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Assessment of Wind Energy in Nigeria for Generation of Electricity in Ikeja and Minna

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ABSTRACT

In this study, the assessment of the potential of wind energy for power generation at Ikeja [latitude 6.59^o and longitude 3.34^o and altitude 41] and Minna [latitude 9.37^o and longitude 6.32^o and altitude 256] location in the south-western and north - western part of Nigeria was carried out. One year [2011] with time interval of 9hrs and 15hrs of daily mean Monthly wind speed measured at 10m height obtained from the Nigeria meteorological agency Oshodi, Nigeria.

The wind parameters, such as Most probable wind speed [V_{mp}] , Maximum energy carrying wind speed [V_{max}] and wind power density distribution were obtained from Weibull Probability Distribution Function. The result showed that the mean wind speed at 9hrs were 4.97ms^{-1} and 8.33ms^{-1} respectively for Ikeja Minna while at 15hrs, they were 8.08ms^{-1} and 6.75ms^{-1} respectively for Ikeja and Minna.

The standard deviation at 9hrs were 3.15ms^{-1} and 4.16ms^{-1} respectively for Ikeja and Minna while at 15hrs,they were 3.17ms^{-1} and 3.10ms^{-1} for Ikeja and Minna, The maximum energy carrying wind speed for Ikeja and Minna at 9hrs were 9.66ms^{-1} and12.96ms^{-1} while Ikeja and Minna at 15hrs were 12ms^{-1} and 9.54ms^{-1}.

The most probable wind speed for Ikeja and Minna at 9hrs was 4.17ms^{-1} and 6.66ms^{-1} while Ikeja and Minna at 15hrs were 6.87ms^{-1} and 5.71ms^{-1} on monthly basis. The wind power density for Ikeja and Minna at 9hrs was 382.75 w/m^2 and 1158.30 w/m^2 while Ikeja and Minna at 15hrs were 1320.47 w/m^2 and 562.18 w/m^2.

The assessment of Monthly mean wind speed and Power density of Ikeja and Minna are good location for generation of electricity in Nigeria.

Keywords: wind energy,wind power,wind speed, density,Weibull distribution parameters.

1 INTRODUCTION

Wind energy is one of the most significant and rapidly developing renewable energy sources in technologically developed countries all over the world. The uses of fossil fuel increase environmental effects while wind energy can be considered as alternative power sources. In this study, the assessment of the potential of wind power generation at Ikeja [latitude 6.59^o and longitude 3.34^o and altitude 41m] and Minna [latitude 9.37^o and longitude 6.32^o and altitude 256m] locations in the south-western and north - western part of Nigeria was carried out. One year [2011] with time interval of 9hrs and 15hrs of daily mean monthly wind speed measured at 10m height obtained from the Nigeria meteorological agency Oshodi, Nigeria were assessed and analyzed using ,Weibull Probability Distribution Function, Most probable wind speed [V_{mp}] and Maximum energy carrying wind speed [V_{max}] and Wind power density distribution function.

Wind Power Density Function:

The knowledge of the wind characteristics and evaluation of the power in wind is very important for an assessment of wind power. The wind power depends on the air density, the cube of the wind speed and the wind speed frequency distribution. Therefore, this parameter is generally considered a better indicator of the wind resource than wind speed [1]. The mean wind power density is proportional to the mean cube of the wind speed, $v^3$and can be estimated by using the following equation [1].

$$P = \frac{1}{2}\rho c^3\left(1+\frac{3}{k}\right) \quad (1)$$

whereρ is the mean air density [1.225 kg/m^3 at average atmospheric pressure at sea level and at 15^{o}C], which depends on altitude, air pressure, and temperature.

Geographical Information of data for the selected Locations for the Nigeria Meteorological [Nimet] Stations.

STATE	LATITUDE(N)	LONGITUDE(E)	ALTITUDE(M)	AIR DENSITY
IKEJA	6.59	3.34	41	1.22
MINNA	9.37	6.32	256	1.24

Table 1: Geographical location.

Hence, this study focused on the analyses of wind speed data from Nimet Oshodi Nigeria. It employed wind speed data covering the period of 2011. Information relating to these stations is given in geographical Table 1 above and the geographical location is as displayed in the table 1 above.

2. METHODOLOGY

Analytical method

A year [2011] Mean monthly wind speed, wind time interval [9hrs and 15hrs] data in m/s measured at a height of 10m in Ikeja with [latitude of 6.59° and longitude of 3.342° and altitude 41m] and Minna with [latitude of 9.37° and longitude of 6.32° and altitude 256m] were used for this study. The data were obtained from the Nigeria Meteorological Agency [NIMET].Various statistical distributions exist for describing and analyzing wind data. Some of these include Weibull Probability Distribution Function [$f_{[v]}$], 2-parameters Weibull Probability Density Function with scale [c] and shape [k] and wind power density distribution function [2]. The statistical methods, has been found to be accurate and adequate in analyzing and interpreting the situation of measured wind speed, and wind time interval and in predicting the characteristics of wind profile over a geographical locations .

The statistical methods are;

Weibull Probability Distribution Function;

This study therefore employed the 2-parameters Weibull Probability Density Function with scale [c] and shape [k] being the parameters. The Probability Density Function [[*f* [*v*]] and the corresponding Cumulative Density Function [*F* [*v*]] associated with the 2-parameter Weibull distribution are given by Equations [2] and [3] respectively.

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

$$F_v = 1-\exp\left(\frac{v}{c}\right)^k \quad (3)$$

$F_{[V]}$ =Weibull Probability density function

$F_{[V]}$ =cumulative probability density function

k= Shape factor [dimensionless]

c =Scale factor [m/s]

v= wind speed [m/s]

The Rayleigh distribution function is a special case of the Weibull Probability Distribution Function when the shape factor [k] is 2.0[3]; we have Rayleigh distribution equation [4] respectively.

$$F_v = \frac{2v}{c^2}\exp\left[1-\left(\frac{v}{c}\right)^2\right] \qquad 4$$

In this study the 2-parameters Weibull Probability Density Function with scale [c] and shape [k] being the parameters is therefore employed to estimate the, monthly wind speed and wind speed time interval [9hrs and 15hrs] are given by Equations [5] and [6] respectively.

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \qquad 5$$

Where C is the Weibull scale parameter [m/s]

$$K = \left(\left(\frac{\sigma}{v_m}\right)^{-1.086}\right. \quad (1 \le k \le 10) \qquad 6$$

Where K is the Weibull sharp parameter [m/s]

The mean value $\mathbf{V_m}$Equation 7 and standard deviation **σ** Equation 8 of the Weibull distribution are closely related to Equations [5] and [6] respectively[4].

$$V_m = c\Gamma\left(1+\frac{1}{k}\right) \qquad 7$$

$$\sigma = \sqrt{c^2\left[\Gamma\left(1+\frac{1}{k}\right)-\Gamma\left(1+\frac{1}{k}\right)^2\right]} \qquad 8$$

Where

V_m =observed wind speed [m/s]

σ = standard deviation.

Γ = is the gamma function.

k= Shape factor [dimensionless]

c =Scale factor [m/s]

The evaluation of the most probable wind speed [V_{mp}] and maximum energy carrying wind speed [V_{max}] is very important to wind energy are evaluated from equation [5 and 6] which are given by Equations [9] and [10] respectively.

$$V_{mp} = \left(\frac{k-1}{k}\right)^{\frac{1}{k}} \qquad 9$$

$$V_{max} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}}$$

10

Where V_{mp}= most probable wind speed and V_{max} = maximum energy carrying wind speed.

Wind speed variation with height:

The mean wind speeds at height is given by equation [11] respectively

$$\frac{V_2}{V_1} = \left(\frac{h_2}{h_1}—\right)^{\alpha}$$

11

Where v_2 and v_1 are the mean wind speeds at heights h_2 and h_1, respectively. The exponent α depends on factors such as surface roughness and atmospheric stability. Numerically, it lies in the range 0.05–0.5, with the most frequently adopted value being 0.14 which is widely applicable to low surfaces and well exposed sites [5].

Wind Power Density Function

It is well known that the power of the wind at speed [V] through a blade sweep area [A] increases as the cube of its velocity and is given by equation [12] respectively [6].

$$P_V = \frac{1}{2}\rho A V^3$$

12

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$P_{[v]}$ =powerof wind of speed v

A = blade sweep area

V= wind speed

P=mean air density=1.225kg/m^3 at average atmospheric pressure at sea level and at 15°C, which depends on altitude, air pressure, and temperature.

The expected monthly or annual wind power density per unit area of a site based on a Weibull probability density function can be expressed as follows: The wind power density [W/m^2] which is the quantitative measure of the wind energy available at any location can be estimated from the Equation [5 and 6] Where ρ is the mean air density at average atmospheric pressure at sea level and at room atmospheric temperature, which depends on altitude, air pressure and temperature [7].

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right)$$

13

Where C is the Weibull scale parameter [m/s], and is given by

equation [5]

the two significant parameters k and c are closely related to the mean value of the wind speed V_m equation [7] and putting k to 2, the power density for the Rayleigh model is found to be

$$P_R = \frac{3}{\pi}\rho V^3 M$$

14

3. RESULT AND DISCUSSION

A yearly mean monthly wind speed [2011], wind time interval [9hrs and 15hrs] data in measured at a height of 10m in Ikeja [latitude 6.59^0 and longitude 3.34^0] and Minna [latitude9.37° and longitude 6.32^0] were used for this study. The data were obtained from the Nigeria Meteorological Agency [NIMET] Oshodi. Various statistical distributions were used for describing and analysing the wind data. These include, Weibull and Rayleigh Probability Distribution Function equation [2,3,4,5,6], Most probable wind speed [V_{mp}] equation [9] and Maximum energy carrying wind speed [V_{max}] equation [10] and wind power density distribution function equation [11] The Weibull parameters k and c equation [5 and 6], characterize the wind potential of the location under the study. Basically, the scale parameter c equation [5], indicates how „windy" a wind location under consideration is, whereas the shape parameter k equation [6] indicates how peak the wind distribution is [i.e. if the wind speeds tend to be very close to a certain value, the distribution will have a high k value and is very peaked].

The mean wind speeds of Ikeja at 9hrs is 4.97 m/s and for 15hrs is 8.08m/s, the standard deviation of Ikeja at 9hrs is 3.15m/s and for 15hrs is 3.71m/s . The maximum carrying energy wind speed [V_{max}] for Ikeja at 9hrs is 9.66m/s and for 15hrs is 12.57m/s, and the most probable wind speed [V_{mp}] for 9hrs is 4.17 and for 15hrs is 6.86m/s.

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Table 2;Results of the Weibull analysis of wind data for Ikeja 9hrs Nigeria.

Month	$\bar{v}(ms^{-1})$	σ	K	c (ms^{-1})	f(v)	V_{mp}	V_{max}	Wind power
January	5.07	5.55	0.91	5.15	0.07	-0.08	15.53	300.91
February	4.79	2.41	2.11	5.21	0.16	5.66	7.41	232.82
March	5.23	1.45	4.01	4.76	0.21	7.60	8.89	199.82
April	5.50	2.97	1.95	6.20	0.13	6.05	8.99	368.60
May	4.03	2.11	2.03	4.55	0.18	4.61	6.39	142.57
June	4.23	3.41	1.26	4.56	0.11	1.59	9.66	195.12
July	6.55	5.50	1.21	6.97	0.07	1.89	15.65	719.51
August	9.48	5.12	1.95	10.70	0.07	10.45	15.35	1894.58
September	4.27	2.30	1.95	4.81	0.16	4.69	6.90	172.16
October	2.61	2.26	1.17	2.76	0.16	0.38	6.47	45.71
November	2.83	2.44	1.18	2.99	0.15	0.69	6.94	57.83
December	5.10	2.32	2.36	5.75	0.16	6.55	7.46	263.38
Whole year	4.98	3.81	4.27	5.13	0.17	6.15	7.90	401.67
Wet season	6.16	4.77	7.13	4.14	0.19	9.27	4.97	88.19
Dry season	4.39	3.07	7.16	4.58	0.14	5.94	3.86	597.69

Table 3;Results of the Weibull analysis of wind data for Ikeja 15hrs Nigeria.

Month	$\bar{v}(ms^{-1})$	σ	K	c (ms^{-1})	f(v)	V_{mp}	V_{max}	Wind power
January	5.55	5.77	0.96	5.45	0.06	-0.22	17.68	407.97
February	7.04	2.31	3.37	7.84	0.16	7.06	9.01	555.94
March	9.68	4.32	2.40	10.92	0.09	8.72	14.06	1787.68
April	8.77	4.90	1.88	9.88	0.08	6.61	14.53	1527.58
May	6.97	2.82	2.67	7.84	0.18	6.57	9.67	624.49
June	8.10	3.96	2.18	9.12	0.10	6.87	12.30	1100.797
July	12.68	4.52	3.06	14.19	0.08	12.44	16.76	3463.47
August	13.81	4.50	3.38	15.38	0.09	13.87	17.65	4188.35
September	6.57	2.30	3.13	7.34	0.17	6.49	8.60	925.06
October	7.29	4.53	1.68	8.16	0.08	4.74	13.04	593.62
November	5.13	2.96	1.82	5.78	0.13	3.73	8.68	311.85
December	5.43	2.97	1.93	6.13	0.13	5.48	8.86	358.81
Whole year	8.11	4.74	2.94	8.56	0.17	3.93	6.36	791.65
Wet season	10.34	4.94	3.25	8.94	0.12	4.59	5.19	395.83
Dry season	6.99	4.23	2.83	9.19	0.17	10.45	7.18	800.91

Table 4; Results of the Weibull analysis of wind data for Minna 9hrs Nigeria

Month	$\bar{v}(ms^{-1})$	σ	K	$c(ms^{-1})$	f(v)	V_{mp}	V_{max}	Wind power
January	13.16	6.94	2.00	14.81	0.06	10.47	20.95	5034.97
February	8.61	3.56	2.61	9.69	0.11	8.05	12.05	1212.51
March	7.00	3.85	1.91	7.89	0.10	5.3	11.49	782.84
April	7.87	3.62	2.32	8.88	0.11	6.97	11.60	995.53
May	7.77	3.49	2.38	8.77	0.11	6.98	11.33	945.36
June	6.93	3.07	2.40	7.82	0.12	6.25	10.07	667.11
July	6.61	3.03	2.33	7.46	0.11	5.87	9.73	588.82
August	7.10	4.40	1.68	7.95	0.09	4.64	12.68	864.53
October	5.77	2.99	2.05	6.51	0.13	4.70	9.08	376.32
September	6.65	2.44	2.50	6.36	0.14	5.19	8.05	350.90
November	8.33	6.37	1.36	9.09	0.06	3.42	17.68	1492.90
December	13.90s	6.58	2.25	15.69	0.06	12.06	20.81	5587.75
Whole year	8.23	5.08	2.11	11.92	0.09	3.96	9.97	400.49
Wet season	6.61	3.43	1.68	9.16	0.18	10.91	12.95	395.97
Dry season	9.05	5.56	2.14	6.93	0.05	8.27	5.39	547.93

Table 5;Results of the Weibull analysis of wind data for Minna 15hrs Nigeria.

Month	$\bar{v}(ms^{-1})$	σ	K	$c(ms^{-1})$	f(v)	V_{mp}	V_{max}	Wind power
January	7.06	2.80	2.73	7.94	0.14	6.72	9.71	651.40
February	5.50	2.41	2.45	6.20	0.16	5.01	7.91	328.70
March	6.71	3.05	2.35	7.57	0.12	5.98	9.84	612.30
April	6.80	2.94	2.48	7.66	0.13	6.22	9.72	615.75
May	7.52	3.47	2.32	8.48	0.11	6.65	11.09	866.70
June	8.30	4.83	1.80	9.33	0.08	5.94	14.17	1008.20
July	7.52	3.00	2.72	8.45	0.13	7.14	10.35	786.66
August	6.68	2.82	2.55	7.52	0.14	6.19	9.44	573.85
October	5.10	2.28	2.40	5.75	0.17	4.41	7.11	234.63
September	5.55	2.71	2.18	6.27	0.14	4.34	7.75	280.07
November	5.83	2.81	2.22	6.59	0.14	5.03	8.38	3559.35
December	7.48	3.74	2.12	8.45	0.10	4.88	9.02	428.53
Whole year	6.68	3.24	2.93	5.93	0.19	5.16	5.19	369.72
Wet season	6.90	3.53	1.98	7.24	0.04	4.69	7.38	296.85
Dry season	6.57	3.08	1.49	5.14	0.16	4.83	6.27	400.95

A yearly variation of Mean monthly wind speed (2011), wind time interval (9hrs and 15hrs) for Ikeja and Minna for each month for 2011 is shown in the below Figures.

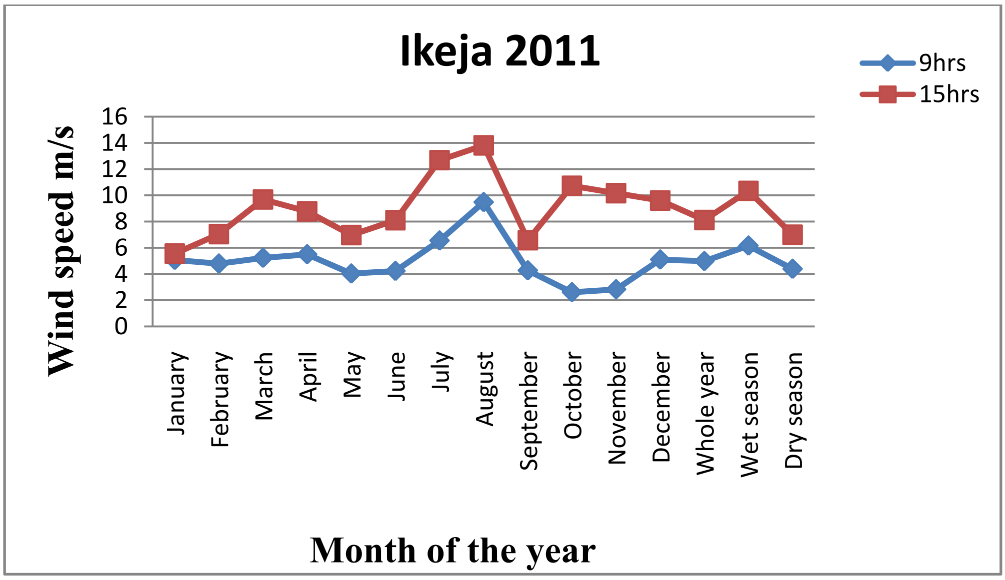

Figure 3; MeanMonthly wind speeds of Ikeja 2011

The actual wind energy for Ikeja [2011] at 9hrs and 15hrs which as the maximum wind energy in august at 15hrs and the minimum wind energy in August at 9hrs.august is a wet season it is heavy cloud cover this could be due to the fact that there is an increase in the amount of solar radiation reaching the surface in the afternoon [15hrs] compare to morning [9hrs]. [Adegoke and Olatona 2013]

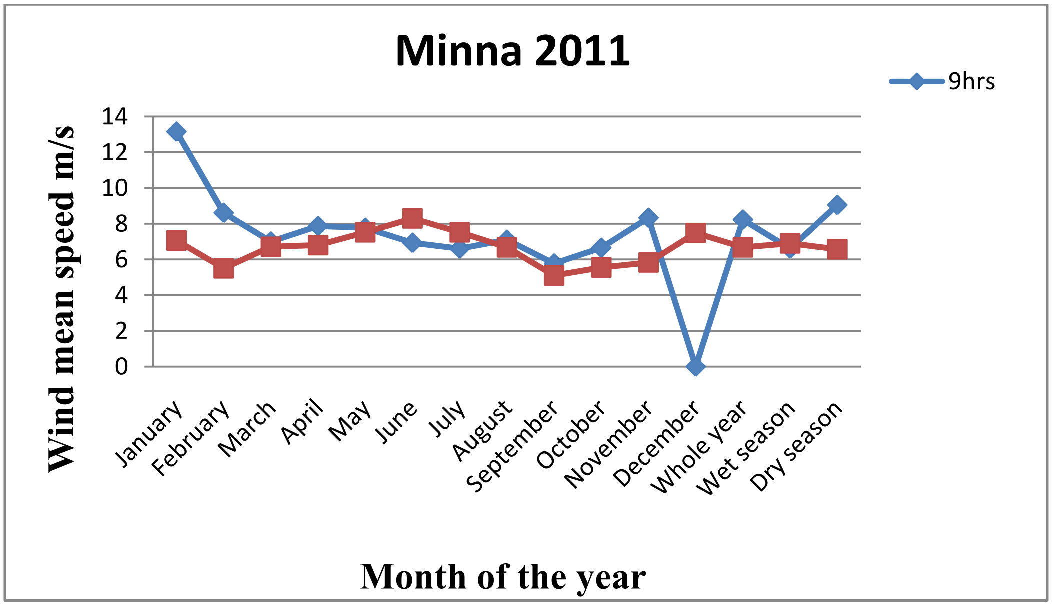

Figure 4;Mean Monthly wind speeds of Minna 2011.

The actual wind energy for Minna [2011] at 9hrs and 15hrs which as the maximum wind energy in January and December at 9hrs and the minimum wind energy in January and December at 15hrs, This could be due to the fact that December and January is the large scale dust-bearing North Easterly wind, locally called the haematin that predominates during the dry season.[Adegoke and Olatona, 2013]

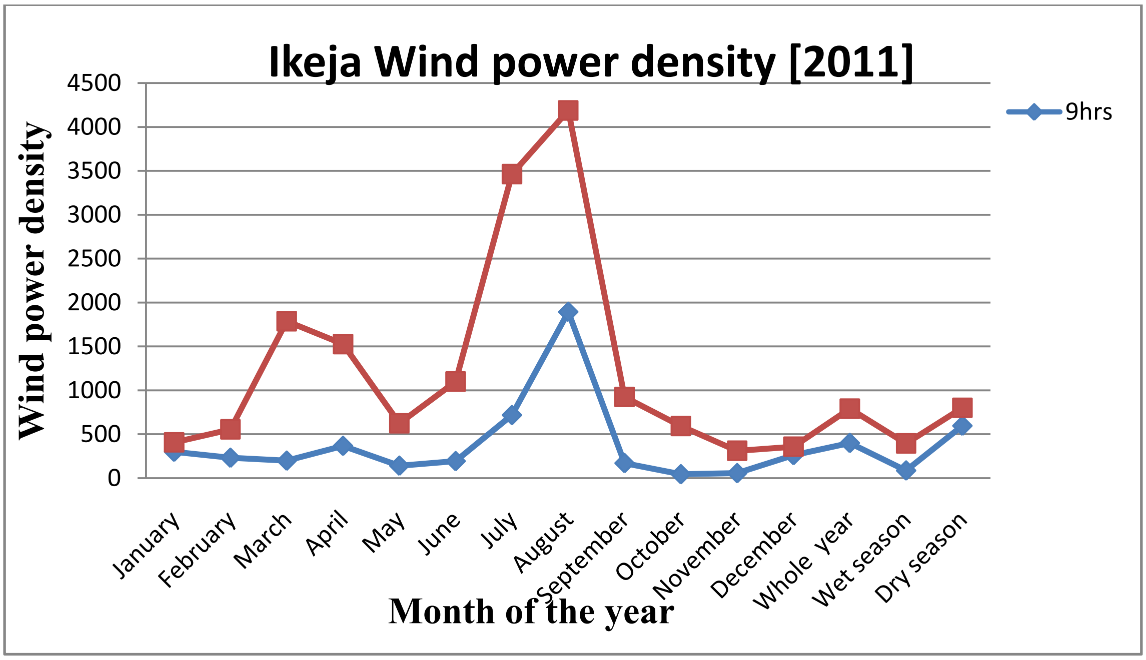

Figure 5; Ikeja Wind power density [W/m^2] versus Month of the year.

The wind power density for Ikeja [2011] at 9hrs and 15hrs which as the maximum wind power density in august at 15hrs and the minimum wind energy in August at 9hrs, August is a wet season it is heavy cloud cover this could be due to the fact that there is an increase in the amount of solar radiation reaching the surface in the afternoon [15hrs] compare to morning [9hrs].

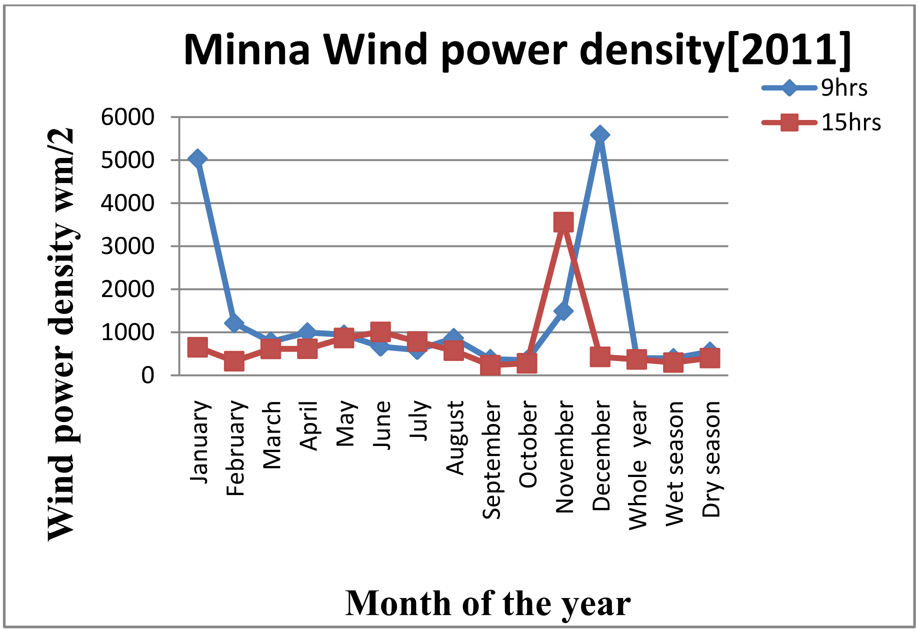

Figure 6; MinnaWind power density [W/m^2] versus month of the year.

The wind power density for Minna [2011] at 9hrs and 15hrs which as the maximum wind energy in January and December at 9hrs and the minimum wind energy in January and December at 15hrs, This could be due to the fact that December and January is the large scale dust-bearing North Easterly wind, locally called the haematin that predominates during the dry season which result as an increase in wind power density during dry season.

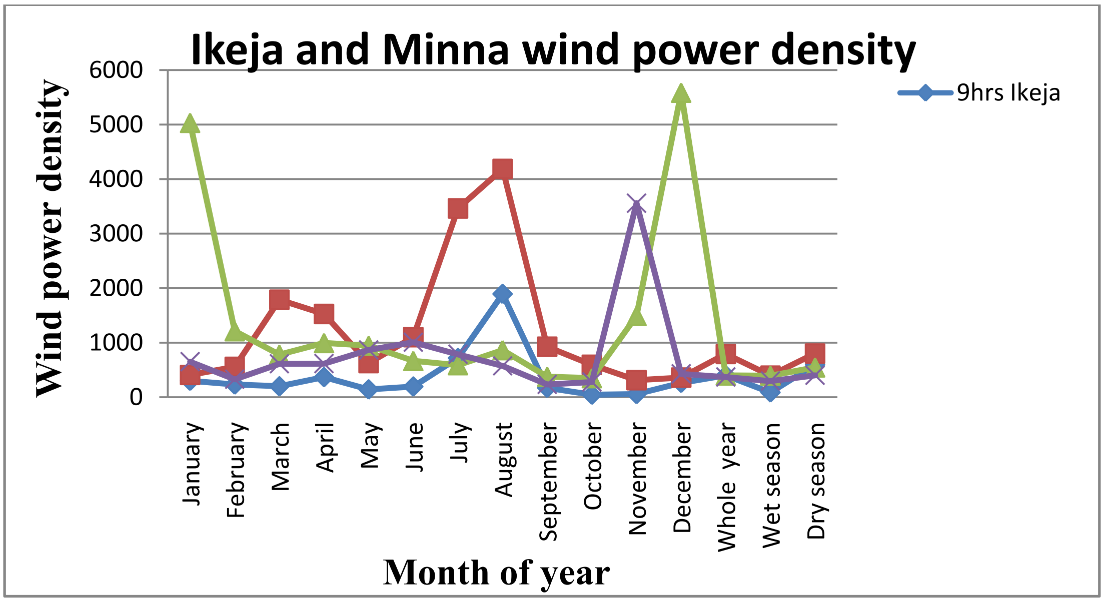

Figure 7; Ikeja and Minna wind power density [W/m^2] versus month of the year

The Mean monthly most probable wind speed [V_{mp}] and Maximum energy carrying wind speeds ([V_{max}] analyses for Ikeja and Minna respectively.

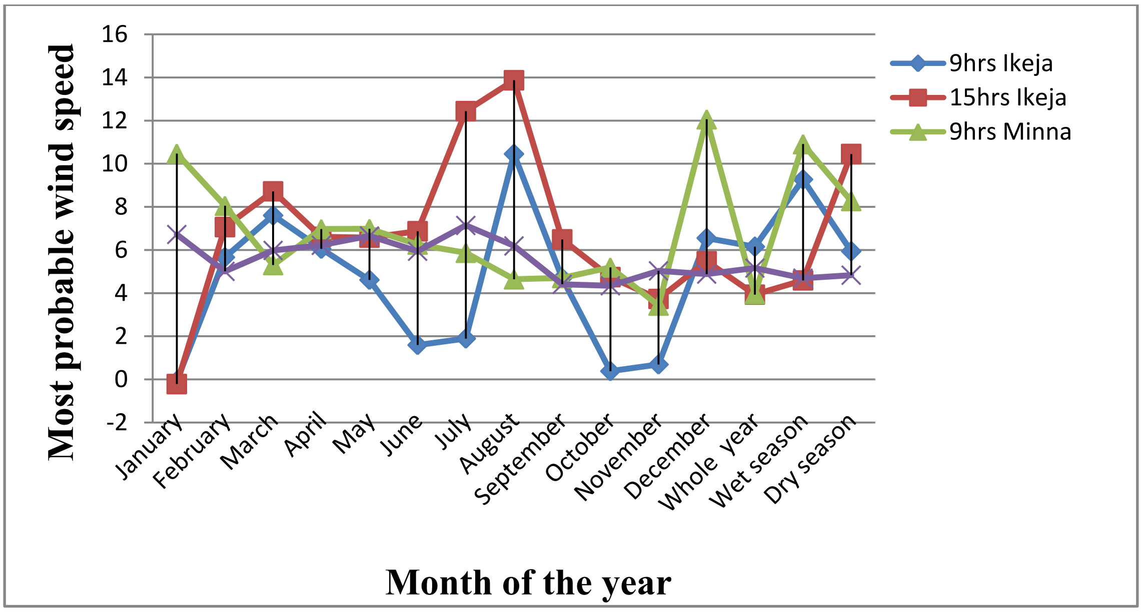

Figure 7; Mean monthly most probable wind speeds [V_{mp}] for Ikeja and Minna

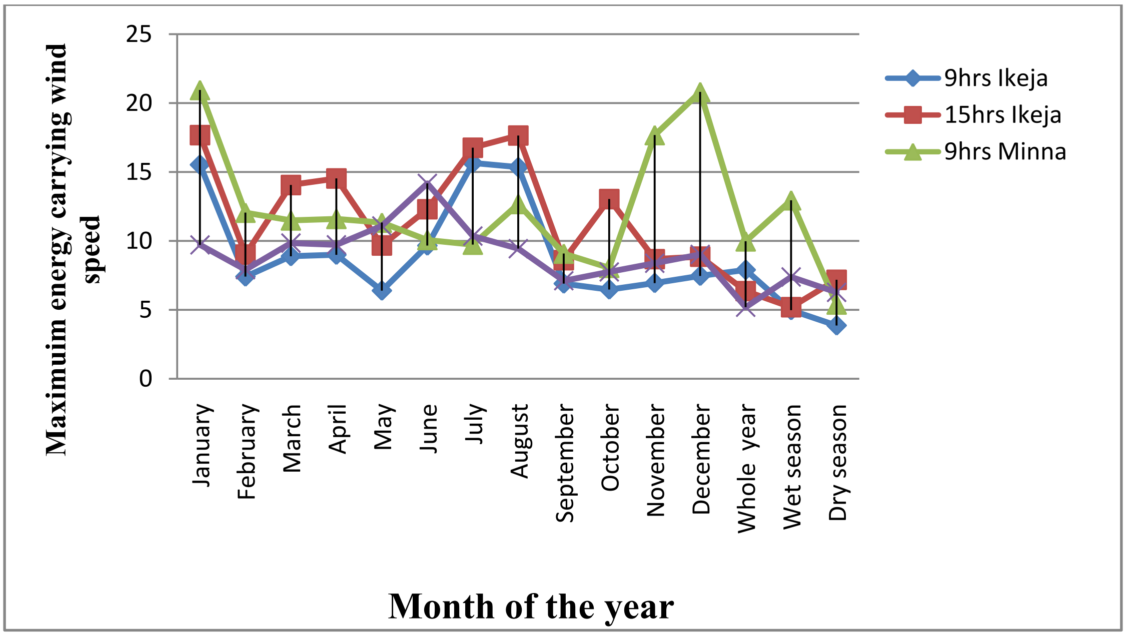

Figure 8;Mean monthly Maximum energy carrying wind speed [V_{max}] for Ikeja and Minna

DISCUSSION

The monthly mean wind speed at 10m height for the Ikeja and Minna is presented in figure 3 and 4, where the wind speed was observed at 4.97m/s and 8.33m/s at Ikeja and Minna 9hrs [2011], 8.08m/s and 6.75m/s at Ikeja and Minna 15hrs [2011] with a standard deviation of 3.15m/s and 4.16m/s at Ikeja and Minna 9hrs [2011] and 3.17m/s and 3.10m/s at Ikeja and Minna 15hrs [2011]. The topography is characterized by some environmental factor such as solar radiation, undulating land, with sand dunes of various sizes spanning across the locations which may affect the wind speed. The Weibull monthly average wind speeds is closely describing the measured wind speed for the whole year of Ikeja and Minna while the monthly mean wind speeds Evaluated Properties for Ikeja and Minna, Nigeria, which includes mean monthly wind speed and standard deviation, mean Monthly and annual values of Weibull parameters [k and C], most probable wind speeds and wind speed carrying maximum energy were presented in the above [Table 2,3,4,5] . The k and c were computed using equation [1 to 14] at 10m height at Minna and Ikeja. The most probable wind speed and wind speed carry maximum energy were computed using equation [9 and 10] respectively, it can be observed from same above tables that, the monthly most probable wind speed for each month of the year [2011] is very closely related to the monthly mean wind for the period. The maximum energy carrying wind speed for the locations were found at Ikeja and Minna [9hrs] for 9.66m/s and12.96m/s and Ikeja and Minna [15hrs] for 12m/s and 9.54m/s. The most probable wind speed for the location were at Ikeja and Minna [9hrs] for 4.17m/s and6.66m/s and Ikeja and Minna [15hrs] for 6.87m/s and 5.71m/s on monthly basis where the annual average most probable wind speed of 5.37m/s was calculated using equation [9] as against 5.36m/s recorded monthly average. The most probable wind speed corresponds to the peak of the probability density function, while the wind speed carrying maximum energy can be used to wind power density function equation [11 to 14] from wind speed data of Ikeja and Minna. The wind power density for Ikeja and Minna at 9hrs was 382.75 w/m^2 and 1158.30 w/m^2 while Ikeja and Minna at 15hrs were 1320.47 w/m^2 and 562.18 w/m^2.The assessment of mean wind speed and power density of Ikeja and Minna are good location for generation of electricity in Nigeria.

4. CONCLUSION

In this research study, the assessment of the potential of wind power generation at Ikeja and Minna locations in the south-western and northern part of Nigeria was carried out. One year [2011] with time interval of 9hrs and 15hrs of monthly mean wind data at 10-m height from the Nigeria meteorological department Oshodi, Nigeria were assessed and subjected to, Weibull Probability Distribution Function equation [1,to 14], most probable wind speed [V_{mp}] equation [9] and maximum energy carrying wind speed [V_{max}] equation [10] and wind power density distribution function equation [11 to 14]. The most important outcomes of the study can be summarized as:

The annual mean wind speeds is 4.97m/s and 8.33m/s at ikeja and minna 9hrs [2011], 8.08m/s and 6.75m/s at Ikeja and Minna 15hrs [2011] respectively.

The most probable wind speed for the location were at Ikeja and Minna [9hrs] for 4.17m/s and6.66m/s and Ikeja and Minna [15hrs] for 6.87m/s and 5.71m/s on monthly basis where the annual average most probable wind speed of 5.37m/s was calculated using equation [9], the maximum energy carrying wind speed for the locations were found at Ikeja and Minna [9hrs] for 9.66m/s and 12.96m/s and Ikeja and Minna [15hrs] for 12m/s and 9.54m/s was calculated using equation [10].

The wind power density for Ikeja and Minna at 9hrs was 382.75 w/m^2 and 1158.30 w/m^2 while Ikeja and Minna at 15hrs were 1320.47 w/m^2 and 562.18 w/m^2. The assessment of mean wind speed and power density of Ikeja and Minna are good location for generation of electricity in Nigeria.

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