# Wind Energy

# Resource Assessment Handbook

**Prepared for**

# APCTT

**Asian and Pacific Centre for Transfer of Technology Of the United Nations – Economic and Social Commission for Asia and the Pacific (ESCAP)**

**By**

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**Chapter 1: INTRODUCTION**

The introductory training modules on the technical, operational and functional aspects of the respective renewable energy technologies (RET) may:

a. Explain the principle of operation/functioning of the identified RET in simple terms.

b. Specify the natural resource/s utilized by the identified RET

c. Explain advantages and limitations of the identified RET

d. Explain the simple techno-economic features of the identified RET

e. Illustrate (list) typical - successful and most useful applications/uses of the particular RET with explanations on how to accommodate the availability pattern of its resource and other peculiar/unique characteristics associated with the technology, if any.

f. Explain the main technical parameters associated with the identified RET and how to interpret its values.

g. Explain how records comprising these parameters are normally maintained and the identified RET's technical/operational performance assessed.

h. Explain what parameters need to be examined while making selection/sizing decisions pertaining to the technology and what are the ideal values of these parameters for various applications.

**Chapter 2: GUIDING PRINCIPLES OF A RESOURCE ASSESSMENT PROGRAMME**

Introduction to the methodologies of resource assessment for the identified RET (solar, mini-hydro, wind and biomass) in three different contexts:

a. **Entire Country**: Assessment of the particular resource done in the context of the entire country.

b. **Province or Region**: Assessment of a resource in context of a province or region.

c. **Local situation**: Resource assessment in the context of a particular local situation - a village/a family or otherwise.

d. To the extent possible, a set of assessment tools - computer based or otherwise may be provided to conduct these assessments.

e. Exercises on resource assessment, using the assessment tools provided, may be developed.

f. Provide a list of reputed sources from where data/information for resource assessment can be obtained.

**Chapter 3: HOW CAN RESOURCE ASSESSMENT BE USED TO DEVELOP TECHNICAL SPECIFICATIONS/SIZING TO ACQUIRE RENEWABLE ENERGY TECHNOLOGIES**

a. Provide appropriate tools - preferably computer based, that make it possible to estimate the size and other important configuration related parameters for the identified technology for a particular application and local situation.

b. Exercises on estimation of size and other related parameters, using the tools provided, may be developed.

## Chapter 4: CONCLUSION

a. Summary

b. General Guidelines

**References:** Provide reference of useful data (web links, books, reports and other available material) related to resource assessment and RE technology selection.

Chapter I

INTRODUCTION

Wind power has been harnessed for centuries and prior to the advent of heat engines, wind power was one of the most exploited resources. The disadvantage of not being available when needed coupled with low energy density made this resource take a back seat for nearly two centuries. Many of the lessons learnt have been lost with march of time. However, being a freely occurring resource it is at once confused to be a simple matter to design conversion systems. In the present day scenario nothing is farther than this assumption. Wind energy convertors present one of the most interesting design challenges.

*b. Explain the principle of operation/functioning of the identified RET in simple terms.*

Wind is air in motion. Air has a density of 1.225 kg/m$^3$ at 15°C at 0 m amsl. There are methods of estimating air densities at different temperatures and atmospheric pressures. From the first principles of Physics, we know that any mass that is moving with a speed will have a momentum (product of mass and the velocity). This is a form of energy defined as kinetic energy/unit time is defined by a simple energy balance equation.

$$P = \frac{1}{2}.m.v^2$$

$$= \frac{1}{2}.a.\rho.v.v^2$$

$$= \frac{1}{2}a.\rho.v^3$$

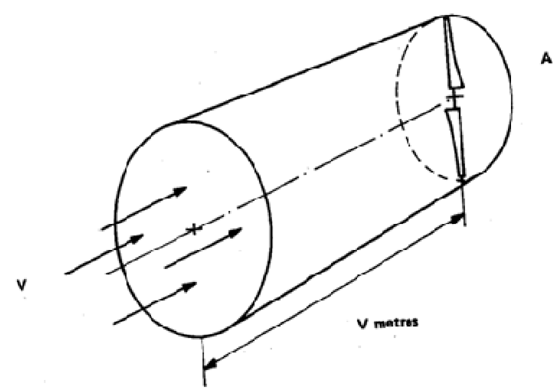
Where a = swept area (m$^2$)

m = mass of air passing through the area a (kg)

v = velocity of air passing through the area (m/s)

$\rho$ = density of air (kg/m$^3$)

P = Power (watts)




Wind power equipment extracts the kinetic energy in the wind and this form of energy cannot be stored like water at a higher elevation. These devices work more like ‘run of the river’ convertors. There are two distinct ways this is done. One depends on the drag effect where the rotor runs in the same direction as the wind itself. The other method utilizes the aerodynamic effects of the air passing over the airfoil shapes.

Conversion efficiency of different devices is found to vary considerably and depend upon the speed at which the rotor turns. A most commonly used factor known as 'tip speed ratio' is defined as follows:

$$\lambda = \frac{V_{tip}}{V_{\infty}}$$

Where $\lambda$ = tip speed ratio

$V_{tip}$ = Linear velocity of the blade tip

$V_{\infty}$ = Undisturbed wind velocity

The conversion efficiency is related to this ratio. Figure 1.2 shows how different configurations of wind rotors relate to the coefficient of power which is defined as the ratio of the power extracted & the power in the wind stream.

$$C_p = \frac{P_e}{P_w} \quad Where\ P_w = \frac{1}{2}\rho A V^3$$

Drag devices will have slightly lower tip speed ratio than 1 implying that they will not be able to have the rotors turning faster than the wind passing through them. Efficiency of devices using drag forces will also be lower compared to devices which make use of lift force. The blade tips in these rotors will be travelling faster than the free stream velocity and are able to give higher efficiencies.

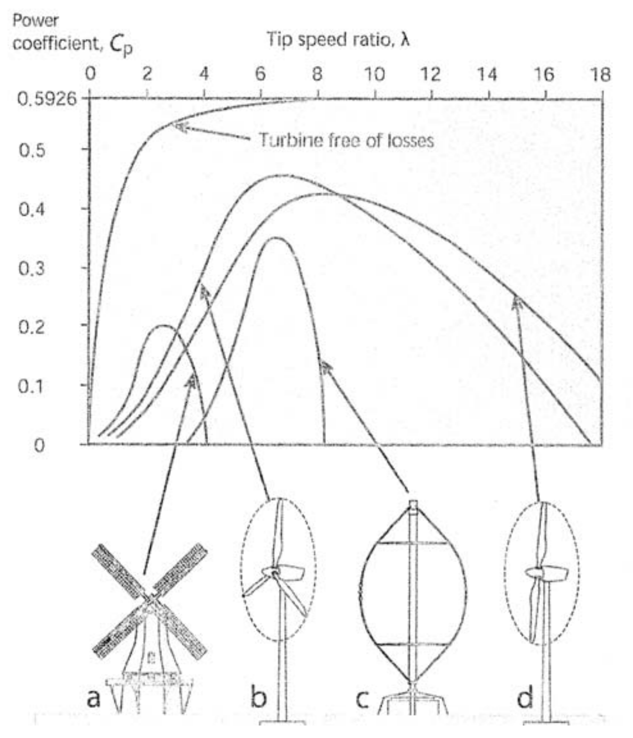



Figure 1. 2 Different wind power conversion concepts (Adopted from Tore Wizelius 2006)

It does not necessarily mean that they have no possible applications. Some of the earliest windmills were designed based on this principle (fig 1.3). It is characterized by simplicity of construction, ability to accept winds from any direction without having to have elaborate arrangements and have no risk of over speeding like in the case of lift based machines.

Dutch design with four blades were based on drag principle dotted country side over the entire Europe and even to this day conjures up the picturesque images were drag based designs.

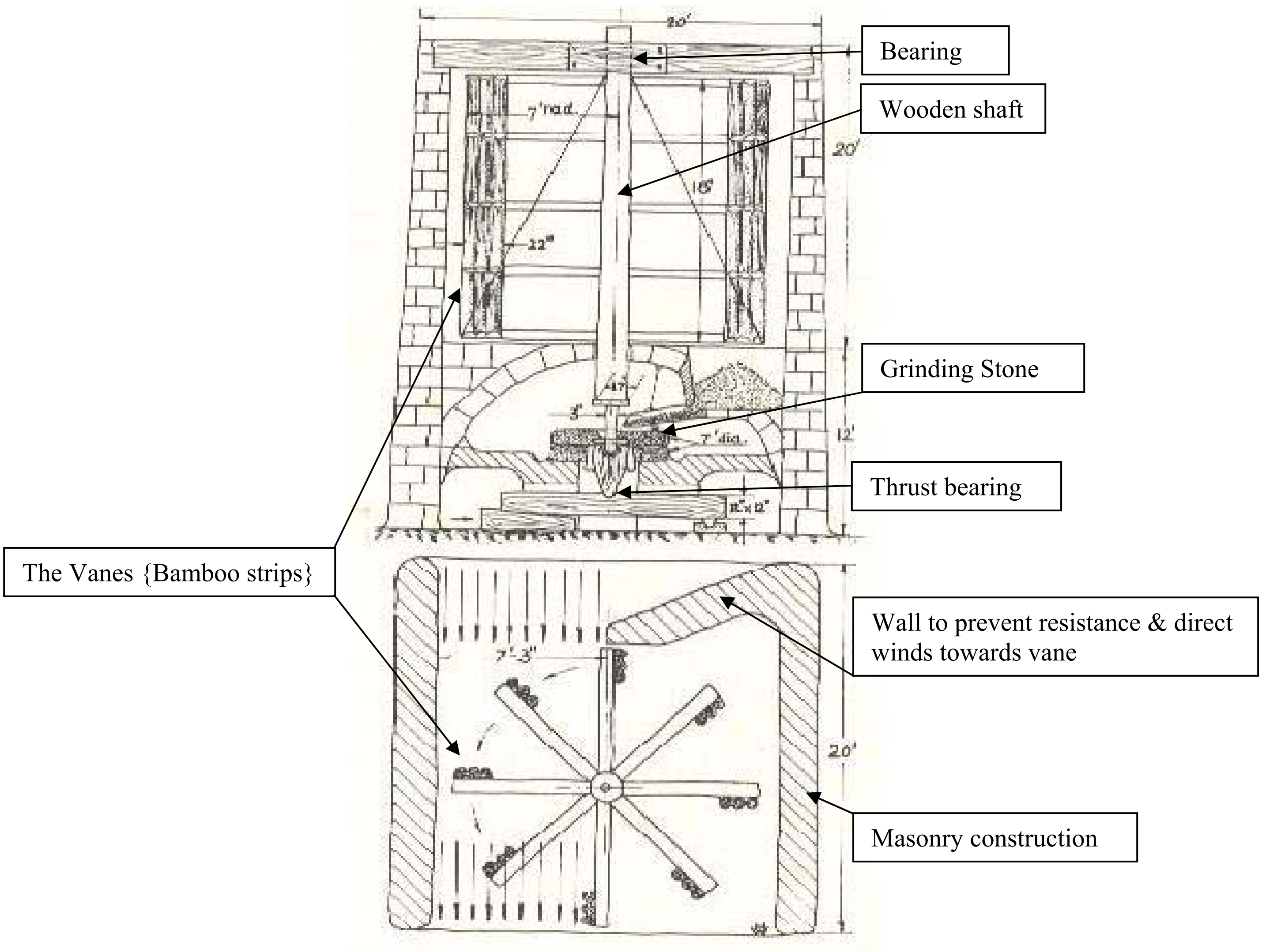
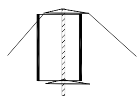
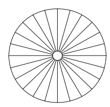
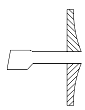
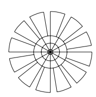
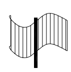
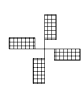



Figure 1.3 An early Persian windmill (circa 100 B.C.)

| | | | | | |
|---|---|---|---|---|---|
| Propeller (Lift)  | 6 to 20 | 0.42 | High | Low | Electric Generator |
| Darrieus (Lift)  | 5 to 6 | 0.40 | High | Low | Electric Generator |
| Cyclo gyro (lift)  | 3 to 4 | 0.45 | Moderate | Moderate | Electric Generator or pump |
| chalk Multi-blade (lift)  | 3 to 4 | 0.35 | Moderate | Moderate | Electric Generator or Pumps |
| Sailwing (lift)  | 4 | 0.35 | Moderate | Moderate | Electric Generator or pumps |
| Fan Type (Drag)  | 1 | 0.3 | Low | High | Pump |
| Savonius (Drag)  | 1 | 0.15 | Low | High | Pump |
| Dutch type (drag)  | 2 to 3 | 0.17 | Low | High | Pump or Mill stone |

Drag devices

The most common device that makes use of drag effect is the cup anemometer. Some of the earliest windmills used the drag effect. From first principles, it is possible to prove that the maximum efficiency of conversion that can be attained will be 5/32 or 15.625 %. This implies that the devices which are based on the drag principle are generally less efficient compared to the devices which make use of principles of aerodynamic lift and drag. A well designed drag device would work very well for many years. Considerable attention needs to be paid to detailed engineering evaluation. Due to the simple fact that they do not run at very high speeds, they have the capacity to withstand high winds without getting damaged due to centrifugal forces. However, it should be recognized these are low efficiency devices. Due to low efficiency, to obtain a given power from the machines they have to be relatively large. This in turn has an impact on the usage of material to construct the windmill. In any mass produced product costs cannot be controlled effectively if we need to put in more steel or other materials. With this background it is difficult to accept wind energy convertors of this type particularly in large sizes. However when we are looking at very small applications, where reliability is more important than the initial cost, drag devices scores over lift devices. The idea is that once deployed, the windmill should require minimum scheduled and unscheduled maintenance. It is very difficult to provide effective post installation service back up for small applications.

**Wind mills using lift action**

Most of today's wind turbine designs are based on the aerodynamic effects of wind flow over the blades. It can be shown that the maximum efficiency that can be expected from a wind rotor will be equal to 16/27 or 59.3 %. This is known as the Betz limit. This limit is applicable to un-augmented wind mills. There are a number of augmentation techniques proposed and experimented with over centuries, but they are never known to be successful in a commercial sense.

**The aerodynamics of a lift device**

When any object is placed in a fluid flow it experiences two types of forces. A drag force that acts along the flow direction and the other the lift force that is perpendicular to the direction of flow (fig 1.4).

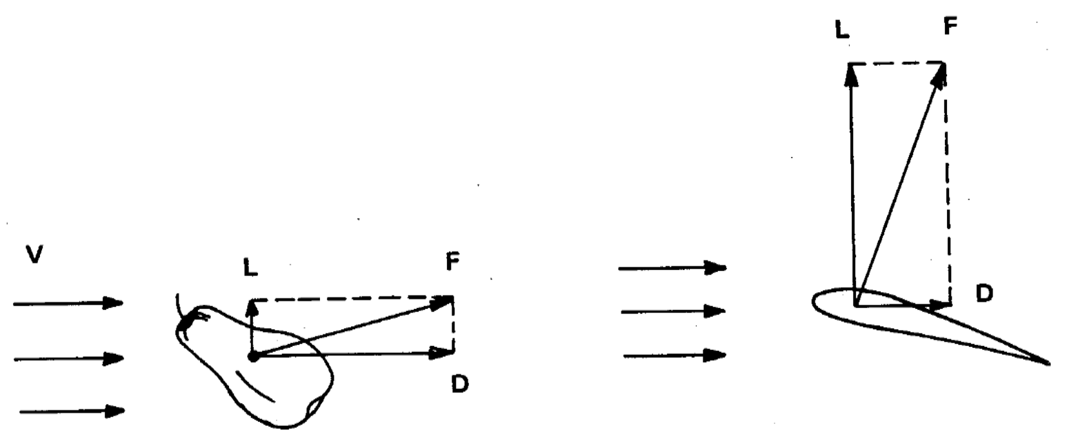



Figure 1.4 Lift and drag forces on a body immersed in fluid flow (adopted from H.Lyson 1979)

Drag force is somewhat easy to understand. Any object in the flow would be dragged along the stream. Lift force needs a little imagination and the knowledge of Bernouli's law. When flow divides over the pear shape or airfoil shape the underside of the body experiences an increase in pressure due to flow retardation in that area. On the upper side there will be a reduction in the pressure. When this happens, the pressure differential will cause a net force pushing the body upwards. When we want to maximize the net lift force and minimize the drag force, we create special cross sections which are known as Airfoils. The figure 1.4 shows how by having a special shape the Lift forces have been increased and drag force minimized.

The lift and drag forces are calculated by:

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

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

$F_l$ & $F_d$ are lift and drag forces and $C_l$ and $C_d$ are the coefficients of lift and drag respectively. The lift and drag coefficients are dependent on what is known as the angle of attack generally denoted by $\alpha$. Figure 1.5 shows a typical relation between angle of attack and lift and drag coefficients.

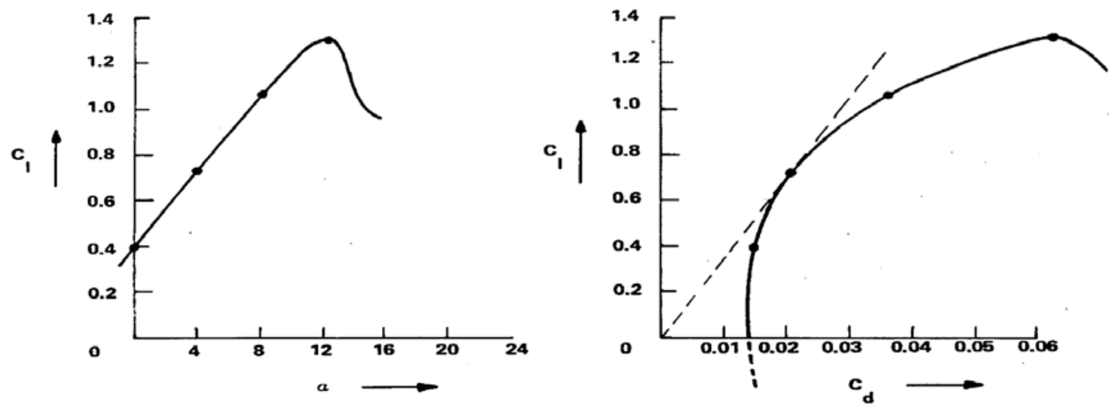



Figure 1.4 Dependence of Lift and drag coefficients on angle of attack (adopted from H.Lyson 1979)

The $C_l$ increases with increasing $\alpha$ up to a point after which it drops off sharply. However the $C_l$ Vs $C_d$ plot shows that beyond a point $C_d$ also increases thereby resulting in a net loss of force and therefore power. The point to note is that there is an optimum angle that needs to be maintained at each blade section to get maximum output. Figure 1.6 shows a typical wind mill rotor blade with the blade twisted along the length of the blade.

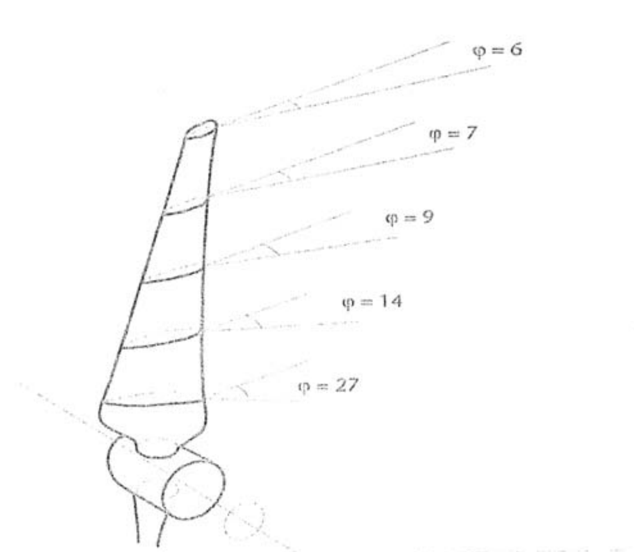



Figure 1.6 Blade twist to maximize power (adopted from Tore Wizelius)

Typical values for the Cl, Cd, etc are given in the table below:

| | Shape | $C_l$ | $\alpha$ | $C_d/C_l$ |
|---|---|---|---|---|
| Flat Plate | | 0.8 | 5° | 0.1 |
| Curved Plate | | 1.25 | 3° | 0.02 |

| | | | | |
|---|---|---|---|---|
| Curved plate with tube inside |  | 1.1 | 4° | 0.03 |
| Curved plate with tube outside |  | 1.25 | 14° | 0.2 |
| Airfoil NACA 4412 |  | 0.8 | 4° | .01 |

For small applications, even curved plates can be used as blade material thus keeping costs down. For larger applications specially designed airfoil sections are employed.

### *c. <u>Specify the natural resource/s utilized by the identified RET</u>*

Wind Energy is one of the manifestations of Solar Energy that reaches the earth's surface. The way the solar energy gets converted into kinetic energy imparted to the air is a combination of differential heating of the earth surface and its immediate atmosphere, solstice and rotation of earth. Just to over simplify, we know that equatorial region receives much more sun shine compared to the polar regions. This would result in the earth's surface near equator heating up air over it. When hot air starts raising, the lower reaches of earth surface will have low pressure while the air near polar region would have higher pressure. There fore the air from high pressure region would start moving towards the equator thus starting up a large movement of air towards the equator near the earth's surface.

The axis of the earth oscillates by 23 degrees as it goes around the sun. This causes heating and cooling of earth's surface with vast differences in the amount of heat that reaches different parts of the earth. For example during summer somewhere around May the northern hemisphere would be tilted towards the sun. At this time Southern hemisphere would be going through winter. With colder temperatures, there would be air with higher pressure in the southern hemisphere as opposed to the low pressure regions in the northern hemisphere. This causes circulation of vast amounts of air. It should not be forgotten that all the while earth is also rotating around it's own axis. Therefore the air moving towards equator and beyond will also get a twisted path due to a phenomena known as Corriolli's effect. This is normally termed global circulation and has dimensions of the order of thousands of kilometers. It should however be noted that this simplistic explanation gets considerably modified in reality. Here it will suffice to know that wind energy is a form of solar energy.

Scales of atmospheric motion

There are four scales of atmospheric motion both in time and domain scales.

1. Global Circulation has time scales of weeks to years and length scales of 1000 to 40000 kms. Trade winds, jet streams are some examples.
2. Synoptic scale ranges from days to weeks and length scales of 100 to 5000 km. Some examples are cyclones and anti-cyclones, hurricanes.
3. Mesoscale motions have time scales in minutes to days. The length scales are in the range of 1 to 100 kms. Tornados, thunderstorms, land and sea breezes fall in this range.
4. Micro-scale motions occur over seconds to minutes and length scales will be less than a kilometers.

### *d. Explain the advantages and disadvantages of identified RET*

Wind power is inexhaustible and is a distributed source of energy that can be anticipated with better certainty compared to hydraulic power. It is also not possible to restrict its availability by manmade barriers such as embargos or artificial shortages due to break down of supply chain. There are no environmental costs to pay. In grid connected mode wind turbines work like any other generating plants with some limitations. It is possible to add more and more turbines to increase the installed capacity and thereby increase generation from a given area. Gestation period for wind power projects where the resource availability is already known can be as small as six months. Among all RE technologies wind power devices are technically most mature and has a developed and established market place. O & M of wind mills is considerably simpler compared to any other generating technologies except perhaps hydro electric plants.

Some of the disadvantages

Wind power availability and demand may not always match. This requires a reorientation of how wind power is to be integrated with other sources of energy. It is a rather dilute resource (compared to hydraulic energy or chemical energy stored in fuels) and therefore would require voluminous machinery for converting kinetic energy into useful work.

a. *Explain the simple techno-economic features of the identified RET*

A typical wind energy convertor consists of the rotor, transmission system, pump or generator. As the system is expected to work with uncontrolled wind forces, safety systems need to be in place to protect the hardware and its surroundings. A support structure will be essential to mount the equipment. Generally the foundation design would depend upon the soil conditions and the static and dynamic loads the wind energy convertor would exert.

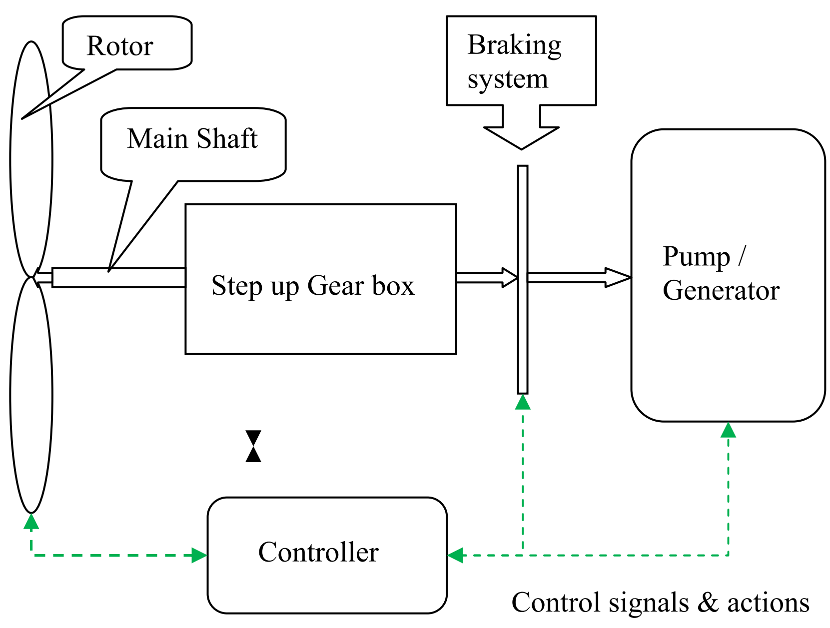



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Figure 1.7 Components of a typical Wind Energy Convertor

Figure 1.7 gives basic components of a windmill or a wind turbine. Depending on the design many variations can be seen in practice. The design of wind mills and wind turbines (electricity generating wind machines) will be somewhat different. A rough indicative break up of individual costs will be:

| | |
|---|---|
| Rotor blades | 18 to 20 % |
| Hub | 2 to 3 % |
| Gear box | 15 to 20 % |
| Generator | 4 to 6 % |
| Nacelle | 5 to 8 % |
| Tower | 15 to 20 % |
| Yaw bearing | 5 to 6 % |
| Covers, ladder/lift elevator etc. | 3 to 5 % |
| Control system | 10 to 12 % |
| Electrical & other accessories | 2 to 4 % |

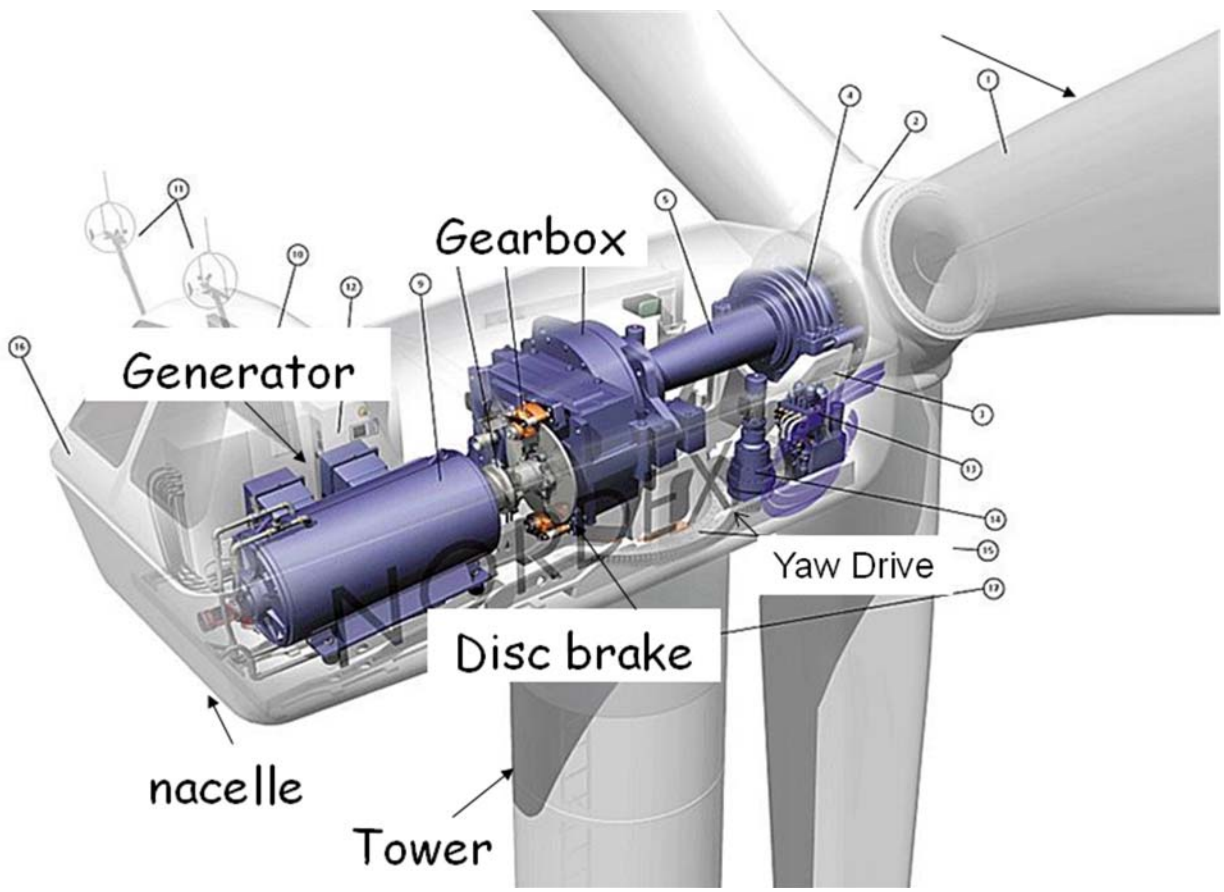


Figure 1.8  A typical modern Wind turbine

A modern wind turbine would have a parts list that would run into scores of pages.  Figure 1.8 shows the typical assembly of mechanical parts.  In addition there would be the electrical and control systems which are basically same as any standard power plant.

A small water pumping wind mill normally consists of a rotor with fixed blades mounted on rolling bearings using a shaft of sufficient capacity. There may be no gear box although some designs do have gear boxes for speed matching with the pump. Professionally designed windmills have a brake which can be manually actuated. For automatic shut down, a number of innovative ideas are used. One of the common methods is to mount the rotor slightly offset from the yaw bearing axis.

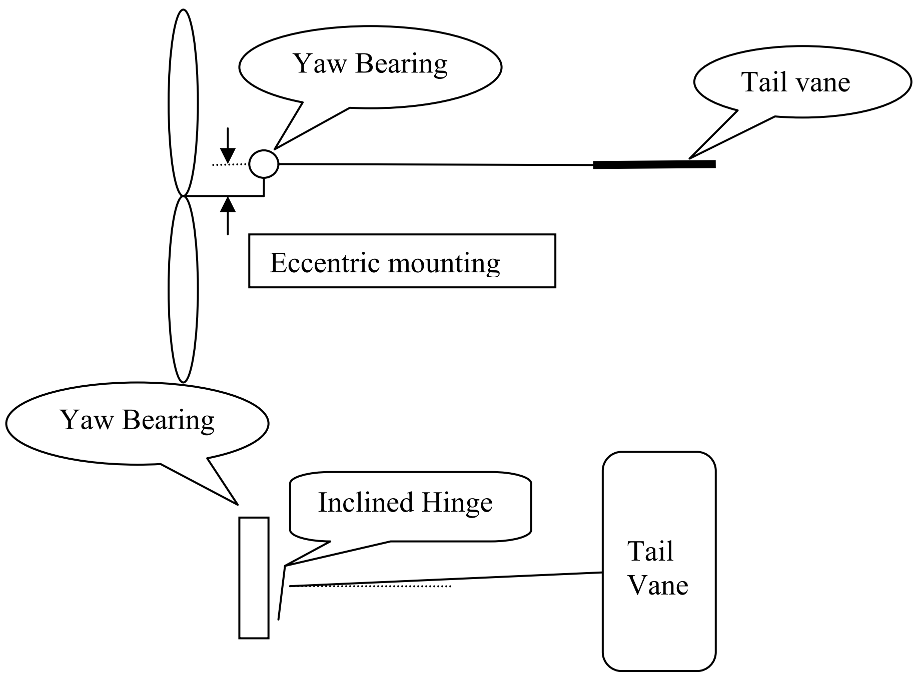


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Figure 1.9 Passive Safety system for small windmills and wind battery chargers.

As the wind speeds go on increasing, the rotor thrust (fig1.9) the rotor starts shying away from the winds and in the process lift the tail vane. This action would reduce the projected swept area of the rotor thereby reducing the input power. This action would result in rotor not speeding up with increased wind speeds. When the winds fall the tail vane will occupy its normal position to make the rotor face the winds.

Typically a wind energy convertors can cost about US$1000/kW. In smaller capacity it may be in the range of US$1500/kW. Typical wind mill of 5 m rotor diameter for water pumping would cost about US$3500.00 by the time it is installed. Though it is possible to do some cost benefit analysis, in standalone mode it should be noted that one should not expect such deployments to be economically fully viable in terms of cost per kWH vis-à-vis hydro or thermal energy. Though fuel prices keep going up in most developing countries, it may be wrong to assume that due to this, COE from renewable energy devices would become competitive at a future date. The general inflationary trends would have impact on the hardware and therefore it would take longer to become cost competitive.

b. *Illustrate (list) typical - successful and most useful applications/uses of the particular RET with explanations on how to accommodate the availability* *pattern of its resource and other peculiar/unique characteristics associated with the technology, if any.*

Two cases: large Grid connected wind turbines

Small stand alone applications in hybrid mode or water pumping or other applications

Grid Power:

Grid connected wind power is the best example of commercially successful deployment of renewable energy technology. As generated power gets consumed somewhere on the grid, there would be no need to have elaborate storage systems. This has made wind power most attractive renewable energy option. Till 2009 March the installed capacity of wind power in the world has reached 120,879 MW by December 2008. The Table below gives world wide deployment statistics:

**Global Installed Wind Power Capacity (MW)**

| | **End 2007** | **new 2008** | **End 2008** |
|---|---|---|---|
| **Africa & Middle East** | | | |
| Egypt | 310 | 55 | 365 |
| Morocco | 124 | 10 | 134 |
| Iran | 67 | 17 | 85 |
| Tunisia | 20 | 34 | 54 |
| Other | 17 | 14 | 31 |
| **Africa & Middle East Total** | **539** | **130** | **669** |
| **Asia** | | | |
| China | 5,910 | 6,300 | 12,210 |
| India | 7,845 | 1,800 | 9,645 |
| Japan | 1,528 | 356 | 1,880 |
| Taiwan | 281 | 81 | 358 |
| South Korea | 193 | 43 | 236 |
| Philippines | 25 | 8 | 33 |
| Other | 5 | 1 | 6 |
| **Asia Total** | **15,787** | **8,589** | **24,368** |
| **Europe** | | | |
| Germany | 22,247 | 1,665 | 23,903 |
| Spain | 15,145 | 1,609 | 16,754 |
| Italy | 2,726 | 1,010 | 3,736 |
| France | 2,454 | 950 | 3,404 |
| UK | 2,406 | 836 | 3,241 |
| Denmark | 3,125 | 77 | 3,180 |
| Portugal | 2,150 | 712 | 2,862 |
| Netherlands | 1,747 | 500 | 2,225 |
| Sweden | 788 | 236 | 1,021 |
| Ireland | 795 | 208 | 1,002 |
| Austria | 982 | 14 | 995 |
| Greece | 871 | 114 | 985 |
| Poland | 276 | 196 | 472 |
| Norway | 326 | 102 | 428 |
| Turkey | 147 | 286 | 433 |
| Rest of Europe | 955 | 362 | 1,305 |

| | | | |
|---|---|---|---|
| **Europe Total** | **57,139** | **8,877** | **65,946** |
| | | | |
| **Latin America & Caribbean** | | | |
| Brazil | 247 | 94 | 341 |
| Mexico | 85 | 0 | 85 |
| Costa Rica | 70 | 0 | 70 |
| Caribbean | 55 | 0 | 55 |
| Argentina | 29 | 0 | 29 |
| Others | 45 | 0 | 45 |
| **Total** | **531** | **94** | **625** |
| **North America** | | | |
| USA | 16,824 | 8,358 | 25,170 |
| Canada | 1,846 | 523 | 2,369 |
| Total | 18,670 | 8,881 | 27,539 |
| Pacific | Region | | |
| Australia | 824 | 482 | 1,306 |
| New Zealand | 322 | 4 | 326 |
| Pacific Islands | 12 | 0 | 12 |
| Total | 1,158 | 486 | 1,644 |
| **World Total** | **93,823** | **27,056** | **120,791** |

*Source: GCWC*

Small Stand alone applications:

The water pumping windmills, which have a reasonably good machine design, have lasted longer. The need to make them very cheaply and with minimum facilities has always had a debilitating effect on the durability of windmill components. The focus of such designs should be on the durability and easy maintainability. On the wind battery chargers, there are added electronic devices with questionable reliability. Most of the manufacturers swear by their products, but there will be a need for more careful evaluation, particularly about the long term operations. There will also be a tendency to deploy them without adequate analysis. But, there are some niche areas where these machines have been such a good fit. One such example is the micro-wave repeater stations with uncertain or no grid power. In the Indian Antarctic station, there was a microwave repeater station that was used for maintaining communication link between the Maitri station and the Ship anchored in the Antarctic sea. With convoy movement, it used to be safety critical to have fully functional radio link. The repeater station was powered by batteries and it was absolutely essential to physically transport charged battery everyday and bring back the spent battery. The energy required was in terms of a few hundred watt hours per day while it used to cost enormously to allocate man power and a 350 Horse power snow vehicle to transport the battery. A wind power battery charger was deployed on site and it was very effective in maintaining the batteries in full charge under all weather conditions.


*Figure1.8 Some snaps of niche areas of small battery charging applications*

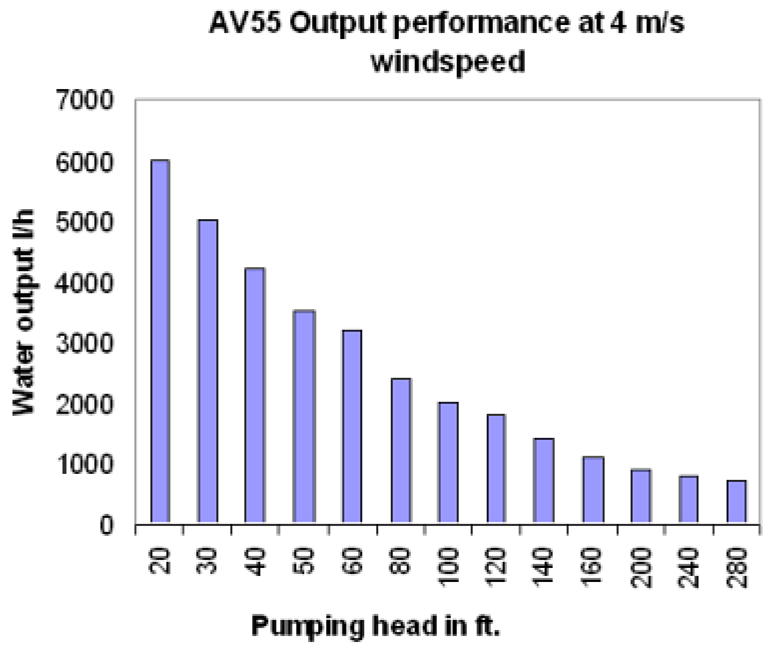
A seemingly simple application of wind energy is the water pumping windmills. Though some claims are made to the application possibility of wind

c. <u>*Explain the main technical parameters associated with the identified RET and how to interpret its values.*</u>

In order to get a feel of specifications of a wind mill a typical water pumping windmill has been chosen. It should be noted that the output of a given windmill can vary considerably with each installation and certain amount of pre-calculations will be required to see if the given model will meet the requirements. It becomes essential to have complete information on the windmill. AV 55 is a windmill model that has been designed by Auroville Windsystems for water pumping applications. It is one of the designs which has stood test of time. The specifications are also sufficiently detailed and therefore chosen in this illustration

**Specs of a typical windmill (source:Auroville wind Systems web page)**

| | **Model** |
|---|---|
| Design tip speed ratio | 1,2 |
| Max. rotor speed | 5.2 rad/s (approx.50rpm) |
| Rotor diameter | 5.7m (19ft) |
| Area of blades | 10.8 m² |
| Number of blades | 24 |
| Pump stroke | 160 or 230 mm |
| Ratio | 1:1 direct drive |
| Safety mechanism | fully automatic (inclined tail hinge) |
| Cut-in windspeed | 1:5 m/s |
| Cut-out windspeed | 10 m/s |
| Survival windspeed | 40 m/s |




***Bearings:***
*Rotor shaft : Two sealed roller bearings*
*Connecting rod : top is a sealed roller bearing; bottom is a teflon bush bearing (maintenance free)*
*Cross head : Sleeve bearing (low maintenance)*
*Jaw bearing : Teflon / nylon (low maintenance)*

***Pumps:***
*Single acting piston pumps.*
*Cylinder bore diameters : 64mm / 82mm / 108mm / 130mm / 160mm*
*Cylinder materials : stainless steel*
*Cup washer : synthetic rubber*
*Foot valve : synthetic material*
*Piston valve seat : stainless steel*
*Pump rods : round steel rod, diameter 16mm*

***Foundations:***
*The tower foundations and the delivery pipe clamp anchoring have to be executed according to our layout drawings.*
*Tower foundation : 3x0.3m³ concrete*
*Delivery pipe anchor : 1x0.2m³ concrete*

***Range of application:***
*The windmill can be used for pumping water from deep borewells - max. 100m depth with the AV55 as well as for low lift high volume output from shallow wells.*

The specifications are self explanatory and generally complete. For small wind power equipment it to be expected that there could be large variations. It is important to seek explanation about the averaging time for various parameters such as the power curve. Power curve is a plot of wind power and the power output. Standard requires that the averaging is done with 10 minute average values. Many a times manufacturers specify values based on instantaneous values and it is not acceptable. Safety systems

d. *Explain how records comprising these parameters are normally maintained and the identified RET's technical/operational performance assessed.*

Wind turbines

Wind turbines are also some times called windmill generators, wind energy convertors, grid cconnected wind energy convertors and so on. IEC defined the term Wind Turbine to represent this type of wind energy convertor. Wind turbines once are deployed they would have in all cases a log book opened in which the operator records extracts from the controller. Some of the salient factors are the energy meter reading on the wind turbine display unit, number of low wind hours (actual generation hours), energy consumed and reactive power consumed. The log book also holds details of shut downs, component failures and replacements carried out, overhauls, and other actions that the operator or maintenance team executes as required. In more modern wind farms a Supervisory Control And Data Acquisition (SCADA) system is installed that permits remote data acquisition and some rudimentary operations such as restarting of the turbines switching off turbines. The SCADA can be configured to give overview of the wind farm performance and status of the wind farm on a 24 x 7 basis and store various parameters with average, standard deviation, maximum, minimum functions, status signals etc. on the computer installed in the control room. The site control room houses the Central Monitoring System (CMS) from where the data stored and displays can be uploaded to a remote location such as the wind farm owner's office. This was originally achieved using V-SAT terminals. In the recent times there are GSM based facilities where feasible. With these systems it is possible to get connected to the wind farm computer as and when required.

Wind battery chargers & Water pumping windmills

These are small applications and what may be desired can be listed and often no records are kept. There would be no billable numbers that need to be kept and hence there would be no records kept. Having said that, it is desirable to have a log book written regularly. The log book should carry complete specification of the windmill and all the systems. Details of the manufacturer, sub component suppliers, contact details of the service engineer/technician. It should also list the periodic maintenance requirements and have clear instructions. Where the need for trained personnel is required should be clearly specified. It would be desirable to have records regarding any O & M carried out, date for next maintenance noted. Though it is desirable to have a ampere hour meter or a water meter installed so that some idea about the performance can be obtained in the first year of operation. Another important factor that needs to be kept track of in case of lead acid batteries is the specific gravity of the acid. Weekly records of the Specific gravity could reveal effectiveness of the battery charging process. It would also help in determining any need for an occasional boost charging. Batteries are known to 'get used to' overcharging and under charging thus impacting on their ability to provide rated charge capacity. In practice, it has been found that manual data collection is fraught with operator apathy and malfunctioning of instruments used is a very difficult task. To use advanced data logging systems is equally difficult and except when we look at it as a research project. In commercial deployment data collection can be a nightmare. However it should be noted that these are desirable data and the expectation that they will actually happen when deployed in large numbers is most often not met.

e. *Explain what parameters need to be examined while making selection/sizing decisions pertaining to the technology and what are the ideal values of these parameters for various applications.*

Grid connected wind turbines have verifiable performance characteristics and specifications on a comparable basis because they more often than not conform to accepted standards. International Electro Technical Committee (IEC) has framed certain standards for evaluating wind turbines and are used as the common ground for type certification of wind turbines. Similarly Germanischer

Lloyd (GL) from Germany is an accredited Certification Agency that has framed extensive rules for type certification of wind Turbines.(IEC, GL rules etc.). India has framed its own standards known as Type Approval Provisional Scheme (TAPS) for type certification of wind turbines. It is possible to get wind turbines certified by an accredited certification body such as GL, TUV, CWET etc., as per different certification standards. Unfortunately it has not been possible to have such standard formulation for small machines for a variety of reasons. The most important factors that need to be checked are:

Cut in Wind speed.
Rated Wind speed
Cut out wind speed
Survival wind speed
Rated Capacity
Status of Type Certificate
Expected out put in a given windy site
Anticipated service life
Major and minor maintenance during the service life
Infrastructure needed for installation and maintenance
Permits and grid connectivity issues.

For smaller machines but for the permits all other factors need to be checked out. There are very few small machines which have any certification at all. Sometimes there would be an attempt from the manufacturer to obtain some adhoc test certificate from universities and engineering colleges, but they do not provide any verifiable frame work under which such certificates are issued. More often than not it will not be possible to accept such certificates. Unfortunately the standards against which the design can be verified is not as developed as those for the large grid connected wind turbines. IEC specifies 200 sq.M of swept area as the upper limit for small windmills and have to be checked against IEC 61400-2.

## Wind Turbine Type Specification:

Most of the specifications are self explanatory. The IEC classification or GL classification indicates the wind zones in terms of extreme wind speeds and annual average wind speeds for which the design life time has been verified. That is, the wind turbine will be able to withstand extreme gusts below a specified value under various operating conditions. Further, probability of accumulated fatigue damages exceeding the failure limit of critical component within the design service life would be small. The table below shows the IEC. Germanischer Lloyd also has specified four wind zones to which certification is carried out.

| Wind Turbine Class | I | II | III | S |
|---|---|---|---|---|
| $V_{ref}$ (m/s) | 50 | 42.5 | 37.5 | Values Specified by the designer |
| A $I_{ref}$ (-) | 0.16 | | | |
| B $I_{ref}$ (-) | 0.14 | | | |
| C $I_{ref}$ (-) | 0.12 | | | |

| **Wind Turbine Type Specification:** | | |
|---|---|---|
| **Machine parameters:** | **Units** | **Explanations (values are typical)** |
| **Model** | **Model number** | Could be S82/ V39 etc generally number refers to the rotor diameter |
| manufacturer and country | | |
| IEC WT class | I/II etc.. | |
| Rated power | [kW] | For example 900 kW |
| Rated wind speed $V_r$ | [m/s] | 12.5 m/s |
| It s Rotor diameter | [m] | 44 |
| Hub height(s) | [m] | 65 |
| Hub height operating wind speed range $V_{in}$-$V_{out}$ | [m/s] | 3-25 m/s |
| Design life time | [y] | 20 |
| **Wind conditions:** | | |
| Characteristic turbulence intensity I15 at $V_{hub}$ = 15 m/s | [-] | 0.12 or 12 % |
| Annual average wind speed at hub height $V_{ave}$ | [m/s] | |
| Reference wind speed $V_{ref}$ | [m/s] | |
| Mean flow inclination | [deg] | |
| Hub height 50-year extreme wind speed $V_{e50}$ | [m/s] | |
| **Electrical network conditions** | | |
| Normal supply voltage and range | [V] | 400/440/690 V |
| Normal supply frequency and range | [Hz] | 50/60 Hz |
| Voltage imbalance | [V] | +/- 10 % |
| Maximum duration of electrical power network outages | [days] | |
| Number of electrical network outages | [1/y] | 20 as per IEC Indian req 350/year |
| | | |
| **Other environmental conditions** | | |
| Design conditions | | |
| Normal and extreme temperature ranges | [°C] | -10 to +45 |
| Relative humidity of the air | [%] | 95 % |
| Air density | [kg/m$^3$] | |
| Solar radiation | [W/m2] | 1000 W/sq M |
| Description of lightning protection system | | |
| Earthquake model and parameters | | |
| Salinity | | |
| **Major components:** | | |
| | | |
| Blade type | | Manufacturer and model number |
| Gear box type | | Make, model number etc |
| Generator type | | Assynchronous/synchronous etc. |
| Tower type | | Tubular/Lattice/concrete |

Design life is normally 20 years. Important points to note are that the specifications shown above are for a given type of wind turbine and since the design would have been verified as per agreed standards, there would be a good probability of a given turbine will perform as per known parameters during the design life.

References:


1. Meteorological Aspects of the Utilization of Wind As an Energy Sources WMO Tech Note #175
2. E.H.Lysen , Introduction to Wind Energy, CWD
3. Tore Wizelius, Developing wind Power Projects – Theory & Practice, Earth scan
4. www.aws.auroville.com
5. TAPS 2000, CWET

**Chapter 2**

## GUIDING PRINCIPLES OF A RESOURCE AFSSESSMENT PROGRAMME

Introduction to the methodologies of resource assessment for the identified RET (solar, mini-hydro, wind and biomass) in three different contexts:

Wind speed measurements form the basis of a successful application program for utilization of wind as a source of energy. There are a range of techniques starting from observing physical effects of wind on the vegetation to high end LIDARs & SODARS have been used for qualitative and quantitative measurements. Figure 2.1 shows how continuous and steady winds have deformed the trees


A deformed tree in a high wind area

SODAR being set up for measurements

Figure 2.1 Biological indicators of high wind activity and modern methods of wind velocity measurements

While these methods form the two ends of an assessment, the need for a normal long term measurement cannot be avoided because neither of the two methods give the necessary comfort in concluding that wind energy hardware could be deployed in a given area and if deployed they would give justifiable outputs and have a useful service life. For proper quantification it is necessary to make detailed measurements for periods of several years. While doing so, it will be useful to take guidance from available standards (IEC 61400-12-1).

A typical wind measurement station contains the following:

A minimum of two pairs of anemometers and direction sensors to be mounted at two different heights

A temperature sensor (some data loggers provide this internally)

A pressure sensor (preferable to have one)

If planning to set up a new program of measurements it will be useful to have a Pyranometer (for measuring global radiation).

Compatible data logger.

Good grounding and lightning arrestor.

A monitoring mast of at least 50 m height (figure 2.2).

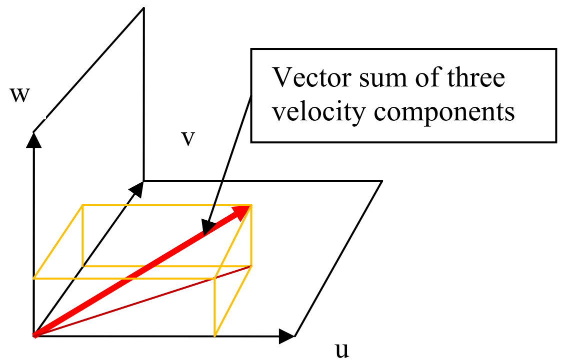
Figure 2.2 A typical wind monitoring mast.

Instrumentation normally used:

A number of parameters are A variety of sensing techniques are employed and each has its own merits and disadvantages. Here a brief outline of each such technique is given. A more detailed treatise on this subject is beyond the scope of an introductory course.

Anemometer

Anemometer is an instrument that is used to measure the wind speeds. Wind Velocity is a vector quantity, that is it has a magnitude and a direction. These are normally signified by 'u', 'v' and 'w' components. Wind energy convertors are designed to extract wind velocities that exist in a horizontal plane. Therefore the most of the instruments designed look at the horizontal components 'u' and 'v'. The indicated wind speed will be the vector sum of the two orthogonal components.




$$WS = \sqrt{u^2 + v^2 + w^2}$$

Figure 2.3 Three components of wind speed.

A number of designs are in the market with varying degrees of complexities and sophistication. The simplest and most commonly employed instrument is the cup anemometers. At the other end there are (**Li**ght **D**etection **A**nd **R**anging (LIDAR) instruments and **So**und **D**etection **A**nd **R**anging (SODARs) instruments and ultrasonic anemometers. Cup anemometers consists three or four cups mounted on a vertical shaft. The speed of rotation of the cups is a measure of the wind speed.

| | | | |
|---|---|---|---|
|  Cup Anemometer |  Propeller anemometer with integrated direction sensor |  Ultra-sonic Wind Velocity Sensor |  SODAR |

Figure 2.4 Some commercially available wind speed/velocity sensors

The rotating cups or propeller would be carrying a magnet that would induce an AC voltage in a coil that is placed in the field. The frequency of the induced voltage is measured. With suitable conversion factors the wind speed is determined. The propeller anemometer shown in fig 2.4 has a tail vane which aligns the propeller to face wind at all times. The position of the tail vane relative to North is sensed using a potentiometer.

Many of wind energy applications particularly in complex terrain (hilly, uneven terrain) it becomes essential to measure the Ultra sonic anemometers make use of three transmitters and three receivers of the ultrasonic waves.  The shift in frequency due to superimposed wind velocity is a measure of wind velocity. Since the three probes and transmitters are placed in three mutually perpendicular directions, the instrument will be able to measure wind speeds in three mutually perpendicular directions.  The vector sum of the three velocities will give the total wind speed with the directions.

The SODAR sends sound waves in three directions up and receive echoes from the particles in the air. Due to the wind movement there will be a difference between transmitted and received signals will be a measure of the wind velocity. The beam from the transmitter carries out scanning across a wide spectrum of heights and thus is able to capture wind velocities (both speed and direction) at large number of heights thus giving the velocity profile. The two techniques are based on what is known as Doppler effect.

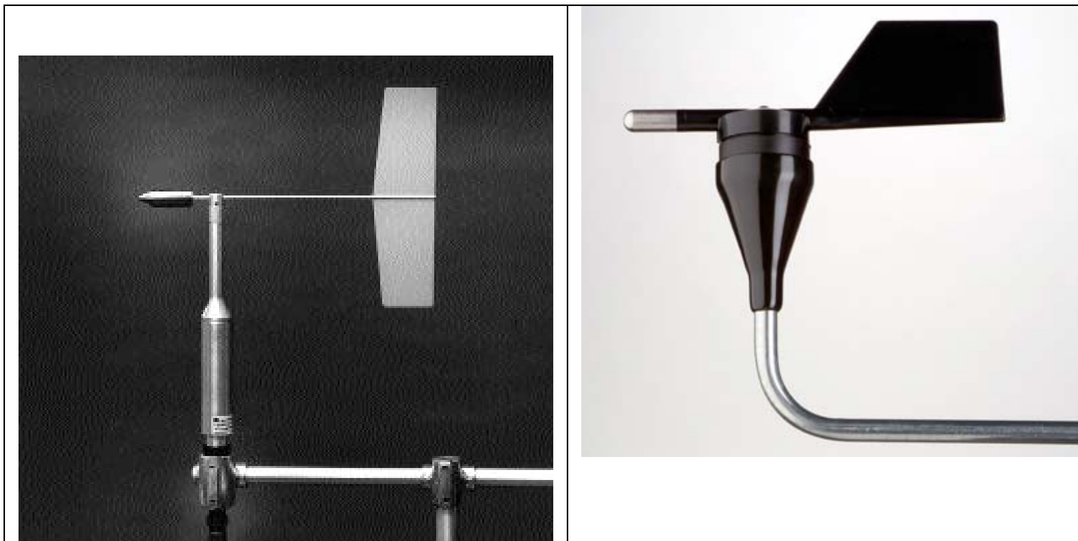


Figure 2.5  Typical Direction Vanes

Direction Sensors

These instruments are used to measure the angle from which the winds are coming. It is a standard practice to measure this angle with reference to the North and is either defined in °N.  Meteorologists define eight or sixteen sectors as North, North-North East, North East and so on.  In wind energy work the direction the former method is used.  The sensor consists of a potentiometer with the viper connected to the vane.  The viper makes contact with a circular carbon film resistor which gets DC voltage pulses when the measurements are to be carried out.  In more accurate instruments wire-wound resistors are also used in lieu of carbon resistors.

Pressure transducer

Pressure transducers are used to measure atmospheric pressure at the given site and normally mounted close to the data logger.

Pressure Transducers produce Electrical signal output proportional to ambient pressure

It is a practice in the recent times to include a pressure transducer and Temperature sensor in the measurement program because it is an important parameter that is required to estimate the site air density.

Temperature sensors are sometimes built into the data logger and can be used to get some idea about the ambient temperatures at the site. However, it is important to have a calibrated and stable temperature sensor installed at site. It would be a good idea to mount it with a radiation shield as shown below:

Temperature sensor

Pyranometers

Pyranometers are instruments that measure global radiation and it will be a very good idea to include them in the measurement campaign. Often measured data for global radiation will be required when planning large deployments of solar energy devices and it only adds an incremental cost to the measurment programme.

Data logging equipment

Data logging equipment for extended measurement period need to be chosen very carefully and studied in great detail before deployment. It is necessary to have all the instruments calibrated against traceable standards. Validity of calibration during the measurement period needs to be ensured. A variety of data loggers are available in the market. The data loggers used for outdoor work for long intervals must have very low energy consumption or the system must have facility to maintain charge for extended periods of time. The areas where such deployment be difficult to access and therefore must be as sturdy as is feasible.

The measurement program should be planned in great detail starting from site and equipment selection. It is essential to note that the following points are addressed:

1. The site should be representative of a large area around so that future extrapolation should not become an issue.
2. There should be easy access to the site so that any malfunction of the data logger or sensors can easily be attended to.
3. Mast design should be such that the instruments fitted can be repaired or replaced quickly and easily.
4. Instruments should be so chosen that they are very reliable, retain calibration for as long as is feasible. It is preferable to have sensors which consume as little energy as is feasible.
5. Maintain linearity over the operating range and over a wide range of atmospheric conditions.
6. Data logging equipment should be simple to operate, very highly reliable and extremely energy efficient. The front panel should be fool-proof so that there should be no loss of stored data due to faulty operation.
7. Must be capable of operating over a wide range of operating conditions.

Other special requirements are that the station should be so secured that casual vandalism is prevented to the extent feasible. It should however be kept in mind that such events cannot be completely avoided.

g. **Entire Country**: Assessment of the particular resource done in the context of the entire country.

When an entire country is considered, it is essential to have a separate wind monitoring program. All other inputs, the national weather monitoring stations, other publicly available data sets etc. are essentially to be used as tools to quickly screen vast tracts of land and sea. Based on these data sets it is normally possible to determine relative windiness of the country as a whole and at a global level, it should be possible to delineate better areas where further investigations could be carried out. Presently meso scale modeling techniques are commercially available. Therefore it is generally a good idea to get some indicative picture of possible potential. This will greatly reduce the risks one runs while planning to deploy wind energy convertors in a large measure.

Not all windy areas become available for wind energy exploitation purposes. That is to say even if wind potential is sufficiently high, if mining activities or agricultural activities are also going on in the given area, it is unlikely that wind power can get a foot hold in the area. Therefore but for academic interest, it may not be useful to have a full fledged measurement carried out. The delineation of areas for wind measurements has to be selected keeping in view the following:

1. All the available information on wind and other meteorological parameters should be analyzed for getting a clear picture of the climatology.
2. Climatologically analyses should cover both global and local scales.
3. Preliminary analyses as to possible energy production using wind shall be carried out.
4. Use upper air data.
5. Numerical modeling at global and meso-scales taking into account the terrain features.

**Site selection guidelines:**

There are several indicators of high wind activity.

1. Meteorological and topographical indicators of wind:
    a. Corridors of frequent and strong pressure gradients
    b. Long sloping valleys parallel to prevailing winds
    c. High elevation plains in areas of strong geostrophic winds
    d. Plains and valleys with persistent down slope winds associated with strong pressure gradients
    e. Exposed ridge crests in areas of geostrophic winds
    f. Folklore sometimes give a good indication.
2. Vegetation & Aeolian indicators:

In data sparse regions, it is essential to relay on long term wind action on the local vegetation (figure 2.1) and other geo-morphological indicators. Satellite images, aerial photographs and other such data sources will on careful interpretation yield considerable information. Remote sensing products such as satellite images taken over sand dunes, sea surfaces at different times and seasons can give an indirect indication of wind speeds and directions prevailing over large areas. They have the advantage of the fact that the modifications would have occurred over large time scales and therefore more reliable. Notwithstanding the dependable nature of such indicators, it will be very essential to carry out physical measurements over a period of time at the prospective sites.

It is essential to set up measurement systems as outlined in the previous section. A number of project related issues need to be addressed in a master plan with regard to the site selection for setting up the measurement systems. These topics are addressed in greater detail in subsequent paragraphs. The central idea being quantification of the potential, it becomes important that programmes are designed with long term utility of data that is collected and presented.

h. **Province or Region**: Assessment of a resource in context of a province or region.

The national program would encompass the regional climatology except that one has to go into land use issues and other region specific information. If there is no indigenous population setting up small and medium size projects may not be justifiable even if the resource is reasonable. However, in these days of global energy shortage, it could be really a big opportunity to plan for large exposure of the technology. A trade off shall be carried out keeping in view resource availability, availability of other sources of energy, funds available, expertise of local engineers in the field among other things.

i. **Local situation**: Resource assessment in the context of a particular local situation - a village/a family or otherwise.

Local situations such as access to other energy services are an issue, such as really remote hills virtually in accessible by road or otherwise, use of wind energy in combination with other such locally available sources could be a good answer. In such cases the resource assessment should be more holistic in the sense that the solar radiation, availability of biomass and seasonal availability of winds are all to be assessed in greater detail. In such difficult to access locations, availability of rudimentary man power to look after the measurement and at a later date the energy conversion systems could be very challenging. The measurement system should be fault tolerant and absolutely reliable. An example would be the data loggers deployed in Leh – Ladakh region and upper reaches of Himalayas. During winters, the sites become completely in accessible. If the data logging equipment, sensors are unable to withstand the extreme low temperatures, all data would be lost. Energy services during those months carry a premium just during that time. Therefore loss of data would result in a difficult situation. These aspects should be taken into account while designing measurement programmes.

j. To the extent possible, a set of assessment tools - computer based or otherwise may be provided to conduct these assessments.

A number of parameters need to be assessed while preparing an analysis report for a given site. The most important results of such an analysis are

1. A national and regional map showing the location of all monitoring stations.
2. Physical or relief map giving elevations and forest cover and other information
3. At the project site
    a. A location map showing the surrounding areas of the station.

b. Clear photograph of the station

c. 12 or 8 directional photographs taken from the base of the tower starting from the North (30° or 45° sectors)

d. Complete specifications of the monitoring equipment and the mast. Particular attention is to be paid to the mounting arrangements and drawings used to manufacture the tower.

e. Complete details of the settings used in the data logger, sampling rates, averaging periods (to be set to 10 minutes as a rule) memory available. Method of ensuring that the data logger and its accessories have necessary power available for un-attended operation shall be documented.

f. Persons responsible for operating the monitoring station shall be given specific and detailed training to install and operate the data logger and carry out minor repair/replacements guided by detailed written and illustrated instructions.

g. In case of further problems, a team of experts shall be identified and provided with necessary training and tools to handle all situations.

h. Calibration certificates shall be available for all sensors at a central place and strict adherence to quality maintenance is a must.

A standard data logger used for wind data collection would store at the minimum the following:

1. Time series of 10 minute averages based on real time clock, standard deviations based on each sample during the ten minute interval, maximum and minimum values.
2. Generally the data would be stored in machine readable binary format to conserve space.

A data retrieval program is normally provided by the makers of the data logger. They would also provide some additional utilities for presenting the data as the industry requires. These special programs are tailored to suit the specific data logger and have a provision to see that the data is stored in a structured manner. When handling one or two locations, the structured approach could be somewhat restrictive, but it will quickly become evident that a pre-defined structure of data collection, collation and analysis is an absolute requirement. The most important factors that are presented in graphical form are the plot of time series data, wind rose, diurnal plots, turbulence intensity and other measured parameters such as the temperature, solar radiation, pressure etc.

k. Exercises on resource assessment, using the assessment tools provided, may be developed.

The incoming data should be screened for determining if the data makes sense. Though the data retrieveal programmes programs have in them a provision to carry out some preliminary analysis and data presentation, apart from some very broad based exclusions, they will not be able to, give any direct warning about a malfunctioning anemometer or a direction vane or any other sensor.

Just to understand the meaning of various calculations time series data as collected from a typical station and the steps followed to make the reports is presented. The algorithms used to calculate various factors is also provided in the EXCEL sheet provided with this material.

Table 2.1 Typical Wind monitoring data logger records

| | | | | | | |
|---|---|---|---|---|---|---|
| Site Name: | Thosegarh | | | | | |
| Site Number: | 8 | | | | | |
| Start Time: | 13:00 | 6/9/1996 | | | | |
| Finish Time: | 7:00 | 8/12/1996 | | | | |
| Total Time: | 63 | day(s) | 18 | hour(s) | 0 | minute(s) |

| DATE TIME<br>Sensor make | Anem A<br>Maximum<br>Average<br>hourly | Anem A<br>Maximum<br>Std Dev<br>hourly | Anem B<br>Maximum<br>Average<br>hourly | Anem B<br>Maximum<br>Std Dev<br>hourly | Anem C<br>Maximum<br>Average<br>hourly | Anem C<br>Maximum<br>Std Dev<br>hourly | Vane A<br>Wind Van<br>Average<br>hourly | Vane B<br>Wind Van<br>Average<br>hourly | Vane C<br>Wind Van<br>Average<br>hourly |
|---|---|---|---|---|---|---|---|---|---|
| | m/s | m/s | m/s | m/s | m/s | m/s | deg | deg | deg |
| Jun 9,1996 13:00 | 5.5 | 1.3 | 5.9 | 1.4 | 5.8 | 1.4 | 271.4 | 278.4 | 275.6 |
| Jun 9,1996 14:00 | 5.8 | 1.1 | 6.2 | 1.2 | 6.1 | 1.2 | 278.4 | 282.7 | 279.8 |
| Jun 9,1996 15:00 | 6.6 | 1.4 | 7 | 1.4 | 6.9 | 1.4 | 278.4 | 284.1 | 281.2 |
| Jun 9,1996 16:00 | 7.8 | 1.3 | 8.1 | 1.3 | 7.8 | 1.4 | 271.4 | 277 | 274.2 |
| Jun 9,1996 17:00 | 9.4 | 1.2 | 9.1 | 1.2 | 8.7 | 1.3 | 241.9 | 250.3 | 248.9 |
| Jun 9,1996 18:00 | 10.2 | 1.1 | 9.9 | 1.2 | 9.4 | 1.4 | 241.9 | 250.3 | 248.9 |
| Jun 9,1996 19:00 | 10 | 1.2 | 10 | 1.3 | 9.7 | 1.3 | 251.7 | 258.8 | 257.3 |

Taken on a ten minute average basis, there would be 52560 pairs of wind speed and direction information per year per pair of the sensors. It is essential to have different heights of measurements to characterize the site wind conditions. This implies that at a national level and even region wise, there would be enormous amount of data to be handled. In order to describe the site wind conditions a number of statistically derived quantities are essential:

1. Yearly, monthly, daily average wind speeds, standard deviations & wind power densities
2. Wind Rose
3. Diurnal wind speed patterns
4. Frequency distribution
5. Joint frequency distribution
6. Omni directional and direction wise Weibull factors
7. Inter-annual variations
8. Turbulence intensity
9. Wind Shear
10. Yearly & Monthly average wind speeds and wind power density

These calculated values give an indication of the windiness at a given location. While grading different sites in respect of wind power availability, annual wind speed and wind power density are used as a measure. Presently most data loggers designed for wind energy work sample data every second and have option of obtaining averages at user selectable intervals. 10 minutes averaging period is the standard used in wind energy work. There are good reasons for having averaging intervals in the range of 10 to 60 minutes. This averaging period avoids the seasonal bias and it avoids high variance due to dominant turbulence. The monthly and annual wind speeds are the averages of the ten minute or hourly average values stored or recorded. Average of all wind speeds defined by

$$V_{mean} = \frac{\sum_{i=1}^{i=n} v_i}{N}$$

$$\sigma = \frac{\sqrt{\sum_{i=1}^{N} v_{i_i}^2}}{N}$$

$$WPD = \frac{1}{2}\rho \frac{\sum_{i=1}^{n} v_i^3}{N}$$

Where,

$V_{mean}$ = mean wind speed in m/s

$V_i$ = hourly or ten minute average wind speed in m/s

N= number of samples ≅ 720 in case of hourly averages & 8760 samples for a year. (52560 samples for ten minute averages).

WPD = wind power density in $W/m^2$.

ρ = Density of Air 1.225 $kg/m^3$ at mean sea level.

The air density is a function of temperature and pressure at the site and is defined by:

$$\rho_{10\min} = \frac{B_{10\min}}{R.T_{10\min}}$$

Where:

$\rho_{10\ min}$ is density in ($kg/m^3$) is the derived air density averaged over 10 min;

$T_{10min}$ is the measured absolute air temperature averaged over 10 min;
$B_{10min}$ is the measured air pressure averaged over 10 min;
$R$ is the gas constant 287, 05 J(kg .° K).

There are methods available to take into account the effect of humidity on the density. When no pressure measurements are available, data from the nearest meteorological station could be used to extrapolate to the site temperature and pressure. This may not be the best way to do it, but sometimes the only way it can be done.

**Diurnal wind speed patterns**

The wind speed experienced over a typical day on a hour by hour basis is known as diurnal variations. It can vary significantly from place to place and time of the year. Table 2.2 gives the wind speed summary for a typical month at Jogimatti in Karnataka, India. Figures 2.3, 2.4 & 2.5 show plots of hourly averages, directions and diurnal patterns of winds during the month of September 1995.

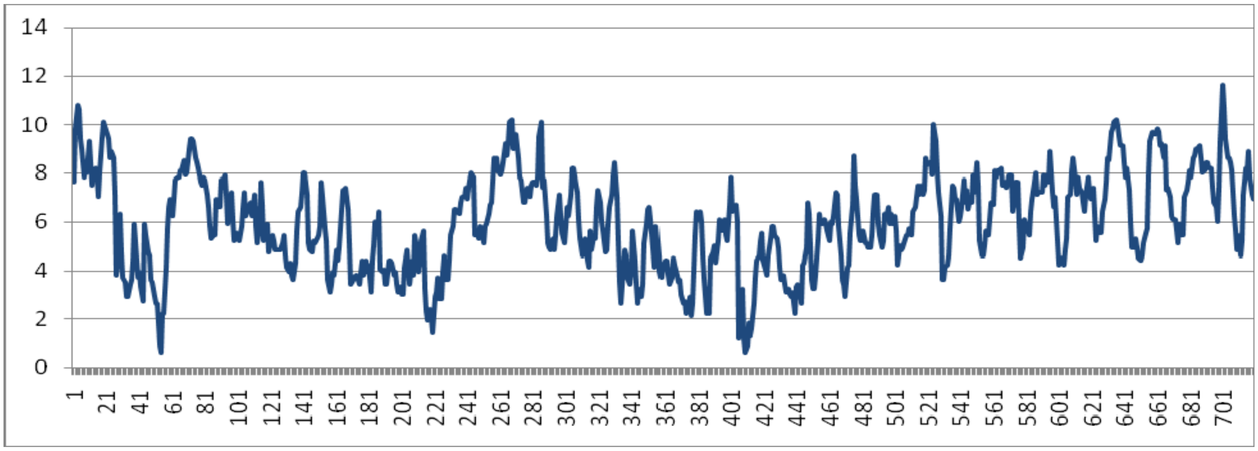



Figure 2.3 Monthly windspeed plot

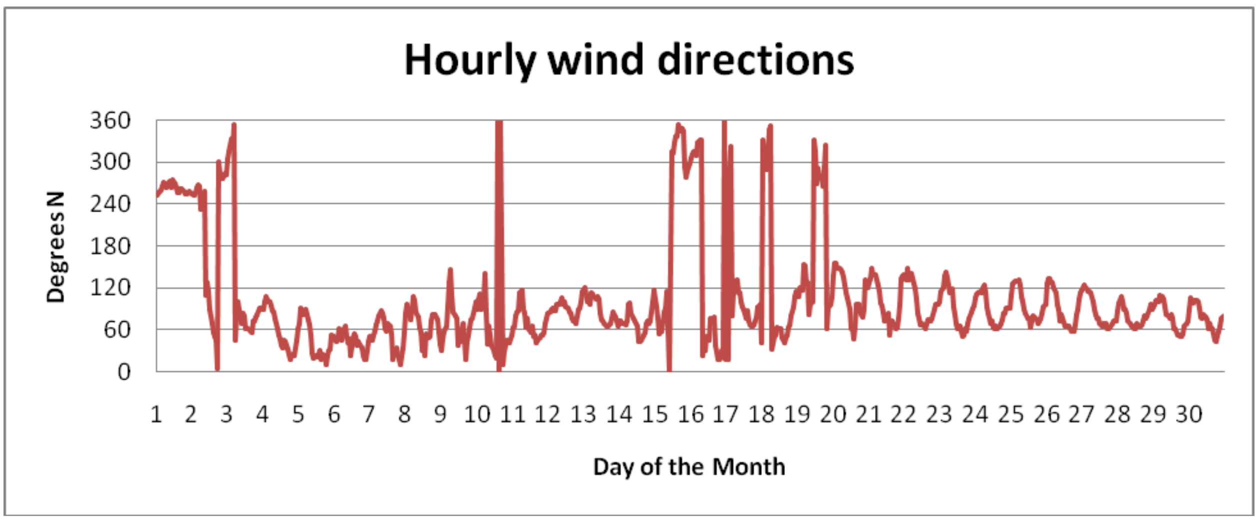



Figure 2.4 Monthly wind direction variations

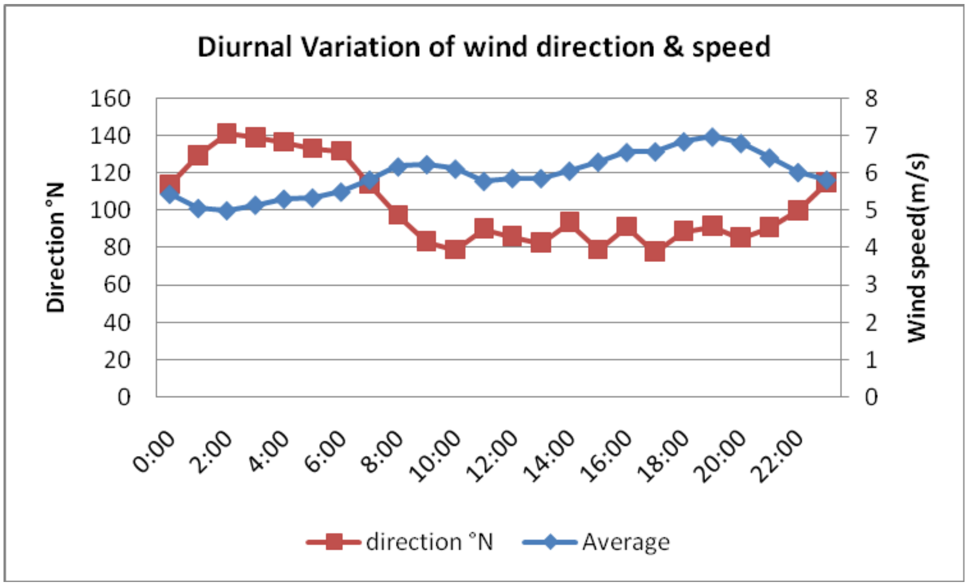



Figure 2.5 Monthly mean dirurnal wind speeds and directions during September

Diurnal patterns give an indication about the wind power availability over the day and helps in scheduling minor maintenacne of the hard ware. For example, if winds are consistantly low early mornings at a given location, one could plan to clean the foot valve in a wind pump. In large wind turbine applications, the endevor will be to track peak demand and check out the wind power availability for grid management purposes.

Table 2.2 Sample Time series wind data

| sample # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W.Spd | 7.6 | 9.8 | 10.8 | 10.6 | 9.4 | 9 | 7.8 | 8.2 | 8 | 9.3 | 8.4 | 7.5 |
| Dir °N | 253 | 256 | 259 | 260 | 266 | 271 | 264 | 266 | 271 | 273 | 264 | 274 |
| sample # | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| W.Spd | 8.1 | 8.2 | 7.8 | 7 | 8 | 9.5 | 10.1 | 9.9 | 9.6 | 9.4 | 8.6 | 8.9 |
| Dir °N | 270 | 264 | 256 | 256 | 262 | 262 | 259 | 255 | 255 | 256 | 259 | 256 |
| sample # | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| W.Spd | 8.6 | 7.1 | 3.8 | 4.7 | 6.3 | 4.7 | 3.7 | 3.5 | 2.9 | 2.9 | 3.4 | 3.6 |
| Dir °N | 255 | 252 | 257 | 264 | 267 | 266 | 232 | 235 | 259 | 110 | 128 | 115 |
| sample # | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
| W.Spd | 4.4 | 5.9 | 4.4 | 3.7 | 3.9 | 3.3 | 2.7 | 5.9 | 5.4 | 4.7 | 4.6 | 3.6 |
| Dir °N | 90 | 70 | 56 | 51 | 45 | 4 | 300 | 284 | 276 | 281 | 284 | 283 |
| sample # | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
| W.Spd | 3.5 | 2.9 | 2.6 | 2.6 | 0.9 | 0.6 | 2.2 | 2.2 | 4.1 | 5.7 | 6.6 | 6.9 |
| Dir °N | 305 | 315 | 333 | 322 | 354 | 45 | 82 | 100 | 79 | 69 | 83 | 80 |
| sample # | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 |
| W.Spd | 6.2 | 6.9 | 7.7 | 7.8 | 7.8 | 8.1 | 8.1 | 8.5 | 7.9 | 8 | 9 | 9.4 |
| Dir °N | 62 | 61 | 61 | 59 | 56 | 72 | 73 | 79 | 82 | 91 | 91 | 90 |

The process of obtaining frequency distribution is rather cumbersome when done manually. Frequency distribution of a large number of samples gives the statistical characteristics of the data set. The frequency distribution does not consider time history. Winds can take values between 0 m/s to 30 m/s over a given interval of time. In order to determine the occurrence of wind speeds in various ranges, what are normally called bins are defined. That is, a bin of 5 – 6 m/s implies that within the bin, the number of times the average wind speed would be in the range of 5 to 6 m/s is to be counted. It could be 0.5 m/s bins or 1m/s bins. The idea is to find out the persistence of wind speeds in a given range. The steps are:

- Determine the class intervals to be used to obtain the frequency distribution. Choose one of the bin range, say 5 to 6 m/s.
- Scan the data from the first value of the data set.
- Compare it with the range chosen.
- If it falls within the range, count it as one occurrence. Otherwise go to the next sample.
- Repeat the process with each data point. It will help to skip the wind speeds already counted in earlier bins.
- Repeat the process with all bins into which the data should have been checked.
- At the end, the sum of hours/samples from each bin should be equal to the number of data samples.

Table 2.2a shows a logical way of counting the number of times wind speeds lies in a given range.

Table 2.2a time series windspeed data

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7.6 | 9.8 | 10.8 | 10.6 | 9.4 | 9 | 7.8 | 8.2 | 8 | 9.3 | 8.4 | 7.5 |
| 8.1 | 8.2 | 7.8 | 7 | 8 | 9.5 | 10.1 | 9.9 | 9.6 | 9.4 | 8.6 | 8.9 |
| 8.6 | 7.1 | 3.8 | 4.7 | 6.3 | 4.7 | 3.7 | 3.5 | 2.9 | 2.9 | 3.4 | 3.6 |
| 4.4 | 5.9 | 4.4 | 3.7 | 3.9 | 3.3 | 2.7 | 5.9 | 5.4 | 4.7 | 4.6 | 3.6 |
| 3.5 | 2.9 | 2.6 | 2.6 | 0.9 | 0.6 | 2.2 | 2.2 | 4.1 | 5.7 | 6.6 | 6.9 |
| 6.2 | 6.9 | 7.7 | 7.8 | 7.8 | 8.1 | 8.1 | 8.5 | 7.9 | 8 | 9 | 9.4 |

Frequency distribution

| $0<V\le1$ | $1<V\le2$ | $2<V\le3$ | $3<V\le4$ | $4<V\le5$ | $5<V\le6$ | $6<V\le7$ | $7<V\le8$ | $8<V\le9$ | $9<V\le10$ | $10<V\le11$ | $11<V\le12$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | xxxx | xxx | xxx | Xx | |
| | | | | | | X | xx | xxxx | xxxx | X | |
| | | Xx | Xxxxx | Xx | | X | x | x | | | |
| | | X | Xxxx | xxxx | xxx | | | | | | |
| xx | | xxxxx | X | X | x | Xx | | | | | |
| | | | | | | Xx | xxxxx | xxxx | x | | |
| 2 | 0 | 8 | 10 | 7 | 4 | 6 | 12 | 12 | 8 | 3 | |

Table 2.3 Frequency Distribution for the 72 data samples

| Wind Spd | Frequency |
|---|---|
| $0 < V \le 1$ | 2 |
| $1 < V \le 2$ | 0 |
| $0 < V \le 3$ | 8 |
| $0 < V \le 4$ | 10 |
| $0 < V \le 5$ | 7 |
| $0 < V \le 6$ | 4 |
| $0 < V \le 7$ | 6 |

| | |
|---|---|
| $0 < V \leq 8$ | 12 |
| $0 < V \leq 9$ | 12 |
| $0 < V \leq 10$ | 8 |
| $0 < V \leq 11$ | 3 |
| $0 < V \leq 12$ | |
| $0 < V \leq 13$ | |
| $0 < V \leq 14$ | |
| $0 < V \leq 15$ | |

As can be seen, manual process will be time consuming and error prone. Fortunately the data comes in digital form and amenable for computer based processing. Generally spread sheet based programs are the automatic choice for large scale data processing. They provide most of the built in functions that are required for statistical treatment of large volumes of data. Even so, while handling large number of stations spread sheet based programs can be a limitation.

It should be noted that some of the software generally used in wind energy work assign the top end of the bin intervals as the value to which the number of wind speed samples in the corresponding bin. Due care needs to be taken while calculating mean wind speeds using time series data and frequency distribution.

**Joint Frequency Distribution & Wind Rose**

One of the important aspects that needs attention is the wind direction information. The raw data from the data logger is sorted in terms of directions in discrete steps. Normal practice is to use 12 sectors and quite often one comes across 8 to 16 sectors being used. Higher number of sectors are also used in some special cases. The worksheet named WINDROSE takes the users through the steps of preparing the joint frequency distribution. Once the wind speeds are segregated direction wise, the frequency distribution is determined.

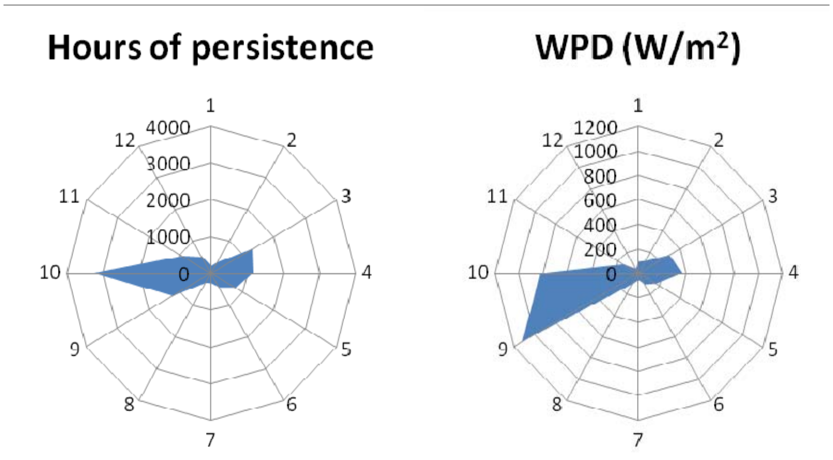



Figure 2.6 Typical Wind Rose from a monsoon based inland site.

The Wind Roses are plotted using various wind data processing software which are part of the data logger software package. There are independent packages also available for wind data processing[1]. Wind rose is a very important figure that is used while locating and planning wind farm layouts. It is also important to pay careful attention to it while siting smaller machines in stand-alone mode. While carrying out quality control of

[1] Try the link http://mistaya.ca/windographer/overview.html to read about one of the commercially available wind data processing software.

data collected, much attention is paid to the direction information. Wind rose for the sample data above is given in figure 2.6 in terms of persistence from 12 directions and the energy content from each direction.

**Measured wind speeds are, in effect, pairs of wind speeds and directions taken individually do not make much sense to describe a given site wind conditions. A normal practice while dealing with wind measured data is to see if the wind regime can be described as a statistical distribution. Wind data from various locations has been collected for years and it has been found that the distribution follows what is known as Weibull distribution. The mathematical expression for the distribution is given by:**

$$f(v) = \frac{k}{c} \times \left(\frac{v}{c}\right)^{(k-1)} \times e^{-\left(\frac{v}{c}\right)^{k}}$$

$$k \approx \left(\frac{\sigma}{\overline{V}}\right)^{(-1.086)}$$

$$c = \frac{\bar{V}}{\Gamma\left(1+\frac{1}{k}\right)}$$

Where,

| | | | |
|---|---|---|---|
| f(v) = | Probability density function | k = | Shape factor |
| c = | Speed factor | V = | Mean wind speed |
| Γ = | Gamma function | σ = | Standard deviation |

There are many methods of estimating the ‘k’ or shape factor. Most of them are empirical. The formulae given above gives a reasonable estimate.

This fit is found to give a good for k values in the range of 1.5 to 10.

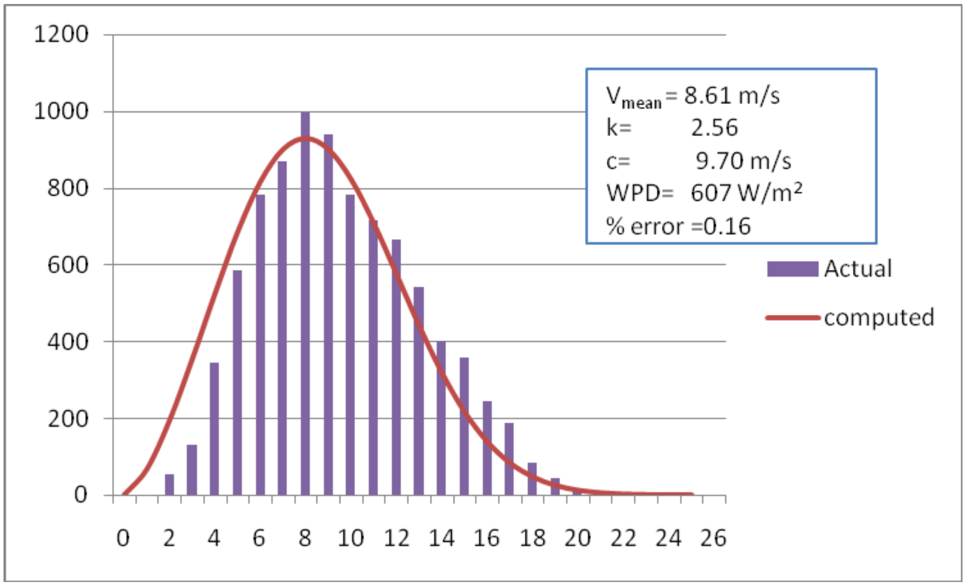



Figure 2.7 Actual & fitted frequency distribution. It is to be noted that though there seems to be a shift in the two distributions, the wind power density estimate has a small error.

The Gamma function $\Gamma^k$ can be estimated by the approximation:

$$\Gamma^k = 0.568 + \frac{.434}{k}$$

Also, EXCEL provides a built in function that computes the Gamma function for a given argument (EXP(GAMMALN(1+1/k)).

**Rayleigh Distribution**

Sometimes when the standard deviation information is not available, the shape factor is assumed to be equal to two and the wind speed distribution is calculated. It is important because Annual Energy Production comparison from different wind turbines is sometimes based on the Rayleigh Distribution. This is particularly true of large wind turbines. Along with the course material an EXCEL sheet is provided that carries out the calculations for different wind speeds and corresponding standard deviations. There are several manual and computer based algorithms to estimate the Weibull factors [1]. The excel sheet must be experimented with to get an understanding of the effects of different real life situations. It is possible to force the program to use A & k values to carry out the experiments. If user is not familiar with workings of excel sheet, it would be safe to work with a copy.

**Wind Shear**

It is generally expected that wind speeds increase with height near the earth's surface. When measurements are available at different heights, a number of methods are available to calculate what is known as wind shear. It is nothing but the rate of change of wind speeds with increasing heights. Wind shear is a function of many meteorological factors and the ground roughness. There are two distinct issues here. One is the instantaneous vertical profile of wind speeds. This is influenced by the roughness, atmospheric stability and various other factors. The other case is where one takes long term averages of monthly or yearly averages from two or more heights

$$U(z_2) = U(z_1)\left[\frac{\ln\left(\frac{z_2}{z_0}\right)}{\ln\left(\frac{z_1}{z_0}\right)}\right]$$

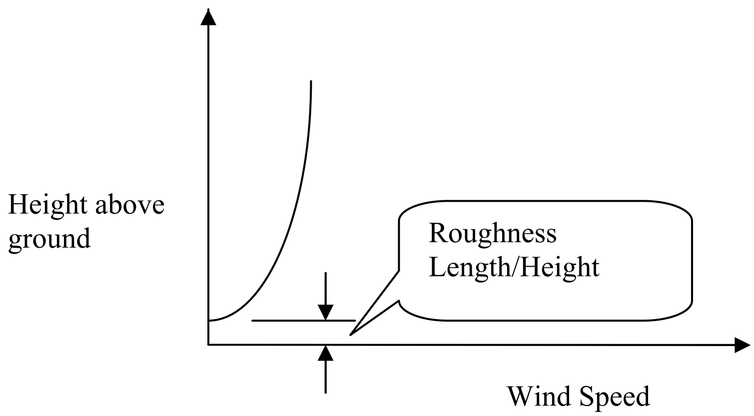
Where $z_2$, $z_1$ are elevations above ground level and U(z) is the wind speed at $z_2$ & $z_1$ heights respectively. $Z_0$ is the roughness height at the measurement site. This is found to show variations over different seasons and over extended periods of time. When long term data is available, a simplified approximation favoured:

Table 2.6 gives various roughness lengths in meters for different commonly occurring terrain features. $Z_0$ is the height above the ground where the wind speed becomes zero when a logarithmic profile for the windspeeds above ground is assumed.

Table 2.6 Roughness lengths of different terrain features

| Terrain features | $Z_0$ (m) | $\alpha$ (power law index) |
|---|---|---|
| Very smooth ice or mud | 0.00001 | |
| Calm open Sea | 0.0002 | |
| Blown or rough sea | 0.0005 | |
| Snow surface | 0.003 | 0.10 |
| Lawn grass | 0.008 | |
| Rough pasture | 0.01 | |
| Fallow field | 0.03 | 0.13 |
| Farmland | 0.05 | 0.19 |
| Few trees | 0.10 | |
| Many trees, hedges, few buildings | 0.25 | |
| Forest & woodlands | 0.50 | |
| Shrubs | 1.5 | |

| | | |
|---|---|---|
| Urban area | 3.0 | 0.32 |




Most commonly used method for determining wind speeds at a heiht above ground refered to as the power law index method.

$$\left(\frac{V_2}{V_1}\right) = \left(\frac{H_2}{H_1}\right)^{\alpha}$$

This requires concurrent wind speeds from at least two levels above the ground. $\alpha$ is known as power law index and is known to be influenced strongly by the terrain features including roughness. There are a number of methods available to estimate this. If we have wind data from two levels, $\alpha$ can be calculated using the above formula. The shape of velocity profile changes significantly when the terrain conditions and/or roughness changes (fig 2.8)

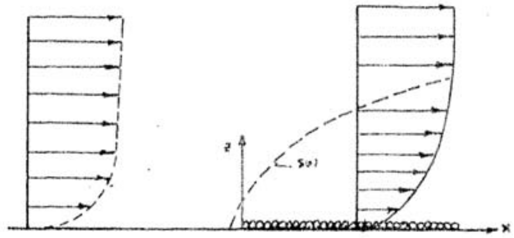


Figure 2.8  Shape of the velocity profile changing with changes of ground roughness

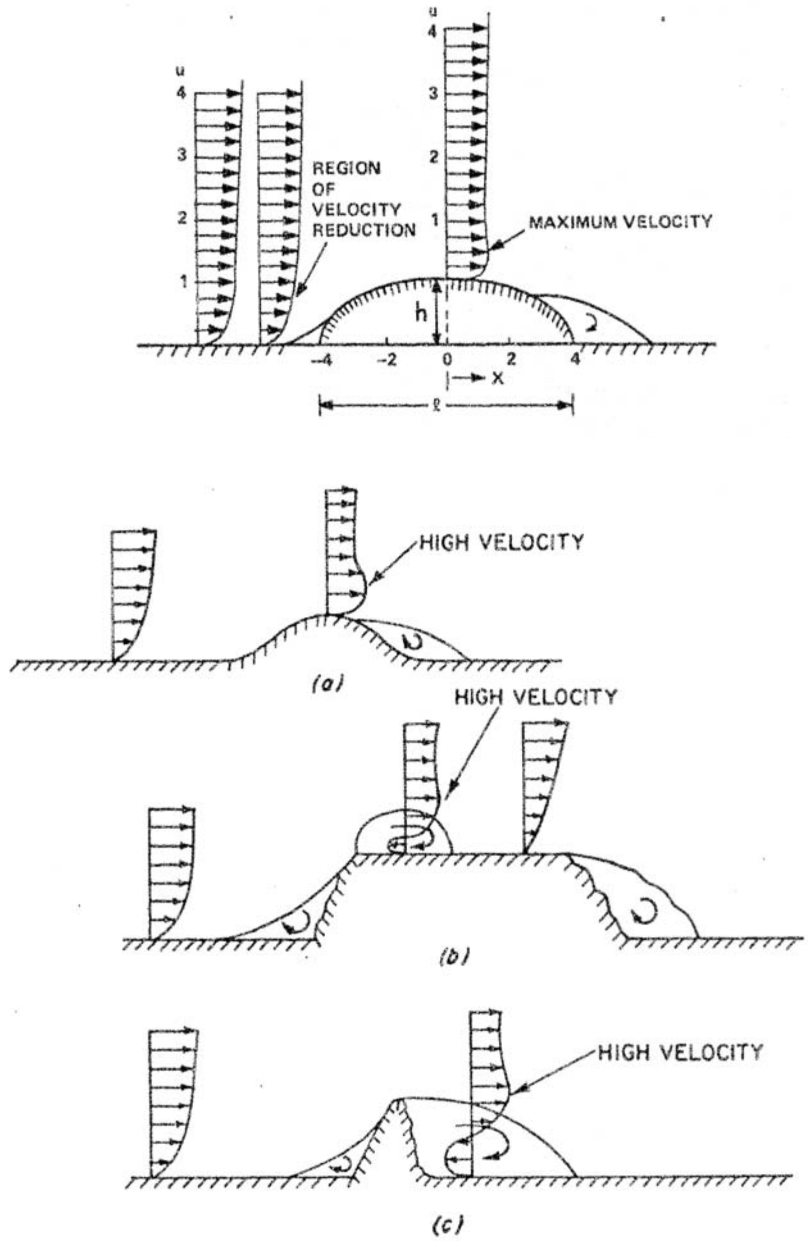



Figure 2.9  Velocity profiles changing with terrain changes (Adapted from C.J.Justus 1975)

With increasing hub heights it becomes very essential to carefully evaluate the hub height wind speeds. Though there are several statistical and numerical methods of modeling the velocity profile, it is preferable to obtain wind speed statistics at hub height or atleast from a number of heights.

l. Provide a list of reputed sources from where data/information for resource assessment can be obtained.

Generally the different countries publish their data as monthly summaries through the meteorological departments which give various meteorological parameters at specific hours. This data source has limitations, but in the absence of any other information it is still feasible to obtain a rough idea of the potential. Airports have continuous records of wind speeds and directions. This information is traditionally kept in paper form and required some effort to make use of such records. In many cases the traceability of calibration records will become an issue.

One of the most used source of data comes from NOAA/NCEP downloadable from:

http://www.cdc.noaa.gov/cgi-bin/Timeseries/timeseries

Six hourly and monthly wind speeds from about 15 elevations above ground are available free of cost for nearly sixty years. The data is available on a 2.5° latitude x 2.5° longitude grid. Though this data could be used to get an understanding of inter annual variations, it should be understood very clearly that the results are based on respective country's meteorological data and is the result of a rather complex assimilation process. In such processes, the uncertainty of results could be quite high.

Meteorological departments have a number publications such as weather summaries. Meteorological departments routinely fly balloons (figure 2.10) to collect upper air meteorological data through a radio link. The path of the balloon is tracked at regular intervals during the ascent. This gives a measurement of wind speed and direction at different heights above ground. This is a very important source of information while scanning large tracts of land. It should however be understood that the data will be at best indicative.

Figure 2.10 A Pilot Balloon being launched

References

1.C.J.Justus,  Winds and Wind Systems Performance, 1975
2. Erij Lyesn

## Chapter III

**HOW CAN RESOURCE ASSESSMENT BE USED TO DEVELOP TECHNICAL SPECIFICATIONS/SIZING TO ACQUIRE RENEWABLE ENERGY TECHNOLOGIES**

a. Provide appropriate tools - preferably computer based, that make it possible to estimate the size and other important configuration related parameters for the identified technology for a particular application and local situation.

b. Exercises on estimation of size and other related parameters, using the tools provided, may be developed.

In the last chapter we have seen how to make various computations with wind speed and direction information. Here we shall link the results of such measurements to output estimation from wind mills or wind turbines.

It is important to note that the energy in the wind is proportional to cube of the wind speed. Winds vary considerably over short periods of time and therefore the output varies equally rapidly (fig 3.1).

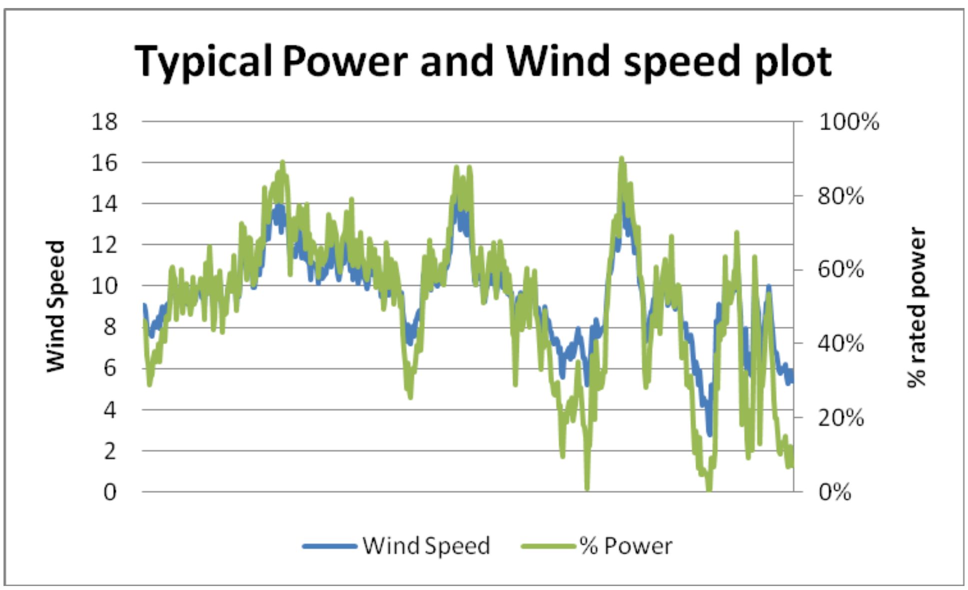



Figure 3.1 Typical time series plot of wind speeds and corresponding power

It may be seen that the power falls rather rapidly with lower speeds and ramps up and down far more rapidly as the wind speeds increases or decreases. This can be understood by the following:

Figure 3.2 shows the relationship between the power in the wind to that extracted by a typical wind turbine. It can be seen that the average wind mill will start producing power at around 3.5 m/s and power available at wind speeds below this limit is also quite low. As the wind speed raises the WPD increases quite sharply where as the machine converts a lower fraction of the available power. The conversion efficiency tables off at around 8 to 10 m/s after which the available power is spilled by a variety of mechanisms. Therefore the conversion efficiency also falls with increasing wind speed. There will be a temptation to 'get everything out' of winds over the entire spectrum. This has two pit falls. One is the frequency of occurrences of higher wind speeds beyond 16 m/s falls rapidly even most of the windy sites. Second equally important issue is that a correct operating range of frequencies needs to be decided to optimize the rotor design. Otherwise we would have a rotor size that is too small and ineffective most of the time if we aim at a wind turbine that extracts maximum power at high wind speeds. If it is designed for winds which are very low – like 3 to 4 m/s for example, the rotor sizes would be very unwieldy and protecting the windmill at higher wind speeds will become very expensive. Beyond a point, the inertial effects of the rotor will defeat the purpose of having a large rotor to extract power from low winds.

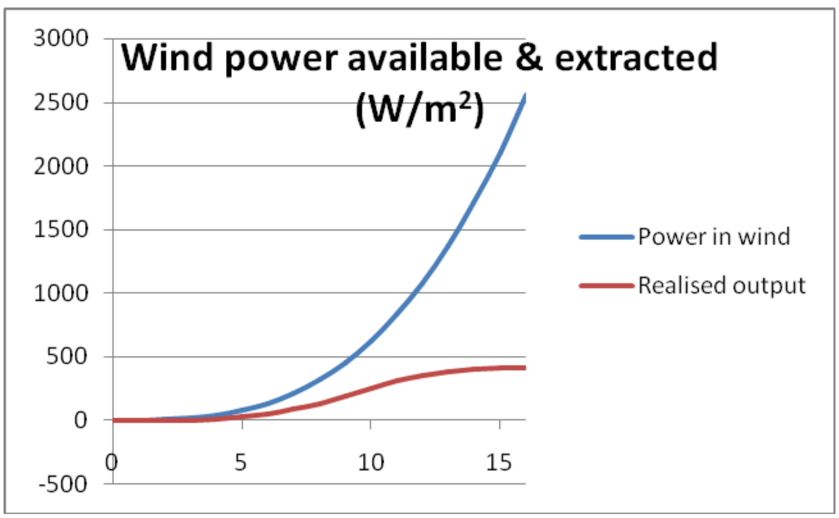



Fig 3.2 Wind speed Vs Power in the wind & out puts from a real machine as a percentage of full load power.

| **Wind Speed** | Power in wind | Realised output |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 1 | 0 |
| 2 | 5 | 0 |
| 3 | 17 | 0 |
| 4 | 40 | 11 |
| 5 | 78 | 29 |
| 6 | 135 | 54 |
| 7 | 214 | 86 |
| 8 | 320 | 135 |
| 9 | 456 | 193 |
| 10 | 625 | 255 |
| 11 | 832 | 312 |
| 12 | 1080 | 354 |
| 13 | 1373 | 385 |
| 14 | 1715 | 403 |
| 15 | 2109 | 412 |
| 16 | 2560 | 414 |

While designing a wind turbine it will be important to look at the frequency distribution a given location has and this is approximated using what are known as Weibull factors. Chapter 2 has dwelt on the distribution at some length. The excel sheet termed WEIBULL supplied with this material takes you through the computations and it should be possible to estimate approximate output energy at a given location.

Exercises

The EXCEL file gives typical time series data from a high wind site in India. The file has four sheets where in the formulae to be used are given and written down in appropriate cells. User is encouraged to save a copy and experiment with various possibilities. The power curves from wind turbines are normally downloadable from company's web pages. When the power curve is available only in graphical form, it will be necessary to digitise the curve manually.

# CHAPTER IV

# CONCLUSION

## 4.0 Summary

Wind Resource availability needs to evaluated very thoroughly before any big plans are made for utilisation both for small or big applications. Often, this is not the case. It is essential to have a very carefully thought out implementation program the first step of which is the detailed resource assessment program. The Indian Wind Energy program realised this need quite early and developed an independent resource measurement program. When this was done, wind mills and wind turbines had a modest hub height of 10 to 20 meters. It was and is a standard meteorological practice to mount anemometers at an elevation of 10 meters above ground level. What started as a rather innocuous scientific measurement program got extended to the entire country over a span of two decades. Being a government sponsored project response time to changing circumstances and expectations appeared to be inadequate. However, the program did give a better starting point for large scale deployment. The lessons learnt in the process can be profitably used in designing future country specific measurement programs elsewhere. A good estimate of country wide possibilities including extreme weather conditions is an absolute minimum requirement before one embarking on deploying wind turbine hardware. If, for example, wind speeds never cross say 5 m/s at an elevation of 20 m agl, wind power hardware would give precious little energy over a year. If a wind turbine is rated at 10 kW, it would be delivering on an average of 1.5 to 2 kW equivalent powers over the year. Unless other resources are very expensive or not available at all, it may not make sense to deploy the hardware anyway. One example is the need to transport fuel oil to islands for electricity generation. The subsidy Government will have to provide to make it affordable will be so high that a RE technology device can pay for itself in a much shorter time. Another important consideration will be the extreme wind conditions that the machine will be expected to take in its stride. This aspect needs to be paid much attention. Wind Energy convertors normally have an upper limit specified. It has to be adhered to.

## 4.1 General Guidelines

When large scale exploitation of wind as a source of energy is considered, it is absolutely essential to design a proper forward looking resource measurement program, (not a campaign). It should take into account the following elements at the minimum:

### 4.1.1 Resource Estimation:

It is perhaps the most crucial part of any power supply system planning.

1. The measurement station shall be so designed that
    a. It can operate uninterrupted for extended periods of time without manual intervention.
    b. The instrumentation used shall have traceable calibration and available on demand.
    c. Have sufficient redundancy in numbers of sensors such that we get enough data.
    d. Possibility of keeping the station working for three to six years in order to capture inter-annual variability of wind speeds.
    e. Instruments shall be mounted in conformity with IEC 61400-121.

f. A careful watch is kept over deterioration of measurement accuracy of the instruments and has a replacement/repair – recalibration plan ready.
g. Do not shy away from having to bring down the sensors for maintenance.
h. The heights of measurements shall be decided keeping in view that sooner or later the data collected will be used to find out if large machines are going to be deployed. It will help greatly if the measurement program uses towers which are not less than 80 meters with wind speed and direction sensors at as many heights as is feasible. It will also be desirable to see that instruments are mounted keeping in view relevant standards. It is desirable to have temperature and ambient pressures recorded because when the development reaches higher levels, these questions are bound to crop up.

2. The measurement stations shall be so located that
   a. The measurements taken are representative of as large area around it as is feasible.
   b. Sufficient area is available for deployment of wind energy hardware in the vicinity.
   c. There are various thumb rules that are to be kept in view. In level terrain, it is generally acceptable to have long term measurements within 5 to 10 km. In complex terrain, such as hilly region hard core consultants look for measurements much closer to future wind farming sites. .
   d. It would be highly desirable to keep the stations free of any other installations forever.

All such recommendations come with the ‘conditions apply’ caveat. Here it is to be noted that sooner or later the commercial demands on scientific data can suddenly render the effort involved in collecting data useful only for a qualitative appreciation rather than quantification of energy availability. It should also be noted that wind power is no longer in the realms of ‘venture capital’ investment options but is now a standard component of broad based investment portfolios. However, financing companies will look for a very detailed analysis of return on investment. A major part of such a rigorous exercise is the evaluation of the resource availability. Everything associated with the measured data will be scrutinized very carefully and uncertainties assigned to each component of the measurement. The calibration, mounting, site complexities, roughness are a few examples. Therefore, designing a country wide resource assessment program, it is essential to keep in view that there will be an element of commercial viability of deploying RE hardware and not withstanding how the measurement program is going to be financed, the results obtained should be scientifically justifiable and commercially correct. Otherwise, it will not be possible to attract major investments unless the programs of deployment of hardware for power generation or energizing water pumps or battery charging or any other application. There is of course only one other possibility – that is, the Government funds the entire thing for strategic reasons.

4.1.2 Technology selection:

Technology selection has a number of issues to be looked into apart from the resource availability itself. Some of the points to note are the design aspects of the hardware Vis-à-vis the quality of resource itself. Other important aspects are cost of hardware, Load matching capability of the hardware that takes into account the time of availability and energy demand, availability of sustainable man power and spare parts. The energy availability from wind could be different from different seasons as it happens in India. Figure 4.1 shows the wind power densities during different months in a typical site in Tuticorin, a coastal city in Southern tip of India. Incidentally Tuticorin is an important port city and produces common salt from thousands of hectares of land and has a modest potential in terms of wind power. The salt farming community dig bore wells no deeper than 10 meters from which salt water is pumped into large

Figure 4.1 Water pumping windmill installed on the banks of salt pans

evaporation pans known as salt pans. Since the pans are spread over hundreds of square kilometers it is quite difficult to provide electricity for pumps and diesel pump sets are the alternative means of water pumping. Obviously these are expensive options. With winds being what they are, an obvious choice is the water pumping windmill. Yet they do not become as popular as one expects them to become. An average 5 m rotor diameter windmill would cost in the range of INR 150,000/- for installation. There is an additional issue of having to develop a good canal system as it is not practical to move around wind mills like one would move around diesel pump sets.

4.1.3 Cost of hard ware can be divided into the following items:

Cost per installed kW

Hardware
Balance of plant
Infrastructure development
Installation & commissioning charges

O & M Costs

Man power
Spare parts
Major & minor repair works on critical components

Cost of removal & replacement at the end of service life.

### 4.1.4 Deployment imperatives

Certain objectivity is essential while planning large scale deployment of any device or program. It is no different for wind energy conversion systems. Some of the points to note while planning a wind power installation are:

1. A location specific resource assessment in order to determine the suitability of the windmill for the given energy demand.
2. Infrastructure for installation and commissioning of the hardware. Safety aspects shall be investigated thoroughly.
3. One of the most ignored areas in deployment of small devices in large numbers suffers from post installation related problems. Enough thought needs to be applied to this aspect. It should not be rationalized that once installed the O & M will somehow happen.
4. While planning large scale deployment, a cluster wise O & M plan should be worked out. All the 'what if's are addressed objectively and provided for.
5. Usefulness monitoring at a pilot scale will be most helpful in tailoring the programme to the best economic advantage.

### 4.1.5 Type Certification

In order to be able to place a certain confidence in the wind energy convertor hardware, 'type certificate's are obtained. Type certificates are issued by a competent body after a thorough examination of the following:

1. Design documentation.
2. Type testing.
3. Quality of Manufacturing System
4. Foundation design evaluation – optional.
5. Type characteristic measurements – optional.

The type certificates are issued by accredited certification bodies. These establishments are accredited as per ISO/IEC guide 65 by standardization organizations such as DANAK in Denmark or DAR in Germany. Guide 65 stipulates the principles that need to be complied with by a certification body at all times to maintain its own accreditation.
Type certification is carried out based on country specific needs. Essentially there are two widely used systems – one is the IEC system and the other is the Germanischer Lloyd (GL) rules. The country specific modifications are either issued as an add on or it will be included in the reissued country specific system of certification.
The focus of certification has been the large grid connected machines. IEC has attempted a less elaborate procedure to evaluate small machines. The full system as in the case of large machines is not yet in place and often it becomes a contentious issue. In the United States efforts are being made to come up with a formal method of type certification for small machines.
One of the main difficulties in small machine certification is the number of variations possible in output usage – it could be battery charging or it could be space heating or water pumping. The levels of power are also rather low and can introduce large uncertainties in the measurements rendering it somewhat unusable. Similarly maintenance of a quality system can also be a

problem for small establishments with limited production. The costs of testing, maintaining quality system etc would make certification of small systems a difficult issue. It is not to say that it should be done away with. In publicly funded activities, certain accountability for expenditure is a must. Therefore the simplified methods of evaluation should be followed in order to separate very ham handed product designs from better designed systems.

4.2 Future

It is essential to note that the pioneering days for wind technologies are actually behind us and fortunately there is a wealth of information available to design and implement successful programs. While formulating national programs it would always be beneficial to seek and obtain good project advise so that we avoid re-inventing the wheel.

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