# Design and Development of A Hybrid Electric Power System: Wind and Solar

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**Abstract: -** One of the factors for determining the development of any nation/community is its illumination. Due to the irregular nature of power supply in Nigeria, there is the need to look into an alternative, reliable and efficient source of power. The main aim of this work is Rural/Urban Electrification by means of hybrid system that comprises the wind and the solar energy that must also be able to save power. The system will include the Rotor blade, yaw shaft with cable, Tail pole, Tail wind, Generator, Rectifier/inverter, controller, solar panel, Battery, Tower. Our target is to design a viable wind turbine that is solid enough to be mounted on tower tops with the advantage of less noise, easy installation and maintenance, and responds to the wind from every direction. The wind turbine designed is to generate electricity that is sufficient domestic use. This project places emphasis on the electrification of rural/urban areas where load shedding is still done to meet the demand of such areas with minimum cost.

**Key Words: —** ***Wind, Solar, Rectifier/Inverter, Tower, Battery, Solar panel.***

## I. INTRODUCTION

Wind turbine is a device which absorbs energy I the wind converts it to a useable energy form. The conversion of wind energy from the wind and conversion to mechanical energy at the rotor axis, and the secondary process of conversion of such mechanical energy into useful electrical energy. A very important field of science which is very important to the operation of wind turbine is the aerodynamics. Aerodynamics is the scientific study of physical laws about the behavior of different objects in air flow with the forces yielded by the flow of air. The aerodynamic profile of a wind turbine blade is very important the principle of lift and drag associated with aerodynamics. This turbine blade profile is borrowed from the blade profile of an aircraft. Various profiles can be obtained from the United States National Advisory Committee for aeronautics (NACA).

Wind turbine basically is of two types with respect to the axis of rotation. The horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT). The main advantage of VAWT is its single moving part (the rotor) where no yaw mechanisms are required, thus simplifying the design configuration. It is to a great extent admitted that VAWT portrays an appropriate choice for wind power origin in most developing nations. This is basically as a result of the many advantages of this type of machine above the horizontal axis, similar as their simplified fabrication, the absence of necessary over speed control, the reception of wind from my direction without orientation and reducing the mechanical design limitations due to the fact that control system and electric generators are set up statistically on the ground. The main disadvantage is that efficiency is lower than the HAWT.

## II. MATERIALS AND METHODS

This chapter covers material selection, specification, and methods of construction required for this particular project.

### A. Materials

A wind machine is built with different component parts based on the respective functions of the units that make up the machine, specific requirement, and the type of design involved. The Horizontal Axis Wind Turbine (HAWT) blade is modeled to take aerodynamic shape in order to reduce wind resistance in axial motion, the tower is set high above certain height to capture more wind speed and avoid ground surface drag effect (this factor depends on the site location and wind profile), the tail wing is designed with yaw mechanism that swivels under

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the impact of wind action, etc. from the items outlined above, the following materials are found useful for the machine assembly and construction.

*Rotor Blade, Yaw Shaft with Cable, TailPole, TailWing, Generator, Rectifier/Inverter, Controller, Battery, Tower, Solar Panel, Bracket, Accessories.*

### *B. Foundation*

About 1.2m wide and 5 feet deep of excavation work is carried out. A total of 4 wheel barrows of sharp sand, 4 wheel barrows of granite, and 6 bags of cement formed part of the materials used for the foundation structure.

### *C. Perimeter Fencing*

Four sets of 4inches diameter and 6ft high steel pipes, base plates, wire nets, some bricks, etc. are used for the perimeter fencing to condone the project area.

## III. THEORETICAL ANALYSIS

*Design Formula*:

The following parameters and data were used for the 3 blades design:

*Effect of Elevation on Wind Speed:*

To calculate the speed of the wind at a height, if it is known at another height, we can

Use:

$$V_2 = V_1 (h_2/h_1)^n \qquad (1)$$

Where, $V_1$ is wind velocity at height $h_1$ & $V_2$ is wind velocity at height $h_2$; n is the ground surface friction coefficient and takes on different values according to the nature of the terrain. Some example values are:

Water or smooth flat ground: n = 0.1

Tall crops: n = 0.2

City downtown: n = 0.4

From wind speed logging data taken at strategic positions near the site of project located within the university community, wind speed at the ground level, height $h_1$ = 3ft is $V_1$ = 4m/s. therefore, we can determine the speed of the wind at a height of $h_2$ = 80 ft above the ground surface as follows;

$$V_2 = 4\,(80/3)^{0.4} = 14.87\text{m/s}$$

*Tip Speed Ratio, TSR:*

The speed at which the blade tip should run compared to the wind speed is the tip-speed-ratio. The speed of the shaft in revolutions per minute (rpm) also depend upon the tip speed and the diameter.

This is given as,

TIP SPEED RATIO (TSR) = (tip speed of blade)/(wind speed).

$$= R_{rotor}/V \qquad (2)$$

Where,

: Rotational speed of the turbine rotor

Rrotor: radius of the rotor

V: wind speed

But,

$\omega = 2\pi$ (rpm)/60

$\omega = 2\pi$ (600)/60 = 62.8 rads$^{-1}$

Given that N = 600 rpm,

Rotor radius, r = 1.35.

Therefore, TSR = 62.8X1.35/14.87 = 5.7

The ratio of tip speed is a vital parameter in various formulae of design of blade.

Generally it can be said that zippy runners utilize 5-7 as ratio for tip speed, while gradually moving multi-bladed wind turbine rotors move with ratios of tip speed like 1-4. This design uses TSR of 6.

*Lift and Drag:*

Life upon an object is described as the force on the object in the direction that is normal to the direction of flow. Lift can only be available when the fluid includes a flow that is circulatory about the object like that which is found around a spinning cylinder. The speed surpassing the object is accelerated such that the static pressure is minimized. Then the speed under is lowered down, which gives an acceleration in the static pressure. Then, there is a normal upward force called the lift force. The force on the body in a direction parallel to the flow direction defines the drag on a body in an oncoming flow. The lift force should be high and the drag force should be low for a windmill to operate efficiently. The lift force is high and the drag force is low for small angles of attack. When the angles of attack is increased above a particular value, then, the lift force diminishes and the drag force maximizes, the angle of attack plays a very important role.

$$\text{Lift} = 0.5C_L \; AV_a^2 \qquad (3)$$

$$\text{Drag} = 0.5C_D \; AV_a^2 \qquad (4)$$

Where,

$V_a$ is the apparent wind speed.

A is the blade area which is length x chord width, and

is the air density,

$C_L$ is lift coefficient takes value from (0.5-1.5)

$C_D$ is drag coefficient takes value from (0.01-0.14)

Note, A = blade length x chord width (root) = 1.35 X 0.17 = $0.23m^2$

Therefore,

Lift = 0.5 X 1.5 X 1.225 X 0.23 X $14.87^2$

= 46.72 kg/m

Drag = 0.5 X 0.02 X 1.225 X 0.23 X $14.87^2$

= 0.623kg/m

*Lift Force and Drag Force*:

To proceed, the efficiency and the windmill blade shape must be related. To do this, we shall make use of primary blade-element theory in which each span-wise section of the blade is treated as an airfoil with known sectional lift coefficient $C_L$ and drag coefficient $C_D$. Thus, the lift force $d_D$ acting on an element of the windmill blade of length dr at a distance of r from the center are;

Lift force, $d_L = 0.5bd_r \quad V_r^2 C_L$ (5)

Drag force, $d_D = 0.5bd_r \quad V_r^2 C_D$ (6)

Here b is the blade width and $V_r$ is the resultant wind speed at the radius r. the resultant relative wind speed $V_r$ has contribution from the wind speed V and the rotational velocity of the blade $\omega r$. It should be noted that the wind speed V at the plane of the windmill. V is less than the wind speed far ahead of the windmill. Glauert has shown that V is ideally 2/3 of the wind speed far ahead of the windmill. This is true if one ignores the rotational energy in the slipstream downstream of the windmill and any losses due to turbulence of friction.

Thus,

Wind Relative Velocity, $V_r$:

$Vr = SQR\ (v^2 + \quad {}^2r^2)$ (7)

$= SQR\ (14.87^2 + 62.8^2 \text{ X } 1.35^2)$

= 86.07 m/s

Therefore, choosing blade width, b = 0.07m (tip chord), and tip radius $d_r$ = 1.35m.

Life force, $d_L$ = 0.5 X 0.07 X 1.35 X 1.225 X $86.07^2$ X 1.5

= 643.18N

Drag force, $d_D$ = 0.5 X 0.07 X 1.225 X $86.07^2$ X 0.02

= 8.58N

*Generator Power (W):* Considering minimum wind speed of 3 m/s.

Power (W) = $0.6C_PNAV^3$ (8)

= 0.6 X 0.48 X 600 X 5.72 X $3^3$

= 26,687.232W or 26.7Kw

Where the swept or rotor area, A = $\pi r^2 = 3.14 \text{ x } 1.35^2 = 5.72m^2$

*Revolution (RPM)*: at maximum wind speed, v = 14.87 m/s.

Revolutions (rpm) = V x TSR x 60 / (6.28 x R) (9)

= (14.87 x 6 x 60)/ 6.28 x 1.35

= 631.4rpm

However, the design rpm is 600.

Where,

$C_P$ = Rotor efficiency (or wind energy utilization ratio) given as 0.48

N = Efficiency of driven machinery

A = Swept rotor area ($m^2$)

V = Wind speed (m/s)

TSR = Tip Speed Ratio

R = Radius of rotor

Rotor efficiency can go as high as $C_p$ = 0.48, which is used in this design.

*Selecting Blade Chord and Profile:*

This is derived as,

Blade Chord (m) = 5.6 x $R^2$ / (i x CL x TSR x TSR) (10)

R = Radius at tip

r = radius at point of computation

i = number of blades

$C_L$ = Lift coefficient

TSR = Tip Speed Ratio

As can be seen from formula (4) we need to know the lift coefficient "$C_L$" in order to compute the blade cord. 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 NACA 2412 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.

To evaluate the lift coefficient we must have a look at the profile curves from NACA 2412.

By checking the NACA 2412 profile curves CL is determined to be 0.85. lan Cummings formula now looks like this:

*For tip computation, r = 1.35m:*

“Chord” = 5.6 x $1.35^2$/ (3 x 0.85 x 1.35 x6 x 6)

“Chord” = 0.08m or 8cm

*For root computation r = 0.65m:*

“Chord” = 5.6 x $1.35^2$/(3 x 0.85 x 0.65 x 6 x 6)

“Chord” = 0.17m or 17cm

*Angles*:

The angles of the blade are derived as follows from lan Cummings

Close to the hub you should consider an extra increase in the angle of attack, in order to make the blade start easier.

*Angle of apparent wind (Φ):*

Cot Φ = (1.5 x r x Tip Speed Ratio)/ R (11)

“r” is the radius (from the hub) of computation, while “R” is the total radius of the blade.

From lam Cummings:

Cot Φ tip = (1.5 x 1.35 x 6)/1.35 = 6.34

Φ = 6.34 degrees

“r” is the radius (from the hub) of computation, while “R” is the total radius of the blade.

From lan Cummings:

Cot tip = (1.5 x 1.35 x 6)/1.35 = 6.34

= 6.34 degrees

Compute “**Φ”** for different values of different “r” with small intervals at the outer third of the blade.

The angle “β” is used for the construction of the workshop:

*Angle of blade (β):*

β = Φ – a (12)

The angle “a” is the angle of attack, which is constant for all values of “r”. The angle of attack depends on Cl and determined from the Cl-curve. The angle of attack is expected to be small as reasonably possible within the tolerances $5^0$-$14^0$.

From lan cummings:

The “a”/Cl-curve give an angle of attack of 6 degrees

This implies that,

β – at tip = 6.34-6

= 0.34 degrees

Computer “**Φ”** for different values of “r” with small intervals at the outer third of the blade.

*Wind Energy Calculations*:

Wind Power

The power of the wind can be evaluated from;

W = V3 (13)

With Betz’s factor, Cp

W =V3 x Cp

Therefore,

W = 0.5 X 1.225 X 5.72 X 73

= 1,201.70W or 1.2 Kw

Where,

: Density of the air

A: capture area of the wind

v: Rated wind speed – 7m/s

By incorporating the Betz’s factor, Cp = 0.48

W = V3 x Cp

= 1201.7 x 0.48

= 577W or 0.577KW

*Wind Turbine Efficiency*:

The wind turbine efficiency is defined as,

wt= (wind turbine power produced)/wind power

= Wwt/ Cp V3 (14)

*Wine turbine power:*

Wind turbine power produced is therefore,

Wwt = wt Cp V3

Modern Three-blade Wind Turbine

For TSR 2.95: wt 0

For 2.95 TSR 5.4: wt 0.02554 (TSR) 2 + 0.18327 (TSR) + 0.023286

For TSR 5.4: wt 0

Ideal Wind Turbine

For TSR 0.5: wt 0.658(TSR) 0.23233

For 0.5 TSR 1.0: wt 0.196(TSR) 0.32433

For 1.0 TSR 1.5: wt 0.104 (TSR) 0.32433

For 1.5 TSR 2.5: wt 0.055(TSR) 0.399

For 2.5 TSR 4.0: wt 0.022 (TSR) 0.481

For TSR 4.0: wt 0.0041 (TSR) 0.5532

Since this design has TSR of 6, the turbine efficiency is determined as follows:

wt 0.0041 (6) 0.5532 = 0.5778 or 57.78%

Therefore, wind turbine power production is:

Wwt = 0.5778 x 577 = 333.4W

To calculate the rotation speed, we equate the mechanical power of the turbine due to rotation with the wind power that is captured by the turbine or;

. wt Cp V3) = 0.5 1shaft $^3$

*Rotor Moment of Inertia*:

Where $1_{shaf}t$ is the moment of inertia of the rotor about the rotating shaft. If we assume that blades are a parallelepiped (solid rectangle) then for our HAWT we have that,

$1_{shaft}$ = ($N_B$ ($L_B W_B$ $t_B$ ) $L^2{}_B$)/3 (15)

Where,

$N_B$: number of blades

$_B$: density of blade material

$L_B$: length of blade.

$W_B$: ‘width of blade

$t_B$: thickness of blade

Therefore, $1_{shaft}$ = 3 x 2.8 x 1.35 x 0.165 x 0.04 x $1.35^2$) /3

= 0.045Nm

*Starting Torque*:

The Torque to start a wind turbine can be determined from the formula;

Torque = $V^2R^2$/Design $TSR^2$ (Nm) (16)

Where,

V – Wind speed

R – Blade radius

Torque = ($14.87^2$ x $1.35^2$**)**/$6^2$

= 11.19Nm

*Forces On The Wind Turbine Blades***:**

There are three main forces acting on the wind turbine blade. These are:

*Centrifugal:*

This is due to the blades rotation. It is an inertial force which depends upon the rotational speed. According to the ITDG Fibre Glass blade at 500 rpm. This is for the 500W machine with smaller blades. Calculations for 0.5kW blade:

Fcentrifugal = m $\varphi^2$ r (18)

Where m is the mass of the blade, φ is the angular velocity and r is the distance at which the mass acts (assumed a point source mass). The angular velocity is a function of the rpm, which is 500rpm at rated output.

$\omega = 2\pi\ (rpm)/60$

$\omega = 2\pi\ (600)/60 = 62.83\ rad^{s-1}$

Assume r = 1.35m (approx point of action of weight)

Fcentrifugal = m (62.83)2 1.35 = 5,329.3m

This is approximately equivalent to 544 times the weight of the blade (weight = mass x gravity (9.81)).

## IV. PRESENTATION OF RESULTS

### A. Results Measurement

The measurements were carried out at four different period of time, i.e at 9:00am, 12:00pm, 3:00pm and 5:00pm. The readings were taking on the 1st to 5th of February 2011. The measurements were done by using a multimeter to take the readings. The two wires coming from the multimeter connected to the two terminal wires of the solar panel and the wind turbine at different times. When taking the measurement of the solar panel, we made sure that the multimeter was on direct current (D,C) for solar readings and that the multimeter should be on the A.C scale.

Table.1.Table showing reading obtained from solar panel

| **Days** | **9:00am** | **12:00pm** | **3:00pm** | **5:00pm** |
|---|---|---|---|---|
| February 1 2011 | 45 volts | 48 volts | 50 volts | 49 volts |
| February 2 2011 | 43 volts | 50 volts | 46 volts | 48 volts |
| February 3 2011 | 46 volts | 50 volts | 52 volts | 50 volts |
| February 42011 | 47 volts | 50 volts | 49 volts | 49 volts |

| | | | | |
|---|---|---|---|---|
| February 5 2011 | 44 volts | 48 volts | 43 volts | 43 volts |

### *B. Procedure for taking solar panel Reading*

- The meter is then sset to direct current (DC) voltage pointing to 250 volts on the meter.
- The two wires of the meters is connected to the terminals of the solar panel.
- The measured value is then recorded.

*Procedure for measuring Wind Turbine Readings:*

To record the voltage of the turbine, the following procedure is carried out:

- Turn the meter to alternating current voltage (ACV) preferably pointing to 50V.
- The two terminals of the meter is connected to the two terminals from the wind turbine.
- The measured vale is then recorded.

## V. DISCUSSION

The wind speed data indicated that the wind is an intermittent resource that is not available every time. Its occurrence results to the turning of the turbine blades and this is evident in the table of results displayed in the previous chapter where the voltage at different times varies because of this variability in the wind condition. When the reading of the turbine is being taken, the terminal of the wire from the turbine is permanently connected to the wire from the metre and it is observed that as the speed of the wind turbine rotor reduces the voltage reduces along with it. For the solar panel, higher values is noticed during the 12:00pm period because at this period the sun tends to be its peak.

## VI. CONCLUSION

From the table of results above, we can comprehend conclusively that the hybrid electric power system (HEPS) is a project which is feasible to operate in this part of the country giving the weather condition available around Benin City, Edo State, Nigeria.

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