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

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

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:

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

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°°C 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

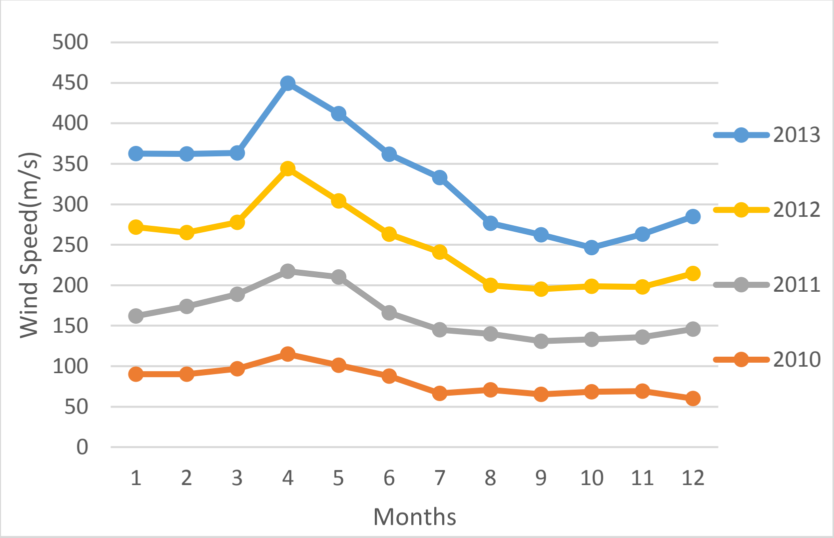

Fig 4.1: Annual Wind Speed from 201o-2013.

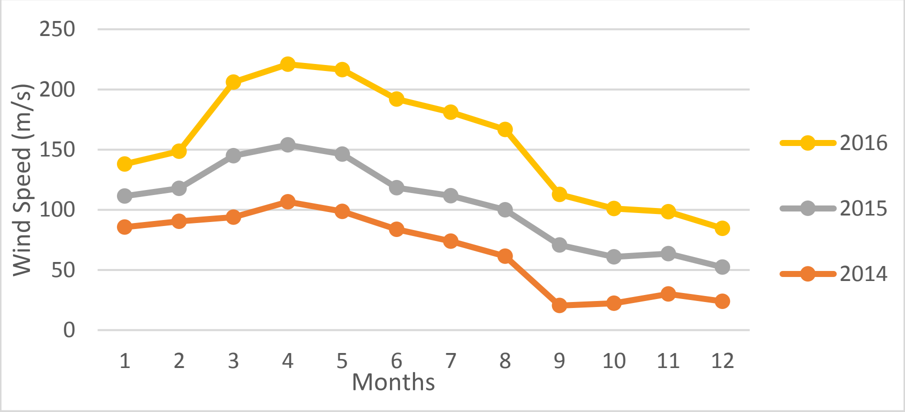

Fig. 4.2: Annual Wind Speed from 2014-2016.

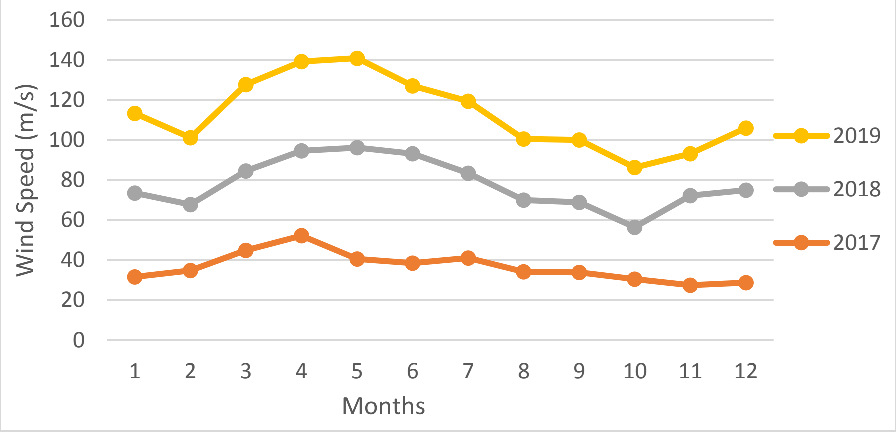

Fig.4.3: Annual Wind Speed from 2017-2019.

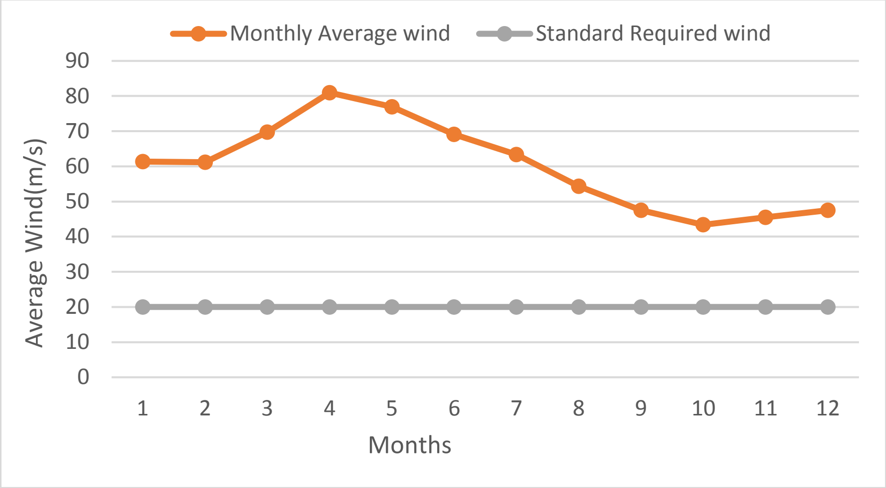

Fig.4.4: Mean Distribution of Wind Speed for 2010-2019.

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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