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***Full Length Research Paper***

# Wind Turbine Site Assessment

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*Abstract*

*Although the wind is available almost everywhere, there is a threshold of speed within which harvesting the power contained is possible. Even when the wind speed is within the cut-in and furling range, there are still other factors that need to be considered before selecting the site. The fast depletion of fossil fuel and the need to reduce individual carbon footprint have all combined to tilt energy policies favourably towards renewable sources of which the wind turbine is an important part of the mix. Part of the assessment of a site will include knowledge of how frequent the wind speed is within the acceptable range. The wind data may be obtained by direct measurement or from regional weather centres. There are three types of anemometer that are used in the measurement of wind data. Where direct measurement of wind data is impossible because of cost and time, the other options may be considered. There is a minimum tower height required for adequate harvesting of the wind and in a site with obstacles, the measurement should start from the top of the highest obstacle.*

***Key Words:*** *harvesting the wind, cut-in speed, furling, anemometer, ground drag, interference factor*

## Introduction

The wind is almost available everywhere but there is a threshold of speed within which the harvesting of the wind is possible. Below or above this range the wind turbine cannot generate electricity. In addition, there are other important factors that must be present for wind turbine operation to be possible. The topography of the location must be adequate for wind turbine installation. If all these factors are favourable the power of the wind is limitless and it has for long been used in powering various devices. The technology has therefore benefitted from this long period of application and has evolved and matured over the years. For centuries wing energy has been employed in powering the sailing ships, the wind mills in grain grinding, the water pumps and other mechanical devices. The Danes, Bhadra (2004) are credited as pioneers in wind energy development for electricity generation. Before the oil crisis of the seventies, wind power development was virtually restricted to countries that have no coal, oil or gas resources. The oil crises, the realisation of the finiteness of fossil fuel, the instability in the regions that fossil fuels are commonly sourced and the need to reduce our individual carbon footprint have all combined to focus attention to the search for alternative sources of energy. Political and economic independence will be threatened if the source of supply of energy is not assured. The urgency to find alternative sources has been exacerbated by global warming attributable to high concentrations of greenhouse gases such as carbon dioxide, methane, water vapour, ozone and nitrous oxide. These greenhouse gases are associated with human activities in the form of deforestation and the burning fossil fuels Achara (1987 &2011A). Governments have joined the green lobby in the search for solution to global warming and are spending huge amount of money to find alternative sources of which wind turbine is an important part of the mix. Energy policies have as a result tilted favourably towards renewable non polluting sources such as wind resources.

The purpose of this study is therefore to access the factors that are required to be present before selecting a site for locating the wind turbine. In order to reduce the maintenance frequency coupled with avoiding the damaging the installation due to uncontrolled turbulence and hence extend the lifespan of the installation, the tower height must be sized appropriately. Even when the wind speed is within the cut-in and furling range, Chiras (2010) has noted that optimum wind power harvesting would still depend on the sizing of the tower.

## Wind Turbine Site

Before choosing the site, it is necessary to carry out wind data and economic assessment to determine the suitability of the site for wind turbine installation. The range of factors that can impact on performance of an installation include availability and frequency of high enough wind speed, topography of the site, turbine height and obstacles such as trees and houses within a minimum radius. There is a threshold of wind speed referred to as the cut-in and cut-out or furling wind speeds within which a given design of wind turbine operates optimally. The acceptable wind speed range varies approximately from 4m/s to 25m/s, below this range the turbine blade may turn without generating any electric power and above this range the turbine may have to be stopped to prevent damage to the blades. There is need for an open area with no obstacles within a 150m radius. Obstacles cause turbulence and turbulence leads to losses and consequently reduced turbine efficiency. The direction from which the prevailing wind flows is also very important and obstacles in the path of the prevailing wind should be avoided. Other factors that have to be considered include the availability of public grid. It will make economic sense for a remote site with no public electric grid utility nearby to consider wind turbine installation even where wind availability is moderate. If the ownership is in a region with generous subsidies, it may prove beneficial to build wind energy facility in a site of moderate wind speed where otherwise a wind system will not be competitive with its electricity generation rate/kW higher than the grid's.

***Wind Resource***

It is important to know how much wind is available and when it is available before the design or selection of the wind turbine. Armed with this knowledge, costs can be evaluated and financial return on investment analysed. Information on available wind resource can be obtained by direct measurement, from the local airport, online resources or from wind maps.

***Wind Data Measuring Instruments***

The anemometer in its various forms is used to measure the wind speed. There are three types of this instrument which are based on the resulting effect of wind speed on some parameters including thrust, pressure and cooling effect. The Robinson Cup anemometer is based on thrust of wind on the hemispherical cups fixed on a vertical shaft. The thrust on the concave sides is higher than that on the convex sides leading therefore to rotation of the vertical shaft. As these cups are on a vertical axis there is no need to consider the orientation of the instrument on the wind direction. There is a linear relationship between the wind speed and the rotation of the shaft which is measured by a photocell-operated digital counter. This may be pre-calibrated for direct wind speed read out.

The pressure tube anemometer is a mechanical device and is suitable for any standalone measurement in a remote location. The instrument has two distinct parts, the head and the recording section. The head is mounted on a mast at the appropriate height and carries a horizontal tube bent at the other end. The vane helps to turn the head to face the wind. The float rises and falls with pressure and this movement is transmitted to a pen tracing record on a sheet of paper.

The hot wire anemometer uses the cooling effect of wind on electrically heated platinum or tungsten wire to measure wind speed. The temperature difference between the wire and ambient air is inversely proportional to the square root of the wind speed and as a result the hot wire anemometer is suitable for measuring small wind velocities.

***Other Sources of Wind Data***

Wind data may be sourced from local airports and weather bureau centres. The data from these sources may be suspect in the cases that staff are not trained and where the anemometers are mounted on short towers where ground drag and turbulence can affect the readings. Because direct measurement is costly and time consuming and the doubt about the accuracy of data from local airports, regional weather map, where available, is one reliable source for obtaining wind data. Wind speeds estimates on the map are likely to be at heights that are different from the design height. There may be therefore the need to extrapolate. The equation for the actual wind speed estimation is given thus:

$$V = (H/H_o)^a V_o \qquad (1)$$

Where $V$ and $H$ are the design wind speed and tower height respectively and $V_o$ and $H_o$ are the annual wind speed recorded and tower height of the wind map respectively. The index $a$ is the wind shear coefficient, a measure of the change in wind speed with height above the ground caused by surface texture or roughness due to trees and building. Typical wind shear characteristics are given in table 1.

**Table 1.** Wind Shear Coefficients for Various Types of Surfaces

| Surface Characteristics | Shear Coefficients(*a*) |
|---|---|
| **Lake or ocean, water or ice** | 0.10 |
| **Short grass or tilled ground** | 0.14 |
| **Level ground, 300mm high grass, occasional tree** | 0.16 |
| **Tall row crops, hedges, short fence rows** | 0.20 |
| **Hilly country with open ground** | 0.20 |
| **Few trees, occasional buildings** | 0.22 |
| **Many scattered trees, more buildings** | 0.24 |
| **Wooded country, small town** | 0.28 |
| **Suburbs** | 0.30 |
| **Urban area** | 0.40 |

Wind maps do have their limitations especially where the topography is complex that wind speed changes over a very short distance in which case the resolution may not be very accurate.

Where regional wind maps are not available, wind site analysis can still be carried out using the extensive online database called Surface Meteorology and Solar Energy developed by NASA (2013). This website covers the whole world and contains tables showing not only the annual but also the monthly average wind speed and direction. The issue of complex topography applies here.

***Annual Wind Hours:***

Moderate high wind speed per se is not the determinant but how many hours of it is available in one calendar year. As a result, part of the assessment of the wind site is a record of the annual distribution of wind speeds in hours at the site, Achara (2011B) and Hansen (2008). Where this record is not available the mean annual wind speed together with Rayleigh distribution function can be used as shown in figure 1 to calculate these values. This function is expressed as:

$$t = 8760\frac{\pi}{2}\frac{v}{\bar{v}^2}\exp(\frac{-\pi v^2}{4\bar{v}^2}) \qquad (2)$$

where $t$ is the time in hours in the year, $v$ the wind speed (m/s), and $\vec{v}$ the mean wind speed obtained at the hub height. The

Rayleigh distribution is a special form of the more general Weibull distribution function. In the more general form of the Weibull distribution function, correction is made for factors such as vegetation, landscape and obstacles for example, nearby houses. Figure 1 is a plot of the Rayleigh distribution function for a mean speed of 12m/s.

For the Weibull distribution, the effect of obstacles is accounted for by the scaling factor, $A$ and form factor $k$. The Weibull distribution is thus expressed as:

$$h_w(v_0) = \frac{k}{A}\left(\frac{v_0}{A}\right)^{k-1} Exp\left(-\frac{v_0}{A}\right)^k \qquad (3)$$

The values for the parameters A and k may be derived from meteorological data.

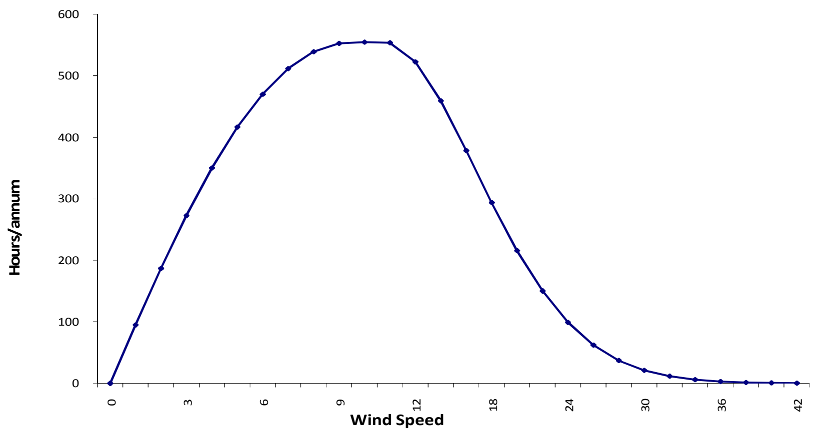



**Figure 1 Annual Wind Speed Hours**

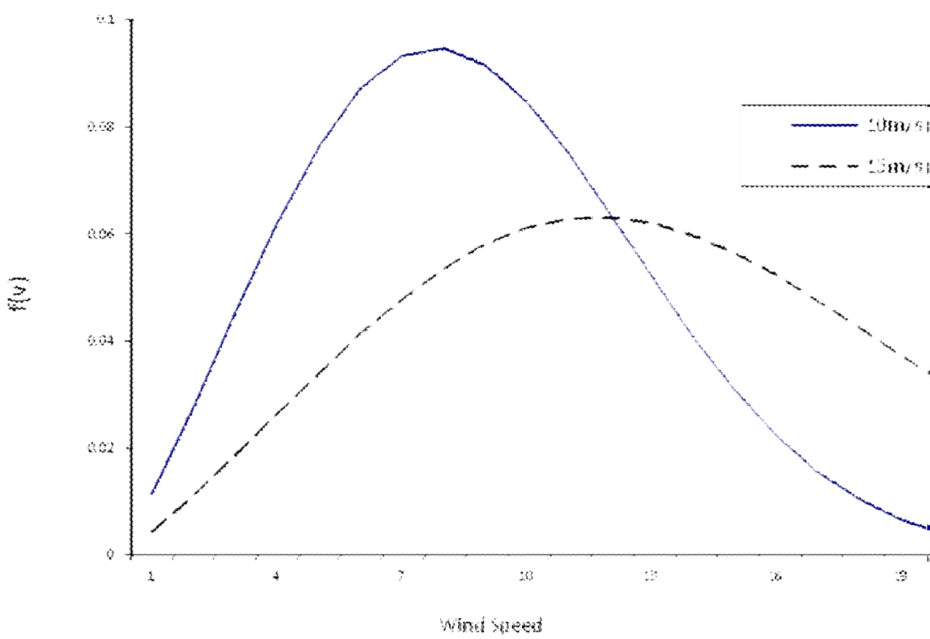



**Figure.2** Weibull Wind Speed Distribution

Figure.2 is the Weibull distribution function plotted for mean wind speed values of 10m/s and 15m/s. To calculate the probability that the wind lies between $v_i$ and $v_{i+1}$

$$f\left(v_i < v_0 < v_{i+1}\right) = e^{-\left(\frac{v_i}{A}\right)^k} - e^{-\left(\frac{v_{i+1}}{A}\right)^k} \qquad (4)$$

Then the total annual energy production (AEP) can thus be evaluated as:

$$\text{AEP} = \sum_{i=1}^{N-1} \frac{1}{2}\left(P\left(v_{i+1}\right) + P\left(v_i\right)\right).f\left(v_i < v_0 < v_{i+1}\right) \qquad (5)$$

where $P(v_i)$ is the power produced at mean wind speed $v_i$.

***Power- wind velocity relationship***

The power in the wind flowing at a velocity of $v_\infty$ is given as:

$P_\infty = (½)mv_\infty^2$ (6)

Where $P_\infty$ is the power content of the wind, $m$ is the mass flow rate and $v_\infty$ is the wind velocity, but

$m = \rho A v_\infty$ (7)

where $A$ is area in $m^2$, therefore from eqns(6 and 7)

$P_\infty = (½)\rho A v_\infty . v_\infty^2$

$= (½)\rho A v_\infty^3$ (8)

Let $C_p$ = power output of wind turbine/(power content of the wind)

Therefore

$C_p = P/P_\infty$, where $P$ is the wind turbine power output, therefore

$P = C_p P_\infty$

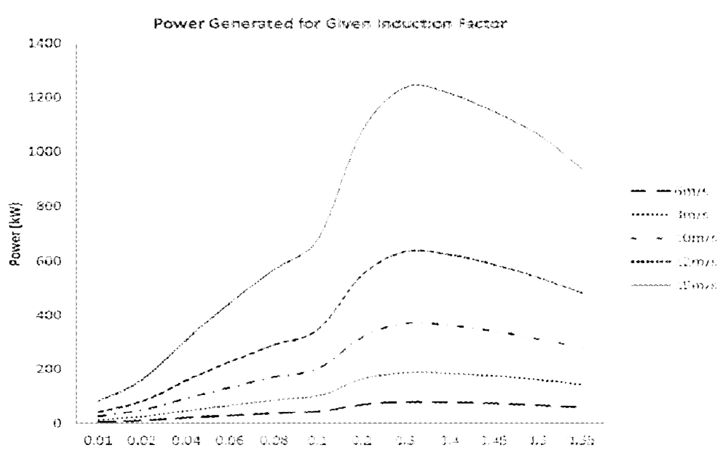
$= (½)C_p \rho A v_\infty^3$ (9)

This shows that the power output of the wind turbine is proportional to the cube of wind velocity and in essence this emphasizes the importance of obtaining wind speed data in any wind turbine studies.

The power developed may be assessed in terms of the axial induction/interference factor, $a$ (Achara,2011A) and this expression can also be used to investigate the effect of velocity on power development.

$P = 2\rho A\, u_a^3 a(1 - a)^2$ (10)

And this expression has also been used to obtain the graph shown in figure 3 where for a given axial induction factor the wind power developed is calculated. Each of the curves relates to a given free stream wind velocity.




**Induction Factor --**

**Fig 3:** Power Generation for Given Induction Factor

The influence of free stream wind velocity on the power developed by the wind turbine is clearly shown by the curves where the free stream velocity ranges from 6m/s to 15m/s. Each of these curves shows a maximum after which the values start to fall with increasing axial induction factor.

## Tower Height

It is no surprise that attention is usually focused on the wind generator when designing a wind turbine since this is the component that harvests the power in the wind. It must be said however that the tower plays important part in the installation of any successful wind turbine system. For the wind turbine to harvest enough energy from the wind, height has to be adequate. The tower design must be such to withstand the violent stresses from the wild wind. The cost of the tower may be as much as that of the turbine itself, see table 2. Cost is a very important factor when designing the tower but a height of about 10m may be considered the adequate minimum in a site without obstacles Bartmann and Fink (2008), Gipe (1998) and Pigott (1977).

When designing for an obstacle-rich environment, the height of the obstacles effectively represents ground level for wind speed estimation. Quality of wind improves away from the ground level. Turbulence is intensified near the ground level due to ground drag and this adversely affects the turbine performance. When calculating turbine output the nature of the landscape over which the wind travels is to be considered. This is known as 'Roughness'. It is rated in terms of class with values from 0 to 4. Klemen (2010) has rated the surface of the sea as *0* and for a landscape with many trees and buildings the value is given 4. Ground Drag is due to the frictional forces on the air flowing along the surface of the ground. The texture and roughness of the surface play a major role in this regard. The rougher or more irregular the ground the higher is the ground drag. The ground drag extends to about 500m above the earth surface; however, the effect is greatest near the ground level especially the first 18m above the ground. The air density decreases with altitude but Chiras (2010) has stated that this reduction does not affect the power developed until about 760m above sea level.

Towers are of three types: fixed guyed, freestanding and tilt-up. The freestanding towers are either monopoles or lattice structures. The freestanding monopole towers are made of high-strength hollow tubular steel. The lattice tower consists of either tubular steel pipes or flat metal bars bolted or welded together. The frame of the fixed guyed towers is usually triangular. They are secured by horizontal as well as diagonal braces. Unlike the freestanding lattice tower the frame of the fixed guyed lattice towers does not taper from base to top. Guyed towers usually carry flanges at the base and are bolted onto concrete foundation and often supported by guy cables. The guy cables usually three in number and $120^o$ apart are often designed to be attached at the top of the tower and to an anchor embedded on the ground. The anchors are designed to be located a distance from the base of the tower. The guyed tower may also be made of tubular steel pipes and should be guyed as in the lattice tower. As shown in table 2, the guyed tower is less costly than the freestanding tower because less material is required in its construction. The fixed guy towers use more space than the freestanding version.

The guyed tilt-up towers are characterized by their ability to be raised or lowered for inspection and maintenance. The guyed tilt-up towers are usually made from steel pipes although few lattice versions are available. A set of four cables located $90^o$ apart is required to guy the tilt-up tower. The gin pole is used to raise or lower the tilt-up tower and this gin pole is permanently attached to the mast. A hinge anchored to the concrete base helps to raise or lower the tower. The gin pole mechanism is designed in such a way that when the tower is down the gin pole stands vertically and is parallel to the ground when the tower is vertical. The guy cables are attached to anchors at appropriate radius round the tower.

The freestanding towers although aesthetically more appealing, are also more costly. The freestanding tower requires more steel material in its manufacture and may require a crane to lift it up during installation. These may explain why this type of tower costs more than the other types, see table 2. It should be noted that the last column in the table does not equal the sum of the corresponding values of the second and third columns. It is not clear if this is a miscalculation or the case of discounting when both material procurement and installation contracts are awarded to the same contractor.

**Table 2: Estimate of Costs for 40m Towers(Source Chiras) – 2007 price**

| Tower Type | Tower Cost($) | Installation Cost($) | Total Cost($) |
|---|---|---|---|
| **Freestanding Monopole** | 25000 | 25000 | 50000 |
| **Freestanding Lattice** | 15000 | 12000 | 25000 |
| **Guyed Tilt-up** | 10000 | 4000 | 11000 |
| **Guyed Lattice** | 8000 | 2000 | 9000 |

## Discussion

A wind turbine site may satisfy all the criteria so far considered but there are other subtle issues that require attention. In some localities, planning permission approval may be required. It would be advisable to apply in good time because the consultation exercise could be frustratingly time consuming especially where objection is raised. Even if no planning approval is required, for good neighbourliness and to protect the installation from sabotage , it would be necessary to obtain the consent of neighbours who may be affected by the noise. It would be too expensive if a neighbor, who during installation never raised any objection to start complaining once the installation is up and running. Written consent is advisable. The Wild Life Trust is a very powerful vocal group to contend with. Some of their demands may be difficult to satisfy. How can an installer ensure that no birds get caught up on the blades? During installation the local ecosystem and habitat may be disrupted but soon after will return to normal. It may be a very tall order to convince Trust members on this. Do not overlook the fact that the site which has been given all the tick marks may still harbour some surprises such as impenetrable rock that may require, as these authors found out, special machinery to crack. On the other extreme, the soil may prove to be very porous that the mast foundation would have to be cast by specialists.

## Conclusions

1. There is a range of wind speeds within which power extraction by the wind turbine is possible. It is part of the task in wind site assessment to establish wind availability within this range.
2. The power harvested from the wind is proportional to the cube of the free stream wind velocity. This power–speed relationship further goes to buttress the importance of wind speed data assessment.
3. Even when site assessment has shown that wind speed is within the acceptable range, it will be necessary to ensure that the tower height is at least the adequate minimum so as to reduce the effect of ground drag.
4. If a site is infested with obstacles, the tower height measurement should start from the top of the tallest obstacle.

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