ANALYSIS OF WIND CHARACTERISTICS OF UMUDIKE, NIGERIA FOR ELECTRICITY POWER GENERATION

*Aririguzo, J. C. and Ekwe, E. B.

Department of Mechanical Engineering, Michael Okpara University of Agriculture, Umudike Abia State
*Corresponding author: Tel.: (234) 8153284600; E-mail: jarixo@gmail.com

ABSTRACT

The project studies and harnesses the wind energy characteristics of the city of Umudike, Abia state Nigeria, to ascertain its viability for generating electricity. This initial stage of a broader project considers and analyzes the available wind energy, looking at very detailed daily wind speed distribution, with a view to extrapolating key integral parametric values for use in a localized/ bespoke wind blade modelling, engineering and design. Weibull probability distribution's two-parameter model was deployed to capture essence of wind speed which was harnessed to between 6.33 to 9.81 m/s when extrapolated at higher regions of altitudes of 30 meters, feasible for application of Wind Energy Conversion System (WECS). Enormous wind power potentials was evaluated at 30 meter heights with monthly power densities in the range of 162.70<WPD<794.82 w/m^2. Similarly, maximum monthly mean wind energy density (WED) values at the same height yielded 591 Kwh/m^2. Overall the prospect for wind turbine utilization in city of Umudike is strong with substantial parametric values. The potential electric power from the study is looking significant with available information indicating minimal environmental impacts on the host community.

1. INTRODUCTION

The application of wind energy for power generation is one of the most attractive renewable energy sources globally due to the advantage of being clean, sustainable and ecological friendly energy source (Mostafaeipour, 2010). The rate at which conventional energy resources are depleting as a result of exploration is high. Consequently, many countries today have re-directed efforts towards harnessing alternative energy resources, such as solar, hydropower, geothermal, wind power and biomass (Majid *et al*., 2014). The world cumulative installed capacity of wind power has progressively increased in the last decade from 7,600 MW in 1997 to 318,117 MW in 2013 (GWEC, 2014). This value was higher than the 263,126 MW in 2011, 198,001 MW in 2010 and 158,975 MW in 2009.

Furthermore, the Global Wind Energy Council (GWEC) has projected a 3.4% annual increase in 2014 with a cumulative increase of 14.9% and growth installed of 47 GW. Other developing countries like Brazil, South Africa, Tanzania, Kenya and Ethiopia being hot market for wind power have posed for growth in the wind power development. For example, South Africa, Mexico and Ethiopia have projected an increase of 9 GW installed capacity by 2030, 2GW by 2024 and 7GW in 2030, respectively (GWEC, 2014). Further works on wind energy assessment, development and economic feasibility for wind farms are contained in (Ozerdem *et al*., 2006; Mostafaeipour *et al*., 2011).

Interestingly, the potential of wind energy in some regions of Nigeria have been investigated (Ojosu and Salawu, 1990; Ohunakin, 2011). The highest wind resources being in the North West and North central parts of the country. Recent studies have shown wind energy potentials for different sites in Nigeria. The stations at Bauchi, Potiskum, Maiduguri, Minna, Markudi, Enugu, Ikeja, Lagos, Guasa and Katsina showed comparatively high wind speeds and power density (Adaramola *et al*., 2012; Oyedepo *et al*., 2010; Ohunakin *et al.,* 2012; Adaramola *et al*., 2014; Adaramola *et al.,* 2014). Apart from these locations other promising sites with good wind energy potential include the shorelines of Nigeria.

Many locations in the Niger Delta region of Nigeria have not been sufficiently investigated. For effective investment and utilization of wind power in the Niger Delta, a detailed assessment of the wind speed distribution is imperative to understand the trend of power obtainable through different months of the year. The main objective of this study is the analysis of the month to month available wind energy in Umudike/ Umuahia. This first phase of the project considers very detailed wind speed distribution analysis with Weibull probability distribution method, to determine the workability of the proposed scheme. The next phase of the project will consider comprehensive modelling and design of the wind turbine blades based on the results obtained from this preliminary phase. The rest of the paper is organized as follows; Section 2 deals with materials and methods used in the project and sets the scene for the wind data analysis.

Section 3 presents results and discussion. This phase of the project is wrapped up and concluded in section 4.

2. Materials and Methods

In the evaluation of the wind energy potential and characteristics in the Niger Delta region, daily wind data for Umudike was collected from the National Root Crops Research Institute, Umudike from (2006-2015). The obtained wind data are of the surface type obtained at 2m height. These have been extrapolated to 10m, 20m, and 30m height using the Weibull distribution technique and the location's wind shear exponents.

2.1 Wind Characteristics Models

The two- parameter standard form of Weibull distribution probability function and the correspondent cumulative probability function adopted in this study are expressed in Equations (1) and (2) (Mostafaeipour *et al*., 2011).

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] (k > 0, v > 0, c > 1) \quad (1)$$

$$f(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)^{k}\right) \quad (2)$$

Where, k is the shape parameter, c (m/s) is the scale parameter and v (m/s) is the location's wind speed. The k and c values are determined by the relationships:

$$k = 0.83v^{0.5} \quad (3)$$

$$c = \frac{v_m}{r(1 + (1/k))} \quad (4)$$

Mean wind speed v_m and the variance σ^2 of the wind data are determined by (Adaramola *et al.,* 2014).

$$v_m = \frac{1}{n}\sum_{j=1}^{n} v_1 \quad (5)$$

$$\sigma^2 = \frac{1}{n-1}\sum (v_1 - v_m) \quad (6)$$

The values of v_m and σ^2 are calculated likewise based on Weibull parameters (Jamil *et al.,* 1995).

2.1.1 Wind Power and Energy Density

The wind power density and energy density for a given site are determined by (Keyhani *et al*. 2010) as:

$$p(v) = \frac{p(v)}{A} = \frac{1}{2}\rho c^3 \Gamma(1 + \frac{3}{k}) \quad (7)$$

$$\frac{p(v)}{A} = \frac{1}{2}\rho c^3 (1 + \frac{3}{k})T \quad (8)$$

Where $p(v)$ = wind power (W), $p(v)/A$ = Wind power density (w/m^2), ρ = density of air at the site, A= rotor blades swept area (m^2) and T, is time.

2.1.2 Most Probable Wind Speed and Wind Speed Carrying Maximum Energy

The wind speed that is most possible or probable (v_{mn}) and that carrying the highest (maximum) energy (v_{maxE}) are necessary for approximating wind power. The two wind speeds are obtained from the scale and shapes factors as expressed in Equation (9) and (10) (Mostafaeipour et al., 2011).

$$v_{mp} = c\left(1 - \frac{1}{k}\right)^{1/k} (m/s) \quad (9)$$

$$v_{\max E} = c\left(1 + \frac{2}{k}\right)^{1/k} (m/s) \quad (10)$$

2.1.3 Extrapolation of Wind Speed at Varying Hub Heights

Wind speed at the reference height (h_0) can be extrapolated to different turbine height (h) by using the power law extrapolation in Equation (11) (Oyedepo et al., 2010).

$$\frac{v}{v_o} = (\frac{h}{h_o})^{\alpha} \quad (11)$$

Where $'v'$ is wind speed at a height of $'h'$, v_O is wind seed at the reference height $'h_0'$ and $'\alpha'$ is the surface roughness.

3. Results and Discussion

The distribution of average daily wind speeds, from January to December for the years considered is shown in Figure 1.

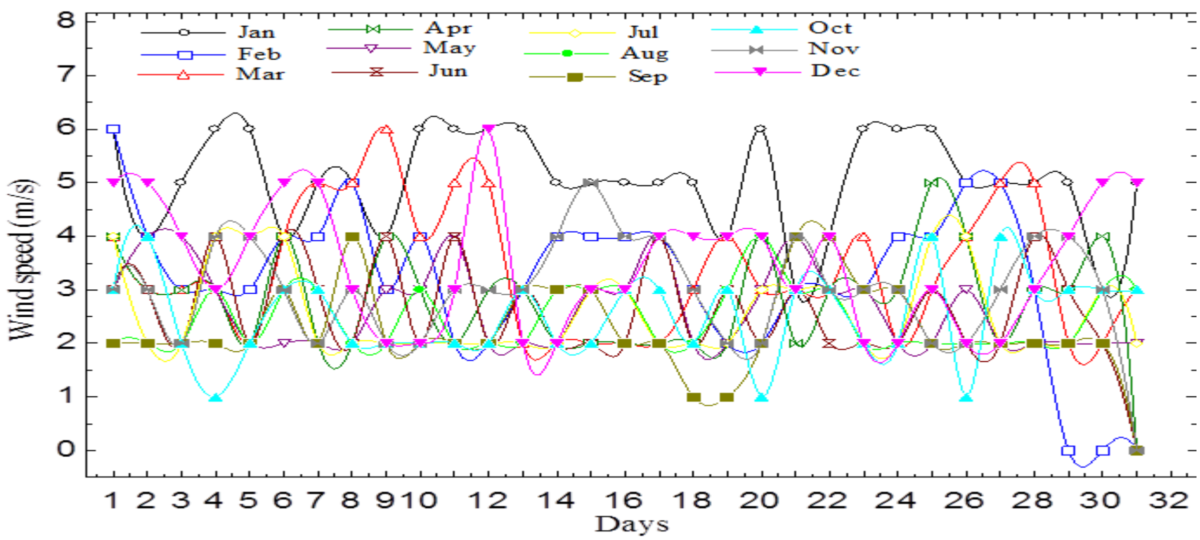

Figure 1: Daily wind speeds at 2m height for different months

The surface daily wind speed variation at the location ranges between $1 \leq v \leq 6\ (m/s)$ with values taken to reflect monthly changes. Wind velocities at 6 m/s occurred in the months of January, February, March and December with probabilities of 0.3548, 0.0357, 0.0323 and 0.0323 respectively. For practical applications, the wind speeds must be up to 3 m/s. The distribution of the wind speed in the range of 3 to 5 m/s, which is minimal to power a turbine is existent in the 12 months and grossly stands at probabilities of 0.645, 0.8214, 0.677, 0.60, 0.484, 0.452, 0.387, 0.419, 0.30, 0.516, 0.33, and 0.839 respectively for the 12 months in that order. The overall probability for observation of this wind speed range is at 0.537 at a surface altitude of 2 m where the data was taken. Consequently, with increasing turbine height at 30 m, it is safe to expect probabilities for this range to have reached a value of 1, as extrapolated results show in Table 2. The parameters of the Weibull distribution are plotted in Figures 2 and 3 for the probability and cumulative density functions respectively. The velocity range of 2 to 5 m/s is a strong possibility in the location based on collected data and is thus depicted in these figures. The peak of each months plot reflects the average monthly values as shown in Table 1. The cumulative function likewise presents the likelihood of observation of the monthly mean wind speeds. However, this trend is observable around values occurring at the saddle point of the graph.

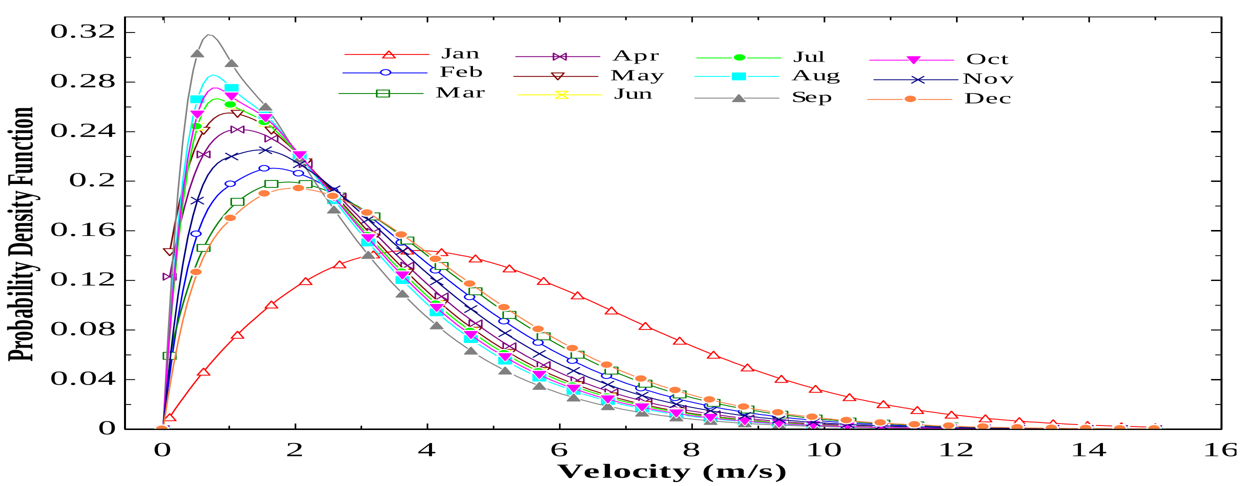

Figure 2: Probability density function at 2m altitude

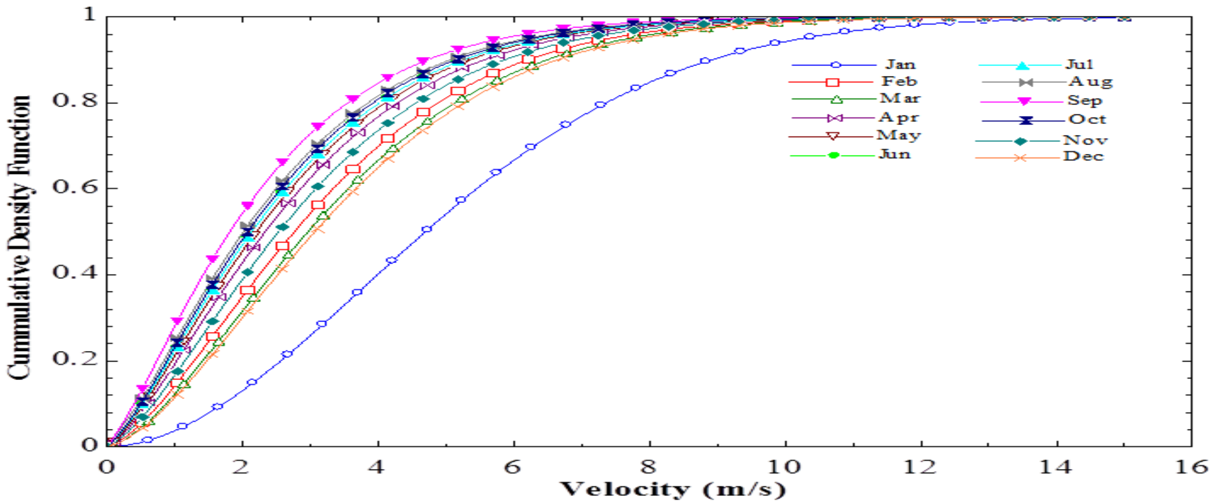

Figure 3: Cumulative density function at 2m altitude

Table 1: Summary of wind energy density and location's wind weibull parameters at 2m

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
c (m/s)	4.44	3.532	3.761	3.037	2.884	2.807	2.807	2.655	2.424	2.732	3.267	3.874
k	1.65	1.48	1.53	1.38	1.35	1.33	1.33	1.3	1.25	1.32	1.43	1.55
P (kWh/m2)	62	34	43	27	25	23	24	21	17	22	31	46

3.1 Wind Speed Extrapolation at 30 m

The obtained wind data was of the surface type but minimal enough to substitute for wind turbine cut-in speed. However, for optimal operation of the proposed system, it is intended to harness the wind energy at higher altitudes since the wind speeds are comparatively higher in those regions. This result is shown on Table 2 where the wind speeds are between 6.23 and 9.81 m/s. the potential for employment of Wind Energy Conversion Systems (WECS) is more feasible in this region. This fact is accentuated by the windy conditions modelled with the high values of Weibull parameters. The most probable wind speeds, and that which carries maximum energy are nearly synonymous with the extrapolated values, as shown in Table 2. The most probable wind speeds expected at 30 m altitude clearly corresponds to the peak values for optimal wind turbine operation.

Table 2: Summary of extrapolated wind energy density and location's wind weibull parameters at 30m

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
c (m/s)	10.97	8.72	9.29	7.51	7.12	6.94	6.94	6.55	5.98	6.74	8.08	9.56
k	2.6	2.33	2.4	2.17	2.12	2.09	2.09	2.04	1.96	2.07	2.25	2.43
$v(m/s)$	9.81	7.88	8.38	6.84	6.55	6.37	6.37	6.05	5.58	6.23	7.34	8.6
v_{maxE}	13.66	11.38	11.96	10.15	9.74	9.57	9.57	9.16	8.56	9.34	10.72	12.24
v_{mp}	9.1	6.86	7.42	5.65	5.27	5.08	5.08	4.71	4.15	4.9	6.22	7.69

Figure 4 shows plots of the energy and power densities against months of the year for the extrapolated 30 m height.

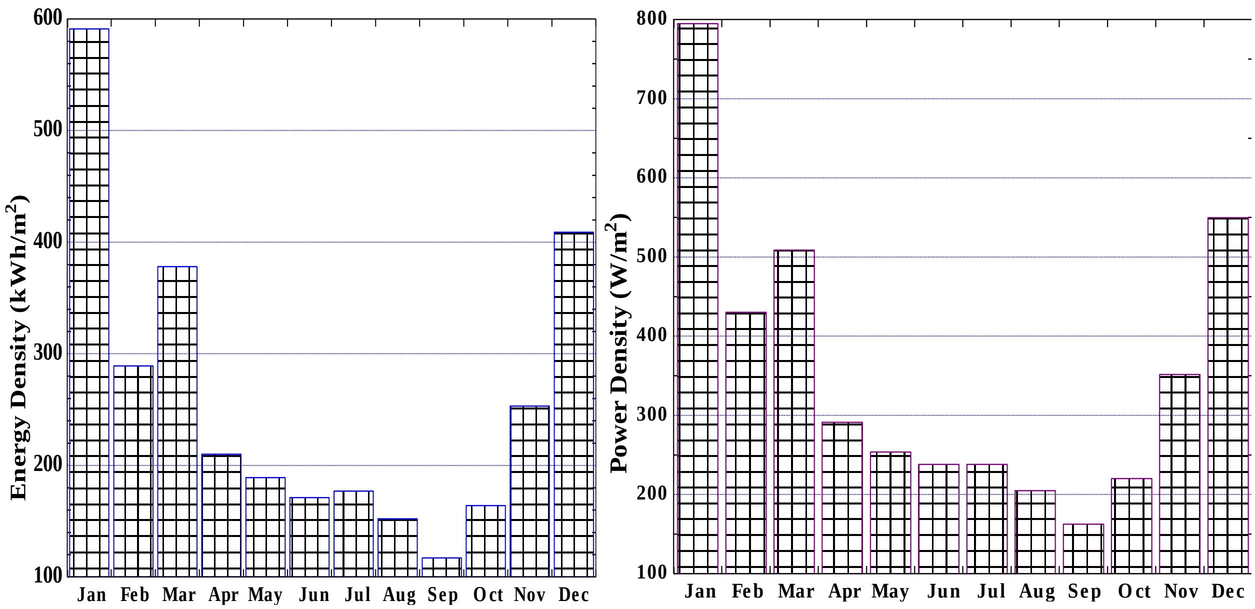

Figure 4: Summary of projected energy generation and power density at 30m altitude

3.2 Wind Power Density

The wind power potential of Umudike was similarly evaluated. The monthly mean wind power density (WPD) and wind energy density (WED) values were evaluated at the extrapolated 30 m altitude where conditions for WECS abound as shown in Fig. 4. Maximum and minimum values of WED were found to occur in January and September at 591 and 117 kWh/m^2 with a standard deviation of 138 kWh/m^2. The high standard deviation shows the energy trend to be normally distributed about a mean value of 258 kWh/m^2. The locations statistics show a possibility of harnessing 3101 kWh/m^2 annually. For selection of wind turbine, the monthly average power densities have also been presented in Fig. 4. Enormous potential is seen to exist with monthly power densities in the range of $162.70 < WPD < 794.82$ W/m^2.

3.3 Wind Classification for Umudike Location

Prospects of wind turbines utilization in Umudike was determined by placing the wind characteristics based on some standard classifications. This study adopted the PNL (Pacific Northwest national laboratory) classification system (Saeidi, et al., 2011). The classification system is developed for different heights of 10, 30, and 50 m with divisions of the wind power density into seven various classes. Based on the PNL classification, the location is suitable for wind energy application.

4. Conclusions

Adequate assessment of wind energy resources available in Umudike/ Umuahia is important and has been made in this work prior to going into a broader multi-disciplinary project. It is centered on wind energy feasibility study for the town in question, using the Weibull two-parameter model. The project has studied, analyzed and harnessed the wind energy from this location for potential localized/ bespoke wind blade modelling, engineering and design for use in electrical power generation. Weibull probability distribution two-parameter model captures the essence of the wind data through the probability and cumulative density functions. The mean maximum wind power density (WPD) and wind energy density (WED) extrapolated to an altitude of 30 meters was significant at 794.82 w/m^2 and 591 kwh/ m^2 respectively. The wind distribution pattern shows enormous potential and basis for application of Wind Energy Conversion Systems (WECS) as outlined in the main topics of the study. The potential electric power from this project is looking significant with available information indicating minimal environmental impacts on the host community.

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