Unit-IV WIND ENERGY

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Wind Energy and Wind Power: Wind is a form of **solar energy**. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern **wind turbines**, can be used to generate **electricity**.

How Wind Power Is Generated: The terms "**wind energy**" or "**wind power**" describe the process by which the wind is used to generate **mechanical power or electricity**. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

Advantages of Wind Energy:

Wind energy has a number of different benefits. We can use it for a variety of purposes, primarily for the production of clean and renewable electricity. Let's jump right in and take a look at the different advantages wind energy has.

1. Wind Energy Is Renewable & Sustainable

Wind energy itself is both renewable and sustainable. The wind will never run out, unlike reserves of fossil fuels (such as coal, oil, and gas.) This makes it a good choice of energy for a sustainable power supply.

2. It's Also Environmentally Friendly

Wind energy is one of the most environmentally friendly energy sources available today. This is based on the simple reason that wind turbines don't create pollution when generating electricity.

Most non-renewable energy sources need to be burnt. This process releases gases such as carbon dioxide (CO_2) and methane (CH_4) into the atmosphere. These gases are known to contribute to climate change. In contrast, wind turbines produce no greenhouse gases when generating electricity.

3. It Can Reduce Fossil Fuel Consumption

Generating electricity from wind energy reduces the need to burn fossil fuel alternatives such as coal, oil, and gas. This can help to conserve dwindling supplies of the earth's natural resources. As a result, they will last longer and help to support future generations.

4. Wind Energy is Free

Unlike most non-renewable energy sources, wind energy is completely free. Anyone can make use of the wind and it will never run out. This makes wind energy a viable option for generating cheap electricity.

5. It Has A Small Footprint

Wind turbines have a relatively small land footprint. Although they can tower high above the ground, the impact on the land at the base is minimal. Wind turbines are often constructed in fields, on hills or out at sea. At these locations, they pose hardly any inconvenience to the surrounding land. Farmers can still farm their fields, livestock can still graze the hills and fishermen can still fish the sea.

6. Both Industrial & Domestic Wind Turbines Exist

Wind turbines aren't just limited to industrial-scale installations (such as wind farms.) They can also be installed on a domestic scale. As a result, many landowners opt to install smaller, less powerful wind turbines. This can help to provide a portion of a domestic electricity supply. Domestic wind turbines are often coupled with other renewable energy technologies. You can often find them installed alongside solar panels and geothermal heating systems.

7. Wind Energy Can Provide Power For Remote Locations

Wind turbines can play a key role in helping to bring power to remote locations. This can help to benefit everything from small off-grid villages to remote research facilities. It might be impractical or too expensive to hook such locations up to traditional electricity supplies. In these cases, wind turbines could have the answer.

8. Wind Technology is Becoming Cheaper

The first-ever wind turbine started generating electricity in 1888. Since then, they have become more efficient and have come down in price. As a result of this, wind power is becoming much more accessible.

Government subsidies are also helping to reduce the cost of wind technologies. Many countries across the world now provide incentives for the construction of wind turbines. In addition, incentives are sometimes available for domestic users to supply electricity back to the grid.

9. It Is Also Low Maintenance

Wind turbines are fairly low in maintenance. A new wind turbine can last a long time prior to it requiring any maintenance. Although older turbines can come up against reliability issues, technological advancements are helping to improve overall reliability.

10. It Has Low Running Costs

As wind energy is free, running costs are often low. The only ongoing cost of wind energy is for the maintenance of wind turbines, but they are low maintenance in nature anyway.

11. Wind Energy Has Huge Potential

Wind energy has huge potential. It's both renewable and sustainable and is present in a wide variety of places. Although wind turbines aren't cost-effective at every location, the technology isn't limited to just a handful of locations. This is an issue that can affect other renewable energy technologies – such as geothermal power stations.

12. It Can Increase Energy Security

By using wind energy to generate electricity, we are helping to reduce our dependency on fossil fuel alternatives. In many cases, a country will source some or all of its fossil fuels from another country. War, politics and overall demand often dictate the price of these natural resources. This can sometimes cause serious economic problems or supply shortages.

By using local renewable energy sources, a country can reduce its dependency on external supplies of natural resources. As a direct result of this, the country can increase its energy security.

13. The Wind Energy Industry Creates Jobs

The wind energy industry has boomed since wind turbines became commercially available. As a result of this, the industry has created jobs all over the world. Jobs now exist for the manufacturing, installation, and maintenance of wind turbines. You can even find jobs in wind energy

consulting. This is a job where specialist consultants determine whether a wind turbine installation is going to be profitable.
According to recent data released by the International Renewable Energy Agency (IRENA), the renewable energy industry employed over 10 million people worldwide in 2017. Of these jobs, 1.15 million were in the wind power industry. China leads the way in providing over 500,000 of these jobs. Germany is in second place with around 150,000 jobs and the United States are a close third with around 100,000 wind energy jobs.

Disadvantages of Wind Energy

We've had a look at the advantages, so now let's take a look at the disadvantages of wind energy. Wind energy has a number of drawbacks and cons, with the NIMBY (not in my backyard) factor playing a large role.

1. The Wind Fluctuates

Wind energy has a similar drawback to solar energy in that it is not constant. Although wind energy is sustainable and will never run out, the wind isn't always blowing. This can cause serious problems for wind farm developers. They will often spend a significant amount of time and money investigating whether a particular site is suitable for wind power.
For a wind turbine to be efficient, it needs to have an adequate supply of wind energy. For this reason, we often find wind turbines on top of hills or out at sea. In these locations, there are fewer land obstacles to reduce the force of the wind.

2. Installation is Expensive

Although costs are reducing over time, wind turbines are still expensive. First, an engineer must carry out a site survey. This may involve having to erect a sample turbine to measure wind speeds over a period of time. If deemed adequate, a wind turbine then needs to be manufactured, transported and erected on top of a pre-built foundation. All of these processes contribute to the overall cost of installing wind turbines.
When we take the above into account for offshore wind farms, the costs become much greater. Installing structures out at sea is far more complex than on land. Some companies have even commissioned bespoke ships capable of transporting and installing wind turbines at sea.

3. Wind Turbines Pose A Threat to Wildlife

We often hear that wind turbines pose a threat to wildlife – primarily birds and bats. However, researchers now believe that they pose less of a threat to wildlife than other manmade structures. Installations such as cell phone masts and radio towers are far more dangerous to birds than wind turbines. Nevertheless, wind turbines still contribute to mortality rates among bird and bat populations.

4. Wind Turbines Create Noise Pollution

One of the most common disadvantages of wind turbines is the noise pollution they generate. You can often hear a single wind turbine from hundreds of meters away. Combine multiple wind turbines with the right wind direction and the audible effects can be much greater. This issue is one of the biggest impacts of wind energy.
Noise pollution from wind turbines has ruined the lives of many homeowners. Although steps are often taken to install them away from dwellings, they do sometimes get built too close to where people live. This is why new wind farms often come up against strong public objection.

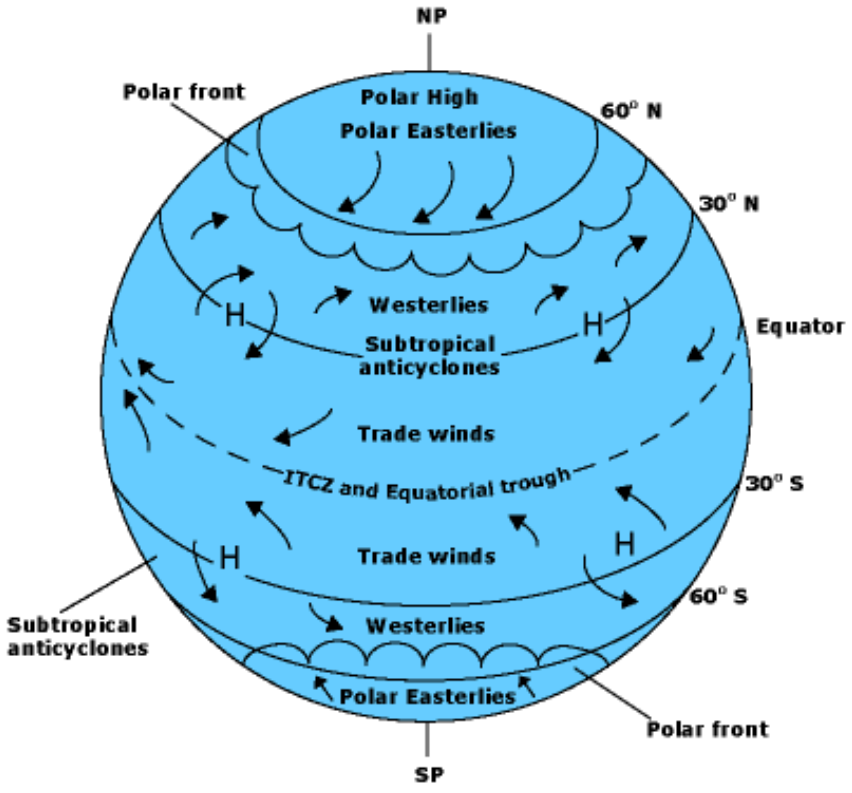
5. They Also Create Visual Pollution

Another common drawback of wind turbines is the visual pollution they create. Although many people actually like the look of wind turbines, others don't. These people see them as a blot on the landscape. This, however, tends to come down to personal opinion. As we build more wind farms, public acceptance is becoming more common.

Global Wind Patterns

The Four Major Wind Systems and Wind Belts:

The four major wind systems are the Polar and Tropical Easterlies, the Prevailing Westerlies and the Intertropical Convergence Zone. These are also wind belts. There are three other types of wind belts, also. They are called Trade Winds, Doldrums, and Horse Latitudes.

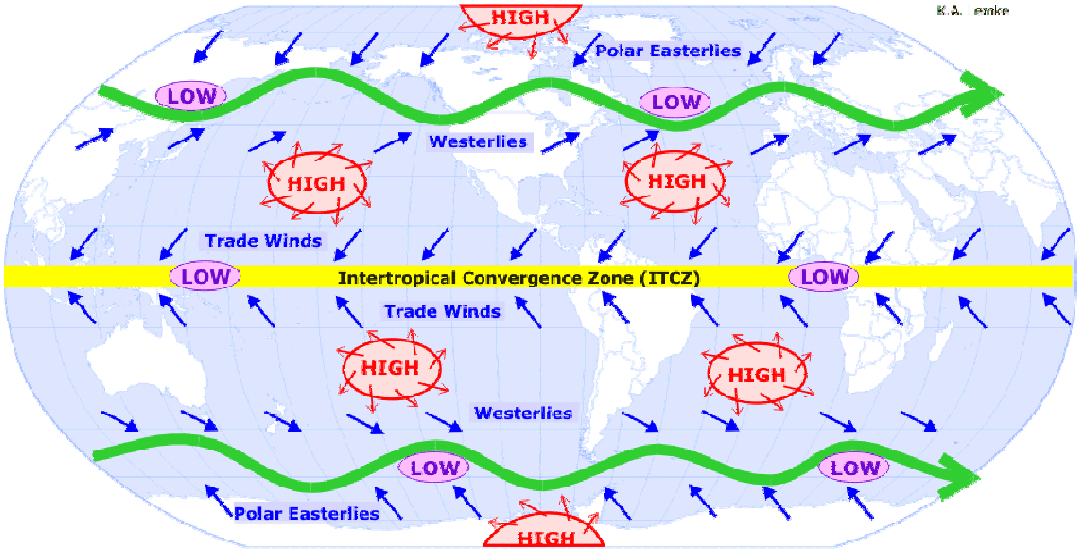


Polar Easterlies- Polar Easterlies can be found at the north and south poles and they are cold and dry because of where it is located, which is at high latitudes. This type of wind system forms when cool air, at the poles, and then transfers to the equator. Polar Easterlies are located 60-90 degrees latitude in both the southern and northern hemispheres.

Tropical Easterlies- Tropical Easterlies take direction in an east to west flow because of the rotation of the Earth. As air from the equator rises, it gets warmer and when it cools down, it comes back down to the equator. Tropical easterlies are located 0-30 degrees latitude in both hemispheres.

Prevailing Westerlies- Prevailing Westerlies are located in the 30-60 degrees latitude in the northern and southern hemispheres. They blow from west to east and occur in the clement part of the Earth.

Intertropical Convergence Zone (ITCZ)- The Intertropical Convergence Zone is also known as Equatorial Convergence Zone or the Intertropical Front. It forms when southest and northeast trade winds converge in a low pressure zone, near the equator. It usually appears as a band of clouds and comes with thunderstorms, which are short but produce extreme amounts of rain.



Horse Latitudes- Horse latitudes, also known as the subtropical high, are about 30-35 degrees north and south of the equator. Horse latitudes is a region where there is weak winds because of high pressure and decreasing dry air.The orgin of the name Horse latitudes is uncertain but it is said that ships that needed wind power couldn't move on the water and the sailors threw the horses and cattle over the ship to save on provisions.

Trade Winds- Trade winds blow from the horse latitudes to the low pressure of the ITCZ. Trade winds get its name from its capability of blowing trade ships across the ocen, very quickly. In the northern hemisphere, the winds blow from the northeast, which is called the Northeast Trade winds. In the Southern hemisphere, the trade winds blow from the southeast, and surprisingly, they're called the Southeast Trade Winds.

Doldrums- Doldrums is the same thing as the Intertropical Convergence Zone, it's just a different name for it. This name originated from some sailor who noticed the stillness in the rising air and called it the "doldrums", which means depression or despondency. Like I've stated earlier, it takes place 5 degrees north and south of the equator the equator and between the two belts of trade winds. When the trade winds converge, it produces convectional storms.

Main Parts of a Wind Turbine:

5.10. BASIC COMPONENTS OF WIND ENERGY CONVERSION SYSTEM (WECS)

Fig. 5.2 shows the block diagram of basic components of a wind energy conversion systems.

— **Wind turbines** (Aeroturbines) *convert* the energy of moving air into *rotary mechanical energy*. These turbines requires pitch and yaw controls for proper operation.

— A **mechanical interface** consisting of a *step up gear* and a suitable *coupling* transmits the rotary mechanical to an **electrical generator.** The output of this generator is connected to the road or power grid as the application demands.

— A **controller** serves purposes of sensing: (*i*) Wind speed, (*ii*) Wind direction, shafts speed and torques at one or more points, (*iii*) Output power and generator

temperature as necessary, (*iv*) Appropriate control signals for matching the electrical output to the wind energy input, and (*v*) Protect the system from extreme conditions brought about by strong winds, electrical faults etc.

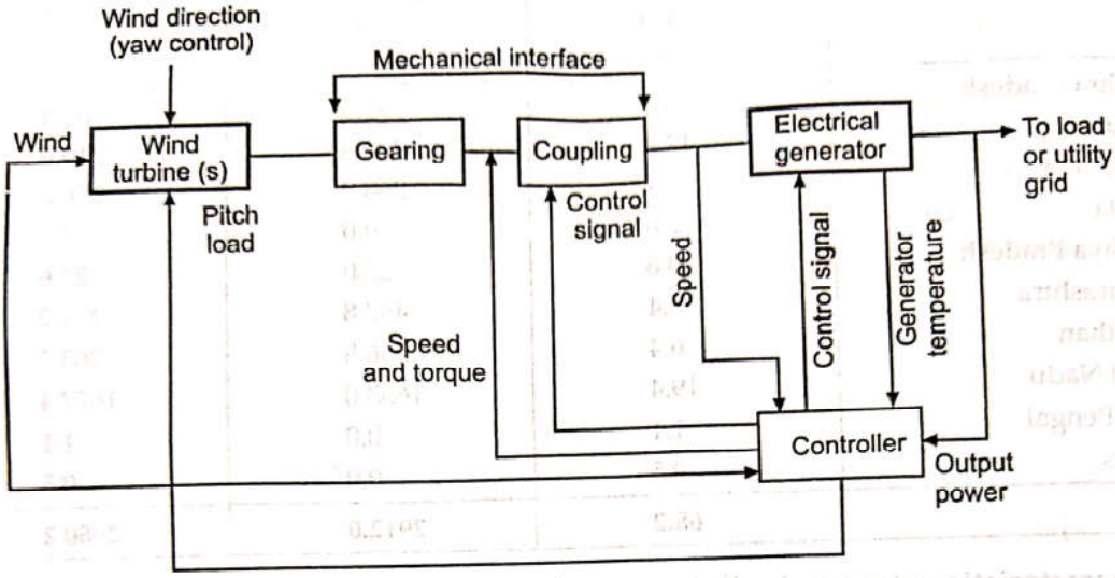
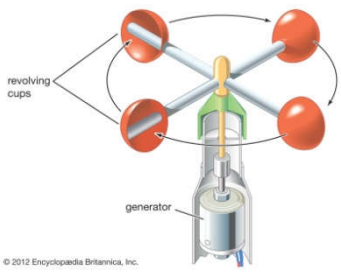


Fig. 5.2. Basic components of a wind energy conversion system (WECS).

Weather vane:



A **weather vane**, **wind vane**, or **weathercock** is an instrument used for showing the direction of the wind. It is typically used as an architectural ornament to the highest point of a building. The word *"vane"* comes from the Old English word *"fana"* meaning "flag". Although partly functional, wind vanes are generally decorative, often featuring the traditional cockerel design with letters indicating the points of the compass. Other common motifs include ships, arrows and horses. Not all weather vanes have pointers. When the wind is sufficiently strong, the head of the arrow or cockerel (or equivalent depending on the chosen design) will indicate the direction from which the wind is blowing.



Anemometer: device for measuring the speed of airflow in the atmosphere, in wind tunnels, and in other gas-flow applications. Most widely used for wind-speed measurements is the revolving-cup electric anemometer, in which the revolving cups drive an electric generator. The output of the generator operates an electric meter that is calibrated in wind speed. The useful range of this device is approximately from 5 to 100 knots. A propeller may also be used to drive the electric generator, as in the propeller anemometer. In another type of wind-driven unit, revolving vanes operate a counter, the revolutions being timed by a stopwatch and converted to airspeed. This device is especially suited for the measurement of low airspeeds.

Site Selection Considerations: This is a list of things to consider when selecting sites for installing wind monitoring devices and wind generators. Site selection will depend on a number of factors including the general terrain and wind flow characteristics of an area and the proximity to the location of intended use. For more detailed information, check the references listed below.

Considerations:

1.Wind Characteristics:

Ideal sites are generally located in areas with good exposure to the prevailing wind, away from structures, terrain or vegetation that might alter the wind or introduce excessive turbulence. For wind measurement, sites that represent a wide area are ideal in order to estimate the wind resource over as wide an area as possible. Vegetation will often show signs of "flagging" if wind is present in sufficient amounts. Proximity to End Use: The costs associated with wind energy grow with increased distance to where the energy might be used. A windy site close to transmission lines or close to a pumping location might be most appropriate.

2.Terrain and Land Use:

Consider the amount of land available, how this land is currently used, it's proximity to other uses such as roads, houses, towns or parks. Avoid potential problems by considering your neighbors and the public in this process. Site Accessibility: To install a monitoring tower or a wind turbine and to provide routine maintenance it will be necessary to get equipment to the site. Accessibility may be important. It may also be useful to have cell phone coverage at the site to obtain help with maintenance issues that might arise.

The following characteristics are important in considering a wind turbine site, and are examined in this

A. Predicted Wind Resource

B. Noise

C. Environmental Issues and Permitting

D. Proximity to Airports

E. Wind Turbine Component Transportation & Access

F. Distance to Transmission/Distribution Lines for Power Distribution

G. Net-metering

H. Production Estimates for Selected Turbines

Betz's law: It calculates the maximum power that can be extracted from the wind, independent of the design of a wind turbine in open flow. It was published in 1919, by the German physicist Albert Betz. The law is derived from the principles of conservation of mass and momentum of the air stream flowing through an idealized "actuator disk" that extracts energy from the wind stream. According to Betz's law, no turbine can capture more than 16/27 (59.3 percent) of the kinetic energy in wind. The factor 16/27 (0.593) is known as Betz's coefficient. Practical utility-scale wind turbines achieve at peak 75% to 80% of the Betz limit. The Betz limit is based on an open disk actuator; if a diffuser is used to collect additional wind flow and

direct it through the turbine, more energy can be extracted. However, such shrouded turbines are costly to build in utility-scale units because of the extra structure required.

5.13. TERMS AND DEFINITIONS

1. **Aerodynamics.** It is the branch of science which *deals with air and gases in motion and their mechanical effects.*
2. **Airfoil or aerofoil.** A *streamlined air surface designed for air* to flow around it in order to produce *low drag* and *high lift forces.*
3. **Angle of attack.** It is the angle between the relative air flow and the closed of the air foil (Fig 5.3).

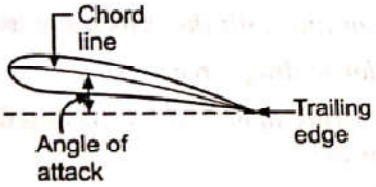


Fig 5.3. Angle of attack

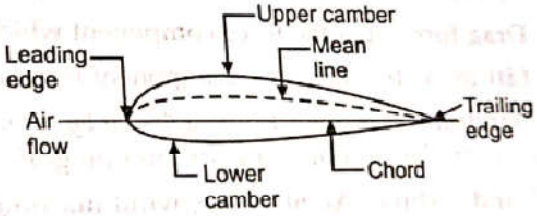


Fig 5.4. Air foil showing edges, camber and chord.

4. **Blade.** An important part of a wind turbine that *extracts wind energy.*
5. **Leading edge.** It is the front edge of the blade that *faces towards the direction of flow* (Fig. 5.4).
6. **Trailing edge.** It is the rear edge of the blade that *faces away from the direction of wind flow* (Fig. 5.4).
7. **Mean line.** A line that is *equidistant* from the upper and lower surfaces of the air foil (Fig. 5.4).
8. **Camber.** It is the *maximum distance between the mean line and the chord line, which measures the curvature of the airfoil.*
9. **Rotor.** It is the *primary part* of the wind turbine that *extracts energy* from the wind. It *constitutes the blade-and-hub assembly.*
10. **Hubs.** Blades are fixed to a hubs which is a *central solid part of the turbine.*
11. **Pitch angle.** It is the *angle between the direction of wind and the direction perpendicular to the planes of blades.*

12. **Pitch control.** It is the *control of pitch angle by turning the blades or blade tips* [Fig. 5.5 (*a*)].
13. **Yaw control.** It is the *control for orienting (steering) the axis of wind turbine in the direction of wind* [Fig. 5.5 (*b*)].
14. **Teethering.** It is see-saw like swinging motion with hesitation between two alternatives. The *plane of wind turbine wheel is swung in inclined position at higher wind speeds by teethering control* [Fig. 5.5 (*b*)].

Pitch control

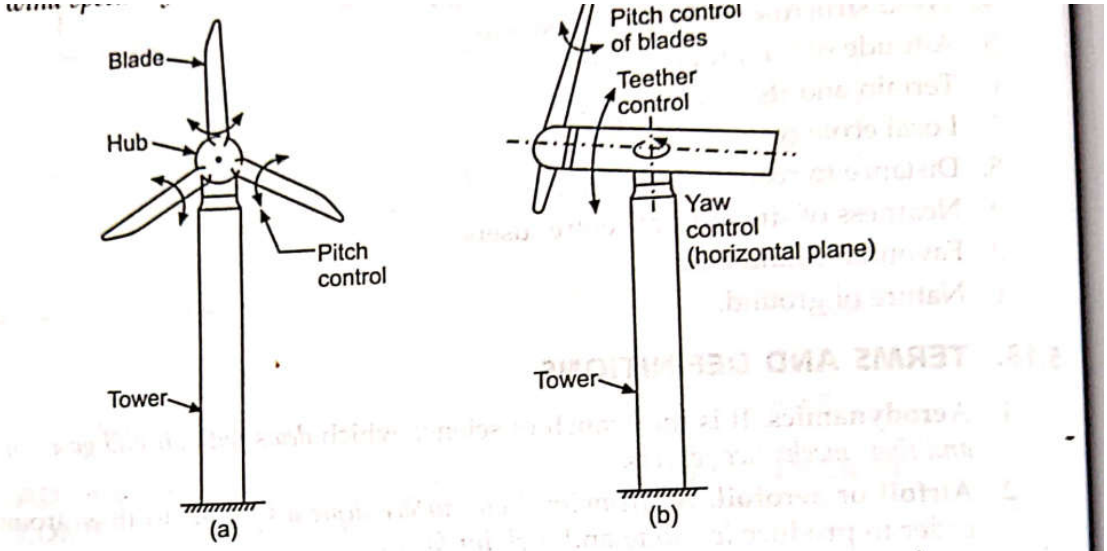


Fig. 5.5. Controls in wind–turbines: Pitch control; Yaw control; Teether control.

15. **Solidity.** *It is ratio of blade area to the swept area* (area covered by the rotating rotor).
16. **Drag force.** It is the force component which is *in line with the velocity of wind.*
17. **Lift force.** It is the force component *perpendicular to drag force.*
18. **Windmill.** It is the *machinery driven by the wind acting upon sails* used chiefly in flat districts for grinding of corn, pumping of water etc.

Wind turbine (Aeroturbine, wind machine). It is a machine which *converts wind power into rotary mechanical power.* A wind turbine has aerofoil blades mounted on the rotor. The wind drives the rotor and produces rotary mechanical energy.

5.14. LIFT AND DRAG–THE BASIS FOR WIND ENERGY CONVERSION

The extraction of power, and hence energy, from the wind depends on creating certain forces and applying them to rotate (or to translate) a mechanism.

Following are the *two primary mechanisms for producing* forces from the wind: Refer to Fig. 5.6

(*i*) Lift force (F_L), (*ii*) Drag force (F_D).

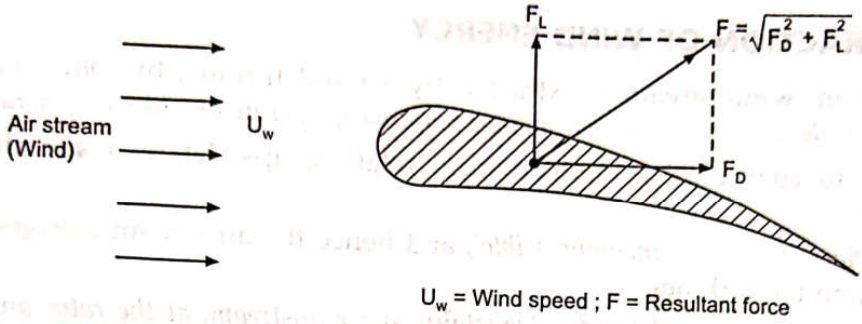


Fig. 5.6. Lift and drag on an airfoil.

Lift force. The component of force at *right angles* to the direction of air stream on the airfoil is called the *lift force* (F_L) .

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

— When air stream approaches the airfoil along the axis of symmetry, the force acting on the body is only the drag force, in the direction of flow and there is *no lift force. The production of lift force requires asymmetry of flow while drag force exists always. It is possible to create drag without lift but impossible to create lift without drag.*

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5.15. EXTRACTION OF WIND ENERGY

Energy from wind stream is extracted by a wind turbine, by *converting the kinetic energy (K.E.) of the wind to rotational motion required to operate an electric generate.*

In order to compute the mathematical relationships, let us make the following assumptions:

1. The *flow of wind is 'incompressible'*, and hence the air stream *diverges* as it passes through the turbines
2. The *mass flow rate of wind is 'constant'* at *far upstream, at the rotor and at far down stream.*

Let,

p = Atmospheric wind pressure,
p_{us} = Pressure on *upstream* of wind turbine,
p_{ds} = Pressure on *downstream* of wind turbine,
U_w = Atmospheric wind velocity,
$(U_w)_{us}$ = Velocity of wind upstream of wind turbine,
$(U_w)_{bl}$ = Velocity of wind at blades,
$(U_w)_{ds}$ = Velocity of wind downstream of wind turbine before the wind front reforms and regains the atmospheric level,
A_{bl} = Area of blades,
$\dot{m}$ = Mass flow rate of wind, and
ρ = Density of air.

The kinetic energy of wind stream passing through the turbine rotor is given by:

$$\text{K.E.} = \frac{1}{2}\dot{m}(U_w)^2_{bl} \qquad ...(5.5)$$

And,

$$\dot{m} = \rho A_{bl}(U_w)_{bl}$$

$\therefore$

$$\text{K.E.} = \frac{1}{2}\rho A_{bl}(U_w)_{bl} \times (U_w)^2_{bl} = \frac{1}{2}\rho A_{bl}(U_w)^3_{bl}$$

The force on the rotor disc, F is given as:

$$F = (p_{us} - p_{ds})A_{bl} \qquad ...(5.6)$$

Also,

$$F = \dot{m}[(U_w)_{us} - (U_w)_{ds}] \qquad ...(5.7)$$

[momentum per unit time from upstream to downstream winds]

Applying Bernoulli's equation to upstream and downstream sides, we get:

$$p + \frac{1}{2}\rho(U_w)^2_{us} = p_{us} + \frac{1}{2}\rho(U_w)^2_{bl} \qquad ...(5.8)$$

and,

$$p_{ds} + \frac{1}{2}\rho(U_w)^2_{bl} = p + \frac{1}{2}\rho(U_w)^2_{ds} \qquad ...(5.9)$$

Solving the above equations, we obtain:

$$p_{us} - p_{ds} = \frac{1}{2}\rho\left[(U_w)^2_{us} - (U_w)^2_{ds}\right] \qquad ...(5.10)$$

Equating Eqns. (5.6 and 5.7), we get:

$$(p_{us} - p_{ds})\,A_{bl} = \dot{m}[(U_w)_{us} - (U_w)_{ds}] = \rho A_{bl}\,(U_w)_{bl}\,[(U_w)_{us} - (U_w)_{ds}] \qquad ...(5.11)$$

Solving Eqns. (5.10 and 5.11), we get:

$$\frac{1}{2}\rho\left[(U_w)^2_{us} - (U_w)^2_{ds}\right] = \rho(U_w)_{bl}\,[(U_w)_{us} - (U_w)_{ds}]$$

or,

$$(U_w)_{bl} = \frac{[(U_w)_{us} + (U_w)_{ds}]}{2} \qquad ...(5.12)$$

In a wind turbine system "*Speed flow work*", W, is equal to the difference in kinetic energy between upstream and downstream of turbine for unit mass flow, $\dot{m} = 1$. Therefore,

$$W = (K.E.)_{us} - (K.E.)_{ds}$$

or,
$$W = \frac{1}{2}\left[(U_w)_{us}^2 - (U_w)_{ds}^2\right] \quad ...(5.13)$$

The *power output* 'P' of wind turbine (rate of doing work) is given as:

$$P = \frac{1}{2}\dot{m}\left[(U_w)_{us}^2 - (U_w)_{ds}^2\right] = \dot{m}\left[\frac{(U_w)_{us}^2 - (U_w)_{ds}^2}{2}\right]$$

$$= \rho A_{bl}\left[\frac{(U_w)_{us} + (U_w)_{ds}}{2}\right]\left[\frac{(U_w)_{us}^2 - (U_w)_{ds}^2}{2}\right]$$

$$\left[\because \dot{m} = \rho A_{bl}\,(U_w)_{bl} = \rho A_{bl}\left\{\frac{(U_w)_{us} + (U_w)_{ds}}{2}\right\}\right] \quad ...\text{using Eqn. (5.12)}$$

or,
$$P = \frac{1}{4}\rho A_{bl}\left[(U_w)_{us} + (U_w)_{ds}\right]\left[(U_w)_{us}^2 - (U_w)_{ds}^2\right] \quad ...(5.14)$$

To get P_{max} (maximum turbine output), differentiating Eqn. (5.14) w.r.t. $(U_w)_{ds}$ and equating to zero, we get:

$$\frac{dP}{d(U_w)_{ds}} = 3(U_w)_{ds}^2 + 2(U_w)_{us}\,(U_w)_{ds} - (U_w)_{us}^2 = 0$$

The above quadratic equation has the following *two solutions.*

$$(U_w)_{ds} = \frac{1}{3}(U_w)_{us} \quad \text{and} \quad (U_w)_{ds} = (U_w)_{us}$$

For power generation $(U_w)_{ds} < (U_w)_{us}$, so we can have only ...(5.14 (*a*))

$$(U_w)_{ds} = \frac{1}{3}(U_w)_{us}$$

Substituting Eqn. (5.14 (*a*)) in Eqn. (5.14), we get:

$$P_{max} = \frac{1}{4}\rho A_{bl}\left[(U_w)_{us} + \frac{1}{3}(U_w)_{us}\right]\left[(U_w)_{us}^2 - \left\{\frac{1}{3}(U_w)_{us}\right\}^2\right]$$

$$= \frac{1}{4}\rho A_{bl}\left[\frac{4}{3}(U_w)_{us}\right]\left[\frac{8}{9}(U_w)_{us}^2\right]$$

or,
$$P_{max} = \frac{8}{27}\rho A_{bl}\,(U_w)_{us}^3 \quad ...(5.15)$$

$$= \frac{16}{27}\left[\frac{1}{2}\rho A_{bl}\,(U_w)_{us}^3\right]$$

$$= 0.593\left[\frac{1}{2}\rho A_{bl}\,(U_w)_{us}^3\right]$$

Total power in the wind, stream, $P_{total} = \frac{1}{2}\rho A_{bl}\,(U_w)_{us}^3$ ...(5.15 (*a*))

$\therefore$
$$P_{max} = 0.593\,P_{total}$$

Now, "*coefficient of power*", $C_P = \frac{P_{max}}{P} = 0.593$ ...(5.16)

The factor **0.593** is known as **Blitz limit.**

Tip Speed Ratio:



The **Tip Speed Ratio** (often known as the **TSR**) is of vital importance in the design of **wind turbine generators**. If the **rotor** of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. Alternatively if the rotor turns too quickly, the blurring blades will appear like a solid wall to the wind. Therefore, wind turbines are designed with optimal tip speed ratios to extract as much power out of the wind as possible.

When a **rotor blade** passes through the air it leaves **turbulence** in its wake. If the next blade on the spinning rotor arrives at this point while the air is still turbulent, it will not be able to extract power efficiently from the wind. However if the rotor span a little more slowly the air hitting each turbine blade would no longer be turbulent. Therefore the tip speed ratio is also chosen so that the blades do not pass through too much turbulent air.

Tip Speed Ratio Calculations

The tip speed ratio is given by dividing the speed of the tips of the turbine blades by the speed of the wind – for example if a 20 mph wind is blowing on a wind turbine and the tips of its blades are rotating at 80 mph, then the tip speed ratio is 80/20 = 4.

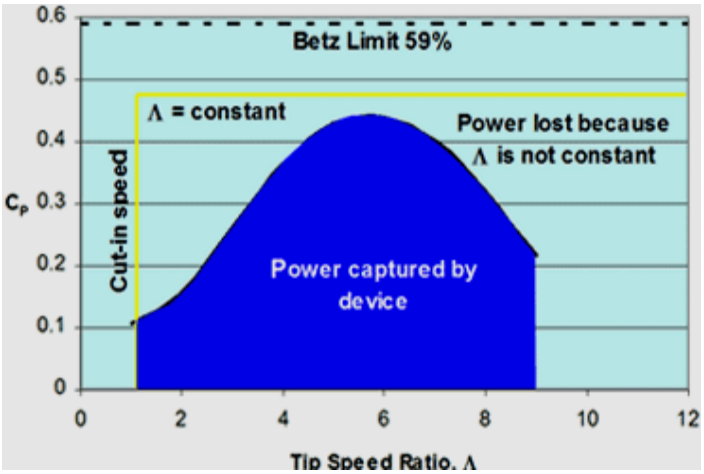
Optimum Tip Speed Ratio

The optimum **tip speed ratio** depends on the number of blades in the **wind turbine rotor**. The fewer the number of blades, the faster the wind turbine rotor needs to turn to extract maximum power from the wind. A two-bladed rotor has an optimum tip speed ratio of around 6, a three-bladed rotor around 5, and a four-bladed rotor around 3.

Highly efficient aerofoil **rotor blade design** can increase these optimum values by as much as 25-30% increasing the speed at which the rotor turns and therefore generating more power. A well designed typical three-bladed rotor would have a **tip speed ratio** of around 6 to 7.

If the tip speed ratio is too low – for example if poorly designed rotor blades are used – the wind turbine will tend to slow and/or **stall**. If the tip speed ratio is too high the turbine will spin very fast through turbulent air, power will not be optimally extracted from the wind, and the wind turbine will be highly stressed and at risk of structural failure.

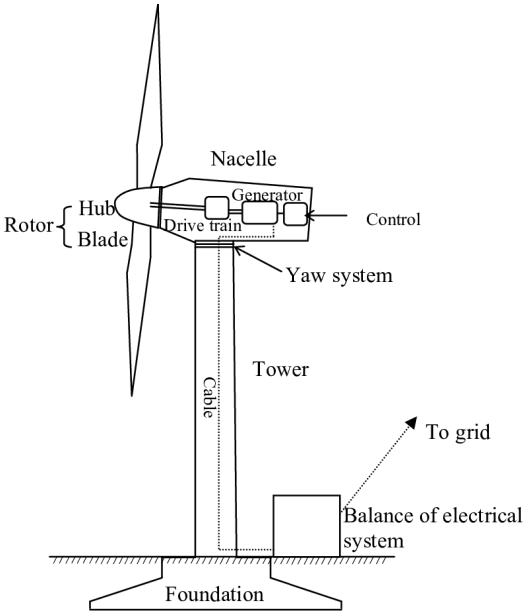
Different types of turbine have completely different optimal TSR values – for example a **Darrieus wind turbine** is a vertical axis (VAWT) design with aerofoil blades which generate aerodynamic *lift* and therefore the TSR can be high, but a **Savonius wind turbine** which is also a VAWT is a *drag* design and so the TSR will always be less than 1 – i.e. it cannot spin faster than the wind hitting it.



Pictured above is a graph showing the **power coefficient** for different values of **tip speed ratio** for a two-bladed rotor. The theoretical maximum efficiency of a wind turbine generator is given by the **Betz Limit** of around 59%. With a tip speed ratio (TSR) of just under 6, the power coefficient for this example turbine is 0.45 (= 45%).

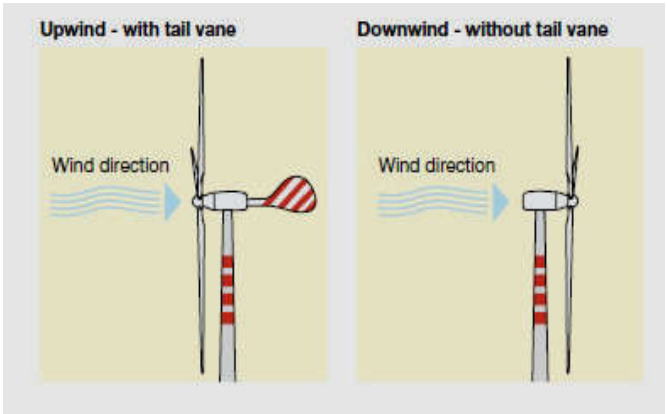
Types of Wind Turbines:

1. Horizontal Axis Wind Turbine:



Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us think of when we think of a wind turbine. A HAWT has a similar design to a windmill, it has blades that look like a propeller that spin on the horizontal axis.

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbines are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.



Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount. Downwind machines have been built, despite the problem of turbulence,

because they don't need an additional mechanism for keeping them in line with the wind. Additionally, in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines.

HAWT Advantages

- The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increase by 20% and the power output by 34%.
- High efficiency, since the blades always move perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring airfoil surfaces to backtrack against the wind for part of the cycle. Backtracking against the wind leads to inherently lower efficiency.

HAWT Disadvantages

- Massive tower construction is required to support the heavy blades, gearbox, and generator.
- Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position.
- Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.
- Downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower).
- HAWTs require an additional yaw control mechanism to turn the blades toward the wind.
- HAWTs generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself.
- Cyclic Stresses & Vibration – When the turbine turns to face the wind, the rotating blades act like a gyroscope. As it pivots, gyroscopic precession tries to twist the turbine into a forward or backward somersault. For each blade on a wind generator's turbine, force is at a minimum when the blade is horizontal and at a maximum when the blade is vertical. This cyclic twisting can quickly fatigue and crack the blade roots, hub and axle of the turbines.

Vertical Axis Wind Turbines (VAWT)

Vertical axis wind turbines, as shortened to VAWTs, have the main rotor shaft arranged vertically. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on sites where the wind direction is highly variable or has turbulent winds.

With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT is it generally creates drag when rotating into the wind.

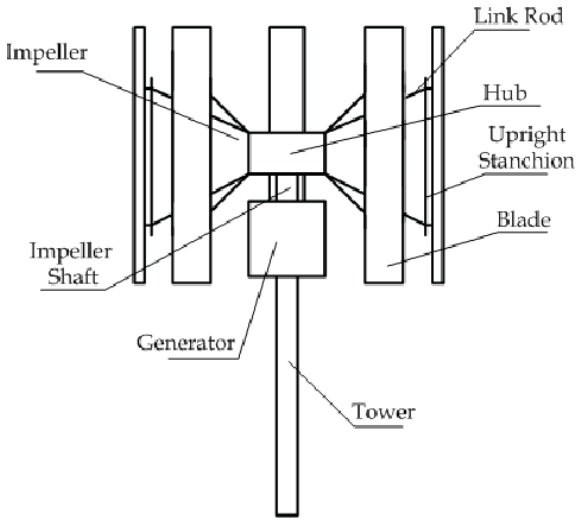


Fig 1: Components of Vertical axis wind turbine

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof, thus doubling the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence.

Traditional VAWT Advantages

- They can produce electricity in any wind direction.
- Strong supporting tower in not needed because generator, gearbox and other components are placed on the ground.
- Low production cost as compared to horizontal axis wind turbines.
- As there is no need of pointing turbine in wind direction to be efficient so yaw drive and pitch mechanism is not needed.
- Easy installation as compared to other wind turbine.
- Easy to transport from one place to other.
- Low maintenance costs.
- They can be installed in urban areas.
- Low risk for human and birds because blades moves at relatively low speeds.
- They are particularly suitable for areas with extreme weather conditions, like in the mountains where they can supply electricity to mountain huts.

Traditional VAWT Disadvantages

- As only one blade of the wind turbine works at a time, efficiency is very low compared to HAWTS.
- They need an initial push to start; this initial push that to make the blades start spinning on their own must be started by a small motor.
- When compared to horizontal axis wind turbines they are very less efficient because of the additional drag created when their blades rotate.

- They have relative high vibration because the air flow near the ground creates turbulent flow.
- Because of vibration, bearing wear increases which results in the increase of maintenance costs.
- They can create noise pollution.
- VAWTs may need guy wires to hold it up (guy wires are impractical and heavy in farm areas).

Darrieus Vertical-Axis Wind Turbine

Figure shows a typical Darrieus vertical-axis wind turbine. The physical appearance of the Darrieus wind turbine looks like a large egg beater.



The blade is mounted on a large monopole, and the generator is located at the bottom of the blade. The top of the pole has a number of guy wires that hold the pole in place when the force of the wind causes the blade to rotate.
Figure 3 shows the internal parts of the Darrieus wind turbine.

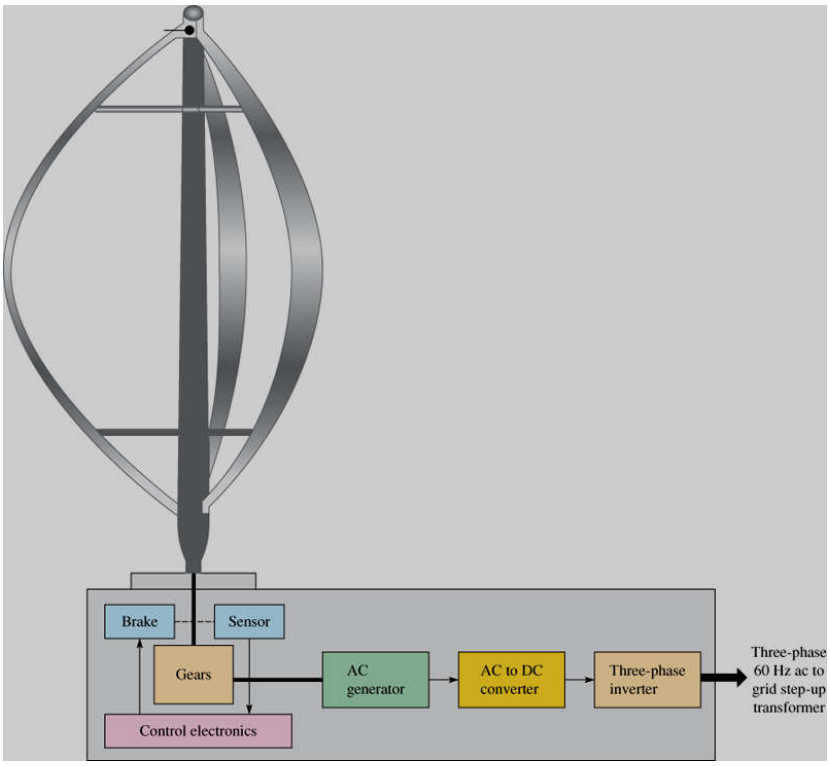
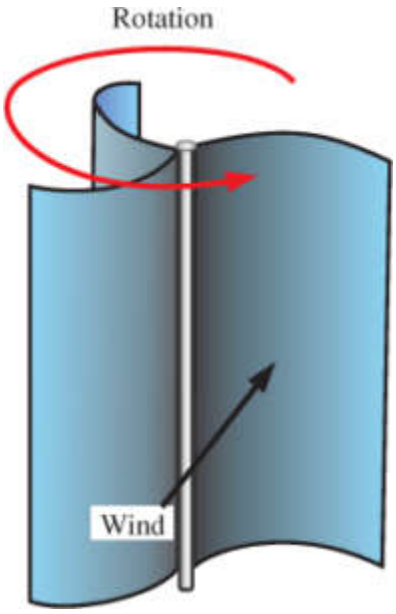


Figure 3 **Internal Parts of the Darrieus Wind Turbine**

When the Darrieus blade is operating, it is moving through the air in a circular path. The oncoming airflow generates a net force pointing obliquely forward and is projected inward past the turbine axis at a certain distance, giving a positive torque to the shaft. This helps the blade to rotate in the direction it is already travelling.
The action of this blade is similar to the aerodynamic principles used in helicopters, and it makes the operation of this type of wind turbine quieter than a horizontal-axis wind turbine of the same size. Because there is less friction on the blade, the blade can rotate with equal torque regardless of the wind's direction.
A problem with the Darrieus wind turbine is that it is not self-starting, so it uses its generator as a motor to get the rotor started. As the wind increases the blade speed, the power to the motor is turned off and it begins working as a generator.

Darrieus wind turbines were installed on early wind farms, but most of them have been taken out of use in commercial applications because they are not as efficient as HAWTs and they require constant maintenance.



Savonius Vertical-Axis Wind Turbine

The Savonius vertical-axis wind turbine uses cups, called scoops, instead of blades to capture wind power. Figure shows an example of a Savonius vertical-axis wind turbine. When the wind blows, it creates a positive force in the scoop and a negative force on the back side of the scoop. This difference in force pushes the turbine around. In a typical Savonius turbine, the wind comes from the front of the cylinder, causing rotation. However, wind also strikes the back of the other scoops, tending to slow the rotor.

Wind Farms:

wind farm or **wind park**, also called a **wind power station** or **wind power plant**[1] is a group of wind turbines in the same location used to produce electricity. A large wind farm may consist of several hundred individual wind turbines and cover an extended area of hundreds of square miles, but the land between the turbines may be used for agricultural or other purposes. A wind farm can also be located offshore.

Many of the largest operational onshore wind farms are located in China, India, and the United States. Wind farms tend to have much less impact on the environment than many other power stations. Onshore wind farms are also criticized for their visual impact and impact on the landscape, as typically they need to take up more land than other power stations and need to be built in wild and rural areas, which can lead to "industrialization of the countryside", habitat loss, and a drop in tourism. Critics have linked wind farms to adverse health effects (see wind turbine syndrome). Wind farms have also been criticized for interfering with radar, radio and television reception.

Design and location:

The location is critical to the success of a wind farm. Conditions contributing to a successful wind farm location include: wind conditions, access to electric transmission, physical access, and local electric prices.

The faster the average wind speed, the more electricity the wind turbine will generate, so faster winds are generally economically better for wind farm developments. The balancing factor is that strong gusts and high turbulence require stronger more expensive turbines, otherwise they risk damage. The average power in the wind is not proportional to the average wind speed, however. For this reason, the ideal wind conditions would be strong but consistent winds with low turbulence coming from a single direction.

Mountain passes are ideal locations for wind farms under these conditions. Mountain passes channel wind blocked by mountains through a tunnel like pass towards areas of lower pressure and flatter land

How do offshore and onshore wind farms work?

First of all, it's useful to go back to basics and explain how a wind turbine works. As the wind turns the carbon-fibre blade on the unit, a motor turns, which turns **kinetic energy into electricity**. This energy is transferred to the gearbox, which converts the slow speed of the spinning blades into higher-speed rotary motion—turning the drive shaft quickly enough to power the electricity generator. Wind farms can be based onshore (on land) or offshore (sea or freshwater), with key differences between the two. Below, we take a look at some of the advantages and disadvantages of each.

What is offshore wind?

Offshore wind power, sometimes referred to as offshore wind energy, is when wind over open water, usually in the ocean, is used to generate power. Wind farms are constructed in bodies of water where higher wind speeds are available.

Advantages of offshore wind:

- Windmills can be built that are larger and taller than their onshore counterparts, allowing for more energy collection.

- They tend to be far out at sea, meaning they are much less intrusive to neighbouring countries, allowing for larger farms to be created per square mile.

- Typically out at sea, there is a much higher wind speed/force allowing for more energy to be generated at a time.

- Wind farms have a relatively negative impact on the environment. They are not built in shipping lanes, fishing areas or in a delicate environment.

- There are no physical restrictions such as hills or buildings that could block the wind flow.

Disadvantages of offshore wind:

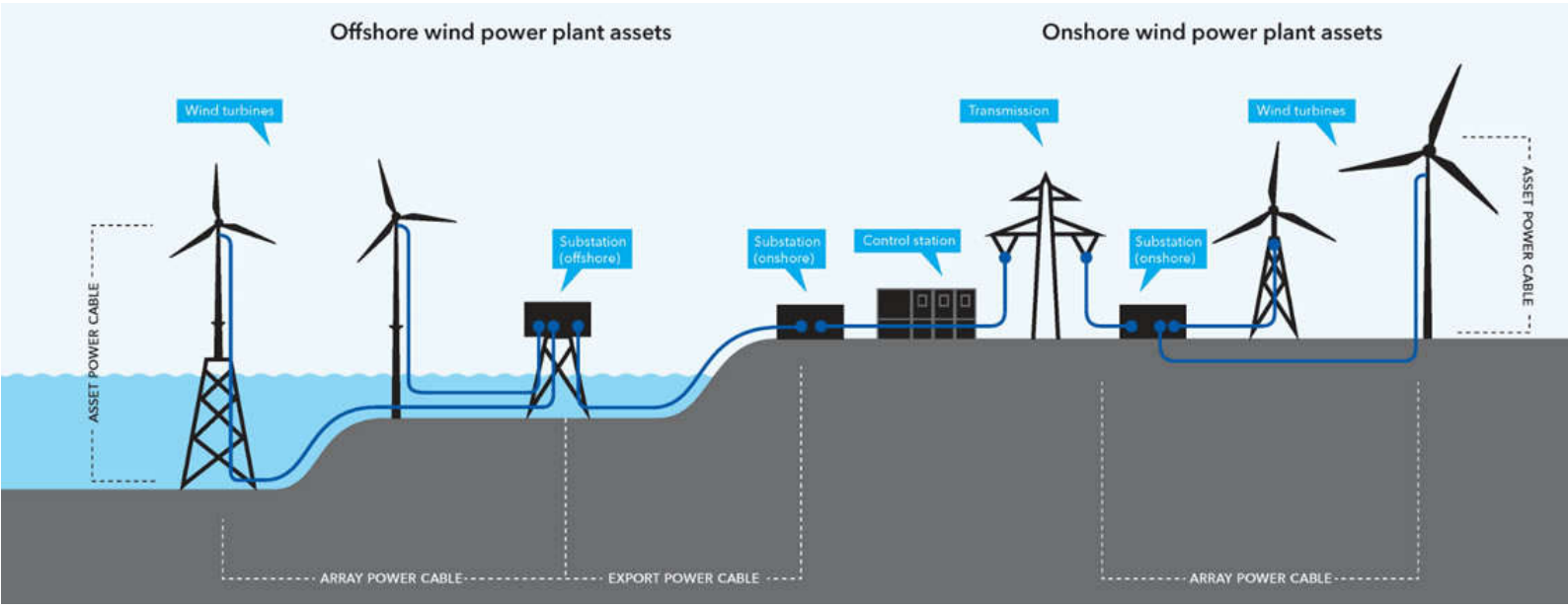
- The biggest disadvantage of an offshore wind farm is the cost. OFF shore wind farms can be expensive to build and maintain and because of their hard to reach locations, they are susceptible to damage from very high-speed winds during storms or hurricanes which is expensive to repair.

- The effect of offshore wind farms on marine life and birds are not yet fully understood.

- Offshore wind farms that are built closer to coastlines (generally within 26 miles) can be unpopular with residents as it can affect property values and tourism.

What is onshore wind?

Onshore wind power refers to turbines that are located on land and use wind to generate electricity. They are generally located in areas where there is low conservation or habitat value.



Advantages of onshore wind:

- The cost of onshore wind farms is relatively cheap, allowing for mass farms of wind turbines.
- The shorter distance between the windmill and the consumer allows for less voltage drop off on the cabling.
- Wind turbines are very quick to install, unlike a nuclear power station, which can take over twenty years, a windmill can be built in a matter of months.

Disadvantages of onshore wind:

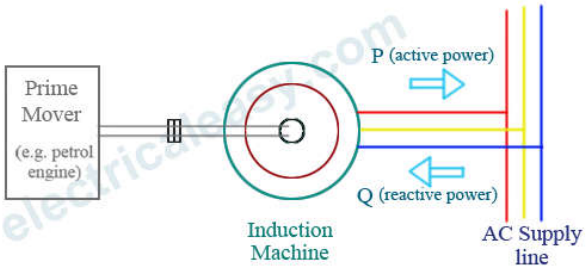
- One of the biggest issues of onshore wind farms is that many deem them to be an eyesore on the landscape.
- They don't produce energy all year round due to often poor wind speed or physical blockages such as buildings or hills.
- The noise that wind turbines create can be compared to as the same as a lawnmower often causing noise pollution for nearby communities.

Selection of generator (synchronous, induction):

Just like a DC Machine, a same induction machine can be used as an induction motor as well as an **induction generator**, without any internal modifications. Induction generators are also called as **asynchronous generators**. Before starting to explain **how an induction (asynchronous) generator works**. In an induction motor, the rotor rotates because of slip (i.e. relative velocity between the rotating magnetic field and the rotor). Rotor tries to catch up the synchronously rotating field of the stator but never succeeds. If rotor catches up the synchronous speed, the relative velocity will be zero, and hence rotor will experience no torque. *But what if the rotor is rotating at a speed more than synchronous speed?*

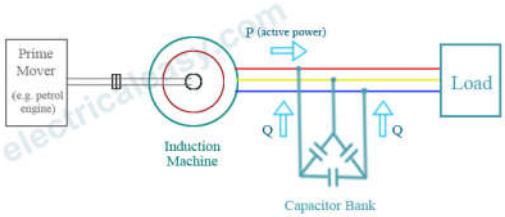
How Induction Generators Work?

- Consider, an AC supply is connected to the stator terminals of an induction machine. Rotating magnetic field produced in the stator pulls the rotor to run behind it (the machine is acting as a motor).
- Now, if the rotor is accelerated to the synchronous speed by means of a prime mover, the slip will be zero and hence the net torque will be zero. The rotor current will become zero when the rotor is running at synchronous speed.
- If the rotor is made to rotate at a speed more than the synchronous speed, the slip becomes negative. A rotor current is generated in the opposite direction, due to the rotor conductors cutting stator magnetic field.
- This generated rotor current produces a rotating magnetic field in the rotor which pushes (forces in opposite way) onto the stator field. This causes a stator voltage which pushes current flowing out of the stator winding against the applied voltage. Thus, the machine is now **working as an induction generator (asynchronous generator)**.



Induction generator is not a self-excited machine. Therefore, when running as a generator, the machine takes reactive power from the AC power line and supplies active power back into the line. Reactive power is needed for producing rotating magnetic field. The active power supplied back in the line is proportional to slip above the synchronous speed.

Self-Excited Induction Generator



It is clear that, an induction machine needs reactive power for excitation, regardless whether it is operating as a generator or a motor. When an induction generator is connected to a grid, it takes reactive power from the grid. But what if we want to use an induction generator to supply a load without using an external source (e.g. grid)?A capacitor bank can be connected across the stator terminals to supply reactive power to the machine as well as to the load. When the rotor is rotated at an enough speed, a small voltage is generated across the stator terminals due to residual magnetism. Due to this small generated voltage, capacitor current is produced which provides further reactive power for magnetization.

Applications of induction generators: Induction generators produce useful power even at varying rotor speeds. Hence, they are suitable in wind turbines. **Advantages:** Induction or **asynchronous generators** are more rugged and require no commutator and brush arrangement (as it is needed in case of synchronous generators).

One of the major **disadvantage of induction generators** is that they take quite large amount of reactive power.

3.14. TYPES OF WIND ENERGY SYSTEMS / POWER PLANTS

(i) Remote or off-grid wind power pants:

Areas which are remote but are blessed with good wind speed and frequency need a wind turbine which is maintenance free or low-maintenance for long period of time. These types of turbines are known as *remote wind power turbines* and they are specifically designed with these objectives in view. These power plants are used in situations in which remote or non-grid-connected power is needed but power must always be available, for example, to keep vaccines cold, or a rural clinic's lights on or communications equipment running continuously.

(ii) Small scale or Stand-alone wind turbines plants:

It is more suitable for small scale wind power such as domestic systems. The control of output is very important for efficient cost effective systems. Figure 3.15 shows the components and its arrangement for small scale domestic wind power system. One choice is to have little control so that the output is of variable voltage for use as heat or rectified power. Such a type of power supply is very useful.

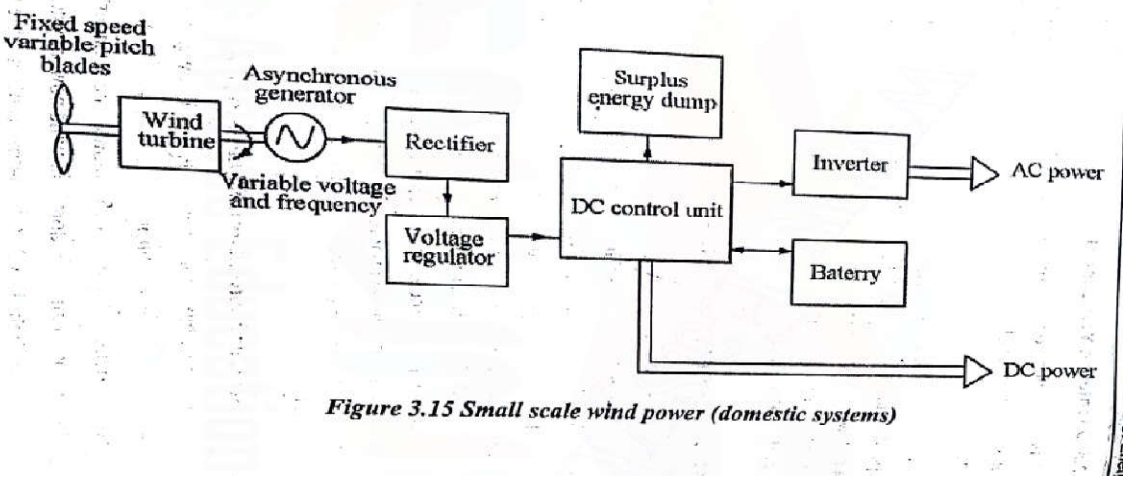


Figure 3.15 Small scale wind power (domestic systems)

The relatively small amount of power that usually has to be controlled at say 240 *V* / 50 *Hz* or 110 *V*/60 *Hz* can be obtained from batteries by inverters. However, it is preferred to have electricity at constant frequency. Mechanical control and pitch power control of wind turbines are generally used for constant frequency generation.

(iii) Medium scale wind turbines plants:

Medium scale wind power plants are used in variety of places such as community center, health clinic or school. The basic aim of the wind turbine is to be a diesel saver. The diesel generator supplies power in windless periods. A reasonable amount of diesel fuel could be saved with a control strategy and system architecture which allows in shutting down the diesel generator when the wind is sufficient to carry the load. In this case, there are two extreme modes of operation.

(a) Single-mode electricity supply distribution:

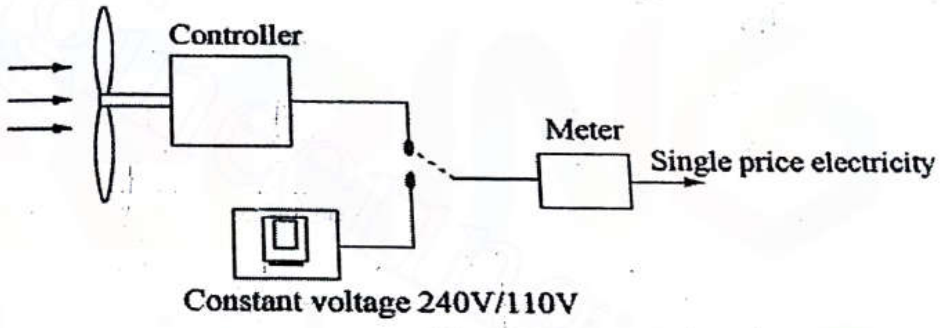


Figure 3.16 Single-mode supply of wind/diesel supply

It is usually a three-phase supply that takes single phase to domestic dwellings with a single set of distribution cables and the system operates in a single mode at fixed voltage. A 24-hr maintained supply without load-management control depends usually on diesel generation due to non-availability of wind. The diesel is either left on continuously or switched off when excessive wind blows. Generally, a large amount (over 70%) of the wind generated power is to be dumped into an outside resistor banks owing to the mismatch of supply and demand in windy conditions shown in Figure 3.16.

(b) Multiple-mode distribution:

In this case, every effort is made to use all wind-generated power. Economic electricity for many applications in windy conditions is offered. The economic service loads are automatically switched off to decrease the demand due to wind drop. Only the loads on the expensive supply are enabled to supply power by a diesel generator without availability of wind. The economic advantage of multiple mode operation is used at all times shown in Figure 3.17.

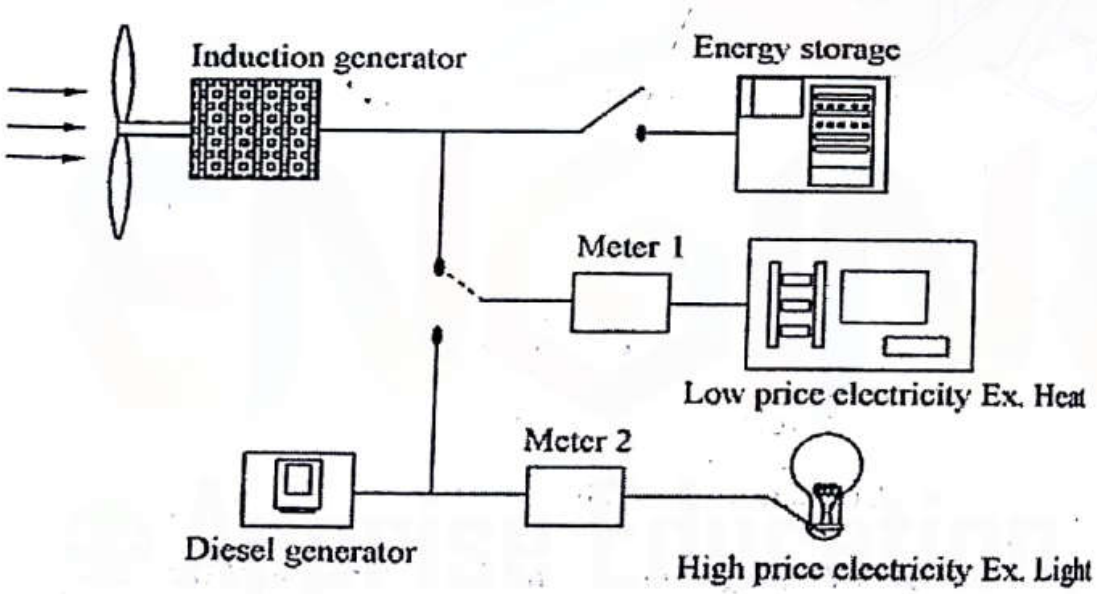


Figure 3.17 Multiple-mode supply of wind/diesel supply

Large and more costly turbines generally have geared with power trains for alternating current output. Also, they are actively focused into the wind. Direct drive generators and aero elastic blades for large wind turbines are being researched.

(iv) Hybrid wind power plants:

Wind is not fully reliable. So, we cannot depend on wind alone for generating power. A wind power plant is combined with some other renewable source of energy such as the sun or solar energy to get more efficiency. Such an arrangement is known as *hybrid arrangement* and it is useful in regions where there is lot of heat and wind.

During electricity generation from wind energy, more than one type of generator is used to avoid the fluctuation in power supply. Usually, a photovoltaic (solar) array, elements of passive solar heating and a back-up diesel generator are combined with wind turbines. During wind resource available period, the system might work as a renewable or single system to produce electricity. During peak period power demand, the hybrid system is mainly used in order to meet the demand. In addition, sometimes, the power system might add biomass, hydro or other generating sources in the hybrid system based on the local resource availability.

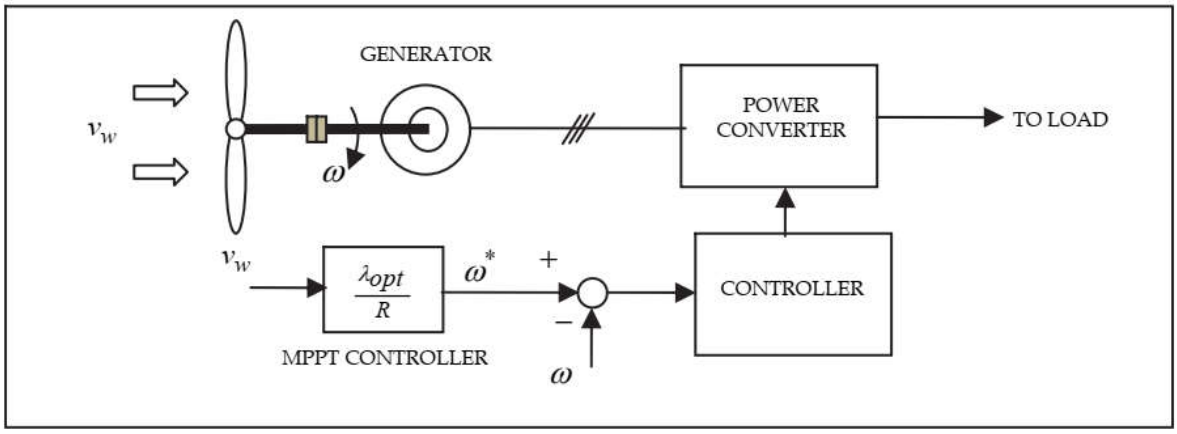
(v) Grid connected wind power plants:

This concept is similar to a hybrid system and the wind power plant is used in conjunction with a main grid which supplies the most of the power. The main purpose of the wind turbines is to supplement the energy supply for the grid whereas the main function in the hybrid system is to complement the energy supply.

Maximum power point tracking :

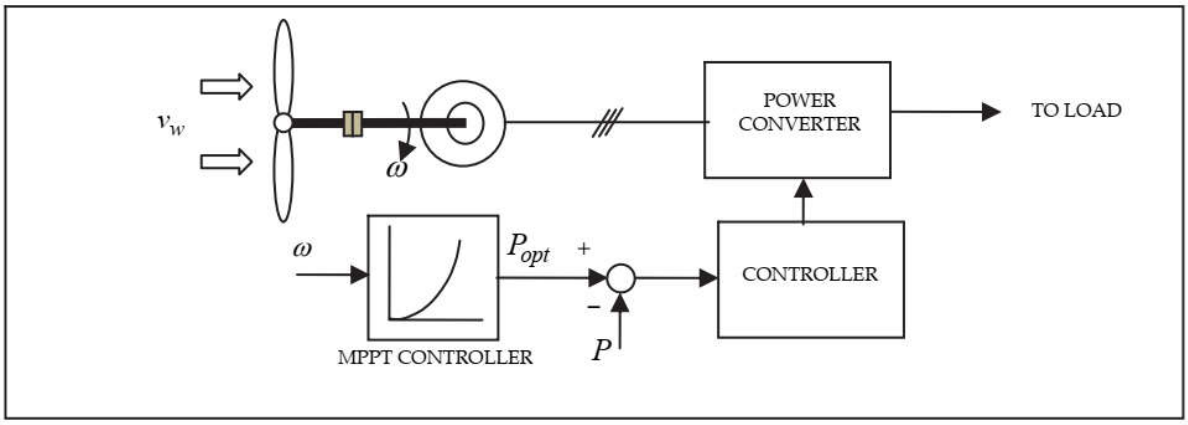
Wind generation system has been attracting wide attention as a renewable energy source due to depleting fossil fuel reserves and environmental concerns as a direct consequence of using fossil fuel and nuclear energy sources. Wind energy, even though abundant, variescontinually as wind speed changes throughout the day. Amount of power output from a WECS depends upon the accuracy with which the peak power points are tracked by the MPPT controller of the WECS control system irrespective of the type of generator used. The maximum power extraction algorithms researched so far can be classified into three main control methods, namely tip speed ratio (TSR) control, power signal feedback (PSF) control and hill-climb search (HCS) control.

The TSR control method regulates the rotational speed of the generator in order to maintain the TSR to an optimum value at which power extracted is maximum. This method requires both the wind speed and the turbine speed to be measured or estimated in addition to requiring the knowledge of optimum TSR of the turbine in order for the system to be able extract maximum possible power. Fig. shows the block diagram of a WECS with TSR control.



In PSF control, it is required to have the knowledge of the wind turbine's maximum power curve, and track this curve through its control mechanisms. The maximum power curves need to be obtained via simulations or off-line experiment on individual wind turbines. In this method, reference power is generated either using a recorded maximum power curve or using the mechanical power equation of the wind turbine where wind speed or the rotor speed is used as the input. Fig. shows the

block diagram of a WECS with PSF controller for maximum power extraction.



The HCS control algorithm continuously searches for the peak power of the wind turbine. It can overcome some of the common problems normally associated with the other two methods. The tracking algorithm, depending upon the location of the operating point and relation between the changes in power and speed, computes the desired optimum signal in order to drive the system to the point of maximum power. Fig.1shows the principle of HCS control and Fig.2 shows a WECS with HCS controller for tracking maximum power points.

