NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY
[IJIERT] ISSN: 2394-3696 Website: ijiert.org
VOLUME 8, ISSUE 9, Sep. -2021

DESIGN AND DEVELOPMENT OF A HORIZONTAL AXIS WIND TURBINE

Tonbra Eyitemi
Department of Mechanical Engineering, Nigeria
MaritimeUniversity, Okerenkoko, Delta State, Nigeria.
eyitemitonbra@yahoo.co.uk

Godfrey Sibete
Department of Mechanical Engineering, Niger Delta
University,Wilberforce Island, Bayelsa state, Nigeria.
godfresibet@yahoo.com

ABSTRACT

The main objective of this research work is Rural/Urban Electrification through hybrid system which comprises wind and solar energy. The aim is wind turbine design which is to be mounted on tops of towers. Therefore, we resolved to design a horizontal axis wind turbine (HAWT). The main advantage of (HAWT) over the (VAWT) is its higher efficiency. The system will include the yaw shaft, Rotor blade, solar panel, Rectifier/inverter, Generator, Tail pole, Tail wind, Tower, Controller Battery. The designed and developed wind turbine is to generate electricity that is sufficient for domestic use in rural / urban settlements.

The generated electricity will be saved in battery, then delivered to the load. The emphasis of this research work is on electrification of rural/urban settlements where load shedding is still done to meet electricity demand.

Keywords: Yaw shaft, Rotor Blade, Turbine, Wind Turbine, Solar.

1 INTRODUCTION AND LITERATURE REVIEW

The relevance of wind turbine over the years have been tremendous. This is due to the ever increasing need of energy generation has been mainly through thermal, hydro and nuclear means for the few industrialized economy. This different means of energy generation has one or two problem associated with them as a result the renewable means of energy generation has gained recognition. Nigeria as a case study, energy generation is mainly through thermal means as can be seen in different site in the country. Thermal generating plant site can be found in Afam, Delta, Egbin, Sapele and Orji rivers. The other form of energy generation in the country is the hydro means and has its site in Jebba, Kainji and Shiroro dam. Apart from the hydro means of energy generation, the thermal means of energy generation is associated with pollution of the environment and this has an adverse effect on the society. Part of it is the depletion of layer of ozone as a result of the gases being emitted in this thermal energy generation.

2 MATERIALS AND METHODS

This chapter covers material selection, specification, and techniques of fabrication required for this particular project.

2.1 Materials

A wind machine is build 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 (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 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.

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.

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.

1.Design Formula

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

1.**Effect of Elevation on Wind Speed**

To calculate the speed of the wind at a height, when it is ascertained at another height, we can
Use:

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

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

- Smooth flat ground or water: n = 0.1
- High crops: n = 0.2
- Downtown of City: 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, speed of wind can be determined at a given height h_2 = 80 ft above the ground surface as follows;

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

3.1 Tip Speed Ratio, TSR:

Comparing the speed at which the tip of the blade should run to speed of the wind is the tip-speed ratio. Speed of the shaft in rpm also dependent upon tip speed and diameter.

This is given as,

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

= R_{rotor}/V ____________ (2)

Where,

: rotational speed of 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.

However, generally it can be said that gradually moving wind turbine with multiple blade rotors function with a tip speediness ratio of 1-4, while quick movers utilize 5-7 as the tip speed ratio. This design uses TSR of 6.

2.1 Lift and Drag. Life upon an object is described as force on the object in the direction that is normal to the flow direction. 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 upon the body in a parallel direction to the flow direction defines drag upon a body in an approaching flow. lift force need be maximum and the drag force need be minimum for windmill to function efficiently. The lift force is maximum while the drag force is minimum for little angles of attack. When angles of attack is increased above a particular value, then, lift force diminishes and drag force maximizes, angle of attack plays a very important role.

Lift = $0.5C_L \; AV_a^2$ □____________ (3)

Drag = $0.5C_D \; AV_a^2$ □___________ (4)

Where,

V_a is the apparent wind speed.

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

is th□ 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

3.3 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 elementary 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, $d_L = 0.5bd_r \; V_r$□C_L ____________ (5)

Drag force, $d_D = 0.5bd_r \; V_r$□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 ωr. It should be noted that wind speed is V at the plane of the windmill. V is less than wind speed far ahead of the windmill. Glauert has shown that V is ideally 2/3 portion of 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,

3.4 Wind Relative Velocity, V_r:

Vr = SQR (v^2 + $^2r^2$)□_____________(7)

= SQR (14.87^2 + 62.8^2 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

3.5 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 = πr^2 = 3.14 x 1.35^2 = $5.72m^2$

3.6 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 = Efficiency of rotor (or wind energy utilization ratio) given as 0.48
N = Driven machinery Efficiency
A = Rotor swept area (m^2)

V = Speed of wind (m/s)
TSR = Ratio Tip Speed
R = Rotor speed
Efficiency of rotor may increase as high as C_p = 0.48, which is used in this design.

3.7 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 evaluated as 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**

3.8 **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 attack angle, in order to make the blade start easier.

3.9 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 . 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:

3.10 Angle of blade (β):

β = **Φ – a ________________________________ (12)**

The angle "a" is attack angle, 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 attack angle 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.

3.11 Wind Energy Calculations

3.11.1 Wind Power

The wind power is evaluated from;
W □□^{3}□□ ______________________ (13)
With Betz's factor, C_p
W □□^{3}□□$_p$
Therefore,
W = 0.5 X 1.225 X 5.72 X 7^3
= 1,201.70W or 1.2 Kw
Where,
: den□ity of the air
A: capture area of the wind
v: Rated wind speed – 7m/s
By incorporating the Betz's factor, C_p = 0.48
W □□^{3}□□$_p$

= 1201.7 x 0.48
= 577W or 0.577KW

3.11.2 Wind Turbine Efficiency

The wind turbine efficiency is defined as,

$_{wt}$ = (wind turbine power produced)/wind power

= W_{wt}/ C_p V^3 ______ (14)

3.11.3 Wine turbine power

wind turbine power produced is therefore,

W_{wt} = w - V^3

Modern Three-blade Wind Turbine

for TSR .95: w 0
for 2.95 SR 5: w 0.0 554 $(TSR)^2$ + 0.18327 (TSR) + 0.023286
for TSR .4: t 0

Ideal Wind Turbine

for TSR .5: w 0. 8(TSR) 0.23233
for 0.5 SR : w 0. 6(TSR) 0.32433
for 1.0 SR 1 : w 0.1 4 (TSR) 0.32433
for 1.5 TSR 2 : w 0.0 (TSR) 0.399
for 2.5 SR 4 : w 0. 2 (TSR) 0.481
for TSR .0: w 0 041 (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:

$\hat{W}_{wt}$ = 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 C_p ^{3}) = 0.5 1_{shaft} ^{3}

3.12 Rotor Moment of Inertia

Where 1_{shaft} is the rotor moment of inertia 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

3.13 Starting Torque

The Torque to start a wind turbine can be calculated with the formula;

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

Where,

V – wind speed
R – blade radius

Torque = $(14.87^2 \times 1.35^2)/6^2$
= 11.19Nm

3.14 Forces On Wind Turbine Blades

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

3.15 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 = $m\,\omega^2\,r$ **_______________ (18)**

Where m is mass of blade, ω is angle velocity and r the distance upon which the mass acts (assuming point source mass) the angle velocity is also a function of the rpm that is 500rpm at output rated. .

$\omega = 2\pi\,(\text{rpm})/60$

$\omega = 2\pi\,(600)/60$ = **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)).

4 PRESENTATION OF RESULTS

4.1 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 utilizing 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 sures multimeter was on direct current (D,C) for solar readings and that the multimeter should be on the A.C scale.

Table 1: Table of result for solar panel readings

Days	**9:00am**	**12:00pm**	**3:00pm**	**6:00pm**
February 1 2011	**18 volts**	**19 volts**	**19 volts**	**28 volts**
February 2 2011	**20volts**	**21 volts**	**18 volts**	**29 volts**
February 3 2011	**21 volts**	**23 volts**	**20 volts**	**32 volts**
February 42011	**17 volts**	**26 volts**	**22 volts**	**30 volts**
February 5 2011	**19 volts**	**27 volts**	**24 volts**	**33 volts**

4.1.1 Procedure for measuring Wind Turbine Readings

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

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

5 DISCUSSION

The wind speed data indicated that the wind is an intermittent resource that is not available every time. It's occurrence results to turning of 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 speed of 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.

6 CONCLUSION

The advantage of this hybrid work is the inability of the work to be independent on seasonal changes. The reason being that during the dry season we have high radiation from the sunlight and even if the turbine is not working optimally at this period, most of the power will be supplied from the solar cell system and during the rainy season when there is little sunlight, there will be appreciable wind blowing at this period, then the turbine will be optimal at this stage and the solar panel would not produce appreciably due to the little or absence of sunlight.

REFERENCES:

1) S. Rajakumar, Dr. D. Ravindran: Computational fluid dynamics of the blade of wind turbine blade at different attack angle and low reynold numbers.
2) Marcelo A. Silva, others: (Formulations for the optimal design of reinforces concrete wind turbine towers). International conference on engineering optimization 2008.
3) Stan Gibilico: Teach yourself electrical electronics. 3rd Edition.
4) Michael Arquin: Science fair wind turbine kit-2008. Michael@kidwind.org.
5) John Blackburn, Ph.D.: Matching Loads of Utility with Wind Power and Solar in North Carolina (Dealing with Intermittent Electricity Sources).
6) Hugh Piggott: The Permanent Magnet Generator (PMG) (A manual for manufacturers and developers).
7) Andrew Corbyn & Matthew Little: Fibre glass wind turbine blade manufacturing guide.