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Wind Turbine Power Plant: A Viable Partial Replacement for Gasoline as Well As Diesel Electric Generators in Nigeria

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Abstract- The inadequate and erratic nature of electricity generation in Nigeria, is one of the contributing factors to the sluggish growth of her industries and the economy. Various researches carried out by scholars show that gasoline and diesel electric generators dissipate CO2, CO, NO and Chlorofluorocarbon to the atmosphere during operation. These greenhouse gases contribute immensely to air pollution and global warming. A study also revealed that Nigeria has a potential of generating huge amount of electricity using wind energy as most parts of the country has an average wind speed of 3.0m/s which is the cut-in speed of wind turbine suitable for domestic purposes. In this paper, a review of the viability and the potentials of generating electricity using wind energy for domestic purposes were carried out. Also, design model and cost analysis for a Stand-Alone Wind Turbine Power Plant (WTPP) suitable for domestic purposes was demonstrated. It was found out that most part of Nigeria has a potential of generating electricity by using Wind Energy. Hence, the possibility of partial replacement of gasoline as well as diesel electric generators in Nigeria by Wind Turbine Power Plants. This will immensely reduce the noise pollution and the emission of greenhouse gases to the atmosphere which is associated with the operation of gasoline and diesel electric generators.

Indexed Terms- Clean Environment, Diesel Generator, Gasoline Generator, Greenhouse gases, Industrialisation, Wind Turbine.

I. INTRODUCTION

Wind is a moving air which is caused by heating and cooling of ground and water surfaces during the day and night. It is also caused by rotation of the earth about its axis and an unequal temperature between the Polar Regions and the Equatorial regions. The kinetic energy contained in the wind is termed wind energy [1]. This kinetic energy could be converted to electrical energy by the use of renewable energy system called a Wind Turbine.

Wind Turbine is a rotary electromechanical machine, which harnesses the kinetic energy of the wind and convert it to electrical energy. In contrast, wind mill is a rotary mechanical machine which converts the kinetic energy of the wind to mechanical energy for the purposes of grinding, pumping water etc. [2].

Wind turbine is classified into utility scale, distributed or small scale and offshore scale. The utility scale constitutes of the wind turbine that are of capacity 100MW to several megawatts, where electricity is delivered to the grid. Distributed or small scale constitutes of single or stand-alone wind turbine of capacity below 100MW. It is usually used to supply electric power to houses, few numbers of streetlight or for small businesses. On the other hand, offshore scale are those erected in large water body (lake, ocean, sea etc.). It is usually larger than the onshore scale and can generate power in thousands of megawatts [2].

a. History of Wind Turbine

The first wind turbine used for the production of electricity was built in Scotland in July 1887 by Prof. James Blyth of Anderson's College, Glasgow. Blyth's 10m hight, cloth-sailed wind turbine was installed in the garden of his holiday cottage at Marykirk in Kincardineshire and was used to charge accumulators invented by the Frenchman Camille Alphonse Faure, to power the lighting in the cottage. Thus, making it the first house in the world to have its electricity supplied by wind power. Blyth offered the surplus electricity to the people of Marykirk for lighting the main street, however, they turned down the offer as they thought electricity was "the work of the devil. Although he later built a wind turbine to supply emergency power to the local Lunatic Asylum, Infirmary and Dispensary of Montrose the invention never really caught on as the technology was not considered to be economically viable. Across the Atlantic, in Cleveland, Ohio a larger and heavily engineered machine was designed and constructed in the winter of 1887-1888 by Charles F. Brush, this was built by his engineering company at his home and operated from 1886 until 1900.The Brush wind turbine had a rotor 17 m (56 foot) in diameter and was mounted on an 18 m (60 foot) tower. Although large by today's standards, the machine was only rated at 12 kW. The connected dynamo was used either to charge a bank of batteries or to operate up to 100 incandescent light bulbs, three arc lamps, and various motors in Brush's laboratory [6].

b. Reason for this Research Work

In recent times, there has been an increased interest in research on Wind Energy so as to ascertain whether it is the best amongst all the sources of renewable energy which could be adopted in Nigeria as a substitute for fossil fuel generators. It is found out that Wind Turbine Power Plant (WTPP) is a viable energy source that could be adopted. This is because the average wind speed in most part of Nigeria is up to 3.0m/s which is sufficiently enough (the cut-in speed for most wind turbines is 3.0m/s) to generate electrical power suitable for powering houses, small business shops etc. Wind turbine power plants do not emit greenhouse gases and is quite in operation, hence it is environmentally friendly [5].

On the 11th of March, 2020, one of the members of the Nigerian Senate who is representing Niger-South: Senator Bima Enagi, has proposed a bill which seeks to ban the importation of fossil fuel generators into Nigeria. The bill, titled “a bill for an Act to prohibit/ban the importation of generating sets to curb the menace of environmental (air) pollution and to facilitate the development of the power sector”. The bill prescribes; at least, ten years imprisonment for any person who knowingly sells generator sets. Other details of the bill suggest that the ban shall not include generator sets used for essential services which include:

- Healthcare facilities
- All Airports (Federal, State as well as private)
- Railway stations/services and or Terminus
- All Elevators (lifts) and or Escalators.
- All Research Institutes, and

All facilities that require twenty-four hours electric power supply. “Approval for exclusion or waiver shall be obtained from the Minister of Power, who shall brief the Federal Executive Council (FEC) on a quarterly basis” The bill further directs “all Nigerian residents to immediately stop the use of electricity generating sets, also known as “Generator” which run on diesel or petrol of all capacities, in the country.” “This bill seeks to ban/abolish the importation and use of generating sets (generators) in the country and to eliminate the harmful effect of environmental pollution which leads to potential health hazards and global warming it poses to the entire residents”. [8].

In view of the proposed bill, it is imperative that Nigerians begin to thick of renewable energy sources such as Wind Turbine Power Plants as a partial substitute for fossil fuel generators.

c. Electric power generator

This is an electromechanical device which converts the mechanical energy of a prime mover to electrical energy. Gasoline or petrol generator is operated on gasoline mixed with air in the carburetor and then compressed by the compressor before the combustion takes place in the combustion chamber. [3]

d. Diesel generators

These are electromechanical machines which use diesel as fuel. It operates by igniting fuel through compression. The air and diesel are supplied to the engine separately. (Absolute Generators, 2016, para. 6).

In this paper, a review on the potentials of wind energy in Nigeria was carried out, as well as the design of Wind Turbine Power Plant of 2.5KW capacity which could be able to power a 3-Bedroom flat is demonstrated.

II. METHODOLOGY

A. 2.5kw Wind Turbine Design for Small Scale Purposes

When the wind attains the cut-in speed of the turbine which is 3m/s in this case, the three blades begin to spin. This spinning motion of the wind turns a shaft of the rotor which is connected to a brushless generator. The generator then converts the kinetic energy of the turning shaft into electrical energy. (good energy, 2018).

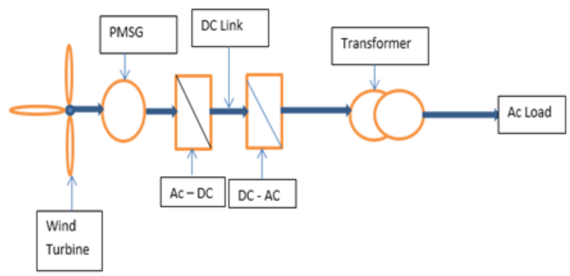

Fig. 1.0: A block diagram of a wind turbine power plant

i. A Typical Wind Turbine Power Plant

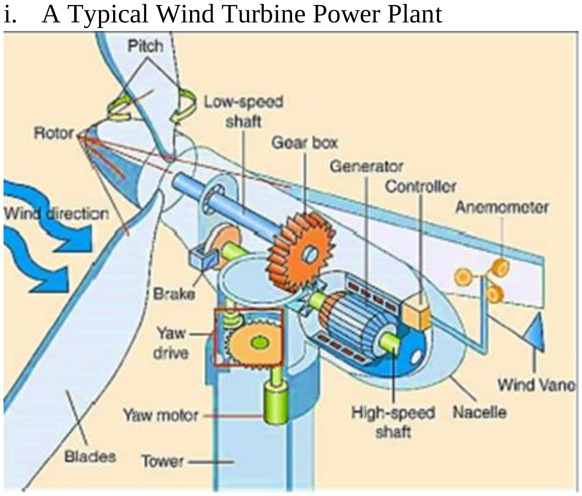

Fig. 2.0: Internal features of a wind turbine. (Madvar, 2019)

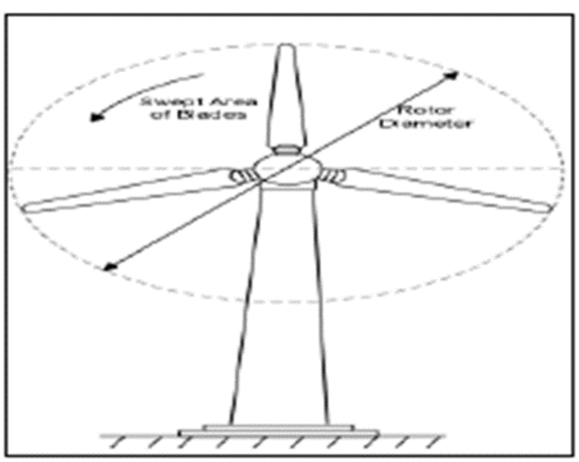

Fig. 3.0: A wind turbine showing the rotor diameter, swept area of blades and the steel supporting structure. Source: (N., Deshmukh, Yadav, & Vade, 2020)

ii. Components of Wind Turbine

- Rotor Blade: The rotor has blades attached to its shaft. The interaction between wind and rotor is responsible for the generation of electrical energy by the wind turbine. The blades are lifted and rotated when the wind is blown over them thereby causing the rotor to spin. The turbine under consideration has three blades. Another part of the rotor is pitch drive that we use it to keep the rotational speed of the blades at an operational range of 1000 to 3600rpm, that prevents the rotor from turning in too high or too low to generate electricity [11].
- Gearbox: It contains a number of gears and bearing which are connected in such a manner so as to increase the speed of the rotor. It connects the low-speed shaft to the high-speed shaft and increases the speed of rotations from about 100rpm to near1000–3600 rpm. Most generators need a rotational speed of this amount to produce electrical energy. [11].
- Nacelle: It is a container which houses the gearbox, low speed shaft, generator, controller, high-speed shaft and brake. [11].
- Electric generator: It is an electromechanical machine which converts the mechanical energy of the wind turbine rotor into electrical energy. A wind turbine that uses a concurrent generator is typically considered as gearless or direct drive wind turbine generator system [11].
- Controller: The controller is responsible for starting the machine when wind speed is about 3.0m/s and shuts it down when the wind speed is about 20 m/s [11].
- Pitch/ Aerodynamic controller: It is used to control the pitch angle and the speed of the rotor and the aerodynamic power [10].
- Maximum Power Point Tracking (MPPT) Control: Its function is to draw the maximum possible energy from a wide range of wind speed values [11].
- Support/Tower: This could be made up of steel, iron or concrete and it is used to supports the turbine system. The larger the diameter of the rotor, higher the hub height and the wider should be the width of the tower so as to be strong enough to withstand the effect of shear force and corrosion [11].

- Rotor Diameter: Is the measure of the diameter of the circle (area swept by the turbine blades while spinning) made by the rotor [10].
- Yaw motor: This is also known as wind direction tracker. It is used to ensure that the wind turbine absorbed the maximal amount of wind energy at all times, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. It is applicable to wind turbines with a horizontal axis rotor. The wind turbine is said to have a yaw error if the rotor is not facing/aligned to the wind direction. (wikipedia, n.d.)
- Anemometer: Is an instrument used in wind turbine to determine the speed of the airflow in the atmosphere. It can also be used to determine the amount of wind flow in tunnels [13].
- Wind Vane: Is used in wind turbine for indicating the direction in which the wind blows. It rotates under the influence of the wind such that its center of pressure rotates to leeward and the vane points into the wind [14].

iii. Weibull Distribution Design procedure

There are three methods of predicting wind power density, namely: Weibull Distribution, gamma Distribution and Rayleigh Distribution. Weibull Distribution is found to be the best method of predicting wind power density in northern Nigeria, followed by the gamma Distribution. Rayleigh Distribution ranked lowest [15]. The procedure for the design of wind power plant using Weibull is as demonstrated in fig. 4.0 below.

Fig. 4.0: Design Flowchart of Wind Turbine using Weibull Distribution

III. RESULT AND DISCUSSION

Table 1.0: Datasheet of 2.5KW ANTARIS Wind Turbine

PARAMETERS	VALUES
Max DC power	1850w
Max input voltage	400V/180V
Turbine mode voltage range	139V-400V
Max input current	12.6A
Max output current	8.6A
Max efficiency	93.5%/91.7%
Dimensions	440 x 339 x 214 mm
Weight	25Kg

Source: https://www.wattuneed.com/en/wind-turbine/1543-wind-turbine-antaris-25-kw-0712971129245.html

Generator

- Permanent-magnet rotor, brushless, gearless, maintenance-free
- Extremely strong permanent magnets for a high level of efficiency
- (NdFeBo permanent magnets, resistant to temperatures up to 150° C)
- 3-phase current
- Separate rectifier
- Either direction of rotation
- Voltage 0-400 V
- Start of feed-in at approx. 145 rpm
- Power: 2.700 watts at 380 rpm and 330 V
- Evenly rising power curve
- Weight: 30kg
- Aluminium housing, surface cooling, base anchoring
- Gondola housing in GR
- Protection class IP56

3.1.2 Rotor

- Hub connection with aluminum flange and pressure-relief plate
- Stainless-steel screw connections with locknuts
- Three rotor blades in glass-fibre / carbon-fibre laminate
- Computer-designed aerodynamic profile
- Winglets on blade tips to minimise noise
- Approx. 3.00 m in diameter (optionally 2.35 m)
- Weight of each blade: approx. 3.2 kg
- Dynamically balanced
- Direction of rotation anticlockwise viewed from front
- Max. rotational speed 410 rpm
- GRP spinner cap
- Rotor colour to client specification

3.1.3 Support element comprising

- Wind vane (weatherproof HDPE, off-white, slightly transparent)
- Square stainless-steel tube as support element

- All screw connections in stainless steel and fitted with locknuts
- Steel bracket as support for generator, configured for plug-in connection with azimuth bearing, fully galvanized.
- Protected by patented rotor-blade positioning system
- Mast adapter with flange connector (tube 114.3 mm)

3.1.4 Storm protection

- Rotor-blade positioning ("helicopter position")
- Control electronics with turbine controller
- 3.1.5 Control cabinet
- Control system with voltage monitor
- 1-phased grid-feed in (1 x Windy Boy 1700)
- Control electronics with 3-phased turbine controller
- Connections / plug connectors protected against polarity reversal
- Controlling of the alternator phases during turbine mode
- Emergency-OFF switch
- Reset switch with key (removable)
- Rectifier, display etc.
- kW braking resistance

https://www.wattuneed.com/en/wind-turbine/1543-wind-turbine-antaris-25-kw-0712971129245.html

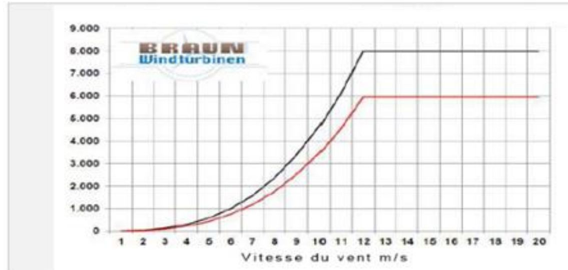

Fig. 5.0: Power curve of 2.5KW ANTARIS Wind Turbine.
Source: [3]

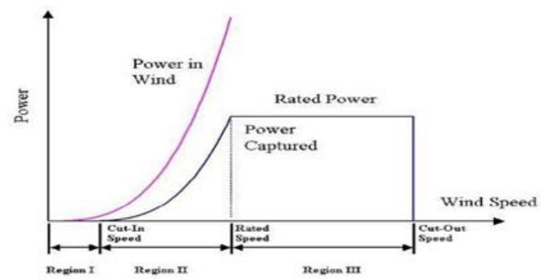

Fig. 6.0: A typical power curve of wind turbine

3.2 Wind Data of Some States in the Sudan Savannah Region of Nigeria

According to [7], the annual wind data of Jos, Sokoto, Kano and Maiduguri obtained from Nigerian metrological agency as at 2016 is as shown in the table below:

Table 2.0: Mean and root mean cube values of wind speed at the investigated sites in some States in the Northern region of Nigeria.

Table 2.0: Mean and root mean cube values of wind speed at the investigated sites in some States in the Northern region of Nigeria.

S/N	Site	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	JOS	$\bar{V}$	5.40	5.77	5.31	5.76	5.68	5.43	5.01	5.13	4.44	4.17	4.77	6.01
		Vrmc	5.77	6.05	5.35	5.77	5.70	5.45	5.06	5.17	4.47	4.27	4.88	6.20
	SOKOTO	$\bar{V}$	3.78	3.99	3.81	4.10	4.66	4.42	3.73	2.85	2.48	3.01	3.35	3.62

2														
		Vrmc	3.90	4.03	3.84	4.45	4.68	4.45	3.77	2.90	2.54	3.12	3.93	3.77
3	KANO	$\bar{V}$	4.46	3.74	4.05	4.36	5.32	5.65	4.83	3.88	3.28	2.90	3.14	4.10
		Vrmc	4.49	3.86	4.21	4.43	5.33	5.73	4.94	3.99	3.46	3.06	3.21	4.15
4	MAIDUGURI	$\bar{V}$	2.54	2.94	3.83	3.25	3.40	3.93	3.67	3.03	2.49	2.37	2.56	2.85
		Vrmc	2.61	3.01	3.86	3.33	3.47	4.02	3.80	3.10	2.57	2.41	2.59	2.97

Source: [6].

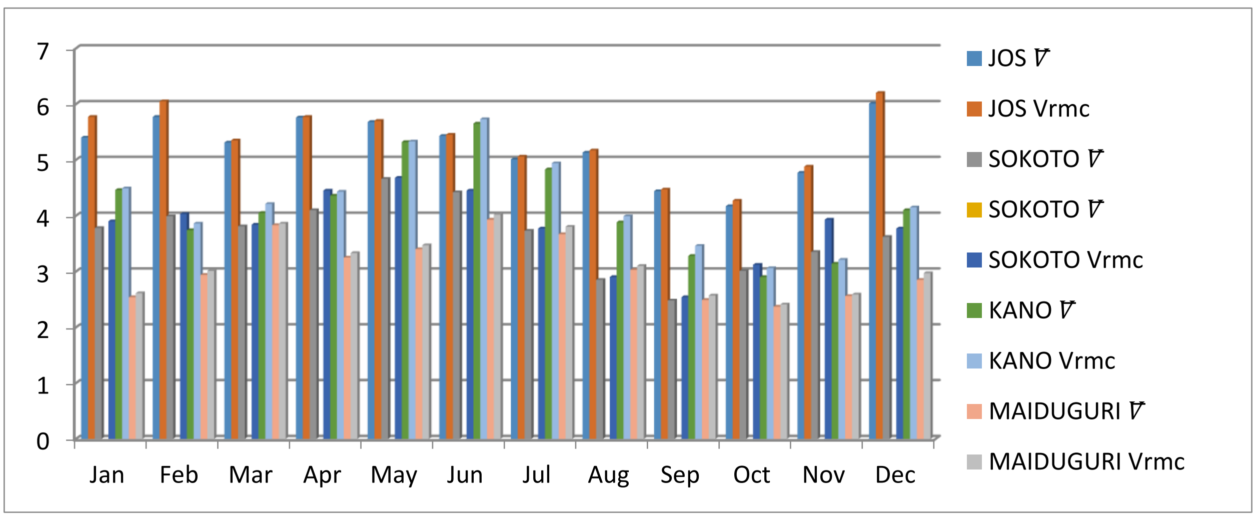

Fig. 7.0: A chart showing the Mean and root mean cube values of wind speed at the investigated sites in some States in the Northern region of Nigeria

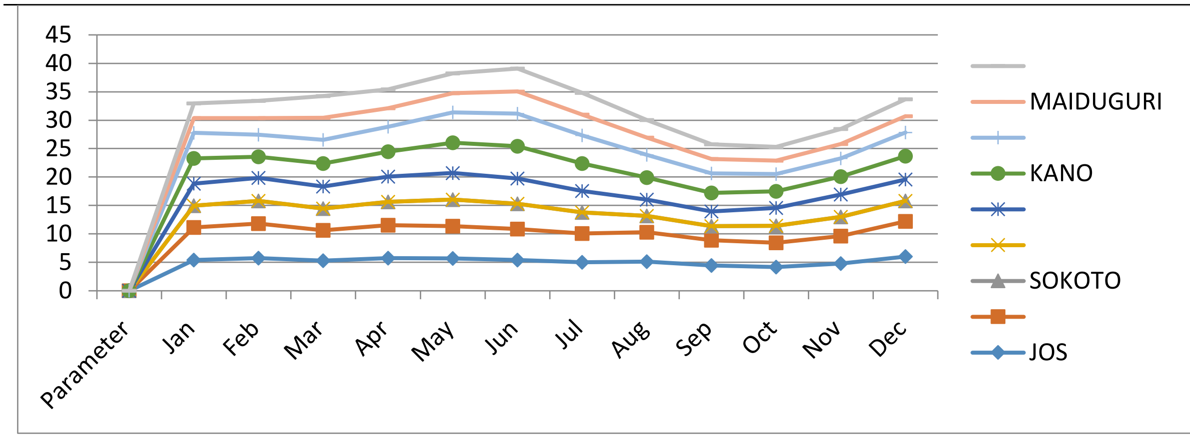

Fig. 8.0: A graphical representation of the Mean and root mean cube values of wind speed at the investigated sites in some States in the Northern region of Nigeria

3.3 Mathematical Design of 2.5KW Wind Turbine

A typical 3-Bedroom flat has a total load of about 2430W, that is, 2.43KW. [1]. This suggests that a wind turbine of 2.5KW capacity can supply adequate power to a three- bedroom apartment.

Table 3.0: Lighting audit of a typical 3-Bedroom Apartment

S/N	Load Type	Conventional Model (CH) in W	Efficiency Energy Saving Model (EESM) in W	Differences = Energy Saved in W
1	Veranda	24 x 2 = 48	10 x 2 = 20	28
2	Pre-Sit	24 x 2 = 48	10 x 2 = 20	28
3	Sitting Room	24 x 5 = 120	10 x 5 = 50	70
4	Dinning	24 x 3 = 72	10 x 3 = 30	42
5	Kitchen	24 x 2 = 48	10 x 2 = 20	28
6	Store	24 x 1 = 24	5 x 1 = 5	19
7	Bedroom 1	24 x 3 = 72	10 x 3 = 30	42
8	Bedroom 2	24 x 3 = 72	10 x 3 = 30	42
9	Bedroom 3	24 x 3 = 72	10 x 3 = 30	42
10	Toilets	24 x 3 = 72	5 x 3 = 15	57
11	Lobby	24 x 2 = 48	10 x 2 = 20	28
12	Security	100 x 9 = 900	20 x 9 = 180	720
	Total Lighting	1,596	450	1,146

Source: [3].

Table 4.0: Appliances load audit of a typical 3-Bedroom Apartment

S/N	Load type	Quantity	Wattage (W)	Net Total (W)
1	Refrigerator	1	1000	1000
2	Standing fan	3	60	180
3	13A sockets	8	100	800
			Total	1980

From table 3.0 and table 4.0, the Grand total load is given by: Total Lighting load plus Total load of appliances. Thus; 450+1980 = 2430W = 2.43W. That is, a wind turbine of 2.5KW capacity could power a 3-bedroomflat of average load of 2.43KW, when 2.8% safety factor is considered.

3.3.1 Determination of the Energy Production of 2.5KW ANTARIS Wind Turbine using Weibull Distribution

3.3.1.1 Unadjusted Energy Production

It is the energy that one or more wind turbines will produce at standard conditions of temperature and atmospheric pressure. The calculation is based on the energy production curve of the selected wind turbine and on the average wind speed at hub height for the proposed site. [4].

- The Weibull Pobability Density Function

This expresses the probability $p(x)$ to have a wind speed x during the year. [4].

The Weibull probability density function could be mathematically expressed as:

$$p(x) = \left(\frac{k}{c}\right)\left(\frac{x}{c}\right)^{k-1} e^{\left[-\left(\frac{x}{c}\right)^{k}\right]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

where: p(x) is the probability density, x is annual wind speed, k is shape factor (a lower shape factor which leads to higher energy production for a given average wind speed) and C is the scale factor.

$C = \frac{\bar{x}}{\Gamma\left(1+\frac{1}{k}\right)}$ ……………………………….……… (ii)

Where $\bar{x}$ is the average wind speed and Γ is the gamma function.

If we assumed k = 1.5, this implied that k = $0.83x^{0.5}$ ……………………..………………………… (iii)

From table 2.0, the average wind speed in Maiduguri is 3.07m/s. therefore, the value of k in equation (ii) can be calculated thus; k = $0.83x(3.07)^{0.5}$ = 1.5

Furthermore, if we assume the gamma coefficient, Γ = 0.3, then the value of the scale factor, C in equation (ii) could be calculated as : $C = \frac{3.07}{0.3\left(1+\frac{1}{1.5}\right)}$ = 6.13

According to (Abdulkarim et al, 2017), air density, in Maiduguri is equals to 1.225kg/m^3.

Wind power density, P_{WPD} is given by:

$P_{WPD} = \sum_{x=0}^{15} 0.5\rho x^3\, p(x)$ ………………..,,… (iii)

Thus, P_{WPD} = 0.5x1.225x$(3.07)^3$ = 17.50W/m^2.

Where ρ is the air density, and $p(x)$ is the probability that there will be a wind speed x during the year. [2]

3.3.1.2 Energy Curve

This is a graphical representation of the amount of energy produced by the wind turbine over a range of yearly average wind speed. 2.5KW ANTARIS Wind Turbine has energy curve that spread from 1-20m/annual average wind speed.

In ideal cases, the personnel who does the designs specifies the wind turbine power curve as a function of wind speed in increments of 1 m/s, from 0 m/s to 20 m/s. Each point on the energy curve. [2].

$E_{\bar{V}}$, is then calculated as:

$E_{\bar{V}}$ = $8760\sum_{x=0}^{15} P_x\, p(x)$ ……………..… (vii)

Where x is the mean wind speed considered ($\bar{V}$=3, 4,..., 20 m/s), P_x is the turbine power at wind speed x, and $p(x)$ is the Weibull probability density function for wind speed x, calculated for an average wind speed $\bar{V}$. [2].

Recall from equation (i) that Weibull probability function p(x) is given by :

Average wind speed is given by:

$p(x) = \left(\frac{k}{C}\right)\left(\frac{x}{C}\right)^{k-1} e^{\left[-\left(\frac{x}{C}\right)^k\right]}$, therefore $p(x) = \left(\frac{1.5}{6.13}\right)\left(\frac{3.07}{6.13}\right)^{1.5-1} e^{\left[-\left(\frac{3.07}{6.13}\right)^{1.5}\right]}$ = 0.12

The turbine power, P_x at wind speed x is equals to the d.c. power of the turbine. For 2.5KW ANTARIS Wind Turbine, the maximum d.c. power is 1850W. that is, P_x is 1850W

- Total amount of energy produced is given by, E_x = 8760xP_xxP(x) ………………….. (iv)
- Therefore, E_x = 8760x1850x0.12 = 1944720J
- The average annual energy density is given by: E_d = P_{WPD} x number of hours in a year. That is, E_d = P_{WPD} x 8760 = 17.50x8760 = 153300J/m^2
- Wind speed at a height greater than 10m could be calculated using:
- $V_b = V_a\left(\frac{h_b}{h_a}\right)^{\alpha}$ …………...…….. (v)
- Where V_a (3.0m/3) is the wind speed at a known height h_a (10m), V_b is the speed at an unknown height h_b(15m) and α(1) is the roughness or wind shear factor. (Aika, 2020). Therefore the speed at 15m height can be calculated thus: $V_b = 3.0\left(\frac{15}{10}\right)^1$ = 4.5m/s
- Pressure adjustment coefficient C_P is given by: $C_P = \frac{P}{P_0}$ …………….. (vi)
- Where P is the yearly average atmospheric pressure at the site, P_0 is the standard atmospheric pressure of 101.3 kPa. As at 28th April, 2020, the atmospheric pressure, P in Maiduguri was 1010mb = 101.325kPa.(World Weather Online, 2020). By substituting the value of P and P_0 in (vi), we obtained: $C_P = \frac{101.325}{101.325}$ = 1
- Temperature adjustment Coefficient, C_T is given by; $C_T = \frac{T_0}{T}$…………………………………..…(vii)
- Where, T is the annual average absolute temperature at the site, and T_0 is the standard absolute temperature of 15.1^{0}C (273 + 15.1 = 288.1 K). [5]. According to (World Weather Online, 2020). The absolute temperature in Maiduguri as at 28th April, 2020 was 311^{0}K. By substituting the values of T and T_0 in (vii), we obtained: $C_T = \frac{288.1}{311}$ = 0.93

3.3.1.3 Gross Energy Production

Is the sum of yearly energy produced by the wind turbine, before losses, at a particular wind speed, atmospheric pressure and temperature conditions? [2].

E_G = E_U x C_H x C_T ………………………………………..…...…… (iiiv)

Where E_U is the unadjusted energy production, and C_H and C_T are the pressure and temperature adjustment coefficients. That is, E_G = 1944720 x 1 x 0.93 = 1808589.60J

- Losses coefficient, C_L given by:

C_L = (1- λ_a) (1- $\lambda_{s\&i}$) (1- λ_d) (1- ……………………………….…...………………... (ix)

Where λ_a is the array losses, $\lambda_{s\&i}$ is the airfoil soiling and icing losses, λ_d is the downtime losses, and λ_m is the miscellaneous losses. Coefficients λ_a , $\lambda_{s\&i}$, λ_d, and λ_m are usually specified by the user in the Energy Model worksheet. [4].

Table 5.0: Typical and used values of losses associated with wind turbine

Types of Losses	Typical Value (%)	Used Value (%)
Array loss	1-8	1.5
Miscellaneous	2-6	2.5
Availability [rate of absorption]	98-100	99
Airfoil soiling and icing loss	1-10	1
Downtime loss	2-7	2

Source: (Oudah, 2016)

From table 3.0 above, λ_a = 0.015, $\lambda_{s\&i}$ = 0.01, λ_d = 0.02, λ_m= 0.025

By substituting the values of the above loss parameters, we obtained:

C_L = (1- 0.015) (1- 0.01) (1-0.02) (1- 0.025) = 0.92

3.3.1.4 Renewable Energy Collected

Renewable energy collected is equal to the net amount of energy produced by the wind energy equipment:

E_c = E_G x C_L ………………………………………….. (x)

Where E_G is the gross energy production, and C_L is the losses coefficient.

By substituting the values of E_G and C_L in (x), we obtained:

E_c = 1808589.60 x 0.92 = 1771417.80J

3.3.1.5 Absorption Rate and Renewable Energy Delivered

The rate of absorption of energy is the percentage of the wind energy collected that can be absorbed by the isolated-grid or the off-grid system. [2].

The model calculates the wind energy delivered according to:

E_D = E_C x µ …..(xiv)

Where: E_C is the renewable energy collected and µ is the wind energy absorption rate. [2].

From table 3.0, the absorption rate, µ used is = 0.99. Therefore, the renewable energy delivered is given by:

E_D = 1771417.80 x 0.99 = 1754693.63J

- Wind Penetration Level:

$WPL = \frac{WPPC}{PL} x\ 100$……………………….. (xv)

Where *WPPC* is the Wind Power Plant Capacity and *PL* is the Peak Load specified by the user.

WPPC is obtained by multiplying the number of wind turbines by their rated, or nameplate, Capacity. [2].

WPPC = Number of wind turbine x the rated power of the turbine

= 1x2500W = 2500W

If the peak load is assumed to be 2480W, then;

$WPL = \frac{2500}{2480} x\ 100 = 99.9\%$

3.3.1.5 Excessive Renewable Energy Available

The available excess renewable energy E_x is the difference between the wind energy collected E_c and the wind energy delivered E_D. [2].Thus;

$E_x = E_c - E_D =$ 1771417.80 - 1754693.63

$E_x =$ 17724.17J

3.3.1.6 Specific Yield

This could be defined as the ratio of the renewable energy collected to the swept area of the turbine. Thus:

$Y = \frac{E_C}{NA}$ ……….. (xvi)

Where: Y is the specific yield of the wind turbine, E_C is the renewable energy collected, A is the swept area of the turbine blade; and N is the number of turbines under consideration.

In this case, the diameter of the rotor is equals to 3m, then the area swept by the rotor is given by:
$A = \pi\frac{d^2}{4} = 3.142\text{x}\frac{3^2}{4} = 7\text{m}^2$. Thus: $Y = \frac{1771417.80}{1x7} = 253202\text{J/m}^2$

3.3.1.7 Wind Power Plant Capacity Factor
Wind Power Plant Capacity Factor (WPPCF) is defined as the ratio of the average power produced by the wind power plant per annum to its rated power capacity. It is given by:

$$\text{WPPCF} = \left(\frac{E_C}{WPPC\ X\ \text{HY}}\right)x100 \ \ldots\ldots\ldots.. \text{(xvii)}$$

Where E_C is the renewable energy collected, expressed in KWH, WPPC is the wind power plant capacity, expressed in KW, and H_Y is the number of hours in a year. [2].
$\text{WPPCF} = \left(\frac{1771417.80}{2500x8760}\right)\text{x}100 = 0.089$
This implied that only 8.9% capacity of the 2.5KW ANTARIS Wind turbine would be generated/produced.

CONCLUSION

This research work demonstrated the possibility of using wind energy to produce electricity in Maiduguri, the capital of Borno State Nigeria. It was pointed out that it is a better option than fossil fuel electricity generators which pollute the environment with noise and greenhouse gases. This has a consequence on the atmospheric condition which will result in global warming and climate change. Renewable energy of 1754693.63J was found to be the possible energy that the 2.5KW ANTARIS Wind Turbine could produce. Also, the wind power density was found to be 17.50W/m^2, with the average cut-in speed of 3.07m/s. This implied that there is availability of wind energy in Maiduguri which could be suitable to produce electricity for houses, small business shops, etc. A step-by-step design procedure for wind turbine power plant was also demonstrated. It is therefore, recommended that wind turbine power plant could be used as partial replacement for fossil fuel generators not only in Maiduguri but also in its environs which have more than 3.0m/s annual average wind speed.

REFERENCES

[1] E. R. Rajput, a Texbook of Power Plant Engineering, New Delhi: LAXMI PUBLICATIONS (P) LTD, 2008.

[2] AMERICAN WIND ENERGY ASSOCIATION, "Basics of Wind Energy," AMERICAN WIND ENERGY ASSOCIATIO, 1996–2020. [Online]. Available: https://www.awea.org/wind-101/basics-of-wind-energy. [Accessed 9 7 2020].

[3] WATTUNEED, "Wind turbine>Wind turbine ANTARIS 2.5 kW," 2014. [Online]. Available: https://www.wattuneed.com/en/wind-turbine/1543-wind-turbine-antaris-25-kw-0712971129245.html. [Accessed 10 7 2020].

[4] U. Okoye and N. O. Adelakun, "Design and Evaluation of Electrical Services for an Energy Efficient Home," Iconic Research And Engineering Journals, pp. 95-102, 2019.

[5] RETScreen International, "WIND ENERGY PROJECT ANALYSIS," in CLEAN ENERGY PROJECT ANALYSIS, Canada, Minister of Natural Resources Canada, 2001-2004, pp. 2-27.

[6] J. Wavhal, R. Kulkarni, P. Kulkarni and S. Gore, "Wind Power Generation," International Journal of Advances in Electronics and Computer Science, pp. 31-37, 2015.

[7] T. Aika, S. Igbinovia and P. Orukpe, "Feasibility Assessment of Wind Energy Potential for Electricity Generation in Nigeria," Jordan Journal of Electrical Engineering, pp. 25-34, 2020.

[8] Q. Iroanusi, "Nigerian Senator Introduces Bill To Ban Importation Of Generators," PREMIUM TIMES special publication on Nigerian Democracy @20, p. 1, 11 march 2020.

[9] good energy, "how do wind turbines work?," 2018. [Online]. Available: https://www.goodenergy.co.uk/how-do-wind-turbines-work/.

[10] N. N., Deshmukh, D. Yadav and A. Vade, "POWER GENERATION FROM WIND

TURBINE," in Institute of Technology, Sector 9A, Vashi, Navi Mumbai – 400 703, 2020.

[11] M. D. Madvar, F. Ahmadi, R. Shirmohammadi and A. Aslani, "Forcasting of Wind Energy Technology domains based on technology life cycle approach," ELSEVIER, pp. 1236-1248, 2019.

[12] wikipedia, "YAW DRIVE," [Online]. Available: https://en.wikipedia.org/wiki/Yaw_drive.

[13] M. Froese, "Increase in wind-power projects fueling anemometer demands," 8 march 2019. [Online]. Available: https://www.windpowerengineering.com/increase-in-wind-power-projects-fueling-anemometer-demands/.

[14] H. Nfaoui, "Comprehensive Renewable Energy," ScienceDirect, 2012.

[15] A. Abdulkarim, S. M. Abdelkader, D. J. Morrow, A. J. Falade and Y. A. Adediran, "STATISTICAL ANALYSIS OF WIND SPEED FOR ELECTRICAL POWER GENERATION IN SOME SELECTED SITES IN NORTHERN NIGERIA," Nigerian Journal of Technology (NIJOTECH), pp. 1249-1257, 2017.

[16] A. S. M. M. D. J. F. A. J. &. A. Y. A. Abdulkarim, " STATISTICAL ANALYSIS OF WIND SPEED FOR ELECTRICAL POWER GENERATION IN SOME SELECTED SITES IN NORTHERN NIGERIA.," Nigerian Journal of Technology (NIJOTECH), pp. 1249-1257., 2017.

[17] American Wind Energy Association, "Windmills vs. Wind Turbines," American Wind Energy Association, America, n.d.