Design and Implementation of 0.5kw Horizontal Axis Wind Turbine for Domestic Use

Imhade P. Okokpujie*, Kennedy O. Okokpujie, Obinna N. Nwoke, Joseph Azeta

***Abstract*— Due to the high demands of energy with the speedy diminishing of fossil fuel assets and the ecological difficulties related with the application of fossil fuel which gave rise to development of alternative energy sources such as wind turbine for power generation in Nigeria. Wind turbine is a machine that is powered by the wind; it is designed to convert the kinetic energy from the wind into mechanical energy and the produces electricity. This study focuses on the design and implementation of 0.5KW horizontal axis wind turbine for domestic usage. It was mounted on a tower height of 5m from the sea level. The major components of the wind turbine which include the blades, hub, shaft and the tower, were machined and fabricated to meet the required 0.5 KW of the wind turbine. The test results showed that the wind turbine is capable of producing about 515 W, at a rotor speed of 153.5 rpm. The necessary design details that have been applied at the design and fabrication stages of the wind turbine guarantees the high hope of this wind turbine performing better in Nigeria.**

***Index Terms*— Wind Energy; Wind Turbine; Turbine Blade Design; Shaft.**

I. INTRODUCTION

The development and utilization of renewable energy such as wind energy has become an important goal to ensure energy security and to lower greenhouse gas emissions, for both the Nigeria and other countries. Energy is the basis of all manufacturing and industrial civilization. Without energy life will be very difficult [1]. Therefore, the economy of any nation depends on the availability and regular supply of energy, hence there is need to properly select a suitable energy source. Energy is used for transportation, heating, cooking, lighting and industrial production.

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Wind is air in motion. The term wind is regularly applied to normal motion of air; vertical motion, nearly vertical direction is known as current. Winds are formed by the changes in atmospheric pressure, which are primarily credited to differences in temperature. Differences in the circulation of pressure and temperature are produced largely by inadequate circulation of heat from the sun, together with variances in the thermal properties of land and ocean surfaces. [2]. Once the temperature of adjacent areas become unequal the warmed air tends to rise and flow over the cooler region. Winds introduced in this system are usually momentously improved by the earth revolution [3]. Wind maybe classified into four main types, which are, the seasonal wind, prevailing winds, local wind, cyclonic and anti-cyclonic winds.

Energy can be derived from different sources as fire wood and animal waste, which are important energy sources for most developing countries. There is worldwide need to increase energy preservation and hence the use of renewable energy properties, such as wind energy, solar energy and geothermal energy. These are very efficient and practical but largely under-utilized alternative sources due to availability of in-expensive non-renewable fossils resources. [4]

Due to the increasing of demands of energy with the rapid diminishing of fossil fuel assets and the ecological difficulties related with the application of fossil fuel have demanded the for advancement of alternative energy sources like wind turbine for power generation in Nigeria. It was stated that the energy generation in Nigeria as of the end of 2016 was less than 3,500 MW due to instability in the accessibility and maintenance of generation sources, causing the loss in supply [5, 6].

However, this research work will make use of wind as a source of energy because of its abundant in nature, free and running cost is low, it is renewable, inexhaustible and has little or no effect on the environment. Wind may be classified into four major types; the prevailing wind, the seasonal wind, the local wind, cyclonic and anticyclone winds. In order to convert the energy in the wind to useable energy, devices known as wind turbines are used. A wind turbine is a mechanical device that is used to convert the wind's kinetic energy into electrical power. It is imperative to note that the power in the wind is proportional to the cube of the wind speed; this means that slight increase in the wind speed will greatly increase the wind power. [8]

Odia et al. [9] Focuses on the practical analysis of a small wind turbine for domestic use on latitude 7.0670n, longitude 6.2670e. The wind turbine was designed to generate 250 Watts of power at the rated speed of 6.5m/s. Novelties planned for very long wind turbine blades include thickened profiles. [1]

Economic parts, the ideal wind turbine develop is not uttered by technology alone, but by a mixture of technology and economy. Wind turbine producers wish to enhance their machines, so that they can deliver electricity at the lowest possible cost per unit of energy. Meanwhile the energy input (the wind) is free, the best turbine design is one with low production costs per KWh of energy [7].

A shaft is a rotating machine component which is used to convey motion from one place to another [10]. The power is distributed to the shaft by the process of wind causing the rotation of the blades, and the torsional moment set up within the shaft permits the power to be transferred to the alternation. [11]. The shaft should be able to with stand the power, it is going to transmit to the alternator, the design will take one shaft, which one end of the shaft will be connected directly to the hub fixed with the blades and the other end is coupled to the alternator. The obvious thing to note here is that the development of wind turbine has enhanced the level of civilization, economic, conducive environment and has led to the technological development of modern industries. It is true that wind turbine manufacturers in the technological advanced countries have developed standard design and constructional details that have resulted in the present level of perfection in turbine design. However, there is the need to develop and implement wind turbine locally, if we ever want to develop as a nation.

The significant way in the collection of resources for erection of the wind turbine included, local availability, low cost, lightness of weight for easy handling during fabrication, weather ability and long service life (ability to withstand environmental and operating conditions) and non-toxic effects.

Furthermore, the uniqueness of this wind turbine is in the design. The wind turbine was built to work in a low wind speed region and in the process, a lot of research were carry out on why must wind turbine does not work in the south-south of Nigeria because it falls on the low wind speed region. Therefore, this wind turbine was built by eliminating some mechanical system that will lead to mechanical losses of the wind energy. Also, when a wind turbine is designed and constructed locally, the knowledge will be documented for further improvement. This knowledge will go a long way to enhance the much-needed indigenous technological bases.

II. MATERIALS AND METHODS

In the design and construction of a wind turbine, through locally available materials an intensive study was carried out taking into consideration the complexity of the blade, hub diameter, understanding the effect of the wind impact in a given region, the height to which the wine turbine is mounted or erected, the size of the shaft diameter and tower. The blade of the wine turbine will be design base on the best airfoil method to transmit maximum energy for electricity generation. The wind turbine was built and installed very closed to river Niger in Asaba Delta State Nigeria

A. *Design theory and calculation of the wind turbine parameters*

The wind turbine designed should be able to generate electricity power of 500walts at an average prevailing wind speed of 20.9m/s, height of 5m, with 1.293kg/m^3 density of air. To design the wind turbine, we know the following parameters.

Expected power generated, P = 500walts
The average prevailing wind speed of the area, V = 20.9m/s
Density of the wind at height of the tower of 5m is, ℓ = 1.293kg/m^3
Assumed values:
Length of each blade L = 1.3m or 1300mm, Thickness of the blade, t =0.4m, Orientation angle of 120^o, Number of blades = 3, Density of the mild steel material, ℓ = 7850kg/h^3, Length of tail vane T_{Lv} = 610mm, Width of tail vane T_{wv}= 370mm, Factor of safety, f.s = 3
The unknown parameters to be determined:
The area of the blades A =?
The width of the blades b =? Speed of the blade, N =? Diameter of the shaft, d_s =? Diameter of the hub, D_h =? Length of the hub, L_h =?

B. *Design of the wind turbine blades*

Fig. I, shows 0ne of the turbine blade, the turbine blades are made up of three (3) blades with an angle of 120^o, to carry out the design the following parameters are known and assumed, as follows
Length of each blade L=1.3m,
Expected power to be generated P=500walts,
Prevailing wind speed V=20.9mls
Area of each blade =?
Width of each blade=?
Therefore. [11]

$$P = \frac{\ell AV^3}{2} \quad (1)$$

Swept area is given as

$$A = \frac{Px2}{\ell V^3} = \frac{500x2}{1.293x20.9^3}$$

$$A = \frac{1000}{11804.2224}$$

$$A = 0.0847\text{m2}$$

To get the swept area of one blade is given by

$$A = \frac{0.0847}{3} = 0.0282\text{m2}$$

To determine the width of one blade, using the formula

$$Area = \text{length } x\ width \quad (2)$$

The area of one blade calculated is = 0.0282m^2
Width of the blade, b =?
Therefore,

$$A = d_r\ x\ b \quad (2a)$$

$$0.0282 = 1.3\ x\ b$$

$$b = \frac{0.0282}{1.3}$$
$b = 0.018\text{m}$
Therefore, the width of one blade b=0.018m.

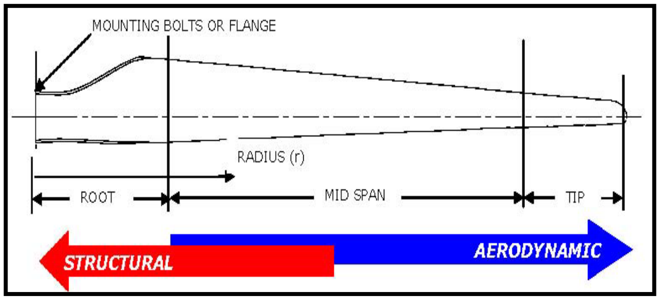

Fig. I: Aeroedynamic blade of the wind turbine [17].

C. The shaft

The rotor shaft should be subjected to two types of actions which are (a) bending moment, due to the weight of the blades (b). A twisting moment or torque due to the effect of the power transmitted.
To determine the diameter of the shaft the following are known.
The thickness of the blade t =0.32m
Distance of the bearing from the blade = 0.125m
Diameter of the blade is = 2xL = 2x1.3=2.6
Density of the mild steel material ℓ = 7850kg/h^3,
There the following are to be calculated,
Bending moment M_b =?
Twisting moment T_e =?
Diameter of the rotor shaft d =?
For the rotor shaft, the total force acting on it, will be given as;
W_t = mass x gravitation force.
That is

$$W_t = \text{m x g} \quad (3)$$

Where, mass of the blade is given as m.
M = density of the material x volume of material.
Volume = Area of the blade x thickness of the blade
Therefore, [10]

$$m = \ell \text{ x a x t} \quad (3a)$$

m = 7850 x 0.0282 x 0.32 = 70.84kg
The mass of the three blades becomes
M = 70.84 x 3 = 212.52kg
Therefore, the total weighty of the blade is the bending moment of the blade. Is given as,

$$W_t = M_b = \text{m x g} \quad (3b)$$

$W_t = 212.52\ x\ 9.81 \quad W_t = 2084.82N$
This force will tend to create a bending moment M_b about the first bearing, if the blade is 0.125m from the bearing, then
M_b = 2084.82 x 0.125 = 260.60N
The angular velocity of the wind turbine is given as;

$$W = \frac{2\pi N}{60} \quad (4a)$$

And N which is the speed of the blade is given as:

$$N = \frac{60\ x\ V}{\pi D} \quad (4b)$$

$$N = \frac{60\ x\ 20.9}{3.142\ x\ 2.6} \quad \text{N} = 153.5 \text{ r.p.m}$$

Therefore,

$$W = \frac{2\ \pi\ x\ 153.5}{60} \quad W = 16.1\ rad/s$$

The twisting moment or torque can be determined by

$$T_r = \frac{Power}{Angular\ velocity\ of\ the\ wind\ turbine} \quad (5a)$$

$$T_r = \frac{500}{16.1} = 31.06\ Nm$$

Therefore, the equivalent twisting moment is given as follows, [8]

$$T_e = \sqrt{(M_b + T_r)^2} \quad (5b)$$

$$T_e = (260.60)^2 + (31.06)^2 = 262.44 \text{ Nm}$$

Therefore, the equivalent bending moment, M_e

$$M_e = \frac{M_b + T_e}{2} \quad (5C)$$

$$M_e = \frac{260.60 + 262.44}{2} = 261.52 \text{ Nm}$$

Hence the rotor shaft should be able to withstand the equivalent bending moment in order to obviate premature failure in operation. Bending moment is a form of tensile stress, but the allowable working stress (σ_w) of a material is generally given as:

$$\sigma_w = \frac{\text{ultimate tensile stress}}{\text{Factor of safety}}$$

$$\sigma_w = \frac{\text{U.T.S}}{\text{F.S}} \quad (6a)$$

For a stainless steel, the U.T.S range from 350 to 370 MN/m^2, therefore safety factor of 3.

$$\sigma_w = \frac{350}{3}$$
$$= 116.667\ MN/m^2$$

Hence

$$\sigma_w = \frac{\frac{\text{Md}_s}{2}}{\frac{\text{d}_s^4}{64}} \quad (6b)$$

$$\sigma_w = \frac{\text{Md}_s}{2\pi} \text{ x } \frac{64}{\text{d}_s^4} \quad (6b)$$

$$d_s^4 = \frac{32\text{M}_b}{\sigma_w} \quad (6c)$$

$$d_s^4 = \frac{32 \text{ x } 261.52}{3.142 \text{ x } 116.52 \text{ x} 10^6} = \sqrt[3]{2.342267 \text{ x } 10^{-5}}$$
$$d_s = 0.0296 \text{ m} = 30 \text{ mm}$$

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D. Computation of hub diameter

The hub diameter in terms of shaft diameter can be calculated by using the equation below

$d_h = 1.5d_s + 25 \text{ mm}$ (7)

Where,
Diameter of the shaft, d_s =30mm,
Diameter of the hub, d_h =?
$d_h = 1.5 \text{ x } 30 + 25 = 70 \text{ mm}$

Therefore, the length of the hub is also calculated using the diameter of the shaft.
Length of the hub

$$L = \frac{\pi d_s}{2} \quad (8)$$

$$L = \frac{3.142 \; x \; 30}{2} = 50 \; mm$$

E. The tower

The tower of the wind turbine was made from mild steel. The angle should be strong enough to carry the entire weight of the system. The cross bar to give rigidity, should also be of mild steel.
The weight acting on the tower will be the weight of the blades, shaft, and basement of the receiver.

F. The weight of the shaft,

$W_{ts} = \ell \text{ x g x v}$ (9)

But volume,

$V = \frac{\pi}{4} \text{ x } d_s^2 \text{ x } 1$ (10a)

$V = \frac{\pi}{4} (0.03)^2 \text{ x } 0.36 = 2.545 \text{ x } 10^{-4}$

Therefore,
$W_{ts} = 7850 \text{ x } 2.545 \text{ x } 10^{-4} \text{ x } 9.81 = 19.599 \text{ N}$

The weight of the basement of the shaft and the bearing

$W_{tb} = \ell \text{ x g x v}$ (10b)

$v = 0.24 \text{ x } 0.13 \text{ x } 0.31 = 9.672 \text{ x } 10^{-3}$
$W_{tb} = 7850 \text{ x } 9.81 \text{ x } 9.672 \; 10^{-3} = 744.83 \text{ N}$
The weight of the basement of the receiver
$v = 0.23 \text{ x } 0.31 \text{ x } 0.082 = 5.847 \text{ x } 10^{-3}$
$W_{tr} = 450.24\text{N}$

Therefore, the total weight of the system is given as,

$W_{total} = W_{ts} + W_{tb} + W_{tr}$ (10c)

$W_{total} = 2086.6 + 19.59 + 744.83 + 450.22$
$W_{total} = 3301.269\text{N}.$

Hence from the design by E.E Steely Structural Steel, angle 120 x 100mm will serve the purpose effectively.
Now the tower shall be mounted on a concrete footing, and the height of the tower is assumed to be 5.70m that is the 0.7m will be mounted to give rigid firm.

G. Tail vane

The tail vane is used to control the wind turbine reference to the change of the wind direction. In this case, the length of 610mm and width of 370 mm in order to get a good control of the direction of the wind turbine. As shown in Fig IIa and IIb.

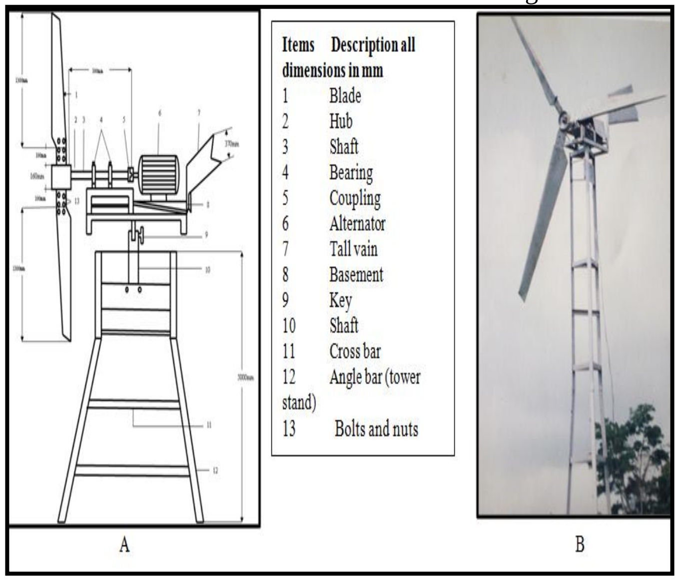

Fig. IIa and IIb: The side view of the wind turbine and complete design of the wind turbine

During the period of manufacturing, metal sheets and angle bar were cut, machined, welded and bolted according to designed specification of machine and the cutting process was carried out with cutting fluid that is friendly to the environment and also to avoid the metals from facing high corrosion effect and creep [14-20].
Operation of the Wind Turbine:

After mounting the wind turbine on the tower, the operation of the wind turbine starts when the wind flows through the turbine blade inducing a rotational motion via lift by the impact of the wind on the blade. The Turning motion is transmitted by means of the rotor shaft to which the blade is fixed. This rotor shaft turns the shaft of the alternator; then the electric power is generated

III. RESULT AND DISCUSSION

The wind turbine was mounted on a tower height of 5m, and the rotor speed, voltage (V) and current (A) was measured. The following reading were obtained using tachometer to measured rotor shaft speed, ammeter to measure the current produce, voltmeter to measure the voltage produced.

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Table 1: Results from the 1st Testing

No of Testing	Rotor shaft speed (rpm)	Voltage (V)	Current (Am)	Power (W)
1	139	23.6	20.17	476
2	150	24.7	19.72	487
3	164	26.1	19.73	515
4	154	25.3	19.49	493
5	161	25.8	19.61	506

From the Table 1, it can be clearly seen that the power (W) produce by the wind turbine varies for the period which the test was carried out and analysised, also the current (Am), voltage(V), and the rotor speed(rpm). This shows that a slight increase in the velocity of the wind, will increase the generated power, whereby increases the electricity generate.

2nd Test: the test was also repeated the second time, within the period of four (4) months that is from September to December. The result is shown in Fig. 3.

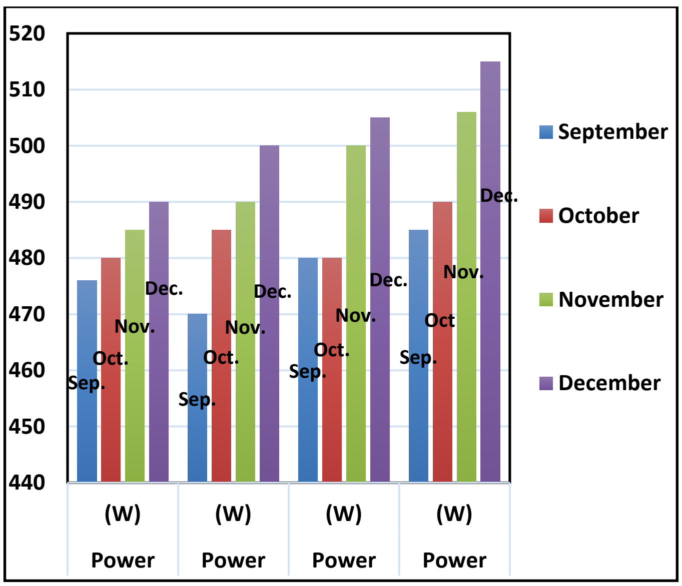

Fig. III: Graph showing power generated per weeks for the period of September - December

The generation of power from the wind turbine depends majorly on the wind. However, since the wind turbine was design to function in the low wind speed environment, the wind turbine was able to generate maximum electricity of about 515 (W) as against the design specification of 500 (W), this shows that the wind turbine was not just design but also the performance of the turbine is satisfactory. When there is increase in the wind speed (wind velocity) the power generated will also increase, the second test was carried out within an interval of four months, September to December. The Figure III clearly shows that during the December period the wind speed increases and the power generated also increase constantly from 490, 500, 505and 515 (W). This specific design is suitable for low wind speed region. Also, with an average wind speed of 20m/s, adequate power could be generated that would be sufficient for electricity generation.

IV. CONCLUSION

The feasibility study of the design and implementation of this work shows that it is possible to generate electricity via wind energy to support alternative means of power generations. The wind turbine was tested and it performed well. Average rotor speed of 153.5 (r.p.m.) was achieved and this was accompanied with an average current of 19.77 (A) and an average voltage of 25.1 (V), which gives an average power of 500 W.

- For the second test, it shows that the wind turbine performed more better as the wind speed increases during the December period and the maximum power generated was 515 (W) The materials used in the fabrication of this design are locally available. However, the cost of developing the wind turbine is a little bit cheap, but when it is mass produced, the cost per unit will be greatly reduced thereby rendering it easily available to consumers at a very cheap rate.

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