Unit - II

1 Wind energy conversion

Wind energy is energy from moving air, caused by temperature (and therefore pressure) differences in the atmosphere. Irradiance from the sun heats up the air, forcing the air to rise. Conversely, where temperatures fall, a low pressure zone develops. Winds (i.e. air flows) balance out the differences. Hence, wind energy is solar energy converted into kinetic energy of moving air.

Wind Energy Converters (WECs) - or short: wind turbines - capture the air flow by converting it into a rotational movement, which subsequently drives a conventional generator for electricity. Wind energy has been used for centuries to pump water and grinding. The industrial breakthrough for the generation of electricity, came in the 1980s.

Today, wind energy is the most mature of the renewable energy technologies apart from hydro. In 2010, the global installation might reach 200GW, up 5GW in 1995 - that equates to an annual growth rate of 27%.

2 Basic principles of wind energy conversion

2.1 The Nature of Wind

The circulation of air in the atmosphere is caused by the non-uniform heating of the earth's surface by the sun. The air immediately above a warm area expands, it is forced upward by cool, denser air which flows in from surrounding areas causing wind.

The nature of the terrain, the degree of cloud and the angle of the sun in the sky are all factors which influences this process.

In general, during the day the air above the land mass tends to heat up more rapidly than the air over water. In coastal regions this manifests itself in a strong onshore wind. At night the process is reversed because the air cools down more rapidly over the land and the breeze therefore blows off shore.

Despite the wind's intermittent nature, wind patterns at any particular site remain remarkably constant year by year. Average wind speeds are greater in hilly and costal area than they are well inland. The winds also tend to blow more consistently and with greater strength over the surface of the water where there is a less surface drag.

2.2 The Power in Wind

Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the energy and convert is into useful work. There are three factors determine the output power generated from the wind mill, they are

(1) The wind speed

(2) The cross section of wind swept by rotor, and

(3) The overall conversion efficiency of rotor, transmission system and generator or pump.

No device, however well-designed, can extract all of the wind's energy because the wind would have to be brought to a halt and this would prevent the passage of more air through the rotor. The most that is possible is for the rotor to decelerate to whole horizontal column of intercepted air to about one-third of its free velocity.

A 100% efficient aerogenerator would therefore only be able to convert up to a maximum of around 60% of the available energy in wind into mechanical energy.

A well-designed blades will typically extract 70% of the theoretical maximum, but losses incurred in the gear box, transmission system and generator or pump could decrease overall wind tubine efficiency to 35% or less.

2.3 Calculation of Power in the Wind

The power in the wind can be computed by using of Kinetics (Kinetic means relating to or resulting from motion). The wind mill works on the principle of converting Kinetic energy of the wind to mechanical energy.

We know that power is equal to energy per unit time. The energy available is the kinetic energy of the wind. The kinetic energy of any particle is equal to one half its mass times the square of its velocity.

i.e., Kinetic Energy of particle $= \frac{1}{2} mv^2$

Kinetic Energy of particle = ½ mv2

Where

M : Mass of particle (kg)

V : Velocity of particle (m/s)

The amount of air passing in unit time, through an area ‘A’, with velocity ‘V’ is A x V, and its mass ‘m’ is equal to its volume multiplied by its density ‘ρ’ of air.

i.e., $m = \rho AV$

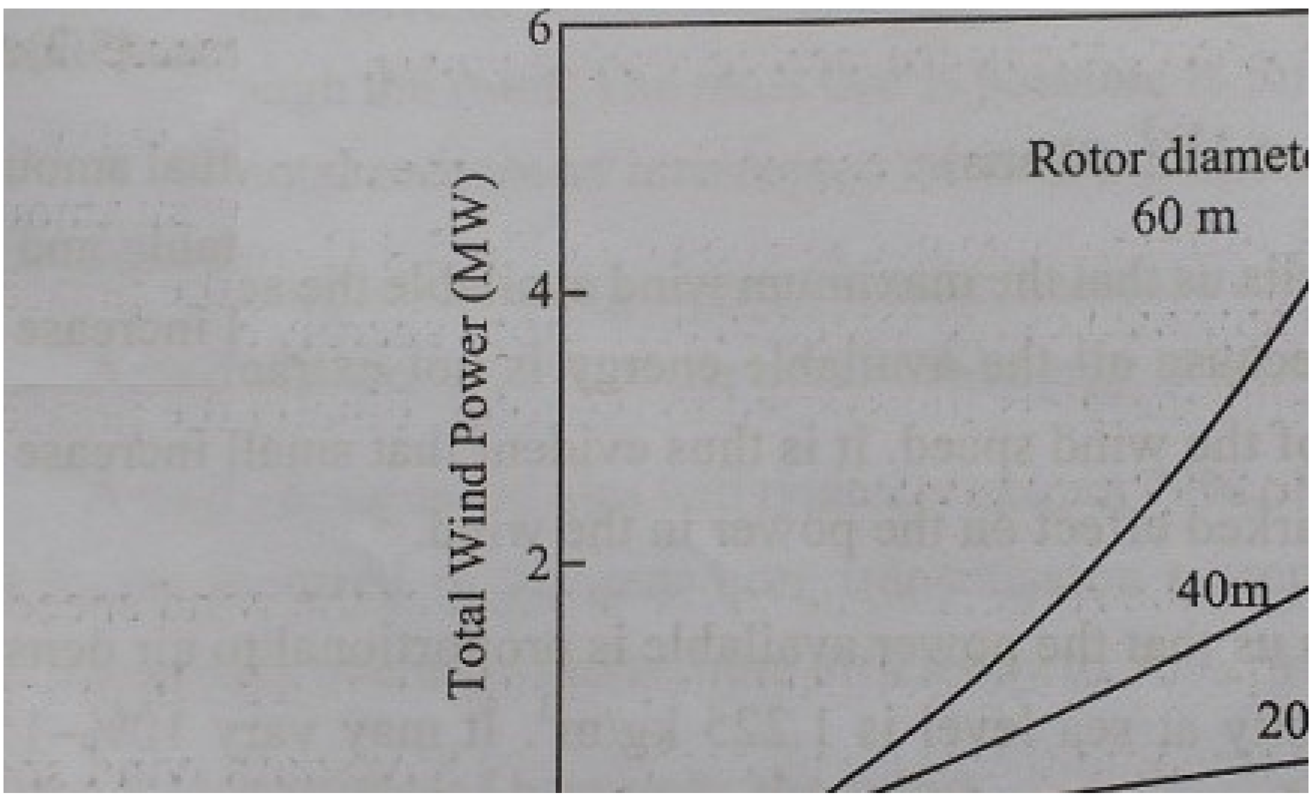
$m = \rho AV$

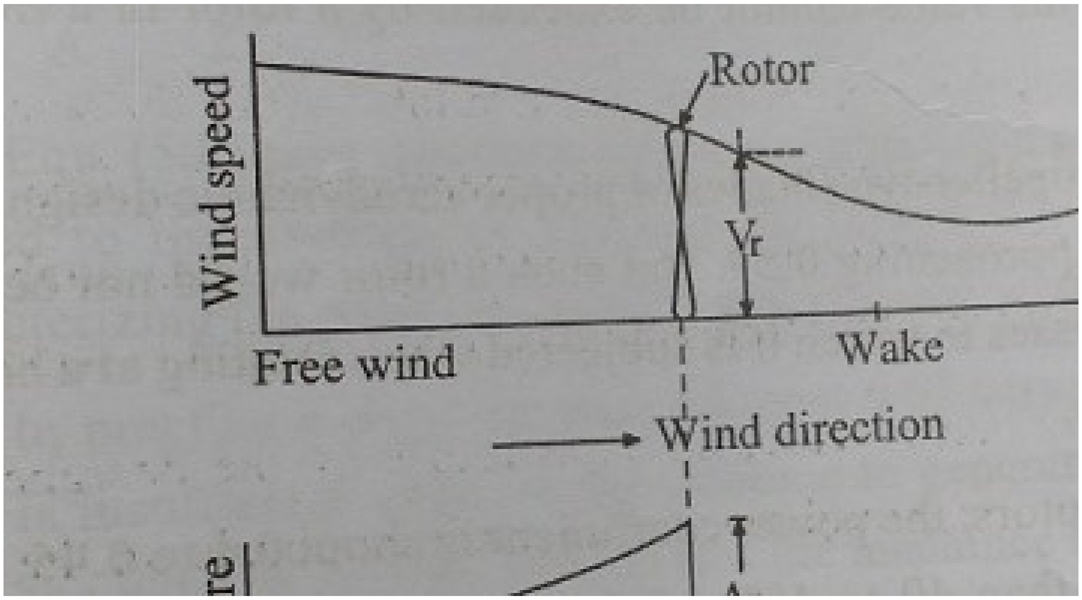
Where, m is the mass of air transversing the area ‘A’ swept by the rotating blades of a wind mill type generator.

Substituting Equ. (5.2) in Equ. (5.1),

We get,

$$\text{Kinetic Energy} = \frac{1}{2}\rho AV \times V^2$$





2.4 Power Coefficient

The fraction of the free-flow wind power that can be extracted by the rotor is called the power co-efficient; Thus,

Power Coefficient = Power of wind rotor / Power available in the wind

Where, power available is calculated from the air density, rotor diameter and free wind speed as discussed earlier. The maximum theoretical power coefficient is equal to 16/27 or 0.593. This value cannot be exceeded by a rotor in free-flow wind-stream.

An ideal rotor, with propeller-type blades of proper aerodynamic design, would have a power co-efficient approaching 0.59. But such a rotor would not be strong enough to withstand the stresses to which it is subjected when rotating at a high rate in a high-speed wind stream.

2.5 Instantaneous Wind Power

'V', in actuality, is not constant but is represented by a statically 'Noisy' wind speed time curve, V(t) then the instantaneous power, in the wind would be,

$$P_{(t)} = \frac{1}{2} \rho A V_{(t)}^3 \text{ Watts} \qquad \text{(From Equ. 5.3)}$$

Since, we are normally more interested in average power, we must take time average of both sides o Equ. (5.6), signified by the bar, and written as,

$$\overline{P}_{w(t)} = \frac{1}{2} \rho A \overline{V^3_{(t)}}$$

Equ. (5.7) tells us that for a non-steady state wind, it is necessary to cube the measured wind speeds and take the average to find the average wind power available.

It is immediately obvious that this non-steady state case is more complex than the simple steady state case, and it is why for the former case such great emphasis is placed on anemometry data at a proposed Wind Energy Conversion System (WECS) site.

Transposing Equ. (5.7) results in Average wind power density, it is given by,

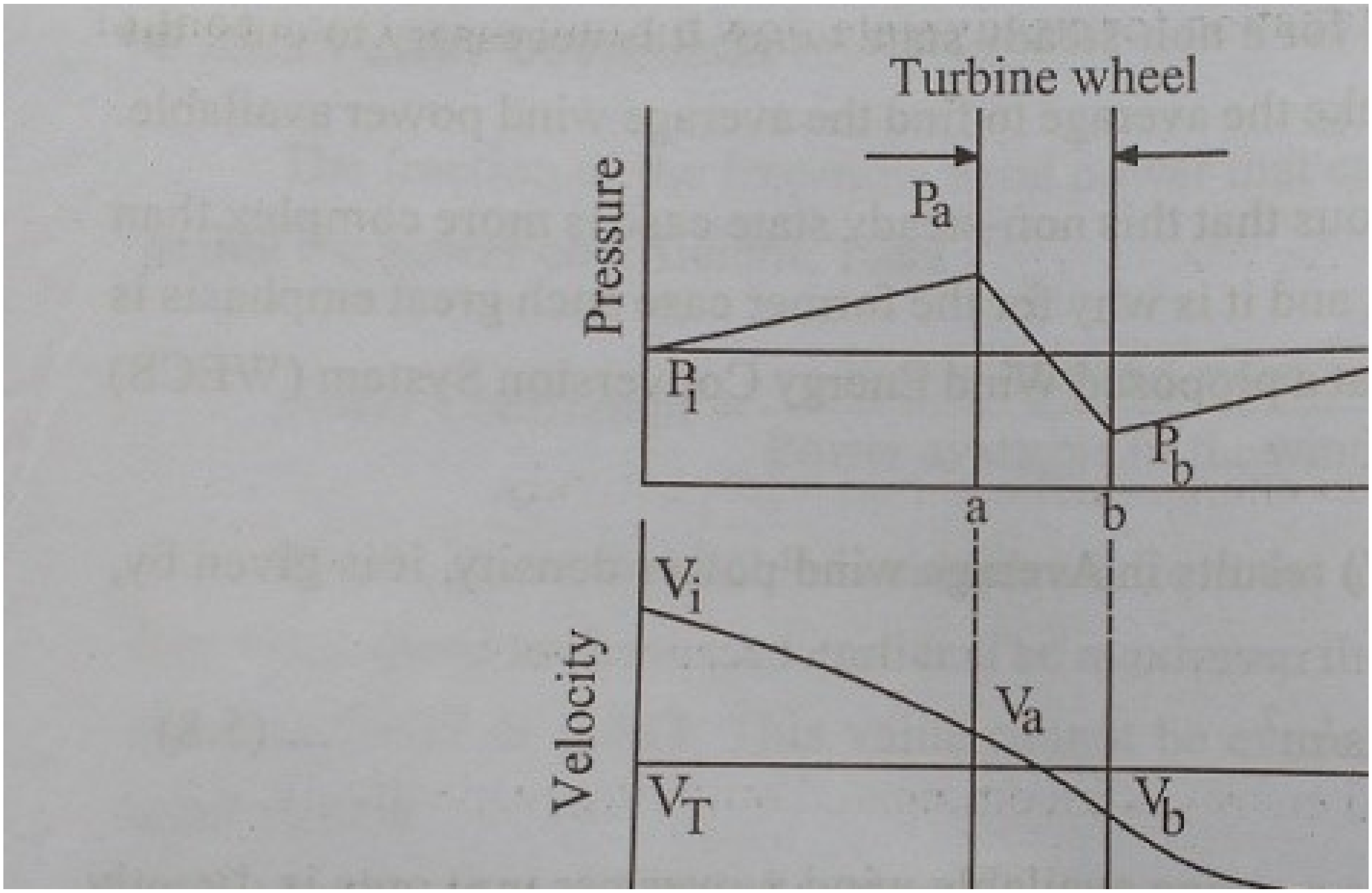
$$\frac{\overline{P_{w(t)}}}{A} = \frac{1}{2} \rho \overline{V^3_{(t)}} \text{ Watts/m}^2$$

Equ. (5.8) says that the average available wind power per unit area is directly related to the average of wind speed cubed. This is one useful method to characterizing the potential specific power in the wind over geographic area.

In practice a wind turbine's output will vary. There will be periods when there is insufficient wind for the machine to generate any power at all, and times when the wind speeds are so high that the machince has to be shutdown to prevent damage.

2.6 Expression For Maximum Power In Wind

As discussed earlier, that the total power can not converted to mechanical power. Consider a horizontal-axis, propeller-type wind mill, henceforth to be called a wind turbine, which is the, most common type today. Assume that the wheel such a turbine has a thickness 'ab' shown in Fig. 5.5.



Let, P_i - Wind pressure at upstream of turbine,

V_i - Velocity at the upstream of turbine,

P_e - Pressure at down stream of the turbi

2.7 Condition for Maximum Wind Power

For optimum exit velocity ‘Ve,opt’, that results in maximum power ‘Pmax’, which can be obtained by differentiating ‘P’ with respect to ‘Ve’, and equating the derivative to zero, i.e.,

$$P_i\, V + \frac{V_i^2}{2g_c} = P_a\, V + \frac{V_a^2}{2g_c}$$

$$\frac{dP}{dV_e} = \frac{1}{4g_c}\rho A\left[(1+0)\,(V_i^2 - V_e^2) + (V_i + V_e)\,(-2\right.$$

$$V_i^{\,2} - V_e^{\,2} - 2V_e\,V_i -$$

$$V_i^{\,2} - 2V_e\,V_i - 3V_e^{\,2} = 0 \text{ (or) } 3V_e^{\,2} + 2V_e\,V_i$$

This is solved for a positive 'V_e' to give $V_{e\,opt}$. Th

solution, i.e., $V_e = V_i$ and $V_e = \frac{1}{3}V_i$, only second solut

$$P_{max} = \frac{8}{27g_c}\rho A V_i^3$$

$$= \frac{16}{27g_c} \times \left(\frac{1}{2}\rho A V_i^3\right)$$

$$0.593 \quad 1\,\rho V_i^3 A$$

The idea, or maximum theoretical efficiency "μmax" (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. It is the maximum fraction of the power in a wind stream that can be extract

$$\text{Power coefficient} = C_p \equiv \frac{\text{Power output from}}{\text{Power availab}}$$

3 Betz limit

The **Betz limit** is the theoretical maximum efficiency for a wind turbine, conjectured by German physicist Albert Betz in 1919.[2] Betz concluded that this value is **59.3%**, meaning that at most only 59.3% of the kinetic energy from wind can be used to spin the turbine and generate electricity. In reality, turbines cannot reach the Betz limit, and common efficiencies are in the 35-45% range.[2]

Wind turbines work by slowing down passing wind in order to extract energy. If a wind turbine was 100% efficient, then all of the wind would have to stop completely upon contact with the turbine—which isn't possible by looking at a wind turbine (figure 1). In order to stop the wind completely, the air wouldn't move out of the way to the back of the turbine, which would prevent further air from coming in—causing the turbine to stop spinning

4 Torque on wind

As discussed earlier, here blades of propeller-type wind turbine is considered there are two types of forces which are acting on the blades. They are

(1) Circumferential force acting in the direction of wheel rotation that provides the torque, and

(2) Axial force acting in the wind stream that provides an axial thrust that must be countered by 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 (Nm),

ω - Angular velocity of turbine wheel (m/s),

D - Diameter of turbine wheel (m) is given by,

5 Wind Energy Conversion

The fact that the wind is variable and intermittent source of energy is immaterial for some application such as pumbing water for land drainage-provided, of course, that there is a broad match between the energy supplied over any critical period and the energy required. If the wind blows, the job gets done; if it does not, the job waits.

However, for many of the uses to which electricity is put, the interruption of supply may be highly inconvenient. Operators or users of wind turbines must ensure that there is some from of back-up can take the form of

(1) Battery storage

(2) Connection with the local electricity distribution systems, or

(3) A stand by generator powered by liquid or gaseous fuels

For utility responsible for public supply, the integration of medium sized and large wind turbines into their distribution network could required some additional plant which is capable of responding quickly to meet fluctuating demand.

5.1 Small Producers

Private citizens in several countries have won to right to operate wind generator and other renewable energy systems and to export power to the grid. For most small wind generators this requires that the output is conditioned, so that in the frequency and phase of the mains supply.

Only few small units are designed to maintain a constant rotational rate, so that can be synchronized to the mains frequency and feed electricity directly into the grid. Most current (DC) or variable output Alternating current (AC).

Power conditioning is readily achieved using an electronic black-box called a "Synchronous Inverter" and although this is an expensive item of equipment, it does eliminate the need for batteries and for conversion of home appliances to run on DC.

Where there is no grid connection, electricity that is surplus to immediately requirements must be stored on site using heavy duty batteries. It can be recovered later when the demand exceeds the supply. An alternative is to dump it (by generating and dissipating heat) or better, to convert it into heat that can be stored, for example as hot water in a well insulated tank.

5.2 Large Producers

Large and medium-sized wind generators are designed to give a stable and constant electrical output over a wide range of wind speeds and to feed current directly into the grid, they operate primarily as fuel savers, reducing the utility's total fuel burn.

The choice of generator type depends on the size of the local distribution grid and its associated generating capacity.

An induction generator would normally be used where there is a significant amount of other generating capacity (which could provide the necessary reactive power for excitation). Induction generators are robust and reliable and require minimal control equipment.

For isolated networks where other local generating capacity is limited, a synchronous generator is more appropriate. Synchronous generator are more complex and therefore more expensive than induction machines.

5.3 Lift and Drag Force

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. There are two primary mechanisms for producing forces from the wind: Lift and Drag.

By definition of Lift forces act perpendicular to the air flow, while drag forces act in the direction flow.

Lift forces are produced by changing the velocity of the air stream flowing over either side of the lifting surface. Speeding up the air flow causes the pressure to drop, while slowing the air stream down leads to increase in pressure.

In other words, any change in velocity generates a pressure difference across the lifting surface. This pressure difference produces a force that begins to act on the high pressure side and moves towards the low pressure side of the lifting surface which is called an **airfoil**.

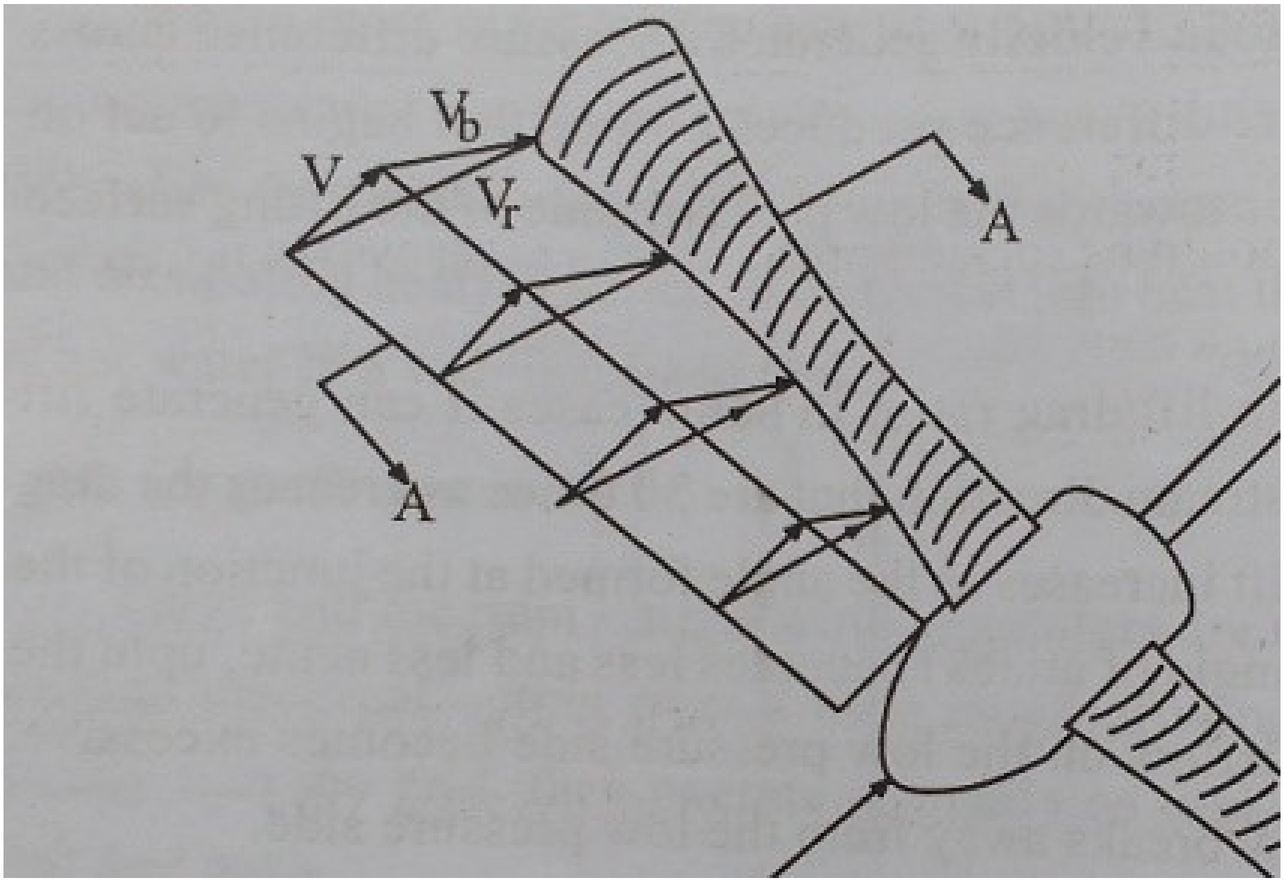
A Good airfoil has a high lit/drag ratio, in some cases it can generate lift forces perpendicular to the air stream direction that are 30 times as great as the drag force parallel to the flow. The lift increases as the angle formed at the junction of the airfoil and the air stream (the angle of attack) becomes less and less actute, upon the point where the angle of the airflow on the low pressure side becomes excessive. When this happens, the air flow breaks away from the low pressure side. A lot of turbulence ensues, the lit decreases and the drag increases quite substantially; this phenomenon is known as **Stalling**.

For efficient operation, a wind turbine blade needs to function with as much lift and as little drag as possible because drag dissipates energy. As lift does not involves anything more complex than deflecting the air flow, it is usually an efficient process. The design of each wind turbine speciies the angle at which the airfoil should bet set to achieve the maximum lift to drag ratio.

In addition to airfoils, there are two other mechanisms for creating lift. One is the so-called **Magnus Effect,** caused by spinning a cylinder in an air stream at a high-speed of rotation. The spinnings slows down the air speed on the side where the cylinder is moving into wind and increases it on the other side; the result is similar to an airfoil. This principle has been put to practical use in one or two cases but is not generally employed. The second way is to blow air through narrow slots in a cylinder, so that it emerges tangentially; this is known as a **Thwaits Slot**.

Thwaits Slots also creates a rotation (or circulation) of airflow, which in turn generate lift. Because the lift drag ratio of airfoils is generally much better than those of rotating or slotted cylinders, the latter techniques probably have little practical potential.

Fig. 5.6 and Fig. 5.7 shows the forces acting on the blade and cross section across A-A. The wind mill balde ‘sees’ the resultant vector ‘Vf’. The blades need to be twisted because ‘r’ varies in proportion to radius.



V
Vb
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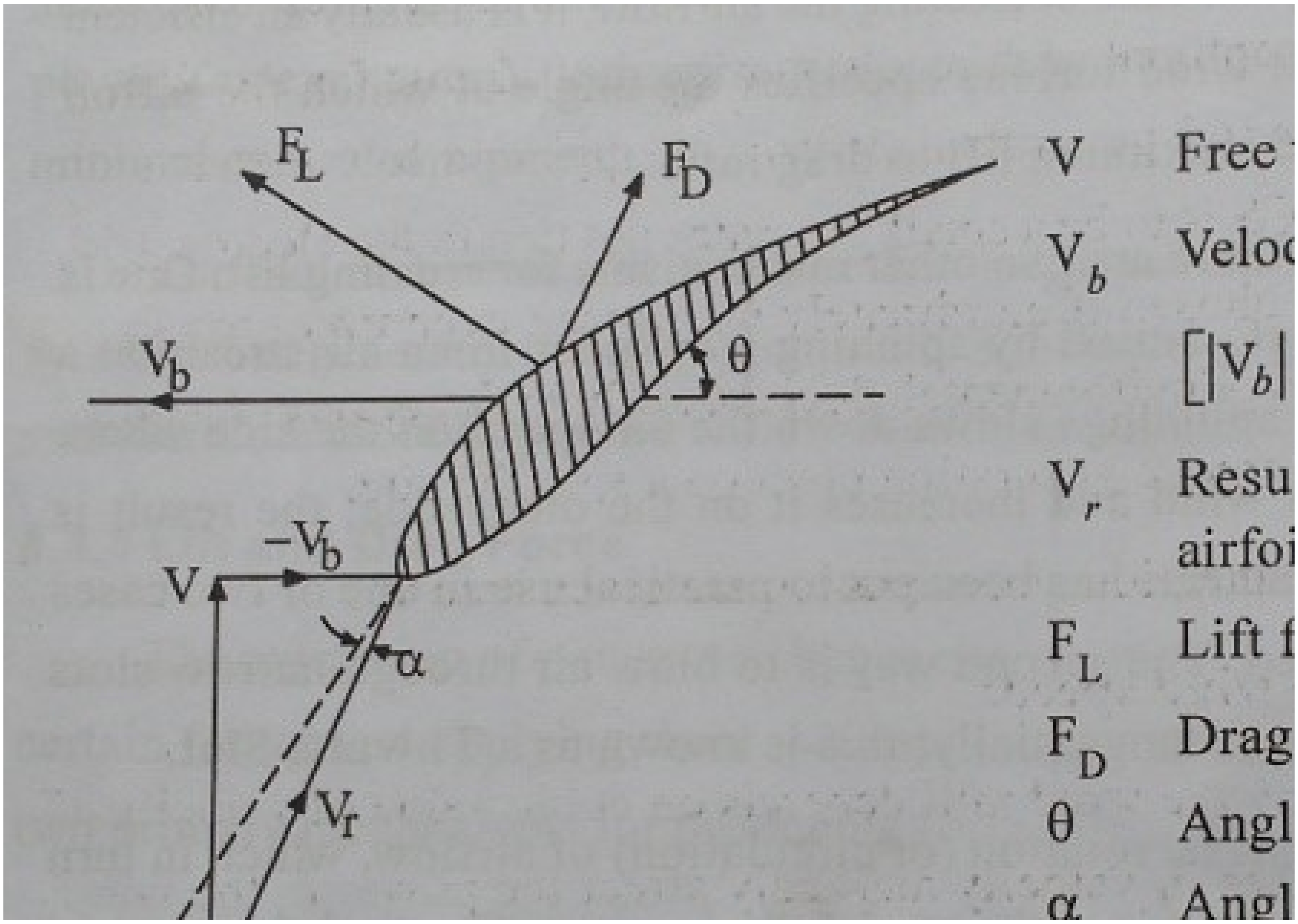


6 Wind speed monitoring

This the 1st of a series of articles that I hope to publish in the next coming months for anyone trying to find out a bit more about wind turbines and what makes them turn. I will start with small wind turbines and very basics points and little by little increase the technicality and complexity of wind site assessment which is often the bread and butter of Wind Energy Analysts. These articles try to summarise the typical questions we get everyday from end users contacting us and by no means implies you should not look a wind analyst's assistance.

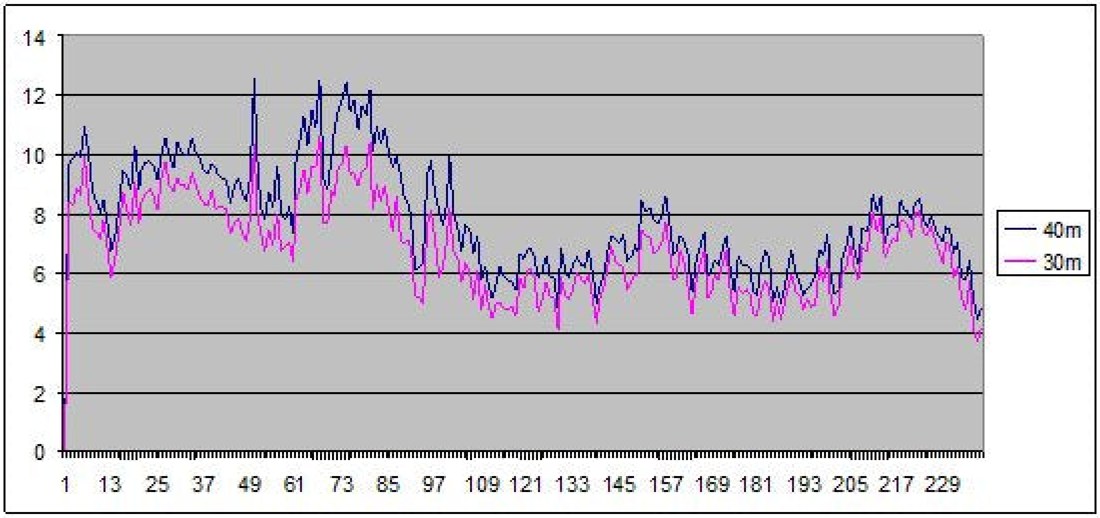
When thinking of installing a small wind turbine at your home or farm, there are a few things to consider, but probably the most important can be summarised in three key points:

- Height
- Location

- Size of the wind turbine

6.1 Height

This is simple, the taller the wind turbine tower the better. The higher, the fewer obstacles and therefore the less turbulence on the wind and usually means higher wind speeds

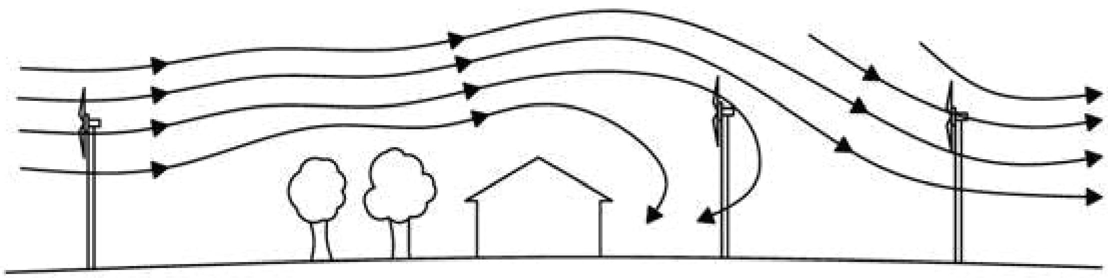


(Real data provided by Logic Energy Ltd)

Above shows the comparison with two anemometer on the same wind mast, one at 40 meters and the other at 30 meters. The 40m anemometer is showing an average wind speed of 1m/s more than the 30m one.

6.2 Location

Location, location, location, like the property market this point is probably one of the most important things to consider when thinking about installing a wind turbine. We may be in a windy area but the particular spot we may be looking at could be surrounded by obstacles like trees, houses or even towns a few miles away. These could have an unwanted effect not just on the increase of wind turbulences but also on the wind speed itself which could be severely reduced.



As you can see above, the higher the hub height of the wind turbine and the better located the wind turbine, the less turbulence on the wind and more steady flow of wind.

6.3 Size of the wind turbine

Think about the sails of a ship, the bigger they are the more wind they capture and therefore the more energy they can harvest from it. Wind turbines are not much different, the bigger the rotor the more wind they will capture.

Of course there are techniques to improve in efficiency output from the wind and all sort of technical advances but it is a rule of thumb worth keeping in mind.

Final point to make here which ties with Locations is that in certain areas where wind is too gusty or turbulent, or even too fast, in these places it may not be the best solution to install a wind turbine with a big rotor and other smaller wind turbines will be able to take full advantage of those high wind speeds.

Your wind analyst or consultant will be able to advice you on this when you have collected enough wind data measurements.

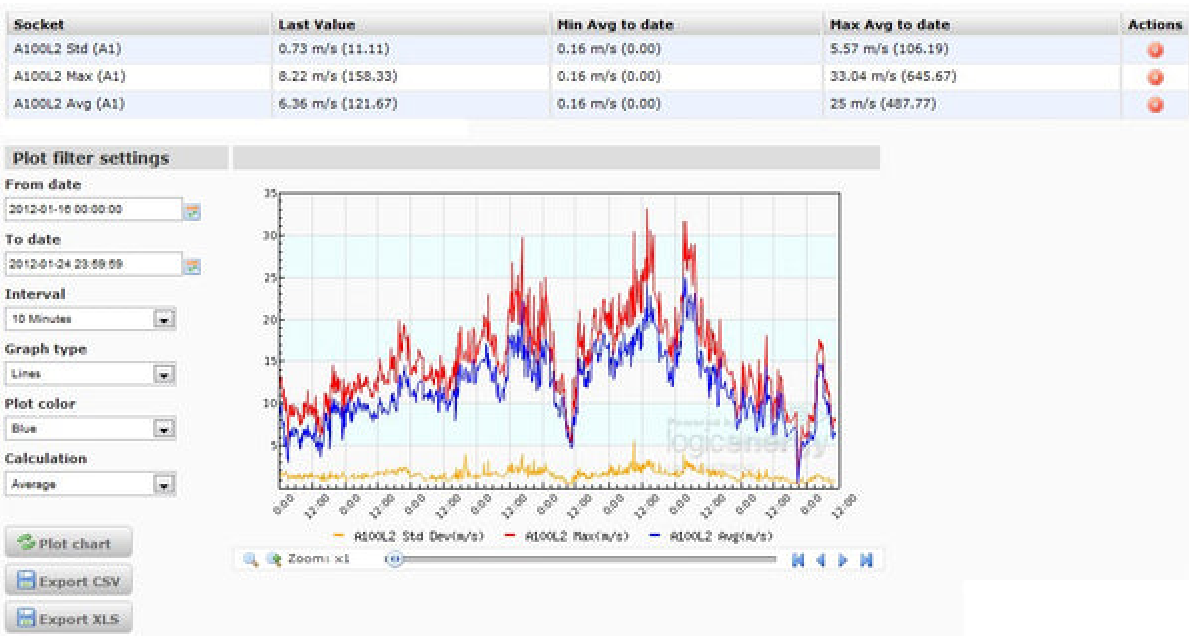
6.4 Planning your wind speed monitoring project

With these three rules in mind, we can look for the "perfect" site to install a wind turbine but before that, you will need to monitor your site's wind speed for a period of time, the longer the better. This can be done in different ways but in general it is advisable to use a professional wind logger which will not just record wind data but also do real time calculations with the data in order to provide all the relevant information for the wind analyst.

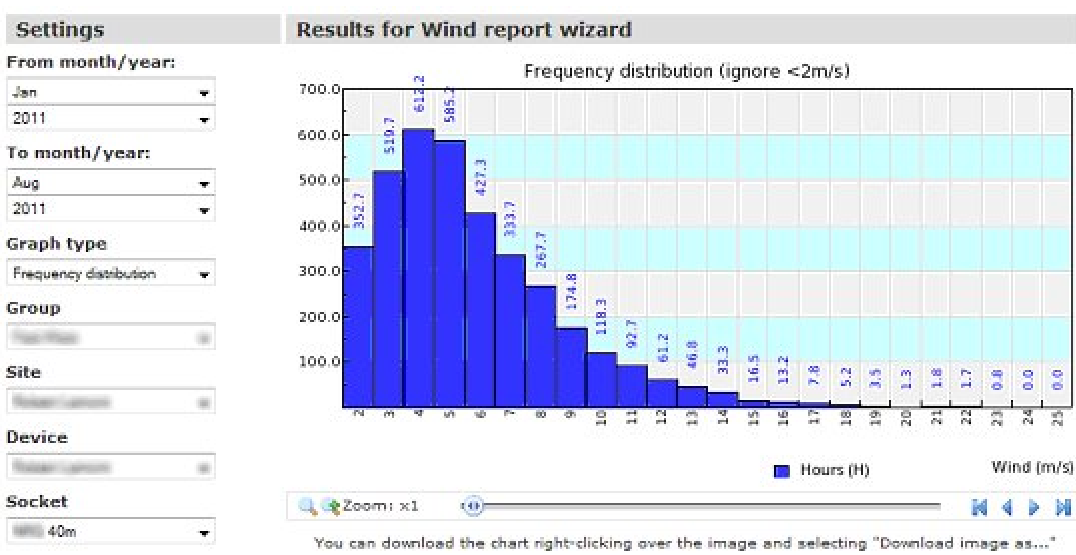
A few things to get familiar with:

- Average, maximum and standard deviation wind speeds: These are usually given in periods of 10 minutes.

- Average: This is the mean average of wind speed during the 10 minutes period, usually given in meters per second [m/s]
- Maximum: This is the maximum or gust wind speed measured during the 10 minutes intervals
- Standard deviation: This is an indication of the wind turbulence intensity during the 10 minutes interval. We need to make sure the “wind turbine is going to work with the wind and not against it”
- Wind direction: you will need to know from where the wind comes most of the time and at which wind speeds.
- MET mast or Wind mast: This is used by professionals with anemometry or wind sensors mounted onto them. Masts need to be free of any vibration or “wobbling” as these will impact the readings taken by the wind logger. Usually a wind mast will have several sensors at different heights in order to get a better of the wind at the site. Things like roughness length or wind shear are very important but also temperature and pressure.
- Wind shear: This is calculated by measuring wind speed at different heights. By measuring at different heights we can get a better understanding of the turbulence intensity but also the impact on wind speeds for higher heights. This is also often used to “extrapolate” to higher heights when measuring at hub height of the wind turbine is not possible. Some other benefits of measuring at different heights is to keep options open when it comes to choosing different wind turbines.



(Example of average, maximum and standard deviation wind speed on LeSENSE, provided by Logic Energy Ltd)



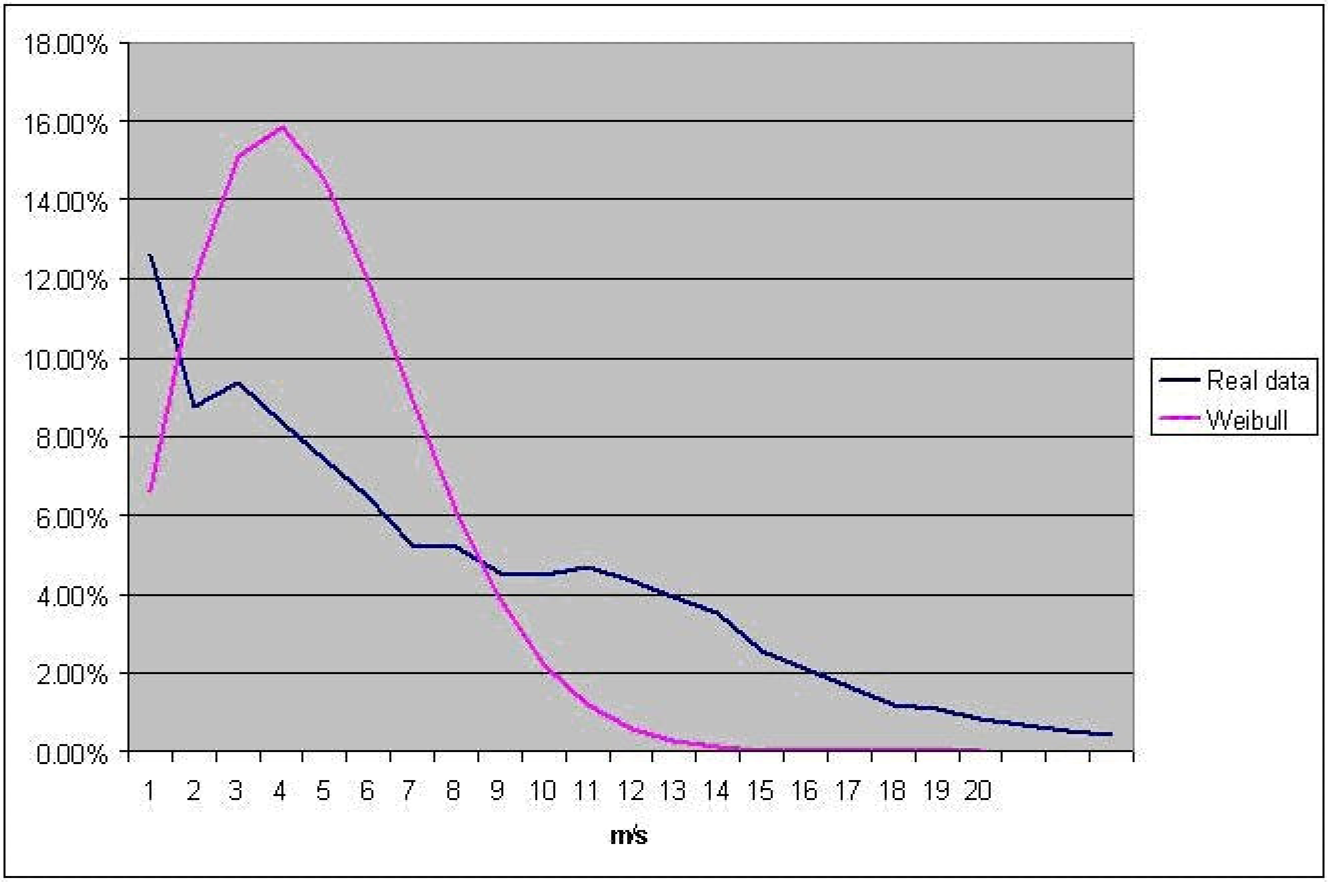
(Frequency distribution chart using LeSENSE, provided by Logic Energy Ltd)

6.5 Equipment

- Anemometers, these should be calibrated with a traceable certificate. With an accuracy better than 1% and a resolution of 0.1m/s. It is always recommended to use at least two anemometers.
- Wind vane, ideally 1* resolution
- Wind logger or monitor:
- It should be able to store historical data. Minimum the following parameters for the wind speed:
- Average, Maximum and Standard deviation of the wind speed
- Wind direction
- Advisable to measure temperature and/or pressure, humidity.
- Advisable to have spare channels for extra anemometry equipment or other sensors
- Power supply of the wind logger or monitor device.
- For short periods of time it is ok to use Alkaline batteries when data can be retrieved quite frequently
- For longer periods of time it is highly recommended to retrieve the data remotely (ie: via GSM or GPRS) and use PhotoVoltaic kit to power the wind monitor

7 Example with a small wind turbine

Let´s have a look at this chart, both of them belong to the same site. One is giving a wind probability based on Weibull distribution with k=2 (which is what the industry standards assume) and the other based on real data logged with the LeNETmobile wind data monitor. Both average wind speed of 3.5 m/s.



The chart below shows on the horizontal axis the wind speed in meters per second and on the vertical axis the wind probability per wind speed. In the case of the Real data there's no probability, just real data!!

With the predicted data we found that we have a 12% probability of wind at 6m/s but with the real data, it shows only 6.5%. This seems bad news at first but look at the higher end of the wind speed: 10m/s, 12m/s, ... these are the sort of wind speeds that usually wind turbines work best, and have their higher efficiency!!

So far so good, but how does this relate to energy production?

We find the numbers of hours the wind has been blowing at different wind speeds for both sets of data (Real data and Weibull). With the total number of hours at different wind speeds, we put them together with the typical power curve supplied by any wind turbine manufacturer, and we find very different values:

Data collected (Real data): 1,492kWh in one month

Data estimated using Weibull: 1,086kWh in one month

You see the difference between knowning real data from your site and guessing it? And in this case it has been a positive approach but what about if it is the other way around? What about if we estimate more energy than really is available on the site? Definitely it is well worth to knowing the real potential of your site before investing in a wind turbine.

But... 1,500kWh per month is not a lot is it?

Well, all depends of the size of the wind turbine and the wind available at the site. This study was done with a very small wind turbine

8 SITE SELECTION CONSIDERATION FOR WECS

The power available in the wind increases rapidly with the speed, hence wind energy conversion machines should be located preferable in areas where the winds are strong and persistent. Although daily winds at a given site may be highly variable, the monthly and especially annual average are remarkably constant from year to year.

The major controbution to the wind power available at a given site is actually made by winds with speeds above the average. Nevertheless, the most suitable sites for wind turbines would be found in areas where the annual average wind speeds are known to be moderately high or high.

The site choice for a single or a spatial array of WECS is an important matter when wind electrics is looked at from the systemspoint of view of aeroturbine generators feeding power into a convertional electric grid.

If the WECS sites are wrongly or poorly chosen the net wind electrics generated energy per year may be sub optimal with resulting high capital cost for the WECS apparatus, high costs for wind generated electric energy, and low Returns on Investment. Even if the WECS is to be a small generator not tied to the electric grid, the sitting must be carefully chosen if inordinately long break even times are to be avoided. Technical, Economic, Evironmental, Social and Other actors are examined before a decision is made to erect a generating plant on a specific site.

Some of the main site selection consideration are given below:

- High annual average wind speed:
- Availability of anemometry data:
- Availability of wind V(t) Curve at the proposed site:

- Wind structure at the proposed site:
- Altitude of the proposed site:
- Terrain and its aerodynamic:
- Local Ecology
- Distance to road or railways:
- Nearness of site to local centre/users:
- Nature of ground:
- Favourable land cost:

8.1 High annual average wind speed:

The speed generated by the wind mill depends on cubic values of velocity of wind, the small increases in velocity markedly affect the power in the wind. For example, Doubling the velocity, increases power by a factor of 8. It is obviously desirable to select a site for WECS with high wind velocity. Thus a high average wind velocity is the principle fundamental parameter of concern in initially appraising WESCS site. For more detailed estimate value, one would like to have the average of the velocity cubed.

8.2 Availability of anemometry data:

It is another improvement sitting factor. The aenometry data should be available over some time period at the precise spot where any proposed WECS is to be built and that this should be accomplished before a sitting decision is made.

8.3 Availability of wind V(t) Curve at the proposed site:

This important curve determines the maximum energy in the wind and hence is the principal initially controlling factor in predicting the electrical output and hence revenue return o the WECS machines.

It is desirable to have average wind speed ‘V’ such that V>=12-16 km/hr (3.5 – 4.5 m/sec) which is about the lower limit at which present large scale WECS generators ‘cut in’ i.e., start turning. The V(t) Curve also determines the reliability of the delivered WECS generator power, for if the V(t) curve goes to zero there be no generated power during that time.

If there are long periods of calm the WECS reliability will be lower than if the calm periods are short. In making such realiability estimates it is desirable to have measured V(t) Curve over about a 5 year period for the highest confidence level in the reliability estimate.

8.4 Wind structure at the proposed site:

The ideal case for the WECS would be a site such that the V(t) Curve was flat, i.e., a smooth steady wind that blows all the time; but a typical site is always less than ideal. Wind specially near the ground is turbulent and gusty, and changes rapidly in direction and in velocity. This depature from homogeneous flow is collectively referred to as "the structure of the wind".

8.5 Altitude of the proposed site:

It affects the air density and thus the power in the wind and hence the useful WECS electric power output. Also, as 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.

8.6 Terrain and its aerodynamic:

One should know about terrain of the site to be chosen. If the WECS is to be placed near the top but not on the top of a not too blunt hill facing the prevailing wind, then it may be possible to obtain a 'speed-up' of the wind velocity over what it would otherwise be. Also the wind here may not flow horizontal making it necessary to tip the axis of the rotor so that the aeroturbine is always perpendicular to the actual wind flow.

It may be possible to make use of hills or mountains which channel the prevailing wind into a pass region, thereby obtaining higher wind power.

8.7 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.

8.8 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.

8.9 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.

8.10 Nature of ground:

Ground condition should be such that the foundation for a WECS are secured. Ground surface should be stable. Erosion problem should not be there, as it could possibly later wash out the foundation of a WECS, destroying the whole system.

8.11 Favourable land cost:

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

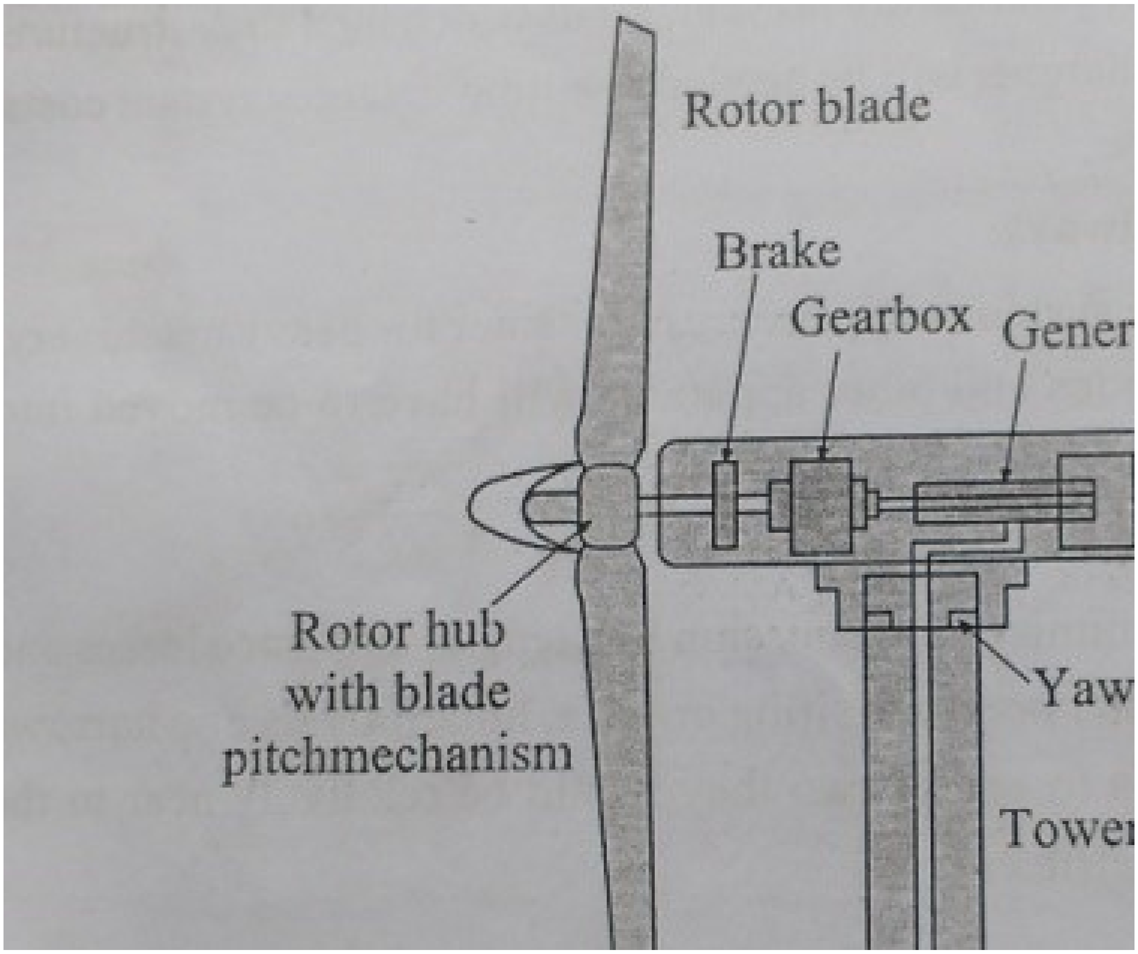
12. Other conditions such as icing problem, salt spray or blowing dust should not present at the site, as they may affect aeroturbine blades or environmental is generally adverse to machinery and electrical apparatus.

9 TYPES OF WIND TURBINES

Wind turbines can be separated into two basic types determined by which way the turbine spins. Wind turbines that rotate around a horizontal axis are more common (like a wind mill), while vertical axis wind turbines are less frequently used (Savonius and Darrieus are the most common in the group).

9.1 Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us 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 as shown in figure.



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 turbine 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.

9.2 Important point to remember recording HAWT:

(1) Lift is the main force

(2) Much lower cyclic stress

(3) 95% of the existing turbines are HAWTs

(4) Nacelle is placed at the top of the tower

(5) Yaw mechanism is required

9.3 HAWT Advantage

1. 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%.

2. High efficiency, since the blades always move perpendicular 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 the wind leads to inherently lower efficiency.

9.4 HAWT Disadvantages

1. Massive tower construction is required to support the heavy blades, gearbox, and generator.

2. Components of horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position.

3. Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.

4. Download 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).

5. HAWTs require an additional yaw control mechanism to turn the blades toward the wind.

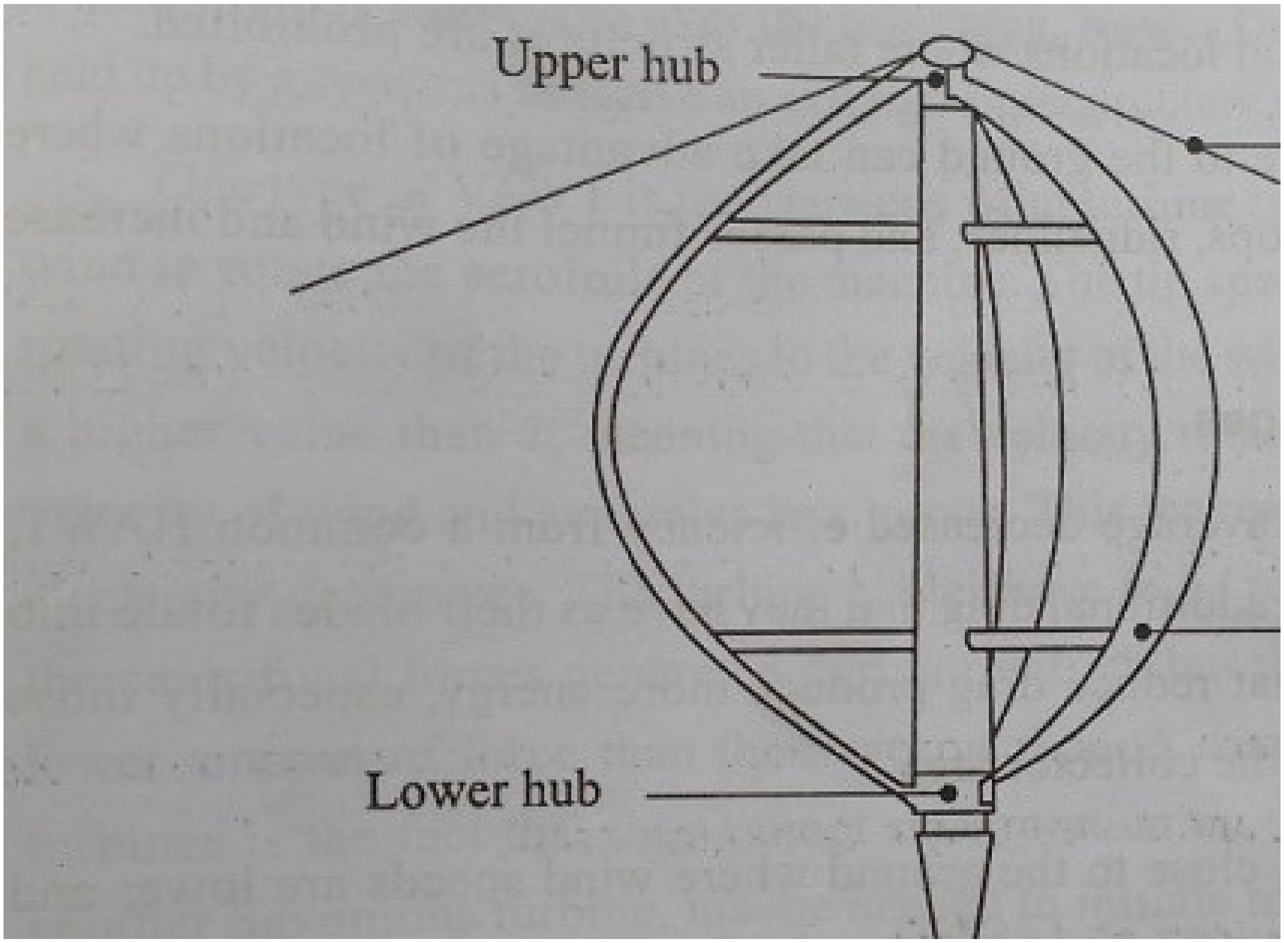
6. HAWTs generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself.

9.5 Vertical Axis Wind Turbines(VAWT)

Vertical wind turbines, as shortened to VAWTs, have the main rotor shaft arranged vertically as shown in Fig 5.9. 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 site 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 generally create drag when rotating into the wind.

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 and this can double 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.



9.5.1 Important points to remember recording VAWT:

Nacelle is placed at the bottom.

Drag is the main force

Yaw mechanism is not required

Lower starting torque

Difficulty in mounting the turbine

Unwanted fluctuations in the power output

9.5.2 VAWT Advantages

1. No yaw mechanisms is needed
2. A VAWT can be located nearer the ground, making it easier to maintain the moving parts.
3. VAWTs have lower wind startup speeds than the typical the HAWTs.

5. VAWTs situated close to the ground can take advantage of locations where rooftops, means hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

9.5.3 VAWT Disadvantage

1. Most VAWTs have a average decreased efficiency from a common HAWT, mainly because o the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area.
2. Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.
3. Because VAWTs are not commonly deployed due mainly to the serious disadvantage mentioned above, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.

9.6 VAMT Subtypes

9.6.1 Darrieus Wind Turbine

Darrieus turbine has long, thin blades in the shape of loops connected to the top and bottom of the axle; it is often called an "eggbeater windmill." It is named after the French engineer Georges Darrieus who patented the design in 1931. (It was manufactured by the US company FLoWind which went bankrupt in 1997). The Darrieus turbine is characterized by its C-shaped rotor blades which give it its eggbeater appearance. It is normally built with two or three blades.

Darrieus wind turbines are commonly called "Eggbeater" turbines, because they look like a giant eggbeater. They have good efficiency, but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability. Also, they generally require some external power source, or an additional savonius rotor, to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in a higher solidity for the rotor. Solidity is measured by blade area over the rotor area. Newer Darrieus type turbines are not help up by guy-wires but have an external superstructure connected to the top bearing.

One type of VAWT is the Darrieus wind turbine that uses the lift forces of the wind to rotate the aerofoils of the machine. The tip speed ratio (TSR) indicates the rotating velocity of the turbines to the velocity of the wind. In this case, the TSR has a higher value than 1, meaning that the velocity rotation here is greater than the velocity of wind and generates less torque. This makes

Darrieus turbines excellent electricity generators. The turbine blades have to be reinforced in order to sustain the centrifugal forces generated during rotation, but the generator itself accepts a lower amount of force than the Savorius type. A drawback to the Darrieus wind turbines is the fact that they cannot start rotation on their own. A small motor, or another Savonius turbine, maybe needed to initiate rotation.

9.6.2 Advantages

(1) The rotor shaft is vertical. Therefore it is possible to place the load, like a generator or a centrifugal pump at ground level. As the generator housing is not rotating, the cable to the load is not twisted and no brushes are requires for large twisting angles.

(2) The rotor can take wind from every direction.

(3) The visual acceptation for placing of the windmill on a building might be larger than for an horizontal axis windmill.

(4) Easily integrates into buildings.

9.6.3 Disadvantages

(1) Difficult start unlike the Savonius wind turbine.

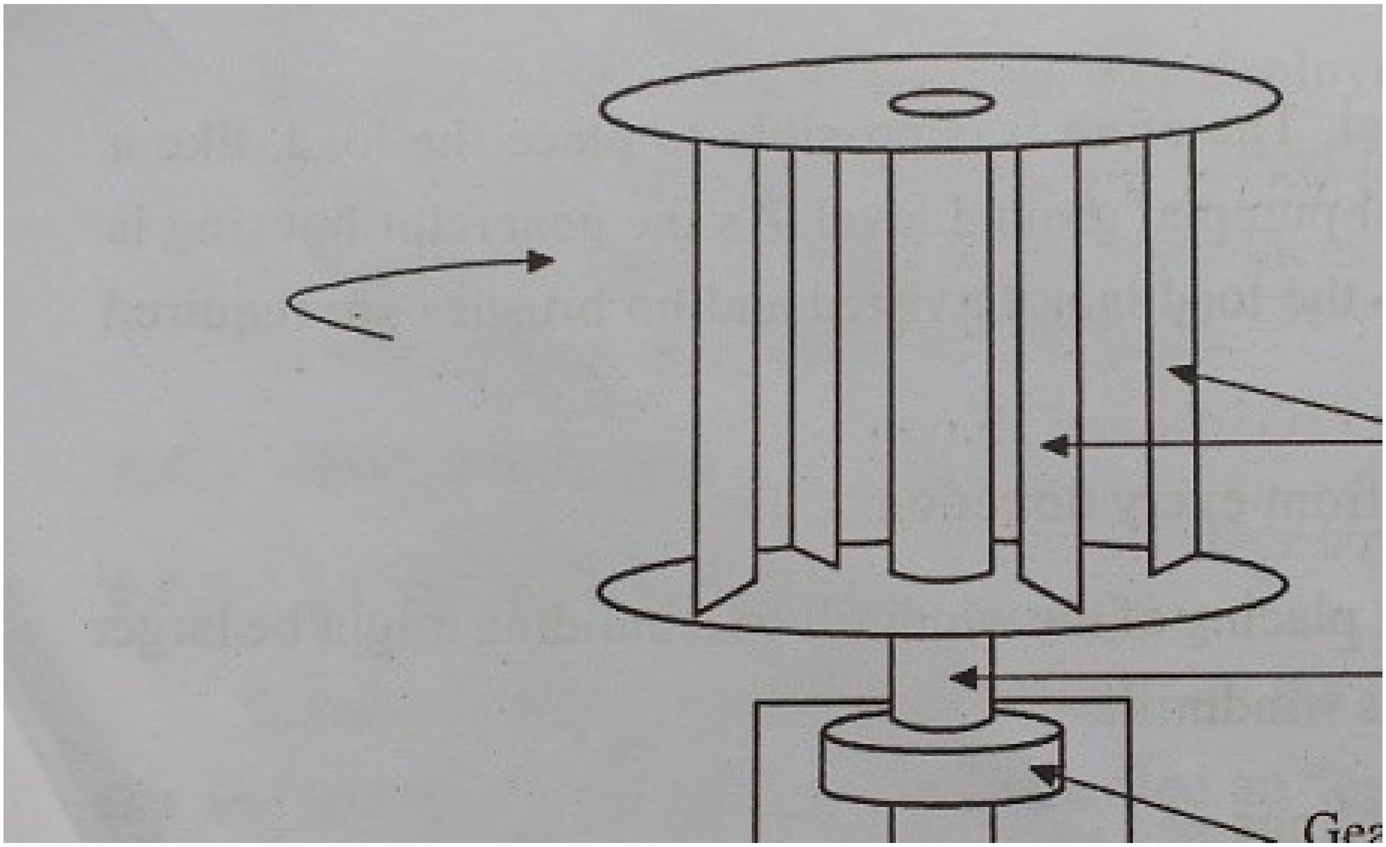
(2) Low efficiency.

10. Savonius wind turbine

The Savonius wind turbine is a type of vertical-axis wind turbine invented by the finnish engineer sigurdSavonius in the 1920's. It is one of the simplest wind turbine designs. It consists of two to three "scoops" that employ a drag action to convert wind energy into torque to drive a turbine. When looked at from above in cross-section, a two scoop Savonius turbine looks like an S-shape. Due to the curvature of the scoops, the turbine encounters less drag when moving against the wind than with it, and this causes the spin in any wind regardless of facing.

Drag type wind turbines such as the Savonius turbine are less efficient at using the wind's energy than lift-type wind turbines, which are the ones commonly used in wind farms.

A Savonius is a drag type turbine, they are commonly used in cases of high reliability in many things such as ventilation and anemometers. Because they are a drag type turbine they are less efficiency than the common HAWT. Savonius are excellent in areas of turbulent wind and self starting. The schematic diagram of savonius wind turbine as shown in fig.5.10.



10.1 Advantages

(1) Having a vertical axis, the Savonius turbine continues to work effectively even if the wind changes direction.

(2) Because the Savonius design works well even at low wind speeds, there's no need for a tower or other expensive structure to hold it in place, greatly reducing the initial setup cost.

(3) The device is quiet, easy to build, and relatively small.

(4) Because the turbine is close to the ground, maintenance is easy.

10.2 Disadvantages

The scoop system used to capture the wind's energy is half as efficient as a conventional turbine, resulting in less power generation.

11. Tip Speed Ratio

The **tip-speed ratio**, λ, or **TSR** for wind turbines is the ratio between the tangential speed of the tip of a blade and the actual speed of the wind, v. The tip-speed ratio is related to efficiency, with the optimum varying with blade design. Higher tip speeds result in higher noise levels and require stronger blades due to larger centrifugal forces. $\lambda = \frac{\text{tip speed}}{}$

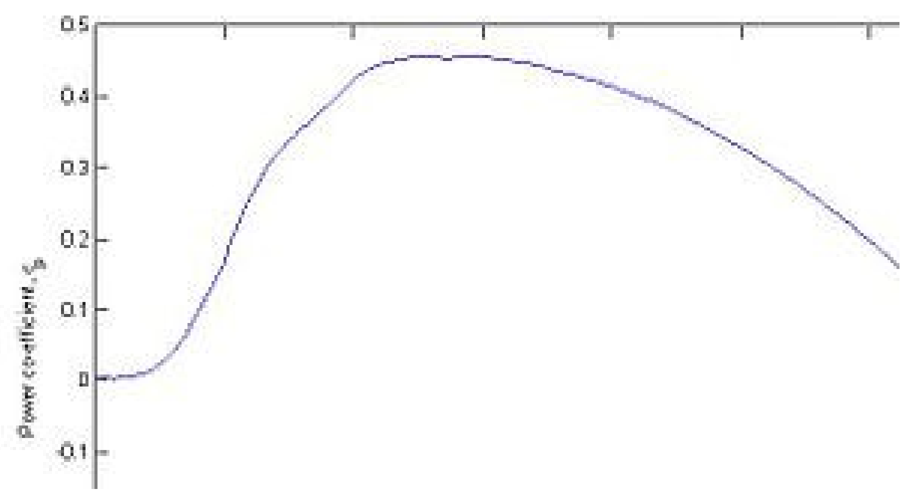
The tip speed of the blade can be calculated as w times R, where w is the rotational speed of the rotor in radians/second, and R is the rotor radius in metres. Therefore, we can also write:

$$\lambda = \frac{\omega}{}$$

where v is the wind speed in metres/second at the height of the blade hub.

12. Cp–λ curves

The power coefficient, C_p is a quantity that expresses what fraction of the power in the wind is being extracted by the wind turbine. It is generally assumed to be a function of both tip-speed ratio and pitch angle. Below is a plot of the variation of the power coefficient with variations in the tip-speed ratio when the pitch is held constant:



13. Types of generators and power converters in WECS

There are four types of wind turbine generators (WTGs) which can be considered for the various wind turbine systems, those are:

1. Direct Current (DC) Generators

2. Alternating Current (AC) Synchronous Generators
3. AC Asynchronous Generators, and
4. Switched Reluctance Generators.

Each of these generators can be run at fixed or variable speed. Due to the dynamic nature of wind power, it is ideal to operate the WTGs at variable speed.

Operating a generator at variable speed reduces the physical stress on the turbine blades and drive, and which improves aerodynamic system efficiency and torque transient behaviours.

12.1 DC Generator

A DC wind generator system has a wind turbine, a DC generator, an insulated gate bipolar transistor (IGBT) inverter, a transformer, a controller, and a power grid. For shunt-wound DC generators, the field current increases with operational speed, whereas the balance between the wind turbine drive torque determines the actual speed of the wind turbine.

Electricity is extracted through brushes, which connect the commentator that is used to convert the generated AC power into DC output. These generators need regular maintenance and are relatively costly because of using commutators and brushes. Using DC WTGs are unusual in wind turbine applications except in the situations of low power demand.

12.2 AC Synchronous Generator

AC synchronous wind turbine generators can take constant or DC excitations from either permanent magnets or electromagnets. This is why they both are called “permanent magnet synchronous generators (PMSGs)” and “electrically excited synchronous generators (EESGs). When the wind turbine drives the rotor, three-phase power is produced in the stator windings that are connected to the grid via transformers and power converters. In the case of fixed-speed synchronous generators, the rotor speed needs to be at exactly the synchronous speed. Or else, the synchronism will be lost.When using fixed-speed synchronous generators, random fluctuations of wind speed and periodic disturbances happen due to tower-shading effects. Moreover, synchronous WTGs tend to have a low damping effect so that they do not allow drive train transients to be absorbed electrically. When synchronous WTGs are integrated into the power grid, synchronizing their frequency with the grid requires a delicate operation. In addition, these generators more complex, costly, and prone to failure compared to induction generators. During the past decades, PM generators have increasingly been used in wind turbine applications due to their high-power density and low mass.

The structure of PM generators is relatively straightforward. The rugged PMs are installed on the rotor to generate a constant magnetic field, and the produced electricity is collected from the stator by using the commutator, slip rings or brushes. Sometimes the PMs are integrated into a cylindrical cast aluminum rotor to lower the cost. The basic principle of operating PM generators is similar to synchronous generators except that PM generators can be operated asynchronously. Some of the advantages of PMSGs are the elimination of commutator, slip rings, and brushes so that the machines are rugged, reliable, and simple.

Due to the variability of the actual wind speeds, the PMSGs can not produce electricity with a fixed frequency. For this, the generators should be connected to the power grid through rectifying AC-DC-AC by power converters. It means the generated AC power containing variable frequency and magnitude is first rectified into fixed DC, and then converted back into AC power. Also, these permanent magnet machines can be useful for direct-drive applications as, in this case, they can get rid of troublesome, gearboxes which cause failures for the majority of wind turbines. One of the potential variants of synchronous generators is the high-temperature superconducting generator.

The superconductor generators have components such as the stator back iron, stator copper winding, HTS field coils, rotor core, rotor support structure, rotor cooling system, and others.

12.3 AC Asynchronous Generators

When the traditional way of power generation uses synchronous generators, modern wind power systems use induction machines, extensively in wind turbine applications.

The induction generators are classified into **two types**: **fixed-speed induction generators (FSIGs)** with squirrel cage rotors, and **doubly-fed induction generators (DFIGs)** with wound rotors.

Generally, induction generators are simple, reliable, inexpensive, and well-designed. These generators have a high degree of damping and can absorb rotor speed fluctuations and drive train transients. In the case of fixed-speed induction generators, the stator is connected to the grid through a transformer, and the rotor is connected to the wind turbine through a gearbox. Until 1998, most wind turbine makers produced fixed-speed induction generators of 1.5 MW and less. These generators were normally operated at 1500 revolutions per minute (rpm) for the 50 Hz utility grid, along with a three-stage gearbox. Squirrel cage induction generators (SCIGs) can be used in variable speed wind turbines, as in controlling synchronous machines.

In such cases, the output voltage, however, can not be controlled, and the external supply of reactive power is required. It means fixed-speed induction generators have restrictions when it comes to operating only within a narrow range of discrete speeds. Other disadvantages of these generators are about the machine size, low efficiency, noise, and reliability. These days, more than 85% of the installed wind turbines use DFIGs, and the largest capacity for the commercial wind turbine product has an increased capacity towards 5MW. The increased capacity offers several advantages, including high energy yield, reduced mechanical stresses, power fluctuations, and controllability of reactive power.

Induction generators are also prone to voltage instability. Additionally, the damping effect may result in power losses in the rotor. There is no direct control over the terminal voltage, nor sustained fault currents. In these cases, it is possible to regulate the speed and torque of the DFIG by controlling the rotor side converter (RSC). In sub-synchronous operation, the rotor-side converter works as an inverter and the grid-side converter (GSC) as a rectifier.
On the other hand, in the case of super-synchronous operation, the RSC operates as a rectifier and the GSC as an inverter.

12.4 Switched Reluctance Wind Turbine Generator

Switched reluctance wind turbine generators have features such as strong rotor and stator. With the rotor's rotations, the reluctance of the magnetic circuit linking the stator and rotor changes. It then, in turn, induces currents in the winding on the armature (stator). The reluctance rotor is built from laminated steel sheets, and it does not have any electrical field windings or permanent magnets. For this reason, the reluctance generator is simple, easy to produce, and assemble. Another obvious feature of these generators is their high reliability. It is because they can work in harsh or high-temperature environments.

Due to the fact that the reluctance torque is only a fraction of electrical torque, the rotor of a switched reluctance generator is usually larger than the other with electrical excitations for a given rate of torque. When reluctance generators are combined with direct drive features, the machines would be quite large and heavy, making them less useful in wind power applications.