that minimizes bending stresses in normal operation.

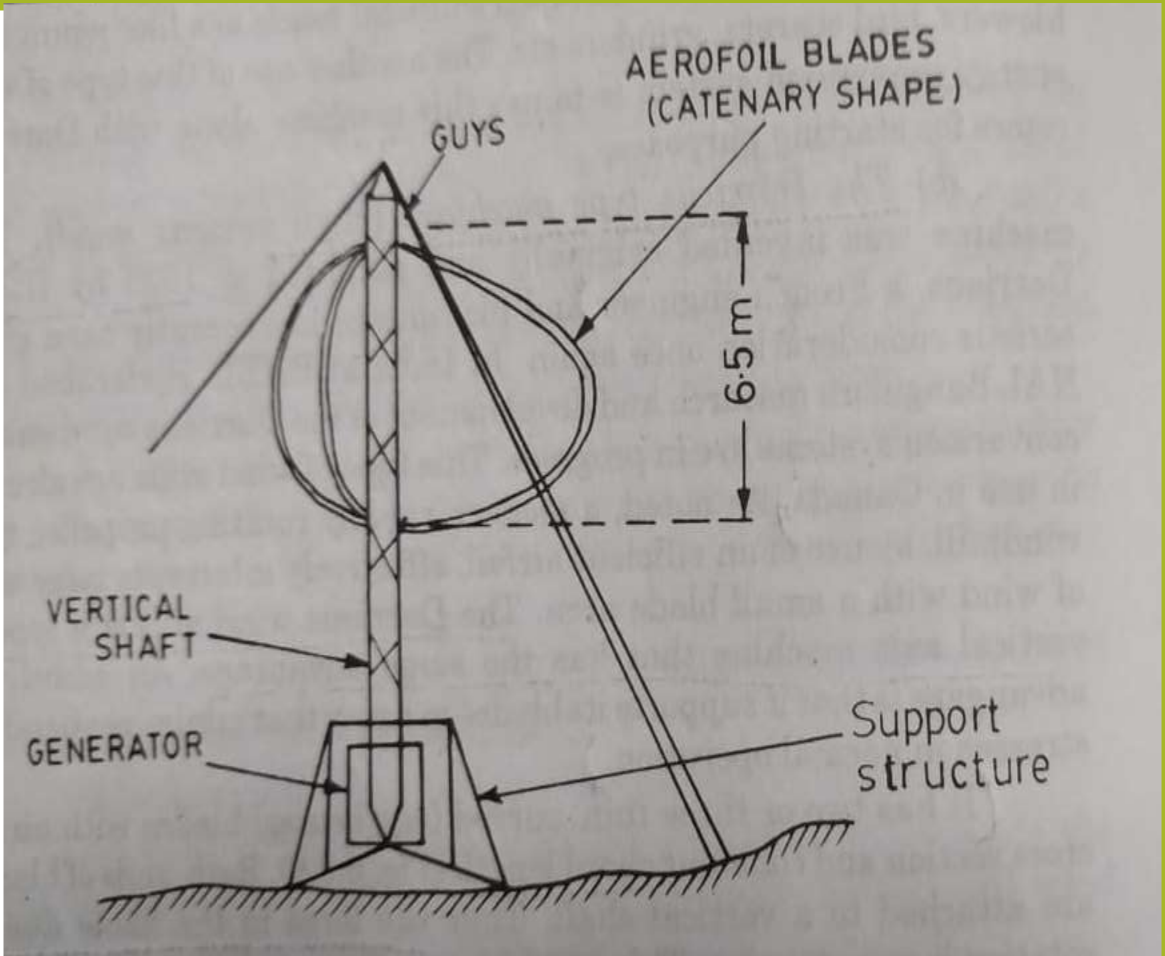


Fig. 6.8.9. Vertical axis wind mill.

It has two or three thin, curved (egg beater) blades with airfoil cross section and constant chord length (Fig. 6.8.9). 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 transmitted to a generator at the base of the central shaft for power generation.

Darrieus rotors can also be combined with various types of auxiliary rotors to increase their starting torques. However such additions increase the weight and cost of the system, so trade-offs in thesecharacteristics must be considered in developing an optimum design fora given application.

Characteristics of Darrieus Rotor

(i) Not self starting
(ii) High speed
(iii) High efficiency
(iv) Potentially low capital cost.

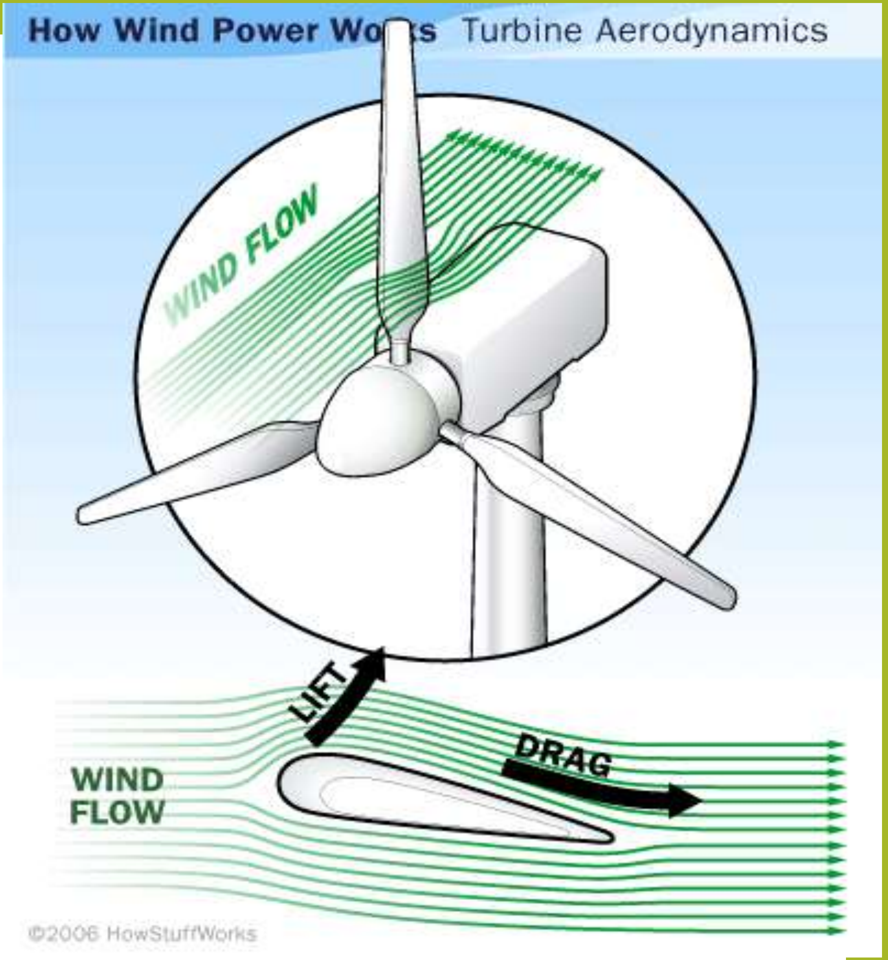
Darrieus-type rotors are lift devices, with air foil cross-section. They have relatively low solidity and low starting torque, but high tip to wind speeds and, therefore, relatively high power outputs per given rotor weight and cost.

Lift/Drag Forces Experienced by Turbine Blades

The two primary aerodynamic forces at work in wind-turbine rotors are

lift, which acts perpendicular to the direction of wind flow;

drag, which acts parallel to the direction of wind flow.



Blade Design

Wind turbine blades have an airfoil-type cross section and a variable pitch (Fig. 6.8.6 a), They are slightly twisted from the outer tip to the root (i.e. where the blade is attached to the hub) to reduce the tendency for the rotor to stall. In a few devices, the blades had a constant chords length i.e. constant distance from edge to the other). As a general rule, however better performance is obtained with blades that are narrower at the tip than at the root.

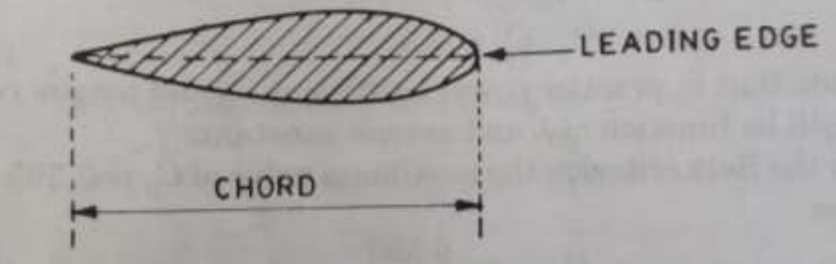


Fig. 6.8.6 (a). Cross-section of airfoil-type wind-rotor blade.

Horizontal Axis Wind Turbine (HAWT)

- Horizontal axis machines have emerged as the most successful type of turbines. These are being used for commercial energy generation in many parts of the world.
- They have low cut-in wind speed, easy furling and, in general, show a high power coefficient.
- However, their design is more complex and expensive as the generator and gearbox are to be placed at the top of the tower. Also, a tailor yaw drive is to be installed to orient them in the wind direction.
- **Main components:**

1. Turbine blades
2. Hub
3. Nacelle
4. Power transmission system
5. Generator
6. Yaw control
7. Brakes
8. Tower

Vertical Axis Wind Turbine (VAWT)

•Vertical axis wind turbine (VAWT) is also known as cross-wind axis machines.

•In these machines, the axis of rotation is perpendicular to the direction of the wind.

•The main **advantages of a VAWT compared to HAWT** are

•The vertical axis wind turbine receives wind from any direction, and hence the yawing system is not required.

•The generator, gearbox, etc. can be installed at the bottom of the tower, hence their tower design and installation is simple.

•Inspection and maintenance is easier.

•They are lighter in weight and cheaper in cost.

•VAWTs are generally not self-starting and have a low power coefficient, these are the major disadvantages. They require a mechanism to start from the stationary position. Additionally, there is a possibility of running the blades at a very high speed and causing damage to the system.

•**Main components:**

1. Rotor shaft or Tower
2. Blades
3. Support structure

Horizontal Axis Wind Turbine	Vertical Axis Wind Turbine
The rotating axis of the blades is parallel to the direction of the wind.	The rotating axis of the blades is perpendicular to the direction of the wind.
The main rotor shaft runs horizontally in HAWTs.	The main rotor shaft runs vertically in VAWTs.
HAWTs are generally used under streamline wind conditions where a constant stream and direction of wind is available.	VAWTs are mainly beneficial in areas with turbulent wind flow such as rooftops, coastlines, cityscapes, etc.
The rotor faces the wind stream to capture maximum wind energy.	The rotor can accept wind stream from any direction.
Inspection and maintenance is difficult in HAWT.	Inspection and maintenance is easy.
HAWTs extract more power from wind.	VAWTs extract less power from wind.
They are more efficient than VAWTs.	They are less efficient than HAWTs.
They operate fine in moderate wind speeds.	They can operate even in low wind speeds.

HAWT

- Electrical generator at the top of the tower
- Lift force is more dominating

VAWT

- The generator and gearbox can be placed near the ground
- Drag force is more dominating

Advantages of Wind energy

(1) The wind energy is free, inexhaustible and does not need transportation.

(2) Wind mills will be highly desirable and economical to the rural areas which are far from existing grids.

(3) Wind power can be used in combination with hydroelectric plants. Such that the water level in the reservoir can be maintained for longer periods.

Disadvantage of Wind energy

(1) Wind power is not consistent and steady, which makes the complications in designing the whole plant.

(2) The wind is a very hazard one. Special and costly designs and controls are always required.

(3) The cost factor, which has restricted the development of wind power in large scale for feeding to the existing grid .

(4) It has low power coefficient.

(5) Careful survey is necessary for plant location.

Modern Wind Turbine

Wind power systems are composed of:

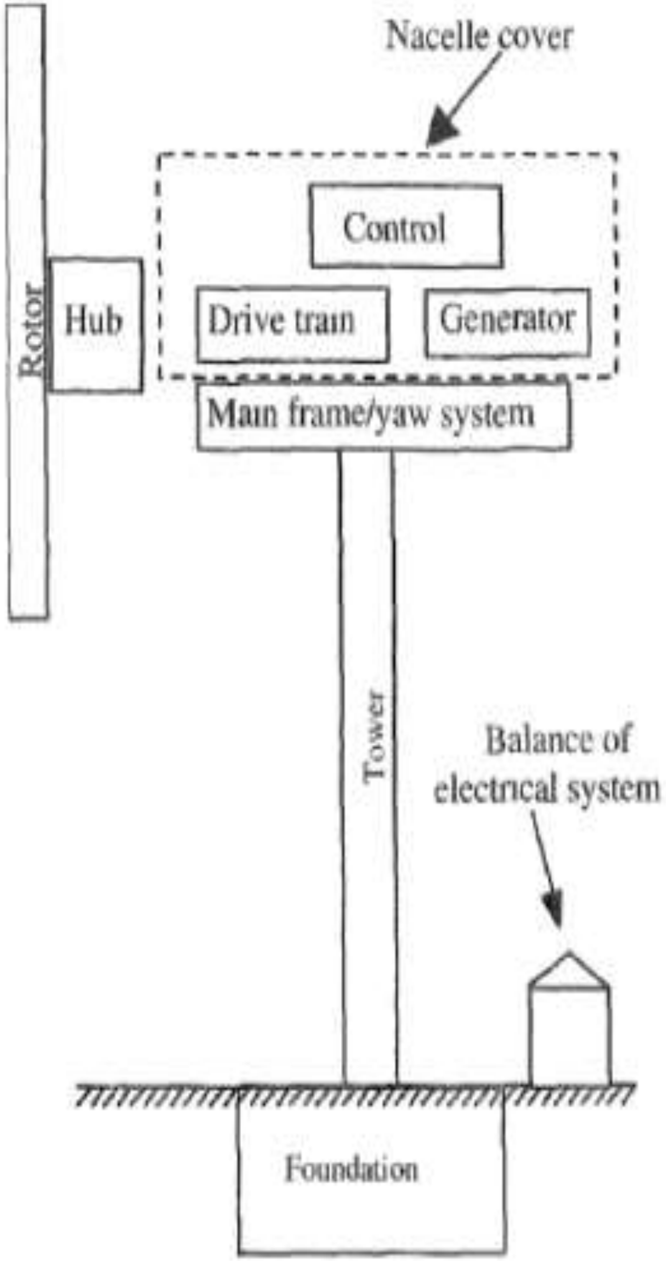
- Tower
- Rotor with 2 or 3 blades (fiberglass reinforced plastics, epoxy laminates
- Yaw Mechanism such as a tail vane
- Low-speed shaft, high-speed shaft, and gearbox

(Mechanical Drive Train)

- Electrical generator
- Speed sensors and control

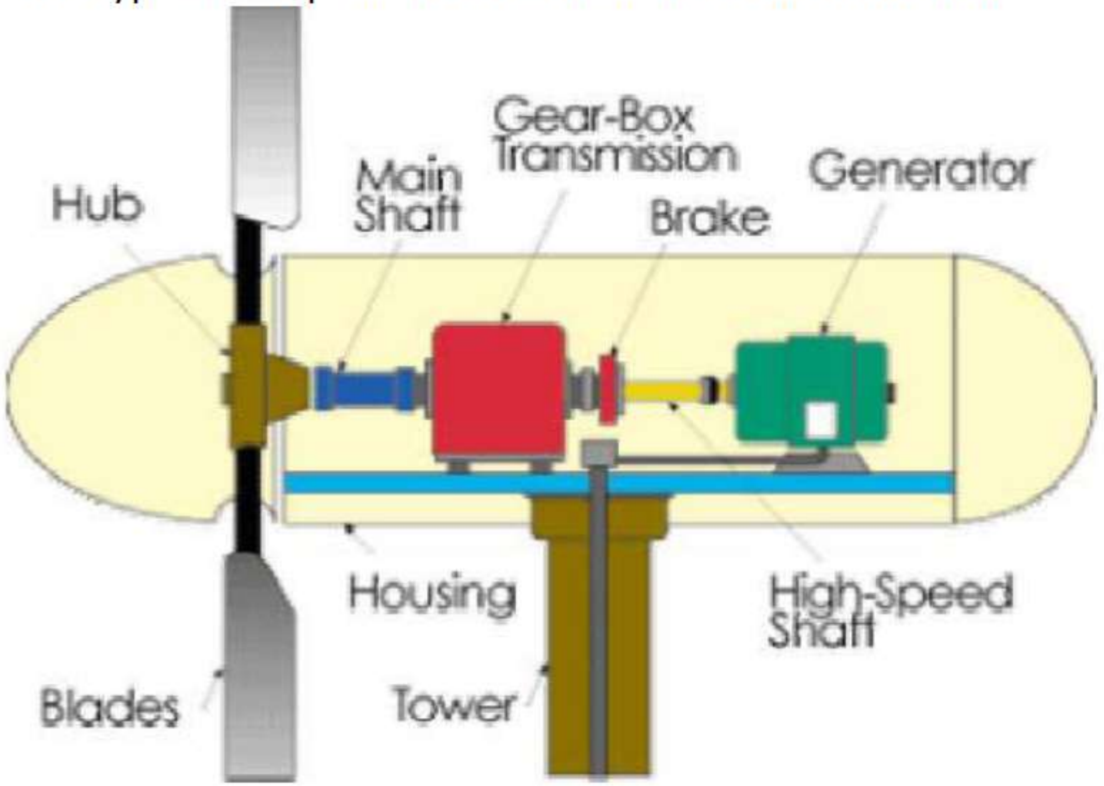
Modern wind power systems also include:

- Power electronics
- Control electronics
- Batteries to improve the load availability when in stand-alone mode
- Transmission link connecting to the area grid



Main Components of a wind-mill :

Following figure shows typical components of a horizontal axis wind mill.



Rotor:

The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft.

Drag Design:

Blade designs operate on either the principle of drag or lift. For the drag design, the wind literally pushes the blades out of the way. Drag powered wind turbines are characterized by slower rotational speeds and high torque capabilities. They are useful for the pumping, sawing or grinding work. For example, a farm-type windmill must develop high torque at start-up in order to pump, or lift, water from a deep well.

Lift Design:

The lift blade design employs the same principle that enables airplanes, kites and birds to fly. The blade is essentially an airfoil, or wing. When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade. When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines have much higher rotational speeds than drag types and therefore well suited for electricity generation.

Tip Speed Ratio:

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speeds. Lift-type wind turbines have maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1.Given the high rotational speed requirements of electrical generators, it is clear that the lift-type wind turbine is most practical for this application.

The number of blades that make up a rotor and the total area they cover affect wind turbine performance. For a lift-type rotor to function effectively, the wind must flow smoothly over the blades. To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it. It is because of this requirement that most wind turbines have only two or three blades on their rotors.

Generator:

The generator is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades.

It is important to select the right type of generator to match intended use. Most home and office appliances operate on 240 volt, 50 cycles AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be adapted to run on DC. Storage systems using batteries store DC and usually are configured at voltages of between 12 volts and 120 volts.

Generators that produce AC are generally equipped with features to produce the correct voltage of 240 V and constant frequency 50 cycles of electricity, even when the wind speed is fluctuating.

DC generators are normally used in battery charging applications and for operating DC

appliances and machinery. They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC.

Transmission:

The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed. Generators typically require rpm's of 1,200 to 1,800. As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production. Some DC-type wind turbines do not use transmissions. Instead, they have a direct link between the rotor and generator. These are known as direct drive systems. Without a transmission, wind turbine complexity and maintenance requirements are reduced, but a much larger generator is required to deliver the same power output as the AC-type wind turbines.

Tower:

The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. Maximum tower height is optional in most cases, except where zoning restrictions apply. The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall.

Operating Characteristics of wind mills:

All wind machines share certain operating characteristics, such as cut-in, rated and cutout wind speeds.

Cut-in Speed:

Cut-in speed is the minimum wind speed at which the blades will turn and generate usable power. This wind speed is typically between 10 and 16 kmph.

Rated Speed:

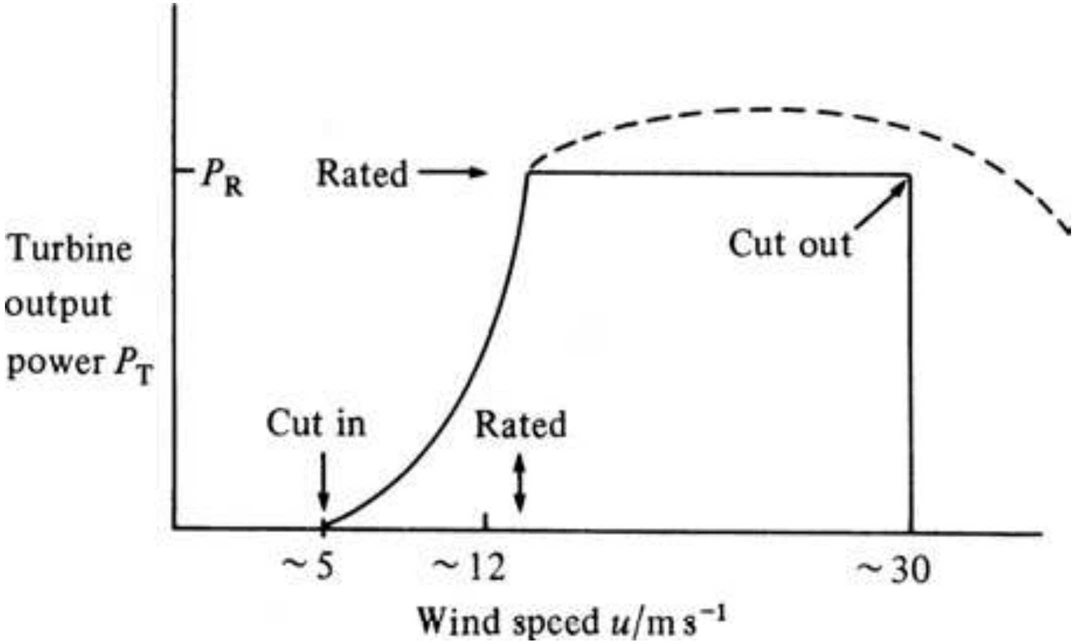
The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10kilowatts until wind speeds reach 40 kmph. Rated speed for most machines is in the range of 40 to 55 kmph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called "power curves,“ showing how their wind turbine output varies with wind speed.

Cut-out Speed:

At very high wind speeds, typically between 72 and 128 kmph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Shut down may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor. Some machines twist or "pitch" the blades to spill the wind. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

Characteristic of Wind Turbines

- Variations in wind speed causes fluctuations in the amount of power produced
  - Short Term: Gusts and Turbulence
  - Long Term: Seasonal Changes
- WTs have a cut-in, cut-out and a peak power output for a given wind velocity
- Power from the wind is proportional to the area swept by the rotors
- In practice, the max power efficiency is 45%

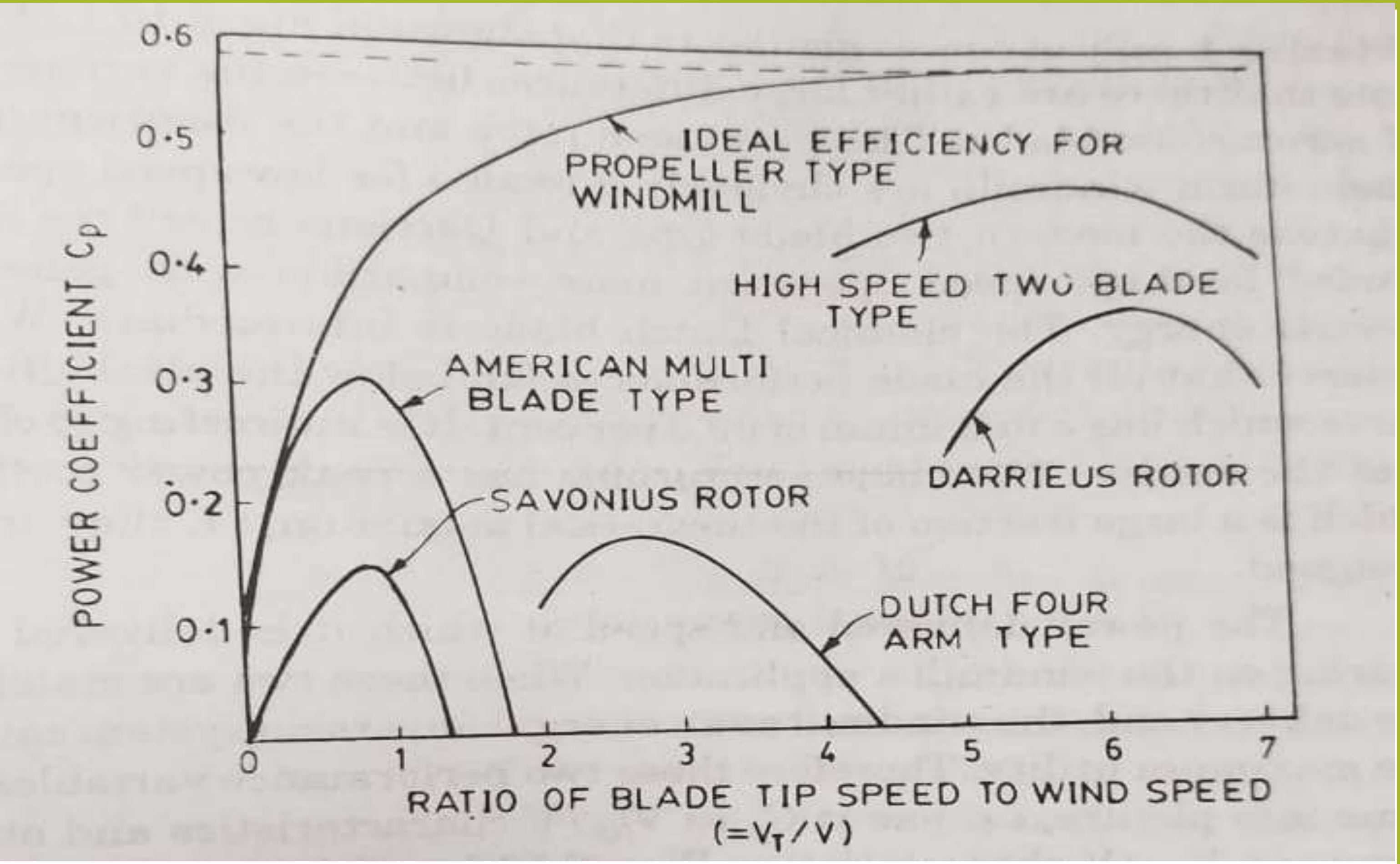


Wind turbine operating regions and power performance
______standard characteristics; requiring exact blade pitch control

_ _ _ _ _actual operating characteristics of many machines, including
stall regulation.

Calculation of Wind Power:
Power in the Wind = ½ρAV3

– Effective swept area, A
– Effective wind speed, V
– Effective air density, ρ



The dependence of the power coefficient on the tip speed ratio for some common rotor types is indicated in Fig. It is seen that the two-bladed propeller type of rotor can attain a much higher power coefficient (i.e. it is more efficient) than the American multi-blade windmill and the classical Dutch four-bladed windmill. In practice two-bladed propeller (horizontal axis) rotors are found to attain a maximum power coefficient of 0.40 to 0.45 at a tip speed ratio in the range a roughly 6 to 10.

Major factors that have lead to accelerated development of the wind power are as follows:

- Availability of high strength fiber composites for constructing large low-cost rotor blades.
- Falling prices of power electronics
- Variable speed operation of electrical generators to capture maximum energy
- Improved plant operation, pushing the availability up to 95%
- Economy of scale, as the turbines & plants are getting larger in size.
- Accumulated field experience (the learning curve effect) improving the capacity factor.
- Short energy payback (or energy recovery) period of about year,

The main considerations in selection of site for WECS are

a) Located where the high average wind velocities available are in the range of 6 m/s to 30 m/s throughout the year since power developed is proportional to cube of wind velocity.

b) The WECS must be located for away from cities and forests since the buildings and forests offer resistance to the air movement. There should be not all structures in 3 km radius from the installation.

c) The wind farms are located in flat open areas, deserts , seas, shores and off shores site since wind velocities are of high in these locations.

d) Historical data of wind mean wind speed must be collected for average velocities during the year to select the site for availability of wind velocities needed for installation of wind farms.

e) Ground surface should have high soil strength to reduce the cost of foundation.

f) If small trees exists at a particular location then it would need to increase the height of tower since any obstruction reduce the wind velocity. It causes the increase in cost of installation.

g) It should be installed away from localities so that the sound pollution caused by wind mills does not affect the habitants in near areas.

h) It is well known, the wind tend to have higher velocities at higher altitudes. One must be carefully to distinguish altitude from height above ground. They are not the same except for a sea level WECS site.

i) Distance to road or railways:

This is another factor the system engineer must consider for heavy machinery, structure, materials, blades and other apparatus will have to be moved into any choosen WECS site.

j) **Nearness of site to local centre/users:**

This obvious criterion minimizes transmission line length and hence losses and cost. After applying all the previous string criteria, hopefully as one narrows the proposed WECS sites to one or two they would be relatively near to the user of the generated electric energy.

k) Local Ecology

If the surface is base rock it may mean lower hub height hence lower structure cost. If trees or grass or vegetation are present, all of which tend to destructure the wind, the higher hub heights will be needed resulting in larges system costs that the bare ground case.

l) Favourable land cost:

Land cost should be favourable as this along with other siting costs, enters into the total WECS system cost.

- Other conditions such as icing problem, salt spray or blowing dust should not present at the site, as they may affect aeroturbine blades or environmental is generally adverse to machinery and electrical apparatus.

The power in wind:

Wind possesses energy by virtue of its motion. There are 3 factors determine the output from a wind energy converter,

1] the wind speed,

2] The cross section of wind swept by rotor

3] The overall conversion efficiency of the rotor, transmission system & generator or pump.

- ❖ Only 1/3rd amount of air is decelerating by the rotors & 60% of the available energy in wind into mechanical energy.

❖ Well designed blades will typically extract 70% of the theoretical max, but losses incurred in the gear box, transmission system & generator or pump could decrease overall wind turbine efficiency to 35%

❖ The power in the wind can be computed by using the concept of kinetics. The wind mill works on the principle of converting kinetic energy of the wind to mechanical energy.

Kinetic energy = k.E= $\frac{1}{2} mv^2$

But $m = \rho A v$

Available wind Power $= \mathbf{P_a = 1/8\ \rho \pi D^2 V^3}$ ……Watts

Maximum Power.

As stated above, that the total power cannot be converted to mechanical power. Consider a horizontal-axis, propeller-type windmill, which is the most common type used today. Assume that the wheel of such a turbine has thickness a b, as shown in Fig. 6.2.3. Let Pi and V; are the wind pressure and velocity at the upstream of the turbine, and P_e, and V_e, are pressure and velocity at downstream of the turbine. V_e, is less than V_i because kinetic energy is extracted by the turbine.

Considering the incoming air between *i* and *a* as a thermo dynamic system, and assuming that the air density remains constant (since changes in pressure and temperature are very small compared to ambient)

Thus $$P_i v + \frac{V_i^2}{2g_c} = P_a v + \frac{V_a^2}{2g_c} \qquad \text{...(6.2.7 a)}$$

where

Pv = flow energy

$\frac{V^2}{2g}$ = kinetic energy

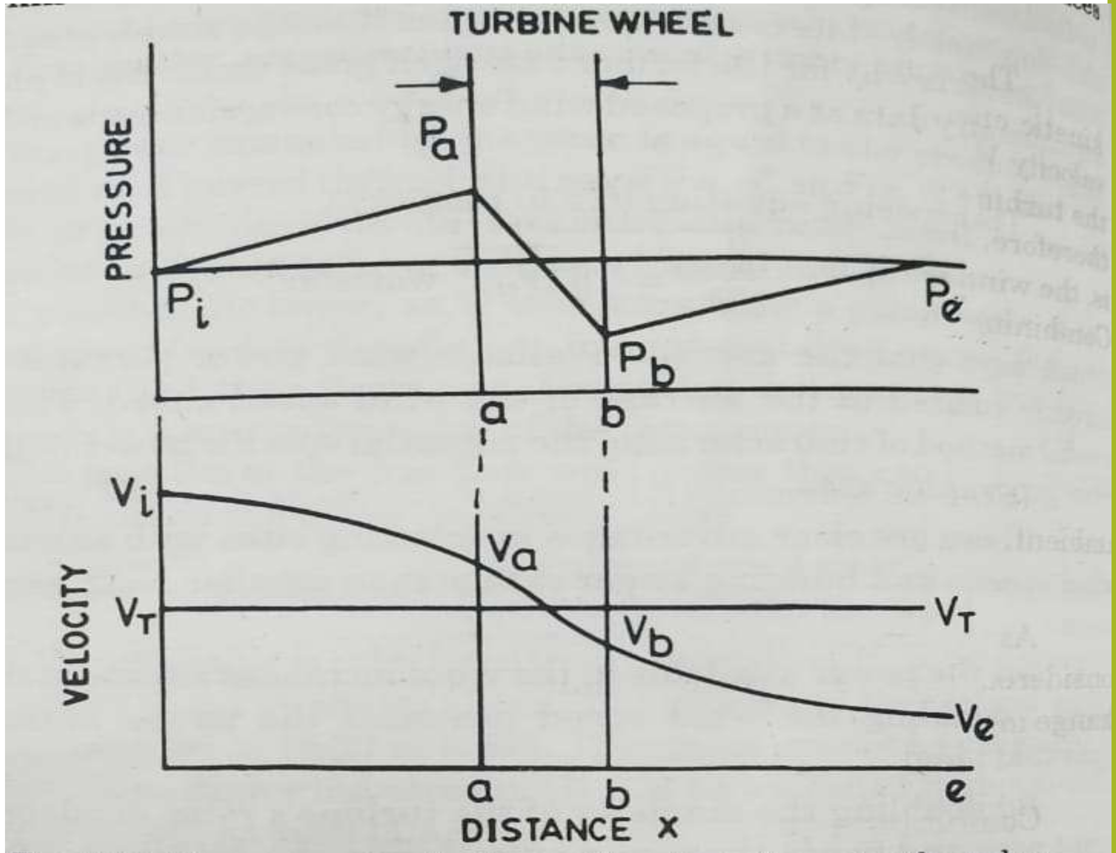


Fig. 6.2.3. Pressure and velocity profiles of wind moving through a horizontal-axis propeller-type wind turbine.

Thus $$P_i v + \frac{V_i^2}{2g_c} = P_a v + \frac{V_a^2}{2g_c} \quad \text{...(6.2.7 } a\text{)}$$

or $$P_i + \rho \frac{V_i^2}{2g_c} = P_a + \rho \frac{V_a^2}{2g_c} \quad \text{...(6.2.7 } b\text{)}$$

where v and ρ are the specific volume and its reciprocal, the density, respectively, both considered to be constant.

Similarly for the exit region be,

$$P_r + \rho \frac{V_e^2}{2g_c} = P_b + \rho \frac{V_b^2}{2g_c} \quad \text{...(6.2.8)}$$

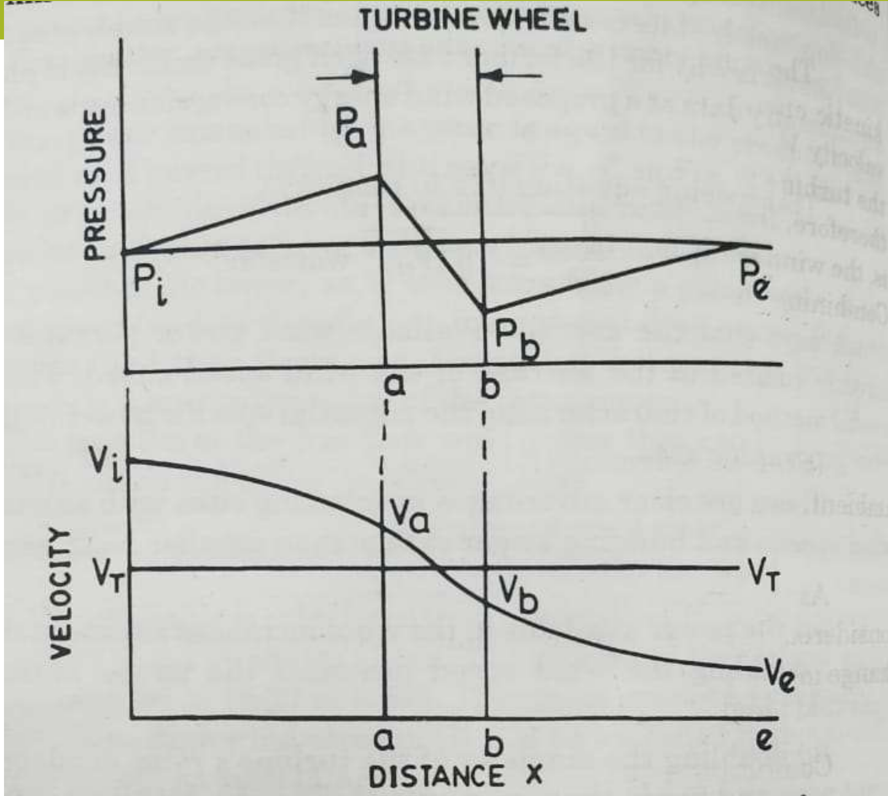


Fig. 6.2.3. Pressure and velocity profiles of wind moving through a horizontal-axis propeller-type wind turbine.

The wind velocity across the turbine decreases from a to b since kinetic energy is converted to mechanical work there. The incoming velocity V_i does not decrease abruptly but gradually as it approaches the turbine to V_a and as it leaves it to V_e. The $V_i > V_a$ and $V_b > V_e$, and therefore, from equations (6.2.7) and (6.2.8), $P_a > P_i$ and $P_b > P_i$; that is, the wind pressure rises as it approaches, then as it leaves the wheel. Combining these equations,

$$P_i + \rho \frac{V_i^2}{2g_c} = P_a + \rho \frac{V_a^2}{2g_c} \quad \text{...(6.2.7 b)}$$

$$P_r + \rho \frac{V_e^2}{2g_c} = P_b + \rho \frac{V_b^2}{2g_c} \quad \text{...(6.2.8)}$$

$$P_a - P_b = \left(P_i + \rho \frac{V_i^2 - V_a^2}{2g_c} \right) - \left(P_e + \rho \frac{V_e^2 - V_b^2}{2g_c} \right) \quad \text{...(6.2.9)}$$

It can be assumed that wind pressure at e can be assumed to ambient, *i.e.*,

$$P_e = P_i \quad \text{...(6.2.10)}$$

As the blade width a . b is very thin as compared to total distance considered, it can be assumed that velocity within the turbine does not change much.

$$V_a \simeq V_t \simeq V_b \quad \text{...(6.2.11)}$$

Combining equation (6.2.9) to (6.2.11) yields,

$$P_a - P_b = \rho \left(\frac{V_i^2 - V_e^2}{2g_c} \right) \quad \text{...(6.2.12)}$$

The axial force F_x, in the direction of wind stream, on a turbine wheel with projected area, perpendicular to the stream A, is given by

$$F_x = (P_a - P_b)A = \rho A \left(\frac{V_t^2 - V_e^2}{2g_c} \right) \quad ...(6.2.13)$$

This force is also equal to change in momentum of the wind (from Newton's second law).

$$F_x = \Delta(\dot{m}V)/g_c$$

where $\dot{m}$ = mass flow rate = $\rho A V_t$

Thus

$$F_x = \frac{1}{g_c} \rho A V_t (V_i - V_e) \quad ...(6.2.14)$$

Equating equations (6.2.13) and (6.2.14),

$$\rho A \frac{(V_i^2 - V_e^2)}{2g_c} = \frac{1}{g_c} \rho A V_t (V_i - V_e)$$

$$V_t = \frac{1}{2}(V_i + V_e) \quad ...(6.2.15)$$

energy equation how reduces to the steady flow work W and kinetic energy terms,

$$\dot{W} = kE_i - kE_e = \frac{V_i^2 - V_e^2}{2g_c} \qquad \text{...(6.2.16)}$$

The power P is defined as the rate of work, from mass flow rate equation

$$P = m\frac{V_i^2 - V_e^2}{2g_c} = \frac{1}{2g_c}\rho A V_t (V_i^2 - V_e^2) \qquad \text{...(6.2.17)}$$

Combining this with equation (6.2.15),

$$P = \frac{1}{4g_c}\rho A (V_i + V_e)(V_i^2 - V_e^2) \qquad \text{...(6.2.18)}$$

maximum power P_{max}, which can be obtained by

$$\frac{dp}{dV_e} = 0$$

or

$$\frac{dp}{dV_e} = 3V_e^2 + 2V_iV_e - V_i^2 = 0$$

This is solved for a positive V_e to give V_e opt. (The quadric has two solutions, *i.e.* $V_e = V_i$ and $V_e = \frac{1}{3} V_i$, only second solution is physically acceptable).

Thus $$V_e \text{ opt} = \frac{1}{3} V_i \qquad \text{...(6.2.19)}$$

Using the equation (6.2.18), for an ideal wind machine, with horizontal axis,

$$P_{max} = \frac{8}{27g_c} \rho A V_i^3 \qquad \text{...(6.2.20 a)}$$

$$= \frac{16}{27g_e} \frac{1}{2} \rho A V_i^{\,3} = 0.593 \left(\frac{1}{2} \cdot \frac{\rho V A_i^{\,3}}{g_c} \right)$$

$$= 0.595 \, P_{total} \qquad \text{...(6.2.20 } b\text{)}$$

The *ideal*, or *maximum*, *theoretical efficiency* η_{max} (also called the *power coefficient*) of a wind turbine is the ratio of the maximum power obtained from the wind, to the total power available in the wind. The factor 0.593 is known as the Betz coefficient (from the name of the man who first derived it). It is the maximum fraction of the power in a wind stream that can be extract.

$$\text{Power coefficient} = C_p = \frac{\text{Power output from wind machine}}{\text{Power available in wind}}$$

Thus C_p can not exceed 0.593 for a horizontal axis wind machine.

Forces on blades and thrust on turbines:

There are two types of forces that acting on the blades

1. Circumferential force acting in the direction of wheel rotation that provide torque.
2. Axial force acting in the wind stream that provides axial thrust that must be counteracted by the proper mechanical design The circumferential force, or torque T can be obtained from,

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

Where

T=Torque in Newton

ω=angular velocity in m/s

D=diameter of the turbine wheel

N= wheel revolution per unit time

$$D = \sqrt{\frac{4}{\pi} A.m}$$

$$real\ effieciency\ \eta = \frac{P}{P_{total}}$$

$$P = \eta P_{total}$$

For a turbine operating at power P, the expression for torque becomes

$$T = \eta \frac{\rho A}{2g_c} \frac{V_i^3}{\pi D N}$$

$$T = \eta \frac{1}{2g_c} \frac{\rho \pi}{4} \frac{D^2}{\pi D N} V_i^3 = \eta \frac{1}{8g_c} \frac{\rho D V_i^3}{N}$$

At maximum effciency i.e,59.3%, Torque has maximum value given by,

$$T_{max} = \frac{2}{27g_c} \frac{\rho D V_i^3}{N}$$

Axial Thrust given by,

$$F_x = \frac{1}{2g_c} \rho A (V_i^2 - v_e^2)$$

$$= \frac{\pi}{8g_c} \rho D^2 (V_i^2 - v_e^2)$$

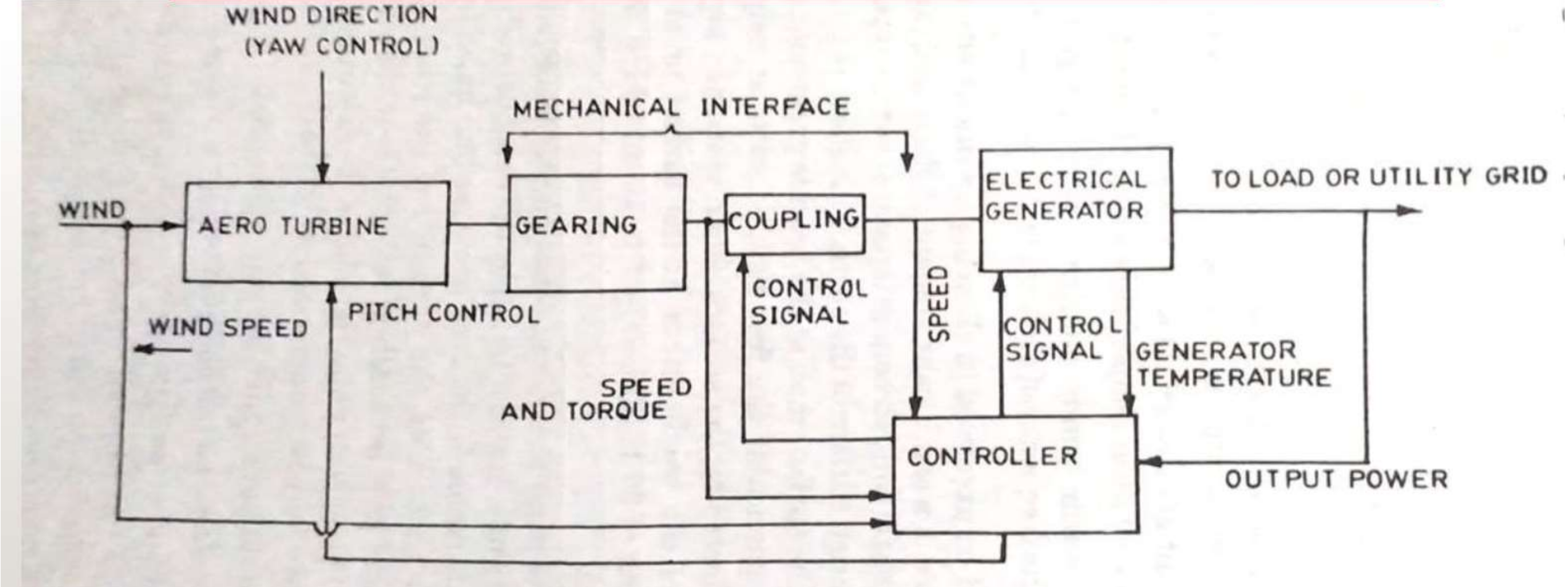
On substituting $v_e = 1/3\ v_i$

$$F_{x\,max} = \frac{4}{9g_c} \rho A V_i^2$$

$$= \frac{\pi}{9g_c} \rho D^2 V_i^2$$

- ❖ It can be seen that axial forces are proportional to the square of the diameter of turbine wheel, this limits the turbine wheel diameter of large size.

BASIC COMPONENTS OF WIND ENERGY CONVERSION SYSTEMS (WECS)



The main components of a WECS are shown in block diagram form.

Summary of the system operation is as follows:

Aero Turbines convert energy in moving air to rotary mechanical energy. In general, they require pitch control and 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 transmits the rotary mechanical energy to an electrical generator. The output of this generator is connected to the load or power grid as the application warrants.

Yaw control. For localities with the prevailing wind in one direction, the design of a turbine can be greatly simplified. The rotor can be in a fixed orientation with the swept area perpendicular to the predominant wind direction. Such a machine is said to be yaw fixed. Most wind turbines, however, are yaw active, that is to say, as the wind direction changes, a motor rotates the turbine slowly about the vertical (or yaw) axis so as to face the blades into the wind. The area of the wind stream swept by the wind rotor is then a maximum.

In the 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-direction sensor controls the yaw motor that keeps the turbine properly oriented.

The purpose of the controller is to sense wind speed, wind direction, shafts speed and torque at one or more points, output power and generator temperature as necessary and appropriate control signals for matching the electrical output to the wind energy input and protect the system from extreme conditions brought upon by strong winds electrical faults, and the like.

The physical embodiment for such an areo-generator is shown in a generalized form in Fig. (6.5.2)

The subcomponents of the windmill are :-

- wind turbine or rotor-wind
- mill head
- transmission and control
- Supporting structure

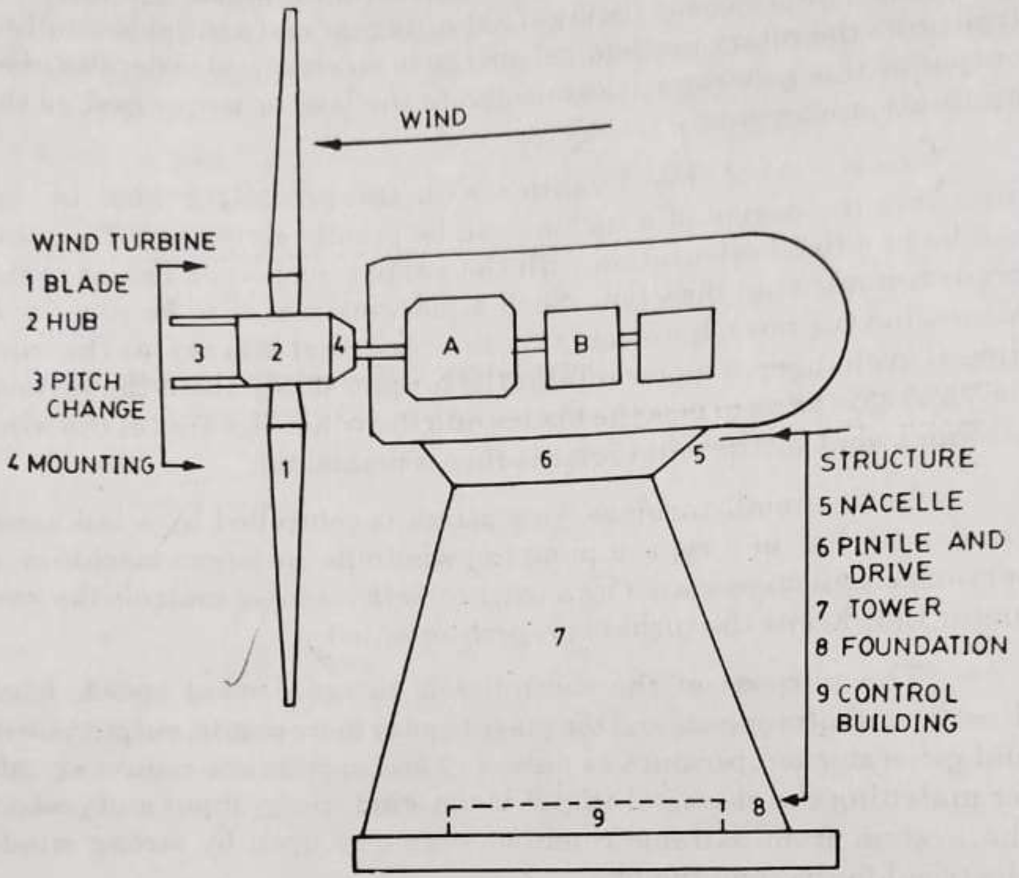
Rotors are mainly of two types:

(i) Horizontal axis rotor

(ii) Vertical axis rotor.

One advantage of vertical-axis machines is that they operate in all wind directions and thus need no yaw adjustment. The rotor is only one of the important components. For an effective utilization, all the components need to be properly designed and matched with the rest of the components.

windmill head: The windmill head support the rotor, housing the rotor bearings. It also houses any control mechanism incorporated like changing the pitch of the blades for safety devices and tail vane to orient the rotor to face the wind. The latter is facilitated by mounting it on the top of the supporting structure on suitable bearings.



A—*Transmission*
Speed Increaser
Driver Shaft add Bearing Brake
Clutch and Coulping.
B—*Electrical*
Generator
Control and indicators (at ground level)

Fig. 6.5.2. Physical embodiment of wind-electric generating station.

Transmissions. The rate of rotation of large wind turbine generators operating at rated capacity or below, is conveniently controlled by varying the pitch of the rotor blades, but it is low, about 40 to 50 revolutions per minute (rpm). Because optimum generator output requires much greater rates of rotation, such as 1800 rpm, it is necessary to increase greatly the low rotor rate of turning. Among the transmission options are mechanical systems involving fixed ratio gears, belts, and chains, singly or in combination or hydraulic systems involving fluid pumps and motors. Fixed ratio gears are recommended for top mounted equipment because of their high efficiency, known cost, and minimum system risk.

Generator. Either constant or variable speed generators are a possibility, but variable speed units are expensive and/or unproved. Among the constant speed generator candidates for use are synchronous induction and permanent magnet types. The generator of choice is the synchronous unit for large aerogenerator systems because it is very versatile and has an extensive data base. Other electrical components and systems are, however, under development.

Controls. The modern large wind turbine generator requires aversatile and reliable control system to perform the following functions:

(1) the orientation of the rotor into the wind (azimuth of yaw);

(2) start up and cut-in of the equipment;

(3) power control of the rotor by varying the pitch of the blades.

(4) generator output monitoring-status, data computation,and storage ;

(5) shutdown and cut out owing to malfunction or very high winds.

(6) protection for the generator, the utility accepting the power and the prime mover ;

(7) auxiliary and/or emergency power; and

(8) maintenance mode.

Many combinations are possible in terms of the control system and may involve the following components:

(1) sensor-mechanical, electrical,

(2) decision elements-relays, logic modules, analog circuits, a microprocessor, or a mechanical unit; and

(3) actuators-hydraulic, electric.

Are commended combination of electronic transducers feeding into a microprocessor which, in turn, signals electrical actuators and provides protection through electronic circuits, although a pneumatic slip clutch may be required.

Tower. Four types of supporting towers deserve consideration, these are:

(1) the reinforced concrete tower,

(2) the pole tower,

(3) the built up shell-tube tower, and

(4) the truss tower.

Among these, the truss tower is favoured because it is proved and widely adaptable, cost is low, parts are readily available, it is readily transported, and it is potentially stiff. Shell-tube tower also have attractive features and may prove to be competitive with truss towers.

The type of the supporting structure and its height is related to towers. cost and the transmission systems incorporated. It is designed to withstand the wind load during gusts (even if they occur frequently and for very short periods). Horizontal axis wind turbines are mounted on towers so as to be above the level of turbulence and other ground related effects. The minimum tower height for a small WECS is about 10 m, and the maximum practical height is estimated to be roughly 60 m.

Classification of WEC Systems

1. **First, there are two broad classifications** :

(i) Horizontal Axis Machines. The axis of rotation and the aeroturbine plane is horizontal and the aeroturbine plane is vertical facing the wind.

(ii) Vertical Axis Machines. The axis of rotation is vertical. The sails or blades may also be vertical, as on the ancient Persian windmills,or nearly so, as on the modern Darrieus rotor machine.

2. **Then, they be classified according to size** as determined by their useful electrical power output.

(i) Small Scale (upto 2 kW). These might be used on farms, remote applications, and other places requiring relatively low power.

(ii) Medium Size Machines (2-100 kW). These wind turbines may be used to supply less than 100 kW rated capacity, to several residences or local use.

(iii) Large Scale or Large Size Machine (100 kW and up). Large wind turbines are those of 100 kW rated capacity or greater. They are used to generate power for distribution in central power grids. There are two sub classes :

(a) Single Generator at a single site.

(b) Multiple Generators sited at several places over an area.

3. As per the type of output power, wind aerogenerator areclassified as:

(i) DC output

(a) DC generator (b) Alternator rectifier

(ii) AC output

(a) Variable frequency, variable or constant voltage AC.

(b) Constant frequency, variable or constant voltage AC.

4. As per the rotational speed of the aero turbines, these are classified as :

(i) Constant Speed with variable pitch blades. This made implies use of a synchronous generator with its constant frequency output.

(ii) Nearly Constant Speed with fixed pitch blades. This mode implies an induction generator.

(iii) Variable Speed with fixed pitch blades. This mode could imply, for constant frequency output.

Types Of Generators Used In Wind Turbine System

Any types of three-phase generator can connect to with a wind turbine. Several different types of generators which are used in wind turbines are as follows. Asynchronous (induction) generator and synchronous generator. Squirrel cage induction generator (SCIG) and wound rotor induction generator (WRIG) are comes under asynchronous generators. Wound rotor generator (WRSG) and permanent magnet generator (PMSG) are comes under synchronous generator. Detailed explanation is given.

2.1 Asynchronous Generator

Squirrel Cage Induction Generator The fixed speed concept is used in this type of wind turbine. In this configuration the Squirrel Cage Induction Motor is directly connected to the wind through a transformer is shown in the figure 3. A capacitor bank is here for reactive power compensation and soft starter is used for smooth grid connection. It does not support any speed control is the main disadvantage

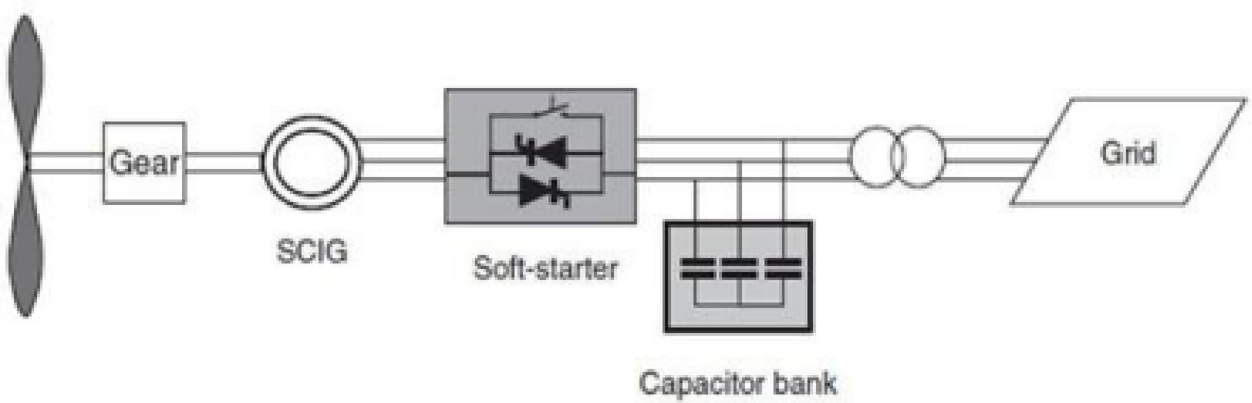


Fig. 3: SCIG wind turbine

2.1.1 Wound rotor induction generator (WRIG)

The variable speed concept is used in this type .In this type of turbine Wound Rotor Induction Generator is directly connected to the grid as shown in the figure. The variable rotor resistance is for controlling slip and power output of the generator. The soft starter used here for reduce inrush current and reactive power compensator is used to eliminate the reactive power demand .The speed range is limited , poor control of active and reactive power, the slip power is dissipated in the variable resistance as losses are the disadvantages of this configuration

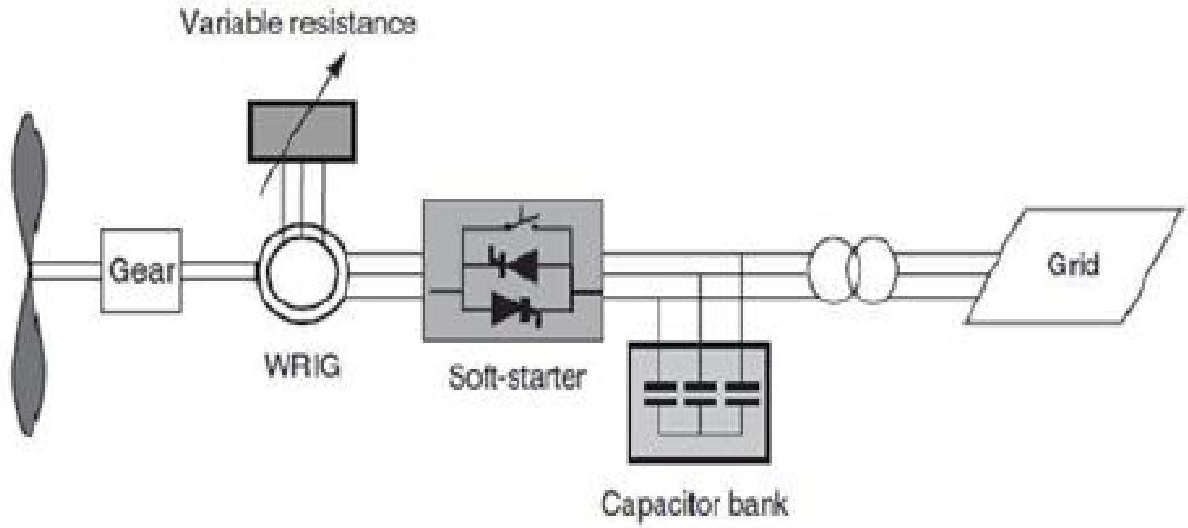


Fig. 4: WRIG wind turbine

2.2 Synchronous Generator

2.2.1 Wound Rotor Generator

Turbine with wound rotor connected to the grid is shown in fig.4.This configuration neither require soft starter nor a reactive power comparator is its main advantage. The partial scale frequency converter used in the system will perform reactive power compensation as well as smooth grid connection. The wide range of dynamic speed control is depends on the size of frequency converter .the main disadvantage is that in the case of grid fault it require additional protection and use slip rings, this makes electrical connection to the rotor.

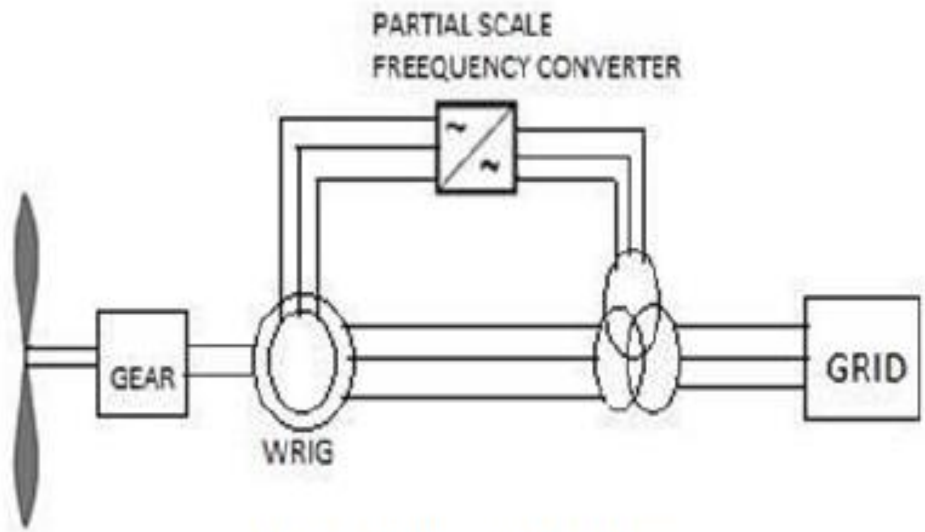


Fig. 5: WRIG wind turbine

2.2.2 Permanent Magnet Generator

The generator is connected to the grid via full scale frequency converter. The frequency converter helps to control both the active and reactive power delivered by the generator to grid.

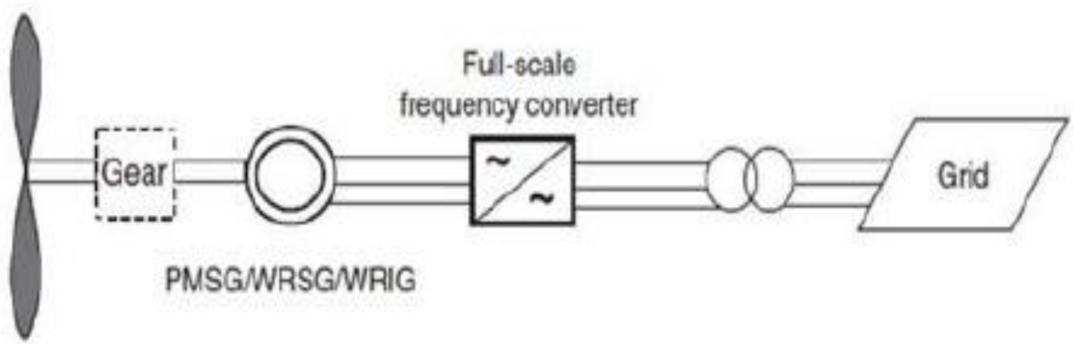


Fig. 6: PMSG wind turbine

2.3 Doubly Fed Induction Generator

In order to satisfy the modern grid codes, the grid turbine system have the capability of reactive power support. Doubly fed induction generator based wind turbine system have more advantages than others. DFIG wind turbine deliver power through the stator and rotor of the generator the reactive power can provide in two sides. Hence use the term doubly. Reactive power can be supported either through grid side converter or through rotor side converter. The stator part of the turbine is directly connected to the grid and the rotor is interfaced through a crowbar and a power converter. The voltage to the stator part is applied from the grid and the voltage to the rotor is induced by the power converter. The power is delivered from the rotor through the power converter to the grid if the generator is operates above synchronous speed.

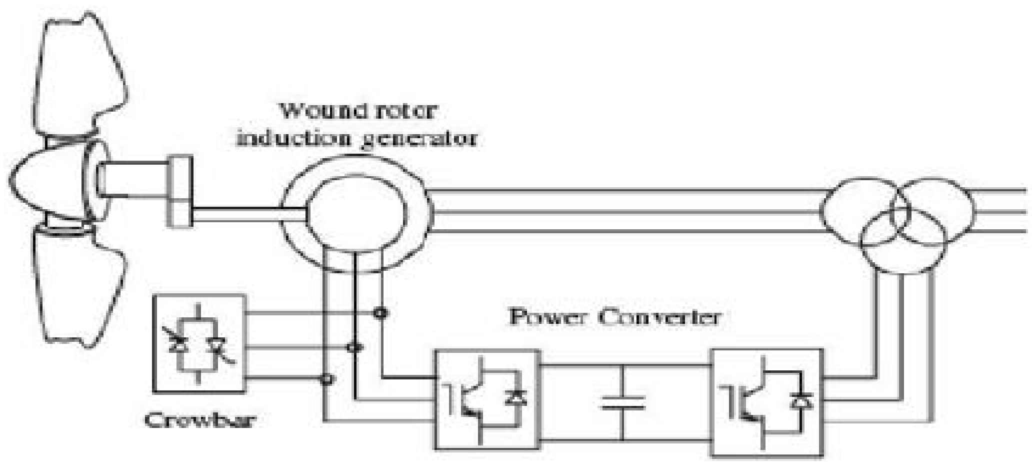


Fig. 7: Doubly Fed Induction Generator wind turbine

If the generator is operates below synchronous speed, then the power is delivered from the grid through the power converter to the rotor The power converter controls both the active and reactive power flow, the DC voltage of link capacitor between the grid and DFIG wind turbine by feeding the pulse width modules (PWM) to the converters .A crowbar is implemented between the generator and converter to prevent short circuit in the wind energy system. Which may result in high current and high voltage. The RSC converter controls the flux of the DFIG wind turbine .which operates at the slip frequency that depends on the rotor speed of the generator. According to the maximum active and reactive power control capability of converter, the power rating of the RSC is determined