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DESIGNING AND MODELING OF A WIND POWER GENERATING PLANT

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ABSTRACT

The current situation of global warming and need for sustainable development calls for pragmatic solution to power generation using renewable and environmental friendly source as every economy of the world today requires electric power supply to run effectively. A large number of modern technology and civilization itself will become undermined without adequate power supply. This paper centers on the use of a wind turbine to harness the free energy in the wind for power generation. It contains results of experiments carried out during the course of the project using a bicycle dynamo and an anemometer to determine the variation of voltage with shaft speed, and wind speed determination, it gives detailed calculations of necessary parameters for the design of a typical model of an indigenous wind turbine and finally concludes with some recommendation for improvement of the wind turbine.

Keywords: global warming, sustainable development, power supply, free energy, wind turbine.

INTRODUCTION

Till date, the two major sources of power generation in Nigeria are hydro power generation and thermal power generation of which about 90 percent is dependent on crude oil [1] which is fast depleting and whose end product possess a lot of hazard to human health. Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth surface. It is a renewable source of energy that has a decentralized mode of operation that reduces transmission and distribution failures, it is cheap, inexhaustible, environmental friendly and is virtually available in every part of the nation in some amount [2]. Therefore, the use of wind turbines as alternate sources of power generation cannot be over emphasized.

A wind turbine works the opposite of a fan, instead of using electricity to make wind; wind turbines use wind to make electricity. The wind turns the blades, which spin on a shaft; the shaft is connected to a generator and produces electricity. The more air that passes by the blades, the faster the blades rotate, and the more electricity the wind generator will produce. A larger rotor area is able to collect more wind and produce more electricity with lower speeds. Wind turbines consist of a rotor which converts the linear motion of the wind into rotational energy. The rotor shaft is set into motion and is used to drive a generator, where electrical energy is generated; a gear box is commonly used to step up the speed of the generator, although designs may also use direct drive of an annular generator [3]. The rotor blades are attached to the rotor shaft at the rotor hub with the blade pitch mechanisms which are used for control of the rotor speed and the power output. The blades are pitched around their longitudinal axes to decrease or increase the aerodynamic torque on the rotor. The inputs of the wind turbine are the pitch angle of the blades, by which the rotor angular velocity is controlled and the wind speed. The output processes are the rotor rotational frequency and power. For a closed system, feedback from the rotational frequency is used to control the pitch angle to keep the rotational frequency close to its desired optimal value. However, more energy can be collected by using a variable speed wind turbines [4].

In order for a wind energy system to be effective, a relatively consistent wind flow is required. Obstructions such as trees or hills can interfere with the wind getting to the rotors. To avoid this, rotors are placed on top of towers to take advantage of the strong winds available higher up. The towers are generally placed 100 meters away from the nearest obstacle. The middle of the rotor is placed 10 meters above any obstacle that is within 100 meters [3].

THEORETICAL ANALYSIS

Power in the Wind:

Because air has mass and it moves to form wind, it has kinetic energy given by: kinetic energy (joules) = $0.5 \times m \times v^2$

Where: m = mass (kg)

v = velocity (metres/second)

Usually we are more interested in power than energy. Since energy = power x tine, and density is a more convenient way to express the mass of flowing air, the kinetic energy equation can be converted into flow equation:

Power in the area swept by the wind turbine rotor:

$P = 0.5 \times \rho \times A \times v^3$

Where: P = power in watts

ρ = air density (about 1.225kg/m^3 at sea level, less higher up)

A = rotor swept area exposed to wind (m^2)

v = wind speed in m/s [6]

This yields the power in a free flowing stream of wind. Back in 1919, a German physicist named Albert Betz figured out that the most you can possibly get out of wind turbine is around 59% of the power in the wind[7]. This limit is known as the Betz limit. There is therefore need to include some additional terms to get a practical equation for a wind turbine.

Wind Turbine Power;

$P = 0.5 \times \rho \times A \times v^3 \times c_p \times Ng \times Nb$.

Where: c_p = coefficient of performance (0.59 {Betz limit} is the maximum theoretical possible, 0.35 for a good design)Ng = generator efficiency (50% for car alternator, 80% or possibly more for a permanent magnet generator or grid connected induction generator)

Nb = gear box/bearings efficiency (depends, could be as high as 95%) [6].

TIP SPEED RATIO (λ)

The 'tip-speed-ratio' is the speed at which the blade tip should run compared to the wind speed. For electrical power generation $4 < \lambda < 10$ [8].

Table 1: relationship between tip speed and numbers of blade [8].

Λ	B
1	8-24
2	6-12
3	3-6
4	3-4
More than 4	1-3

Number of Blades (B)

Using the relation:

$B = 80/\lambda^2$ [2]

Tip speed ratio, $\lambda = 5$

Therefore, number of blades = 3. This agrees with table 1, in accordance to Grant [8].

SHAFT SPEED

The shaft speed in revolutions per minute (rpm) depends on the tip speed and the diameter.

Rpm = wind speed x tip-speed-ratio x 60 / (diameter x π) [9].

BLADE CHORD WIDTH:

The width of the blade is also called the blade chord, it is the longest line within the blade section and it joins the leading edge to the trailing edge.

A good formula for computing this is:

Blade Chord (m) = 5.6 x (R^2/r) (B x C_L x λ^2) [10].

R = Radius at tip

r = radius at point of computation

B = number of blades

C_L = Lift coefficient

λ = Tip Speed Ratio

As can be seen from formula, we need to know the lift coefficient "C_L " in order to compute the blade chord. This means that we have to select a profile. A lot of good profile data can be found in model airplane (gliders) literature. We have chosen the <u>NACA 2412 profile.</u> For this profile, the side facing the wind is flat, which makes the profile easy to construct. It is an effective profile with a good thickness, which makes the blade strong. In order to determine the lift coefficient we must have a look at the <u>profile curves.</u> By checking the NACA 2412 profile curves C_L is determined to be 0.85.

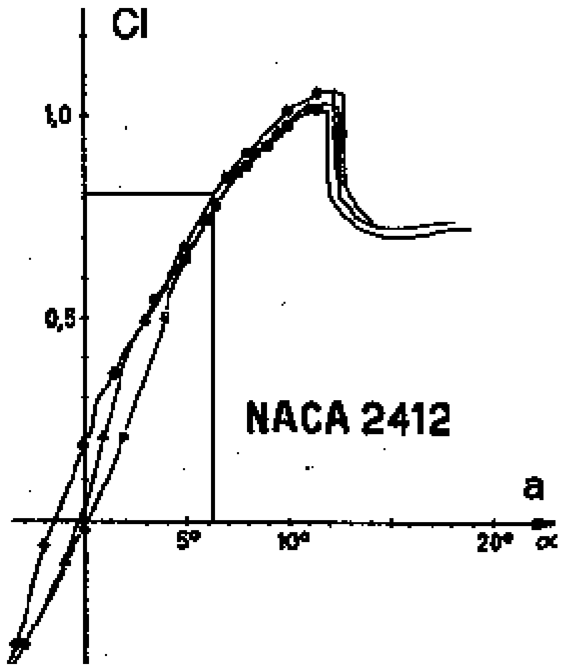


Fig 1 "a"/C_L-curve for NACA 2412 [10].

MODELING AND EXPERIMENTAL PROCEDURES

A wind energy system usually requires an average annual wind speed of at least 15 km/h. The following table represents a guideline of different wind speeds and their potential in producing electricity [3].

Average Wind Speed Suitability	Up to 4 m/s (about 15 km/h)
No good	5 m/s (18 km/h)
Poor	6 m/s (22 km/h)
Moderate	7 m/s (25 km/h)
Good	8 m/s (29 km/h)
Excellent	

The low prevailing wind speed in Benin of an average of 2.2 m/s led to the fabrication of a model.

Blade: The choice of blade length was dependent on the diameter of the fan which was used to simulate the wind. An industrial fan of diameter 0.72m was chosen and a blade of radius 0.35m was used. ABS pipe of various diameters were cut until the required blade angles were obtained. ABS pipe was used because of its high impact strength and resistance to chemicals and corrosion.

An experiment was carried out to investigate the relationship between shaft speed and voltage using a bicycle and a bicycle dynamo rated at 3W, 6V. The dynamo was attached to the bicycle tyre and the whole arrangement was made to rest up-side-down while the tyre was rotated by turning the pedal. This gives a gear system of ratio 38:1. The number of revolution was timed and the voltage recorded. The result obtained is shown in fig 11.

We then proceed to designing an anemometer to enable us measure the wind speed from the fan. The anemometer was designed using the lightest materials available to reduce inertia to the minimum. It consists of a steel base rod step turned at the top to accommodate a very light aluminum plate which carries four spokes on which a hemispherical cup is attached. The spokes were joined to the plate by soldering. The anemometer is shown below.

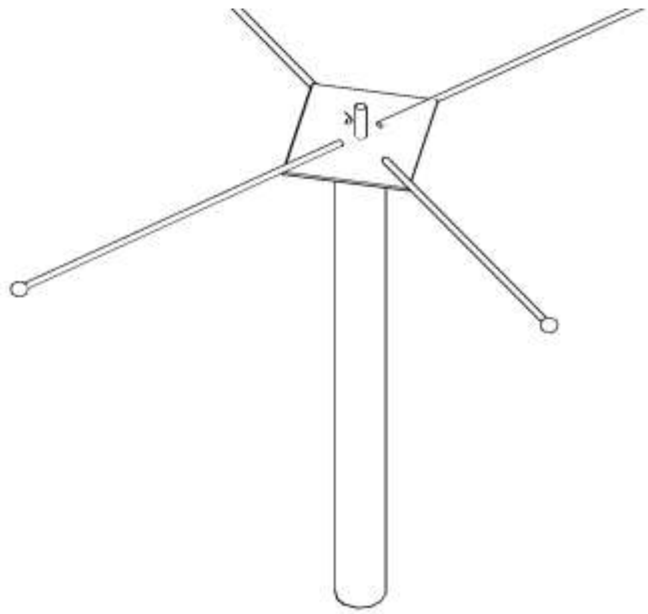


Fig 5 Anemometer

After which an experiment was carried out to calibrate the anemometer. This was done in an enclosed pathway in order to create a still air condition to prevent interference of atmospheric wind; thus simulating a wind tunnel. The anemometer was attached upright to a bicycle which was driven over a pre-determined distance, the time taken to cover various distances and the rotation of the anemometer were recorded. The speed of the bicycle in still air (distance travelled per unit time) was approximated to be the same as the wind speed. The number of rotations per seconds for various wind speed was determined and the resulting graph is shown in fig 10;

SHAFT DESIGN

The type of shaft used is a transmission shaft, it transmits power between the blade and the alternator while it carries machine parts e.g. gear, blade & hub etc. therefore, they are subjected to bending action and twisting.

ASSUMPTIONS:

1. Neglect the holes in the plate
2. The shaft passes through the centre of the plate

Density of aluminium = 2700kg/m^3

Vol of plate = 3.06 x 10^{-4} m^3

Mass of plate = 2700 x 3.06 x 10^{-4}

= 0.826kg

Mass of blade and hub = 32.77N

Mass of front plate = 24.32N

Mass of gear = 1.962N

Mass of back plate and alternator = 136N

Mass of alternator = 127.53

Free body diagram of the shaft is shown below

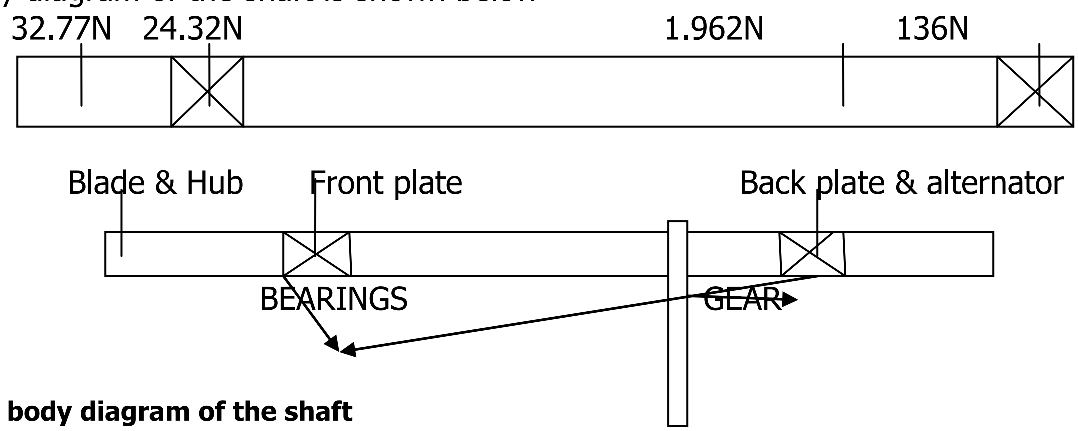
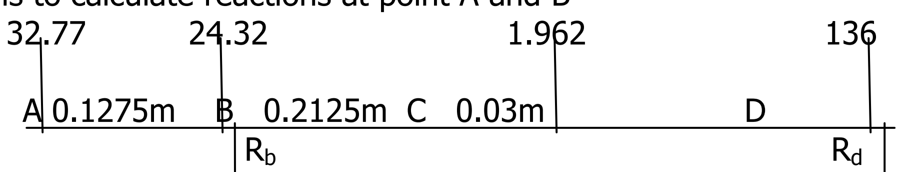


Fig6 Free body diagram of the shaft

Note g = 9.8m/s^2

Next is to calculate reactions at point A and B



R_b + R_d = 32.77 + 24.32 + 1.962 + 136

=195.052

Taking moment about D

R_b = 74.561N

R_d = 195.052 – 74.561
= 120.5 N

Bending Moment;
Taking moment about point A;
M_a = 54.1Nm
Taking moment about point B;
M_b = 4.176Nm
Taking moment about point C;
M_c = 0.4653Nm
Taking moment about point D;
$M_d = -5.6 \times 10^{-4}$Nm.

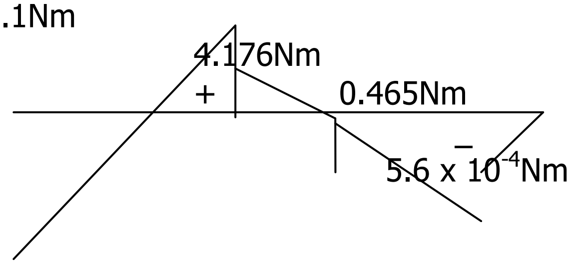


Fig 7 Bending Moment Diagram

Shearing forces

$SF_{d\text{-}c}$ = 120.5 – 136 = -15.5
= -15.55N
$SF_{c\text{-}b}$ = -15.51 – 1.962
= -17.462N
$SF_{b\text{-}a}$ = -17.472 + 74.56 – 24.32
= 32.778N

Since ∑horizontal forces = 0,
Maximum bending moment (M) = 54.121Nm
Recall, Torque (T) = WR
Where W = 13kg = 13 x 9.81 =127.53N
Diameter of rotor = 6cm = 0.06m
Radius (R) =0.06/2 = 0.03
T = 127.53 x 0.03 = 3.8259Nm
$T_e = \sqrt{M^2 + T^2}$
=54.63Nm
Also, $d = (5.091 \times T_e / ح)^{1/3}$
Where ح = allowable shear stress of the shaft = 45Mpa
d^3 = 5.091 x 54.63/ 45000000
= 0.0184m. Say d = 20mm

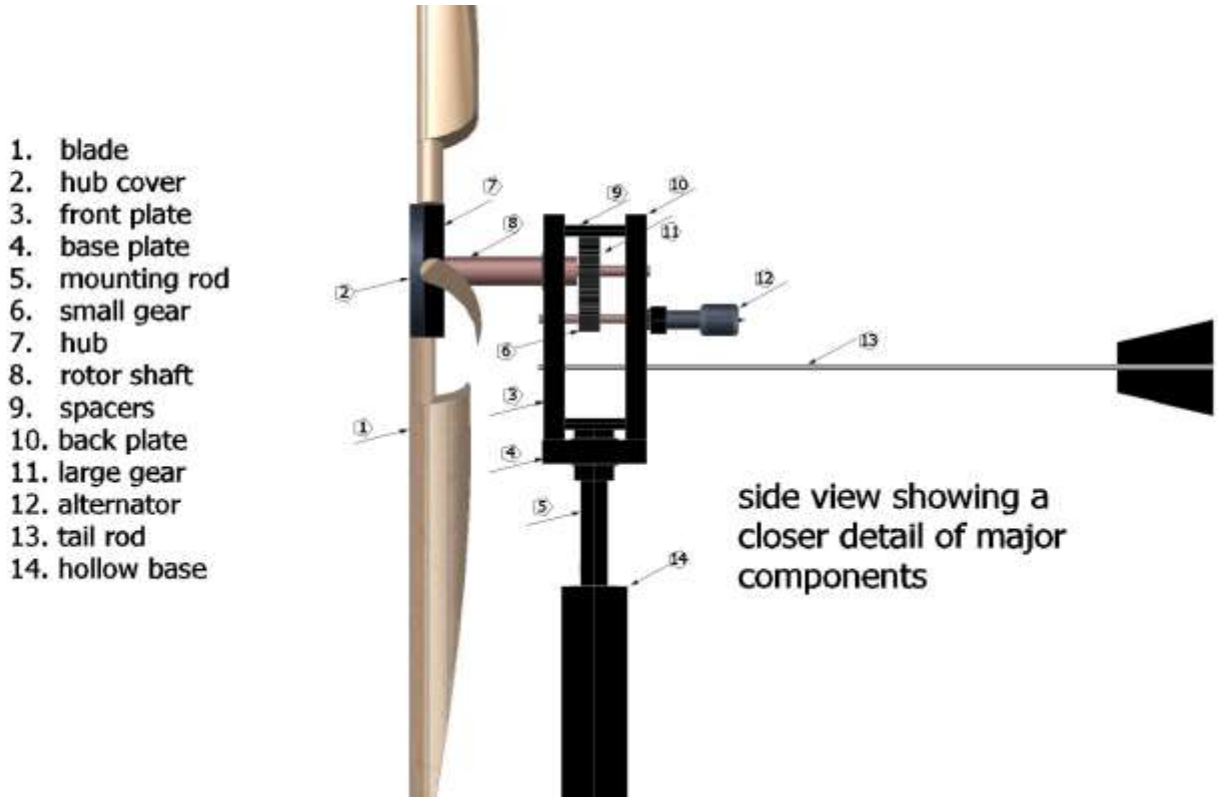


Fig 8 Design Concept

RESULTS AND DISCUSSION

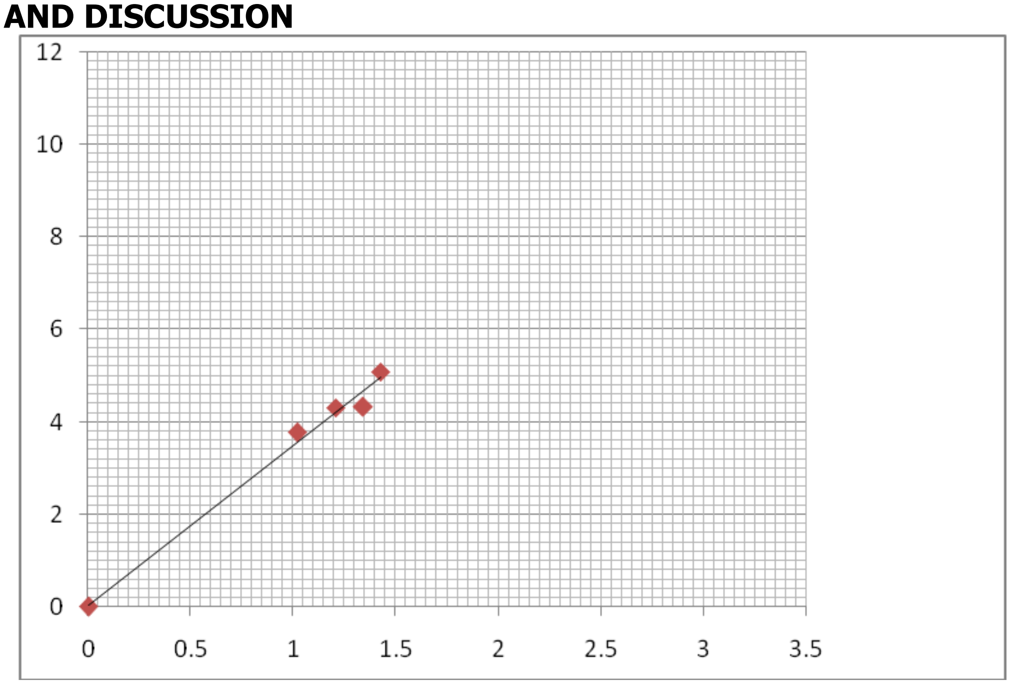


Fig 10 A graph of velocity (m/s) on y-axis against revolution (rps) on x-axis

The scale down model was tested using artificial wind from a fan operating on a 220v power supply, the anemometer reading of the fan speed gave 1.3 rps which from the graph in fig 10 corresponds to a velocity of 4.4m/s and the shaft speed was obtained as 580rpm using a tachometer. The output voltage and current were measured with a multimeter and was able to generate 1.5v, 0.4A respectively at a wind speed of 7.6m/s. Comparing the experimental shaft speed required to generate 1.5v with the theoretical shaft speed and the actual shaft speed gives;

Table 3

Experimental shaft speed from fig 11 with a gear ratio of 38:1	Measured (actual) shaft speed using tachometer with a gear ratio of 4:1	Calculated shaft speed using formulae
60 rpm	580rpm	600.24

Since the output speed = gear ratio x input speed,
Experimental output speed=2280 rpm
Actual output speed = 2320 rpm
Output speed using calculated value and assuming a gear ratio of 4:1 =2400.96

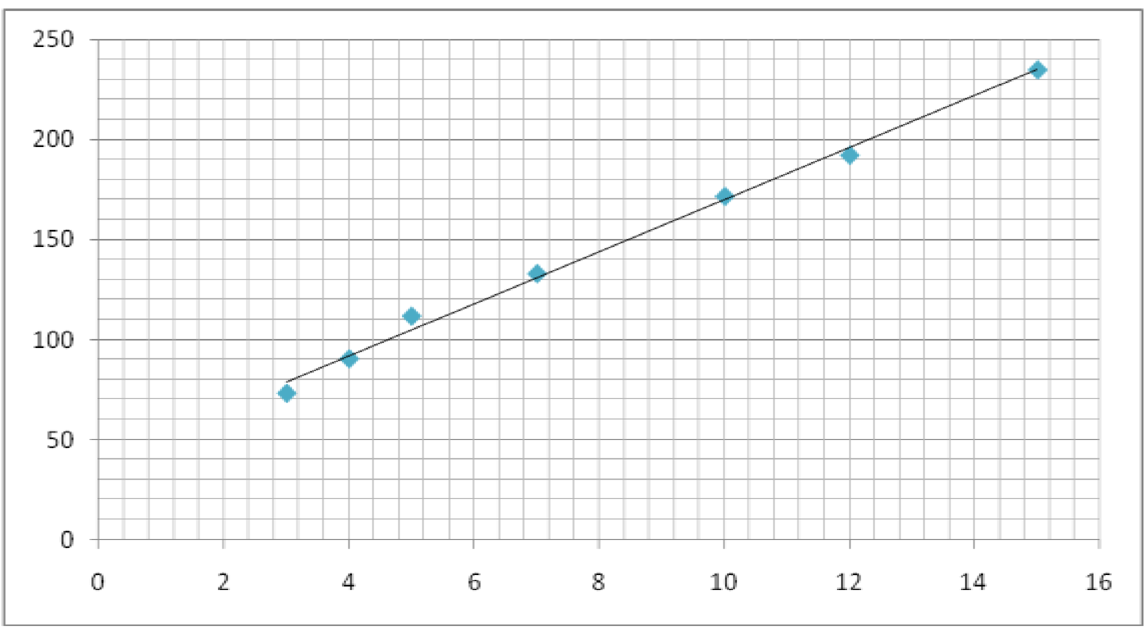


Fig 11 A graph of speed (rpm) on y-axis against voltage (volts) on x-axis

From the test; the power generated is 0.6W (p = IV)
Comparing this with the alternator rating of 3W, it shows that the model was able to generate 20% of the alternator rated power.
The power from an ideal wind turbine working with the same input parameter is given by;

$p = C_p \times \eta \times 1/2 \times \rho \times A \times v^3$ [6]

Using $C_p = 0.35$, $\eta = 0.45$ [6]
$P = 0.35 \times 0.45 \times 0.5 \times 1.225 \times 4.43$
P= 2.58W.
Comparing this with the actual 0.6W generated shows a large discrepancy. This indicates that the actual mechanical-electrical efficiency is quite low compare to the ideal efficiency.
The power generated was used to power a light emitting diode. The machine does not require high level of technical know-how for its operation and does not pose risk to the user, also the design is such that the various sections can be disassembled and this facilitates maintainability of the machine.

CONCLUSION AND RECOMMENDATIONS

In view of the rapid climate change across the globe and the need for sustainable development, the need for wind turbines as a source of alternative power generation cannot be overlooked as it provides a source of power that reduces the dependence on fossil fuel for power generation, provides an environmentally friendly source of power, provides a power source that requires little maintenance and easy maintenance as all parts can be disassembled, reduces the risk of transmission failure as power generated doesn't have to be transmitted through a long distance.

RECOMMENDATIONS

- Further research and development of wind power as an alternative source of energy should be encouraged in this part of the world.
- The mechanical-electrical efficiency of the design should be improved on.
- Wind turbines should be part of power generating system in Nigeria especially in areas with high wind speed.
- Controllers should be added to help in automatic braking of the wind turbine in high speed.
- Solar panel should be incorporated to increase power production especially in times of low wind speed.

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Appendix: Pictorial View of Actual Model