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WIND POTENTIAL ESTIMATION AND PROPOSED ENERGY PRODUCTION IN WUKARI USING WEIBULL DISTRIBUTION FUNCTION

[1]Joseph J. Akpan* [2]John F. Wansah. [1]Paul O. Udom

[1]Chemical Engineering, Federal University Wukari, Taraba State, Nigeria

[2]Pure and Applied Physics, Federal University Wukari, Taraba State, Nigeria

* Author to whom correspondence should be addressed; E-Mail: akpanjohn015@gmail.com

ABSTACT

The Weibull distribution functions is used to estimate the wind energy potential at the centre city of Wukari town. The wind speed data of Wukari Local Government Area of Taraba State has been statistically analysed. Wukari, a town located at latitude 7°52' N and longitude 9°46' E, at an altitude of 252 m. The monthly average wind data for 10-year period (2010-2019) provided by the Nigeria Meteorological Agency (NIMET) was analysed to obtain the average wind speed and maximum power that a household wind turbine will generate. Wind speed as high as 80 m/s was calculated at a height 10m. The highest monthly mean wind speed (80 m/s) occurred in the month of April (Dry season) and lowest wind speed (40 m/s) in October (Rainy season). The power output for a household wind turbine with swept area of 6.16 ㎡, air density of 1.224 kg/m and average wind speed of 20 m/s was calculated to be 30159 W.

Keywords: Wind energy potential, Weibull distribution function, Wind turbine.

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1. Introduction

Energy has been and will still be the main stay of urban development. It is one of the most important factors of national development. The importance of energy and needs for human and economic development are globally increasing. Human beings rely on the conventional sources of energy for their daily needs but the depleting and hazardous nature of this energy prompt the worlds towards the development and utilization of renewable energy sources such as solar, wind, hydropower, wave and biogas that were shown to be clean, available and inexhaustible and are also environmentally friendly. These characteristics have made them more attractive and the energy sector globally is focusing on how to use these sources on a larger scale (Muhammad et al., 2015).

Like other kind of energy, wind energy is ultimately a solar resource. Wind systems are created mainly due to two main causes: temperature differences between the equator and the poles (the earth's latitudes) and the rotation of the earth. Dry air in the vicinity of 30°N and 30°S flows towards the equator where it replaces rising hot air, (Ramachandra, 2005). Wind is air in motion. It is caused by the uneven heating of the Earth's surface by the sun. Today, wind energy is mainly used to generate electricity.

A wind turbine is used to harness the kinetic energy in wind to generate electricity. A typical wind machine consists of blades, generator, cable, and a tower. The blades are connected to a drive shaft that turns an electric generator to produce electricity (Awogbemi and Komolafe 2011). Wind power is the use of air flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels, is renewable form of energy widely distributed, clean produces with no greenhouse gases during operation, consumes no water, and uses little land (Kim, 2009). The net effects on the environment are far less problematic than those of non-renewable power sources.

Wind farms consist of many individual wind turbines which are connected to the electric power transmission network. Onshore wind is an inexpensive source of electric power, competitive with or in many places cheaper than coal or gas plants ((Walwyn and Brent, 2015)). Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Small onshore wind farms can feed some energy into the grid or provide electric power to isolated off-grid locations (Gipe, 1993).

The objective of this work is to estimate the wind potential in Wukari, in the North East region of Nigeria using Weibull distribution function and also, carry out a preliminary examination of the viability of wind energy project in the region.

2. THEORY

Power obtainable in the wind

The kinetic energy of a stream of air with mass m and moving with a velocity V is given by (Meyers and Meneveau, 2012).

$$E = \frac{1}{2}mV^2 \qquad (1)$$

Let's consider a wind rotor of cross-sectional area A exposed to a wind stream, the kinetic energy of the air stream available for the turbine can be expressed as

$$E = \frac{1}{2}PavV^2 \qquad (2)$$

Where ρa is the density of air and v is the volume of air parcel available for the rotor. The air parcel interacting with the rotor per unit time has a cross-sectional area equal to that of the rotor A_T and thickness equal to the wind velocity V. Hence energy per unit time, that is power, can be expressed as

$$E = \frac{1}{2}\rho aA_T V^3 \qquad (3)$$

From equation (3) we can see that the factors influencing the power available in a wind stream are the air density, area of the wind rotor and wind velocity. Effect of the wind velocity is more prominent owing to its cubic relationship with the power (Meyers and Meneveau, 2012).

2.1. Wind energy Collection and Transmission System

In a wind farm, individual turbines are interconnected with a medium voltage (usually 34.5 kV) power collection system and communications network. At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system. A transmission line is required to bring the generated power to (often remote) markets. For an off-shore station this may require a submarine cable. Construction of a new high-voltage line may be too costly for the wind resource alone, but wind sites may take advantage of lines installed for conventionally fuelled generation .One of the biggest current challenges to wind power grid integration in the United States is the necessity of developing new transmission lines to carry power from wind farms, usually in remote lowly populated states in the middle of the country due to availability of wind, to high load locations, usually on the coasts where population density is higher. The current transmission lines in remote locations were not designed for the transport of large amounts of energy. As transmission lines become longer the losses associated with power transmission increase, as modes of losses at lower lengths are exacerbated and new modes of losses are no longer negligible as the length is increased, making it harder to transport large loads over large distances. However, resistance from state and local governments makes it difficult to construct new transmission lines. Multi state power transmission projects are discouraged by states with cheap electric power rates for fear that exporting their cheap power will lead to increased rates. A 2005 energy law gave the Energy Department authority to approve transmission projects states refused to act on, but after an attempt to use this authority, the

Senate declared the department was being overly aggressive in doing so. Another problem is that wind companies find out after the fact that the transmission capacity of a new farm is below the generation capacity, largely because federal utility rules to encourage renewable energy installation allow feeder lines to meet only minimum standards. These are important issues that need to be solved, as when the transmission capacity does not meet the generation capacity, wind farms are forced to produce below their full potential or stop running all together, in a process known as curtailment. While this leads to potential renewable generation left untapped, it prevents possible grid overload or risk to reliable service.

2.3. TURBINE DESIGN

Wind Turbine is a device that converts the wind's kinetic energy into electrical power. Wind turbine design is the process of defining the form and specifications of a wind turbine to extract energy from the wind. A wind turbine installation consists of the necessary systems needed to capture the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and other systems to start, stop, and control the turbine. Wind turbines work by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical energy that can be supplied. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine. When planning a wind farm, it is important to know the expected power and energy output of each wind turbine to enable the calculation of the economic viability.

2.4. WIND TURBINE POWER AND TORQUE

Theoretical power available in a wind stream is given by equation (2.3). However, a turbine cannot extract this power completely from the wind. When the wind stream passes through the turbine, a part of its kinetic energy is transferred to the rotor and the air leaving the turbine carries the rest away. Actual power produced by a rotor would thus be decided by the efficiency with which this energy transfer from wind to the rotor takes place. This efficiency is usually termed as the power coefficient Cp. Thus, the power coefficient of the rotor can be defined as the ratio of actual power developed by the rotor to the theoretical power available in the wind. Hence,

$$C_P = \frac{2P_T}{\rho a A_T\ V^3} \qquad (4)$$

Where P_T is the power developed by the turbine. The power coefficient of a turbine depends on many factors such as the profile of the rotor blades, blade arrangement and setting etc. A designer would try to fix these parameters at its optimum level so as to attain maximum Cp at a wider range of wind velocities. The thrust force experienced by the rotor (F) can be expressed as

$$F = \frac{1}{2}\rho a A_T V^2 \qquad (5)$$

Hence, we can represent the rotor torque (T) as

$$T = \frac{1}{2}\rho a A_T V^2 R \qquad (6)$$

Where R is the radius of the rotor. This is the maximum theoretical torque and in practice the rotor shaft can develop only a fraction of this maximum limit. The ratio between the actual torque developed by the rotor and the theoretical torque is termed as the torque coefficient C_T, thus, the torque coefficient is given by

$$C_T \frac{2T_T}{\rho a A_T 2R} \quad (7)$$

Where T_T is the actual torque developed by the rotor.

2.5 CLASSIFICATION OF WIND TURBINES

Since the inception of the wind energy technology, machines of several types and shapes were designed and developed around different parts of the world. Some of these are innovative designs which are not commercially accepted. Although there are several ways to categorize wind turbines, they are broadly classified into horizontal axis machines and vertical axis machines, based on their axis of rotation. These includes;

- **Horizontal Axis Wind Turbines (HAWT)**
- **Vertical Axis Wind Turbines (VAWT)**
- **Darrieus Rotor**
- **Savonius Rotor**
- **Betz Limit**

The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the power coefficient and is defined as:

$$C_{Pmax} = 0.59 \quad (8)$$

Also, wind turbines cannot operate at this maximum limit. The Cp value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine -strength and durability in particular-the real-world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. By the time we take into account the other factors in a complete wind turbine system e.g., the gearbox, bearings generator and so on, only 10-30% of the power of the wind is ever actually converted into usable electricity.

3. MATERIALS AND METHODS

Site Location and Data Collection

The study area lies on the central city of Wukari, North East Nigeria and is located within latitudes 7° 52'N and Longitude 9° 46'E, with an altitude of 252m. The study area belongs to northern guinea savannah belt of the north-eastern part of Nigeria. It has a tropical climate with high temperature and seasonal rainfall. Wukari local government has an annual rainfall of about 150mm -200mm with a mean temperature of 25°℃ and a maximum temperature of 39°C. Geologically, the area is part of Benue trough.

The data used in this project work were collected from the Nigerian Meteorological Agency (NIMET) Yola Airport Office. The parameters collected are:

I. Wind speed

II. Relative humidity

III. Maximum temperature

IV. Minimum temperature

V. Amount of rainfall

SAS 9.2: SAS 9.2 is statistical software used in analysing wind data to get a Weibull

Probability distribution function.

3.1. METHODS

Weibull Probability Distribution Function

Statistical analysis can be used to determine the wind energy potential of a given site and estimate the wind energy output at this site. To describe the Statistical distribution of wind speed, various probability functions can be suitable for wind regimes. Weibull distribution is the best one, with an acceptable accuracy level. Weibull distribution is a special case of Pierson class III distribution. In Weibull distribution, the variations in wind velocity are characterized by the two functions; (1) The probability density function and (2) The cumulative distribution function. The probability density function (f (V)) indicates the fraction of time (or probability) for which the wind is at a given velocity V. It is given by

$$f(V) = \frac{K}{V}(\frac{V}{c})^{k-1}\, e^{-}(\frac{V}{c})^{K} \qquad (9)$$

Here, k is the Weibull shape factor and c is scale factor. The cumulative distribution function of the velocity V gives us the fraction of time (or probability) that the wind Velocity is equal or lower than V. Thus, the cumulative distribution f (V) is the integral of the probability density function. Thus,

$$f(V) = \int_{o}^{a} f(V)dV = 1 - e^{-}(\frac{V}{c})^{K} \qquad (10)$$

Average wind velocity of a regime, following the Weibull distribution is given by

$$V_m = \int_{o}^{\infty} f(V)dV \qquad (11)$$

Substituting for f (V) in equation (3.3), we get

$$V_m \int_o^\infty V^{\frac{K}{c}} \frac{V}{C} e^{-} (\frac{V}{c})^K \, dV \qquad (12)$$

Which can be rearranged as

$$V_m = K \int_O^\infty (\frac{V}{C})^K e^{-} (\frac{V}{c})^K dV \qquad (13)$$

Taking

$$x = (\frac{v}{c})^k, dv = \left(\frac{c}{k}\right)^x \left(\frac{1}{k} - 1\right) dx$$

Substituting for dv in equation (3.5)

$$V_m = c \int_o^\infty e^{-x} x^{n-1} dx \qquad (14)$$

This is in the form of the standard gamma function, which is given by

$$\Gamma(n) = c \int_o^\infty e^{-x} x^{n-1} \, dx \qquad (15)$$

The average velocity can be expressed as

$$V_m = c \, \Gamma(1 + \frac{1}{k}) \qquad (16)$$

The standard deviation of wind velocity, following the Weibull distribution is

$$\sigma_v = (\mu_2' - V^2{}_m)^{\frac{1}{2}} \qquad (17)$$

Here, μ_2' is the second raw moment of the population which is given by

$$\mu_2' = \int_0^\infty V^2 f(V) dV \qquad (18)$$

Substituting for f (V)

$$\mu_2' = C^2 \int_O^\infty e^{-x} x^{\frac{2}{k}} \, dx \qquad (19)$$

Which can be expressed as a gamma integral in the form

$$\mu_2' = C^2 \Gamma \, (1 + \frac{2}{k}) \qquad (20)$$

Finally, the average wind speed of a particular site can be obtained by using the relationships in equations (14) and (16).

Maximum Power output of a 1KW Wind Turbine

The maximum power output of a 1KW wind turbine can be calculated as follows

$$P = \frac{1}{2} \rho a A_T V^3$$

Where P = power generated in Watts

ρa = Air Density in kg/m3

A_T= Swept Area in m^2

V^3= Wind speed in m/s

Given that air density is 1.224 kg/m3, swept area is 6.16 $m^2$and wind speed of 20 m/s.

Therefore, the maximum power that can be realised is

P = $\frac{1}{2}$ x 1.224 x 6.16 x 20^3

P = 60318.72

P = 30159 W

4. RESULTS, ANALYSIS AND DISCUSSION

The results obtained from monthly mean wind speed, specification of 1KVA wind turbine and annual wind speeds are presented in Tables 4.1, 4.2 and Figures 4.1-4.3, respectively. From equation (9) the Weibull Distribution Function is plotted in Figure 4.13.

Table 4.1 Monthly Mean of Wind Speed (m/s)

Year	Jan	Feb	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2010	90.10	90.07	96.78	114.80	101.10	87.66	66.30	70.61	65.31	68.53	69.14	60.00
2011	71.70	83.73	92.19	102.40	108.90	78.13	78.68	69.24	65.62	64.45	66.72	85.99
2012	110.00	91.31	88.84	126.80	94.00	97.34	96.13	59.98	64.17	65.73	62.26	68.43
2013	91.00	97.24	85.56	105.60	107.90	98.75	92.01	76.68	67.37	47.81	65.14	70.45
2014	85.50	90.48	93.78	106.60	98.74	83.61	74.00	61.44	20.40	22.28	30.07	23.83
2015	25.80	27.25	50.99	47.34	47.52	34.66	37.63	38.40	50.42	38.72	33.47	28.52
2016	26.70	30.91	61.41	66.95	70.15	73.63	69.45	66.81	41.98	40.01	34.74	32.19
2017	31.50	34.68	44.82	52.10	40.49	38.40	40.94	34.04	33.86	30.47	27.38	28.66
2018	42.00	33.07	39.59	42.38	55.62	54.76	42.43	35.89	35.01	25.90	44.81	46.27
2019	39.80	33.35	43.24	44.72	44.70	33.89	35.89	30.58	31.15	29.79	20.94	30.95

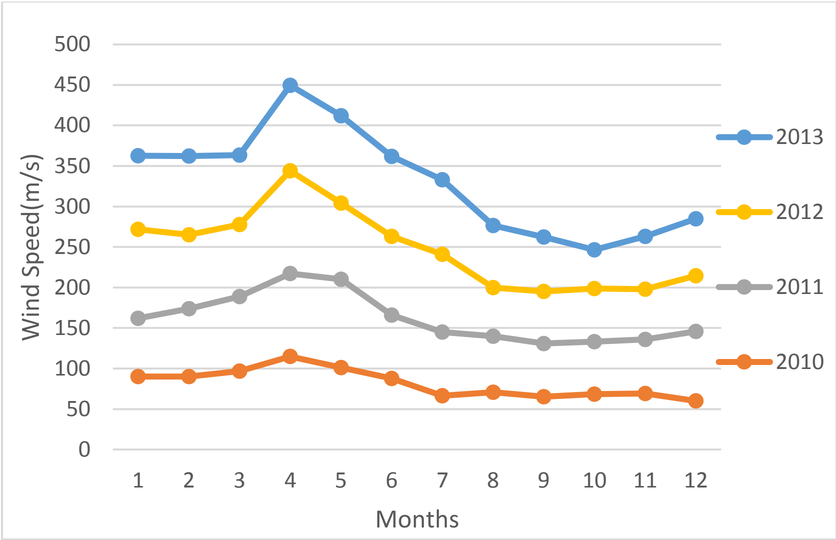

Fig 4.1: Annual Wind Speed from 201o-2013.

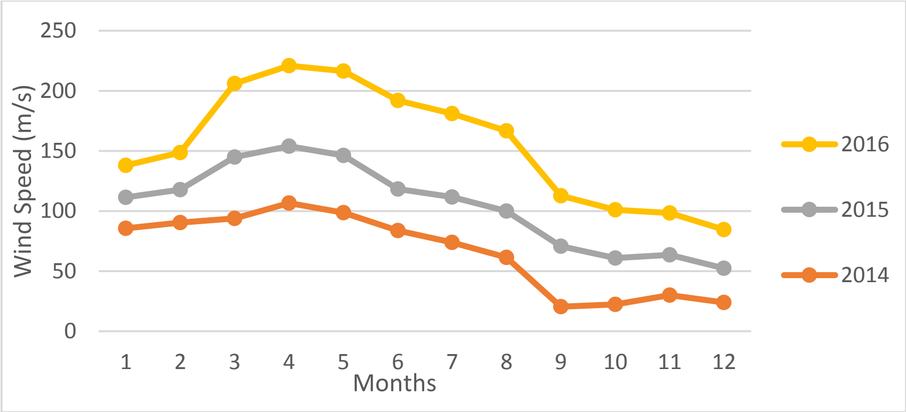

Fig. 4.2: Annual Wind Speed from 2014-2016.

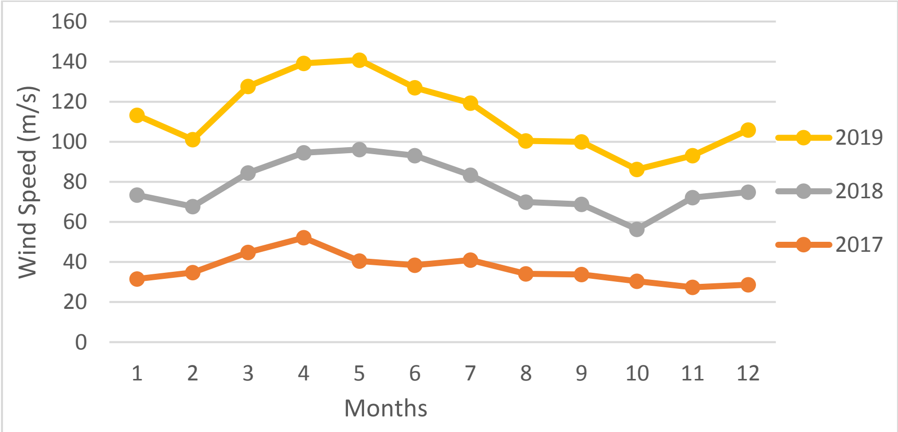

Fig.4.3: Annual Wind Speed from 2017-2019.

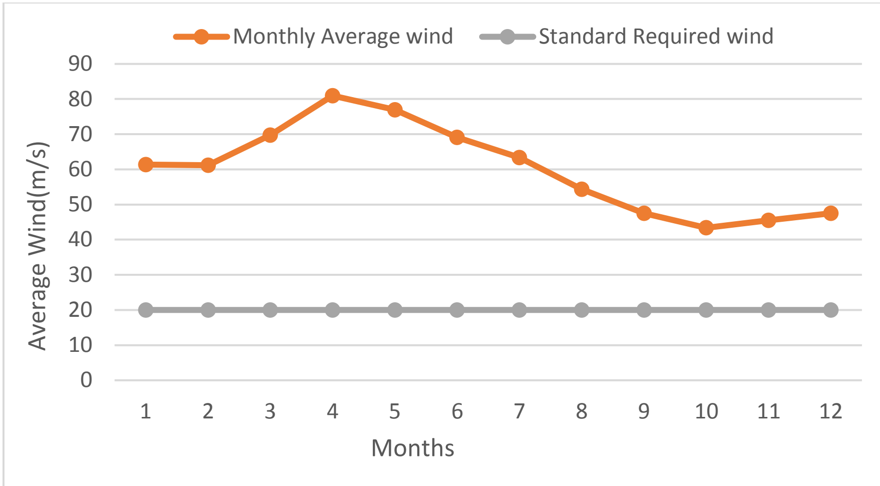

Fig.4.4: Mean Distribution of Wind Speed for 2010-2019.

4.1. Analysis

The graphs were group into three different groups based on the patterns of wind speed observed. The analysis for the figures above is as follows: From Fig.4.1: the highest wind speed for the year 2010 is recorded in the month of April and the lowest is in the month of July. Where 1-12 represent January to December respectively, the highest wind speed for the year 2011 is recorded in the month of May and the lowest is in the month of October. In 2012, the highest wind speed is recorded in the month of April and the lowest is in the month of August. For 2013, the highest wind speed was recorded in the month of May and the lowest is in the month of October.

From Fig.4.2: the highest wind speed for the year 20114 was recorded in the month of April and the lowest is in the month of September and the highest wind speed for the year 2015 was recorded in the month of March and the lowest is in the month of January. For 2016, the highest wind speed was recorded in the month of June and the lowest is in the month of January.

From Fig.4.3: the highest wind speed for the year 2017 was recorded in the month of April and the lowest is in the month of December, in 2018, the highest wind speed for the year was recorded in the month of May and the lowest is in the month of October. For 2019, the highest wind speed was recorded in the month of May and the lowest is in the month of October. From Fig.4.4: the comparison of the monthly average wind speed with the text standard calculated wind speed and the average of the monthly averages wind speed stood at 60.08m/s.

4.2. Discussion

The average wind speed recorded for the period of ten years in Wukari i.e., from 2010-2019, the highest speed being in the month of April with 80.969m/s while the lowest was in the month of October with 43.37m/s. In other words, drop of wind speed on cold season is more severe than warm season. According to (Iacono, 2009), several processes on local, regional and global scales are likely contributing to this decrease such as increasing forest density. For the Weibull distribution of wind speed for Wukari, the value of k and c are 0.6792 and 2.4760 respectively. According to Jiang and Murthy (2011), for the shape parameter k, a value k<1 indicates that the failure decreases over time, when K=1, this indicates that the failure rate is constant over time, the Weibull distribution reduces to an exponential distribution. K>1 indicates that the failure rate increases with time. The Weibull distribution is a pure rejection model. It has been found that for most wind conditions, the value of k varies from 1.5 to 3, whereas c ranges from 3 to 8 (Kaldellis, 1999). Value of c is within the range obtained by Kaldelis.

5. CONCLUSION

Wind speed data of Wukari for the period of 10 years (from 2010-2019) were collected from Nigeria Meteorological Agency (NIMET) Yola Airport. The study has shown that the average wind speed recorded for the period of 10 years within Wukari is around 80 m/s, the month with the highest wind speed is April and least is October. The maximum power that a household wind turbine can generate is approximately 30159W.From the Weibull Distribution, the result obtained while using the statistical analysis software (SAS Version 9.2) is that the shape parameter k is found to be 0.679 and the scale factor c is found to be 2.476.

This project work has been devoted to carrying out a study on potential wind energy estimation and proposed for the establishment of wind farm Wukari. Since the power output for household wind turbine is of a reasonable amount; therefore, the establishment of wind energy farm for power generation in Wukari can be viable.

Recommendation

The study suggests that the location (wukari) in Nigeria has a reasonable amount of wind energy for the installation of wind turbine. We therefore recommend this work for Government and energy planners at various level, to look into the possibility of wind energy installation on this location.

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