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Assessment of wind resource for possibility of small wind turbine installation in Ilorin, Nigeria

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Abstract

This work presents an evaluation of the wind characteristics of a particular location in University of Ilorin, Nigeria. The daily wind data for this location (lat. 8.48N, long. 4.67E) at three different heights of 10 m, 20 m and 30 m were measured over a period of six months. Although there seems to be flashes of higher wind speed at H = 20 m due to not too far away trees having more leaves up there and causing occasional turbulence, consistent wind availability still occurs at H = 30 m. The mean wind speed obtained at H = 30 m was 5.5 m/h (2.5 m/s) which is close to the cut-in wind speed of most modern commercially available small wind turbines. The results obtained ascertained that the wind speed increases with height that produces more power and the resulting wind profile may be useful in determining the type of wind turbine that may be suitable for this location. The adoption of wind energy technology will improve electricity supply, ensure greater energy mix and enhance the overall economic development in Nigeria.

Keywords: Wind characteristics, Wind availability, Cut-in wind speed, Wind turbine, Energy mix

1. Introduction

Along with the fast rising energy demand in the 21st century and the growing recognition of global warming and environmental pollution, energy supply has become an integral and cross-cutting element of economies of many countries [1]. Responding to the climate and energy challenges, many countries have prioritized renewable and sustainable energy sources such as wind, solar, hydro, biomass, geothermal etc., as a replacement for fossil fuels. Wind is clean, inexhaustible and environmental friendly energy source that can provide an alternative to fossil fuel to help improve air quality, reduction of greenhouse gases and diversify the global electric supply.

Wind is a vast potential source of renewable energy. Wind is generated by complex mechanisms involving the rotation of the Earth, the heat capacity of the Sun, the cooling effect of the oceans and polar ice caps, temperature gradients between land and sea, and the physical effects of mountains and other obstacles [2]. Winds can also be described as large-scale movements of air masses in the atmosphere. These movements of air are created on a global scale primarily by differential solar heating of the Earth's atmosphere. Therefore, wind power can be thought of as an indirect form of solar energy [3]. Air at the equatorial regions is heated more strongly than at other latitudes, causing it to become lighter and less dense. This warm air rises to high altitudes and then flows northward and southward towards the poles where the air near the surface is cooler. This movement ceases at about 30°N and 30°S, where the air begins to cool and sink and a return flow of this cooler air takes place in the lowest layers of the atmosphere. The areas of the globe where air is descending are zones of high pressure and where air is ascending, low pressure zones are formed. This horizontal pressure gradient drives the flow of air from high to low pressure, which determines the speed and initial direction of the wind motion. In describing the direction of the wind, we always refer to the direction of the original wind [3]. That is, a north wind is blowing from the north and is going toward the south. The greater the pressure gradient, the greater is the force on the air and the higher is the wind speed. Since the direction of the force is from higher to lower pressure, and perpendicular to the isobars, the initial tendency of the wind is to blow parallel to the horizontal pressure gradient and perpendicular to the isobars. The resulting wind is called the gradient wind. For straight or slightly curved isobars the resultant wind is also called the geostrophic wind. However, as soon as wind motion is established, a deflective force is produced due to the rotation of the earth which alters the direction of motion and this force is known as the Coriolis [3].

1.1 Wind energy

Wind energy is generated by converting wind currents into other forms of energy using wind turbines. Turbines extract energy from the passing air by converting kinetic energy from rotational movement via a rotor. The

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effectiveness of this conversion at any given site is commonly measured by its energy density or, alternatively, as a capacity factor. Wind energy is primarily used for electricity generation, both onsite and for transport to the grid. Wind energy is also used to pump borehole water, particularly in rural areas. Production of wind energy is largely concentrated in Europe and the United States. However, there has also been rapid growth in the wind energy industries in China and India and good potentials in some part of Africa such as Nigeria [4].

1.2 Wind turbine

A wind turbine is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a wind generator or wind charger. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Developed for over a millennium, today's wind turbines are manufactured in a range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats; while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power [5].

2. Wind conditions for turbine design

The wind condition that governs the loading of a wind turbine is usually represented by the 10-minute mean wind speed U_{10} at the site in conjunction with the standard deviation σ_U of the wind speed. Over a 10-minute period, stationary wind climate conditions are assumed to prevail, i.e. U_{10} and σ_U are assumed to remain constant during this short period of time. Only when special conditions are present, such as tornadoes and cyclones, representation of the wind climate in terms of U_{10} and σ_U will be insufficient [6]. The 10-minute mean wind speed will vary from one 10-minute period to the next. This is a natural variability and can be represented in terms of a probability distribution function. In the long run, the distribution of the 10-minute mean wind speed for most sites is taken as a Weibull distribution

$$F_{U_{10}}(u) = 1 - \exp\left(-\left(\frac{u}{A}\right)^K\right) \quad (1)$$

The shape parameter *k* and the scale parameter *A* are site and height-dependent coefficients. The scale parameter *A* at height *z* can be calculated as follows:

$$A = A_H \frac{\ln\frac{z}{z_0}}{\ln\frac{H}{z_0}} \quad (2)$$

Where z_0 is the terrain roughness parameter which is defined as the extrapolated height, at which the mean wind speed becomes zero, if the vertical wind profile has a logarithmic variation with height, then A_H is the scale parameter at a reference height *H*. A common choice for the reference height is H = 10 m. However, in the context of wind turbines, the hub height is a natural choice for *H*. The expression for A is based on a logarithmic wind speed profile above the ground

$$u(z) = \frac{u^*}{k}\ln\frac{z}{z_0} \quad (3)$$

Where u^* is the frictional velocity, $\kappa = 0.4$ is von Karman's constant, and neutral atmospheric conditions are assumed. The frictional velocity is defined as $u^* = \left({}^{t}/_{\rho}\right)$, in which t is the surface shear stress, and ρ is the air density.

For engineering calculations it may sometimes prove useful to apply the following empirical approximation for the scale parameter *A*

$$A = A_{10}\left(\frac{z}{H}\right)^{\alpha} \quad (4)$$

Where the exponent α depends on the terrain roughness and if the logarithmic and exponential expressions for *A* given above are combined, a height-dependent expression for the exponent α results

$$\alpha = \frac{\left[\frac{\ln\frac{z}{z_0}}{\ln\frac{H}{z_0}}\right]}{\ln\left[\frac{z}{H}\right]} \quad (5)$$

The interpretation of the limiting value $\alpha = 1/\ln\left(\frac{z}{z_0}\right)$ is similar to that of turbulence intensity as z approaches the reference height H. As an alternative to the quoted expression for α, values for a tabulated in Table 1 may be used [6].

A homogeneous terrain is characterized by a constant z_0 over the terrain. Typical values for z_0 are given in Table 1 for various types of terrain. For offshore locations, where the terrain consists of the sea surface, the roughness parameter is not constant, but depends on the wind speed, upstream distance to land, water depth and wave field.

For a given value of U_{10}, the standard deviation σ_u of the wind speed exhibits a natural variability from one 10-minute period to another. This variability of the wind speed is known as the turbulence, and σ_u is therefore often referred to as the standard deviation of the turbulence components. Measurements from several locations show that σ_u conditioned by U_{10}, can often be well-represented by a lognormal distribution.

$$F_{(\sigma_u/U_{10})}(\sigma) = \phi\left(\frac{\ln\sigma - b_0}{b_1}\right) \quad (6)$$

In which (ϕ) denotes the standard Gaussian cumulative distribution function. The coefficients b_0 and b_1 are site-dependent coefficients conditioned by U_{10} [7].

Table 1 Wind speed parameters for various types of terrain

Terrain type	Roughness parameter Z_0(m)	Exponent A
Plane ice	0.00001	
Open sea without waves	0.0001	
Open sea with waves	0.0001- 0.003	0.12
Coastal areas with onshore winds	0.001	
Open country without significant buildings and vegetation	0.01	
Cultivated land with scattered buildings	0.05	0.16
Forest and suburbs	0.3	0.30
City centers	1-10	0.40

Caution must be exercised when fitting a distribution model to data. Normally, the lognormal distribution provides a good fit to data, but utilization of a normal distribution, a Weibull distribution or a Frechet distribution is also seen. The choice of distribution model may depend on the application, i.e. whether a good fit to data is required for the entire distribution, only in the body, or in the upper tail of the distribution. It is important to identify and remove data, which belong to 10-minute series for which the stationary assumption for U_{10} is not fulfilled. If this is not done, such data may confuse the determination of an appropriate distribution model for s conditioned by U_{10}. Based on boundary-layer theory, the following expression for the mean value of the standard deviation σ_u, conditioned by U_{10}, can be derived for homogeneous terrain in which κ = 0.4 is von Karman's constant, Z is the height above terrain, Z_0 is the terrain roughness, also known as the roughness length, and A_x is a constant which depends on Z_0. Measurements from a number of locations with uniform and flat terrain indicate an average value of A_x equal to 2.4; [6-7] suggest $A_x = 2.5$ for $Z_0 = 0.05m$ and $A_x = 1.8$ for $Z_0 = 0.3m$. A conservative fixed choice for σ_u is desirable for design purposes.

$$E[\sigma_u] = U_{10} A_x K \frac{1}{\ln \frac{z}{z_0}} \tag{7}$$

$$\sigma_{u,c} = U_{10} \frac{1}{\ln \frac{z}{z_0}} \tag{8}$$

The turbulence intensity I_T is defined as the ratio between the standard deviation σ_u, of the wind speed, and the 10 minute mean wind speed U_{10}, i.e.

$$I_T = \sigma_u / U_{10} \tag{9}$$

It is the standard deviation of horizontal wind speed, vertical wind speed, and wind direction around the 10-minute average. Turbulence intensity (TI) is defined as the ratio of standard deviation to the average. Turbulence intensity is a measure of the atmospheric stability; specifically, it measures rapid changes in wind speed over short intervals. A value of TI that is 0.1 or less is considered low turbulence; TI in the range of 0.1 to 0.25 is considered moderate turbulence; 0.25 or higher is considered high turbulence. TI is used to determine the turbine category appropriate for the site. High turbulence causes energy output to diminish and affects the loading, durability, and operation of a turbine [8].

2.1 Wind shear and power law

Wind shear describes the change in wind speed as a function of height. Assuming there is no slippage on the surface, the surface wind speed is zero. That is, wind speed is zero at an elevation of zero. There are two methods to describe shear: Power law profile and logarithm profile. A widely used wind shear model is the power law, which is an empirically developed relationship given as Equation 10.

$$\frac{U(z)}{U(z)_r} = \left(\frac{z}{z_r}\right)^{\alpha} \tag{10}$$

The equation variables are defined as before, and the power law exponent is α. For fairly flat terrain, many investigators have used the one-seventh power law, where $\alpha = 1/7$. Researchers have also determined empirical relationships for the power law exponent as functions of parameters such as wind speed and surface roughness length [8-9]. Table 2 provides power law exponent values for different types of terrain [10].

Table 2 Typical power law exponents for varying terrain

Terrain description	Power law exponent, α
Smooth, hard ground, lake or ocean	0.10
Short grass on untilled ground	0.14
Level country with foot-high grass, occasional tree	0.16
Tall row crops, hedge, a few trees	0.20
Many trees and occasional buildings	0.22- 0.24
Wooden country- small towns and suburbs	0.28- 0.30
Urban areas with tall buildings	0.4

For each of these shear models, the values for Z, Z_r, $U(z)$, and $U(z)_r$ are available from standard met tower data measurements and one can determine such parameters as z_r and α. The widespread use of these wind shear models, however, does not necessarily mean they are accurate for all situations or that the typical shear parameter values in Tables 2 result in accurate hub height wind speed predictions.

2.2 Wind direction

The wind direction and changes in the wind direction are determined by geography, global and local climatic conditions and by the rotation of earth. Locally, the wind direction will vary with the lateral turbulence intensity and for coast near locations; in particular, the wind direction can vary between day and night.

Though the yaw system of a wind turbine will hold the rotor in the direction of the mean wind direction, the short-term fluctuations in the wind direction give rise to fatigue loading. At high wind speeds sudden changes in the wind direction during production can give rise to extreme loads.

2.3 Site assessment

The wind conditions shall be assessed from monitoring measurements made on the site, long-term records from a nearby meteorological station or from local codes or standards. Where appropriate, the site conditions should be correlated with long-term data from the meteorological station. The monitoring period shall be sufficient to obtain a minimum of six months of reliable data. Where seasonal variations contribute significantly to the wind conditions, the monitoring period shall include these effects [11].

The two variables U_{10} and σ_u , are essential as parameters in the models available for representation of the wind speed. Estimation of wind speed measurements constitutes the most common method for determination of these two parameters. Both U_{10} and σ_u, refer to a 10-minute reference period, U_{10} being the 10-minute mean wind speed and α_{10} being the standard deviation of the wind speed over the 10 minutes. Note that if wind speed measurements are obtained over intervals of duration than 10 minutes, the mean wind speed and standard deviation over these other periods need to be transformed to values referring to duration of 10 minutes. The following approximate formula applies to transformation of the mean wind speed U_{10} in the measurement period T to the 10-minute mean wind speed U_{10} in which T is to be given in units of minutes [11-12].

$$U_{10} = \frac{U_r}{1 - 0.047 \ln \frac{T}{10}} \qquad (11)$$

2.4 Wind speed modelling

The speed of the wind is continually changing and hence to make meaningful estimates of long term energy capture, statistical methods must be introduced. A histogram of the relative frequencies of wind speed is used, based on small wind speed intervals (known as “bins”), and at a given site measured over the period of measurement.

The relative frequency is the proportion of wind speed measurements in each bin. It can be viewed as an estimate of the probability that a wind speed reading will be in that bin. The relative frequency is defined such that the total area under the curve has a value of unity, i.e. the probability of the wind speed being between zero and infinity is one, i.e. it is certain. Two important features can be seen from the frequency distribution.

i. The mean wind speed or the average wind speed. The mean value is far higher than the ‘modal’ wind speed, (that is the wind speed that occurs most frequently).
ii. The occasional occurrences of very high wind speeds. These have some important implications for the structural design of wind turbines [3].

The speed of the wind is continuously changing, making it desirable to describe the wind by statistical methods. Clearly it is of little use to a wind developer to be given the wind speed at a particular instant. What is important is the average wind speed over a given period and how the wind speed is distributed around the mean value. The mean wind speed denoted by *U10*, where the bar above the U denotes ‘average’, can be calculated from the formula:

$$\overline{U} = \sum_{i=1}^{n} = U_i P(U_i) \qquad (12)$$

where U denotes the central wind speed value of the first bin, U_2 the second etc., and P (U) is the probability (or relative frequency) that the wind speed is in bin *i*. In addition to the mean wind speed, it is necessary to know how the wind speeds are distributed over the averaging period. For example, is the wind speed for a site fairly constant in time or is there a large variation? An important quantity is the variance of the wind speed data. This measures the amount of variation from the mean value and is given by:

$$s^2 = \sum_{i=1}^{n} = U_i^2 P(U_i) - (\overline{U})^2 \qquad (13)$$

A site where the wind is fairly constant would have a relatively low variance and a site with very changeable weather would have a relatively high variance. A commonly used measure is the square root of the variance, which is called the standard deviation and denoted simply by s or σ. It is attractive in having a dimension of m/s. To calculate the energy capture from a given wind turbine at a given site and to estimate other useful parameters, such as the proportion of time the wind speed lies in a certain range, the wind speed distribution can be “modelled”. That is, trying to fit a mathematical function that closely resembles the wind speed distribution and which can easily be used in the required calculations.

Based on knowledge of wind statistics, and in particular the mean wind speed and variance at a given site, the selected probability distribution can be identified. There are a number of mathematical functions which have been used. However, in wind energy analysis, the most commonly used is the Weibull distribution.

It has been found that the frequency distribution of wind speeds at most sites can be conveniently and adequately represented by the Weibull distribution function. For this function, the probability of the wind speed having a value U is given by the equation:

$$P(U) = \left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1} \exp\left[-\left(\frac{U}{c}\right)^{k}\right] \qquad (14)$$

The Weibull distribution is controlled by two parameters k (the shape parameter) and C (the scaling parameter). The Weibull distribution tends to get more peaked as k gets larger with the peak moving in the direction of higher wind speeds. The parameter C scales the X-axis (wind speed) to fit different wind regimes. When the value of k is equal to 2 the Weibull distribution reduces to the one parameter *Rayleigh distribution*. This is easier to use, but only applicable to certain wind regimes [12].

2.5 On-site wind measurement

Broadly speaking, there are two types of measurements: In situ measurement and remote sensing. In situ measurements are done with a meteorological tower (met-tower) and remote sensing is done with SODAR (based on sound waves) or LIDAR (based on light waves).

A met-tower is used to measure wind speed, wind direction, temperature, barometric pressure, relative humidity, and few other atmospheric conditions. Met-towers may be classified as: temporary or permanent. A met-tower installed for a period of 1 to 3 years is considered a temporary structure, while a met-tower with a life of about 20 years is considered permanent. Most temporary met-towers are tilt-up with no foundation, while permanent met-towers have a concrete foundation. Some of the more common heights of met-towers are 30, 50, 60, 80, and 100 meters. The 60 m is the most popular met-tower height and the trend is toward taller met-towers.

Anemometers are used to measure wind speed. There are different types including

i. Cup anemometer is the most widely used. Most modern anemometers contain three cups with a vertical axis of rotation. The rotation speed of the cups is proportional to the wind speed. The output signal of an anemometer is a low-level AC sine wave; the frequency of the sine wave is proportional to the wind speed.
ii. Propeller anemometer is also used to measure wind speed. The axis of rotation of propeller anemometer is horizontal. In order to align the axis of rotation with the direction of wind, this type of anemometer also contains a wind vane. This instrument serves two purposes; wind speed and wind direction measurement. A form of propeller anemometer is used to measure the vertical component of wind speed; in this case, the axis of rotation is fixed to be vertical.
iii. Sonic anemometer - Ultrasound waves are used to measure wind speed and direction. Three-dimensional velocity vectors are computed by measuring travel time of sonic pulses between three pairs of transducers.

3. Materials and methods

The site of study is situated behind the Engineering Building, University of Ilorin, Ilorin, Nigeria, which is on latitude 8.48N, longitude 4.67E. The geomorphology of the site is nearly flat, surrounded by trees and buildings. The terrain is about 2-3 plots of land. During rainy season the area is almost completely covered with vegetation.

The site shown in Figure 1 below was chosen mainly because of the radio communication mast (now meteorological tower) situated there. In wind measurement in built environment, there is really no perfect site as the site was littered with vegetation and buildings which were not up to 40 meters away from this metrological mast. Efforts made to condition and improve the site for data collection include;

i. Providing a shelter for the data loggers close to the meteorological mast.
ii. Cutting down nearby trees close to the mast to avoid turbulence.
iii. Alkaline batteries were used to power the data loggers throughout the period of data gathering.

Equipment used was three APRS anemometers mounted at heights H = 10 m, H = 20 m and H = 30 m and data was gathered for six months in early 2012 and the good wind period was analyzed. The wind data loggers that came with the anemometers were designed to provide an affordable and easy-to-use solution for wind site evaluation. It records wind speed, gust, and wind direction, as well as the time and date, temperature, battery voltage, and other important parameters. Capable of recording wind speed from up to three anemometers, it is ideal for more complex studies involving multiple wind speed instruments and other sensors. Recording directly to a Secure Digital (SD™) card provides convenient data downloads and stores many months of data at 30 second intervals and years of data at longer logging intervals, resulting in fewer trips to retrieve data from the wind data logger and a new file is created and saved to the card each day.

The SD™ card is inserted into a card reader attached to the USB port of the laptop and will then show up as a drive. To view and graph the data, it is necessary to click on the spreadsheet corresponding to the day of interest. Microsoft Excel, OpenOffice.org, or practically any spreadsheet program can be used to view, graph, and analyze the wind data recorded.

The following samples are from a wind data logger with one anemometer. Each row of data represents one logging interval. Each file contains data from a single day.

i. Adjustable logging interval: The logging interval is adjustable from 10 to 60,000 seconds (16.6 hours) in one-second increments. For most applications, 1-minute or 10-minute intervals are commonly used.
ii. The wind sensors can be located about 30 meters away from the data logger and the wind data logger is compatible with almost any type of anemometer.
iii. A 16-character x 2 line backlit LCD screen displays current information and is used for configuring the data logger. A simple menu-driven interface using the LCD and three front panel buttons makes setup easy. A bright backlight makes the data logger easy to use at night.
iv. The Wind Data Logger operates directly from any DC voltage source between 7 and 30 volts. Power consumption is approximately 20mA, which allows the Wind Data Logger to be powered from the wall, alkaline batteries, or solar power systems.
v. An accurate real-time clock is used to time-stamp each measurement. The clock is battery backed and is accurate to within 10 minutes per year or better.
vi. The Wind Data Logger mounts directly to a double gang electrical box for clean installation in a wall or an electrical panel.

vii. An RS-232 serial port is a feature of every Wind Data Logger. This port allows communication with computers and other communication equipment. APRS World has free PC software that can display and log data directly to a personal computer or the internet site.

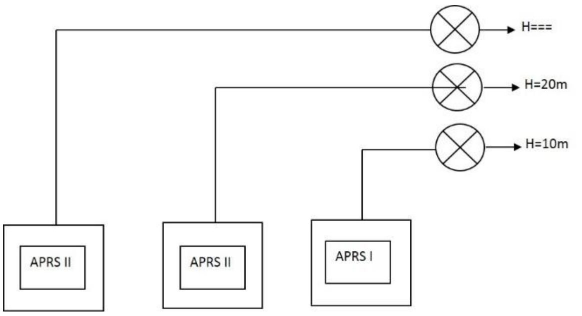

Figure 1 Schematic diagram of APRS wind speed data logger at different height H

4. Results and discussion

A major objective of wind engineering research is accurate prediction of wind and wind-induced forces on structures. As the first step in predicting the wind-induced forces, the nature of the wind must be characterized. For this quantification, wind data collected at a location in the University of Ilorin was used. The time series of interest are the wind speed and longitudinal component speed measured on the meteorological tower. Several criteria were established for selection of wind records for detailed analysis. Record selection criteria included:

i. Record stationarity;
ii. Neutral stability of the atmosphere;
iii. No anomalies in the wind profile;
iv. Homogeneity of wind azimuth;

Neutral stability is assumed to occur in records which are collected at night and in records with high mean wind speeds. When the atmosphere is neutrally stable, atmospheric instability provides a negligible component to the measured wind turbulence. Thus, the measured wind turbulence is considered to be generated from only mechanical sources (surface roughness).

Data used for this analysis is obtained during the study period and stored in the data loggers. Three large data sets of wind speed in mph were obtained height H = 10 m, H = 20m and H = 30 m. This data was obtained in a excel format.

A 10-minute mean speed and its corresponding standard deviation was taken across the entire period of measurement. Data obtained from the logging came in form of daily files. In order to analyze the data there was the need to merge all the data into one file (preferably in Excel format). Using Microsoft Excel VBA, a macro was developed to extract data from all the files into one Excel Spreadsheet. Another macro was developed to compute the mean wind speed and its standard deviation at 10 minute intervals. The final macro was then developed to aggregate this data and plot graphs. Samples of tables and the resultant graphs generated are depicted in Tables 3, 4 and Figures 2, 3, 4 & 5 below.

At H = 10 m, the graph of 10-minute wind speed over the measurement period was plotted against time as shown in Figure 2. It was observed that there was a sharp variation across the profile at a given time and it peaks at 28 mph with an average wind speed of 3.1 mph. A similar trend was observed at H = 20 m having a maximum wind speed of 33 mph and an overall mean wind speed of 3.7 mph and standard deviation of 2.9.

Although there seems to be flashes of higher wind speed at H = 20 m due to not too far away trees having more leaves up there shadowing close to H = 30 m, consistent wind availability still occurs at H = 30 m, with a maximum wind speed of 38 mph and the overall mean wind speed of 5.5 mph and standard deviation of 1.7. The consistency and availability of wind speed at H = 30 m is evident in Figure 5.

The import of the above observation is that at very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the cut-in wind speed and is typically between 2.5 and 5 meters per second for most turbines.

At higher wind speed however, the design of the turbine is arranged to limit the power to the maximum level and there is no further rise in the output power. How this is done varies from design to design but typically with large turbines, it is done by adjusting the blade angles so as to keep the power at the constant level.

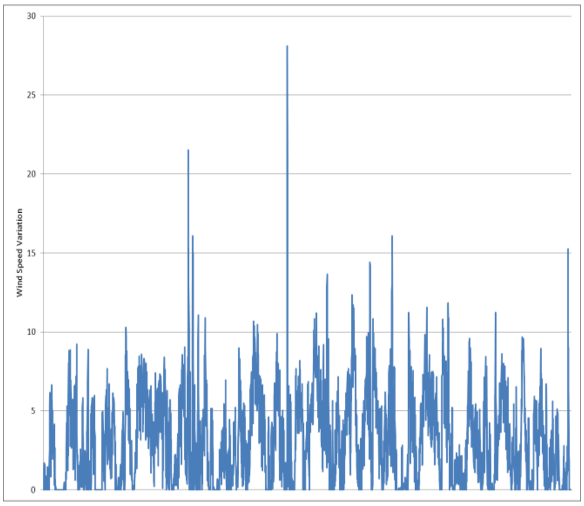

Figure 2 Wind speed variability at H = 10 m

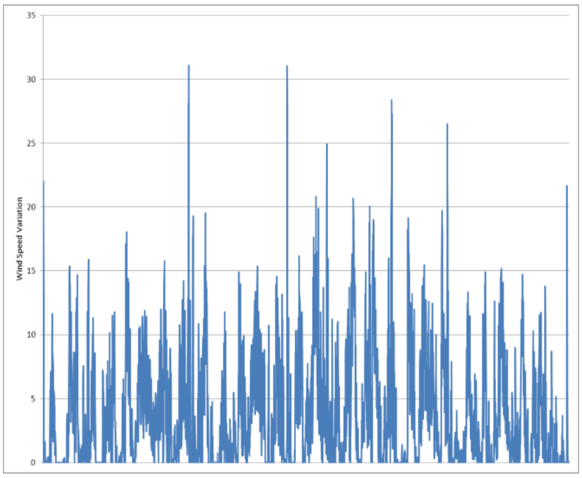

Figure 3 Wind speed variability at H = 20 m

Table 3 Wind data obtained at height H = 10m

	Date & Time	Wind Speed	Gust	Pulse Count	Daily Counter	Input Voltage	Temperature	10 minute mean wind speed	10 minute mean standard deviation
11111	24/04/2012 17:09	22.6	28.8	1406	266928	10.74	226.3	14.87777778	10.5033093
11112	24/04/2012 17:10	12.4	27.7	1300	268230	10.74	226.3	0	0
11113	24/04/2012 17:11	22.6	38.8	1763	269998	10.74	226.3	0	0
11114	24/04/2012 17:12	17.2	29.3	1413	271414	10.74	226.3	0	0
11115	24/04/2012 17:13	11.3	28.6	1314	272730	10.74	226.3	0	0
11116	24/04/2012 17:14	18.1	23.4	951	273685	10.74	226.3	0	0
11117	24/04/2012 17:15	3.8	19	795	274481	10.74	226.3	0	0
11118	24/04/2012 17:16	9.4	23.8	777	275260	10.74	226.3	0	0
11119	24/04/2012 17:17	12.8	21.1	868	276130	10.74	226.3	0	0
11120	24/04/2012 17:18	12	14.7	401	276533	10.74	226.3	0	0
11121	24/04/2012 17:19	8	17.3	515	277050	10.74	226.3	12.76	5.119804684
11122	24/04/2012 17:20	8.9	25.5	944	277996	10.74	226.3	0	0
11123	24/04/2012 17:21	11.9	14.1	578	278577	10.74	226.3	0	0
11124	24/04/2012 17:22	14.9	19.6	771	279351	10.74	226.3	0	0
11125	24/04/2012 17:23	10.3	23.2	999	280352	10.74	226.3	0	0
11126	24/04/2012 17:24	10.1	17.9	710	281064	10.74	226.3	0	0
11127	24/04/2012 17:25	9.2	23.4	894	281960	10.74	226.3	0	0
11128	24/04/2012 17:26	9.2	20.4	741	282703	10.74	226.3	0	0
11129	24/04/2012 17:27	6.1	20.1	758	283462	10.74	226.3	0	0
11130	24/04/2012 17:28	10.4	14.9	611	284075	10.74	226.3	0	0
11131	24/04/2012 17:29	7.9	18.3	802	284879	10.74	226.3	9.89	2.233136807
11132	24/04/2012 17:30	9.8	15.5	543	285424	10.74	226.3	0	0
11133	24/04/2012 17:31	5.2	10.3	337	285762	10.74	226.3	0	0
11134	24/04/2012 17:32	5	8.8	304	286067	10.74	226.3	0	0

Table 4 Wind data obtained at height H = 30m

	Date & Time	Wind Speed	Gust	Pulse Count	Daily Counter	Input Voltage	Temperature	10-minute mean wind speed	10-minute mean standard deviation
11078	24/04/2012 16:37	16.4	25.2	1186	439733	10.62	225.3	0	0
11079	24/04/2012 16:38	16.5	30.3	1346	441082	10.66	225.3	0	0
11080	24/04/2012 16:39	16.9	25	1249	442334	10.66	225.3	19.02222222	4.68586
11081	24/04/2012 16:40	20.4	20.7	778	443116	10.66	225.3	0	0
11082	24/04/2012 16:41	16.9	20.8	941	444061	10.66	225.3	0	0
11083	24/04/2012 16:42	14.7	19.1	753	444817	10.66	225.8	0	0
11084	24/04/2012 16:43	5.2	17.2	622	445440	10.66	225.3	0	0
11085	24/04/2012 16:44	10.6	16.9	741	446183	10.66	225.3	0	0
11086	24/04/2012 16:45	13.7	22.9	1080	447266	10.66	225.3	0	0
11087	24/04/2012 16:46	19.9	21.1	805	448075	10.66	225.3	0	0
11088	24/04/2012 16:47	19.8	24.1	1160	449239	10.66	225.8	0	0
11089	24/04/2012 16:48	14.6	23.8	1005	450246	10.62	225.3	0	0
11090	24/04/2012 16:49	11.9	16.7	716	450965	10.66	225.3	14.77	4.541376
11091	24/04/2012 16:50	6.1	17.3	711	451677	10.66	225.3	0	0
11092	24/04/2012 16:51	18.6	20.1	837	452518	10.62	225.3	0	0
11093	24/04/2012 16:52	8	19.3	800	453319	10.66	225.3	0	0
11094	24/04/2012 16:53	15.8	19.3	628	453950	10.66	225.3	0	0
11095	24/04/2012 16:54	10.2	21.9	1031	454983	10.62	225.3	0	0
11096	24/04/2012 16:55	14.3	19.8	897	455882	10.62	225.3	0	0
11097	24/04/2012 16:56	14.5	14.8	750	456635	10.66	225.3	0	0
11098	24/04/2012 16:57	7.7	16.6	732	457368	10.66	225.3	0	0
11099	24/04/2012 16:58	9.8	16.6	759	458129	10.66	225.3	0	0
11100	24/04/2012 16:59	5.2	12.6	467	458597	10.66	225.3	11.02	4.284344
11101	24/04/2012 17:00	7.5	10.9	448	459047	10.66	225.3	0	0

Sheet1 Sheet2 Chart1 Sheet3

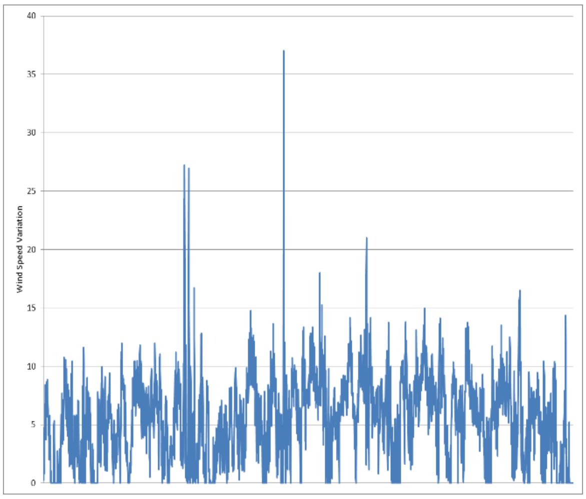

Figure 4 Wind speed variability at H = 30 m

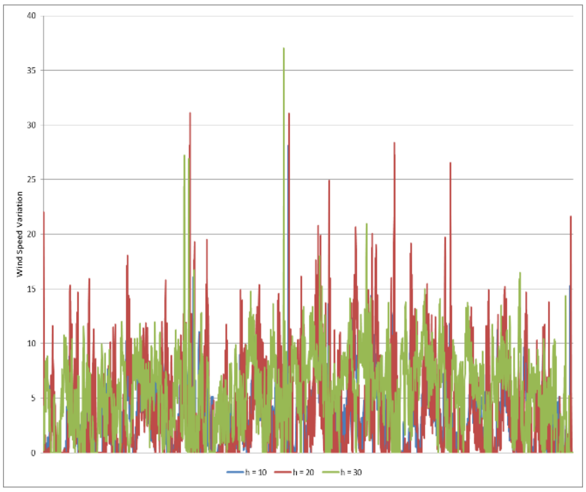

Figure 5 Overall wind speed variability at H = 10 m, 20 m and 30 m

From the analysis of the data obtained, the mean wind speed for heights at 10 m, 20 m and 30 m, standard deviation, the shape factor and mean power are calculated and are shown in Table 5.

It should be noted that the mean wind speed obtained at H = 30 m was 5.5 m/h (2.5 m/s) which is close to the cut-in wind speed of most modern commercially available small wind turbines will perform fairly well if installed at height H = 30 m above the ground at the site under consideration.

Table 5 Mean wind data of the test site

	H = 10m	**H = 20m**	**H = 30m**
Standard Deviation, $\boldsymbol{\sigma}$	±1.747184	±2.943965	±1.931285
Mean Speed, $\boldsymbol{U}$	3.10 m/h	3.71 m/h	5.5 m/h
Unsteady Wind Speed Component, $\boldsymbol{u}$	1.9 m/h	2.06 m/h	4.03 m/h
Shape Factor, $\boldsymbol{k}$	1.854	1.272	3.115
Mean Power Rating, $\boldsymbol{P}$	1.216 kW	0.8 kW	1.55 kW

5. Conclusions

Wind power is now growing rapidly in the world. Although it currently supplies little of the world's electricity needs, it may in near future constitute the largest source of new power supply generating zero-emissions electricity at an affordable cost. It is a matter of common observation that the wind is not steady and in order to calculate the mean power delivered by a wind turbine from its power curve, it is necessary to know the probability density distribution of the wind speed.

The basic measure of the unsteadiness of the wind is the standard deviation of the speed variations. For the above data, the standard deviation at each height was determined, so that the ratio of the standard deviation to the mean speed can be calculated and this almost certainly represents the unsteadiness of the wind. Based on the above findings, a turbine installed at height 30 meters above the ground will perform fairly well at this site bearing in mind that Nigeria is in low wind speed region of the World.

It should be noted that wind speed is a function of height above the ground. Simplifying, there are two effects that influence the shape of the wind speed profile. The first is the contours of the terrain. A rising terrain such as an escarpment will produce a fuller profile at the top of the slope compared with the profile of the wind approaching the slope. In choosing a site for a wind turbine, it is therefore important to look at the local terrain to see if there is the possibility of making use of these effects which can have a very substantial effect on the economics of an installation and because of the stochastic nature of wind. A site which is at least 40 meters away from any obstruction will be more suitable to avoid turbulence and damage to the turbine components.

The other effect that has a strong influence on the wind profile is the aerodynamic 'roughness' of the upstream terrain. This might be natural roughness in the form of woods or man-made roughness in the form of buildings. A large urban area will have an enormous effect on the extent and shape of the velocity profile.

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