DESIGN AND CONSTRUCTION OF VERTICAL AXIS WIND TURBINE

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ABSTRACT

The principle objective of this project is Rural Electrification via hybrid system which includes wind and solar energy. Our intention is to design a wind turbine compact enough to be installed on roof tops. So we decided to design a vertical axis wind turbine (VAWT) over Horizontal Axis Wind Turbine (HAWT). Advantages of VAWT over HAWT are compact for same electricity generation, less noise, easy for installation and maintenance and reacts to wind from all directions. The wind turbine designed to generate electricity sufficient enough for a domestic use. The electricity generated will be stored in the battery and then given to the load. This project emphasizes on electrification of remote areas with minimum cost where load shading still has to be done to meet with demand of urban areas.

Nomenclature

V - Air Velocity
A - Turbine Swept area
D - Rotor Diameter
h - Rotor Height
ρ - Air Density
KE - Kinetic Energy
ω - Angular Speed [rad/s],
R - Rotor Radius [m]
N - Number of Blades
c - Blade Chord
L - Blade length
1. INTRODUCTION

Wind power devices are used to produce electricity, and commonly termed wind turbines. The orientation of the shaft and rotational axis determines the classification of the wind turbines. A turbine with a shaft mounted horizontally parallel to the ground is known as a horizontal axis wind turbine or (HAWT). A vertical axis wind turbine (VAWT) has its shaft normal to the ground.[1]

Fig 1: Configurations for shaft and rotor orientation

The two configurations have instantly distinguishable rotor designs, each with its own favorable characteristics. Vertical-axis wind turbines (VAWT) can be divided into two major groups: those that use aerodynamic drag to extract power from the wind and those that use lift. The advantages of the VAWTs are that they can accept the wind from any direction. This simplifies their design and eliminates the problem imposed by gyroscopic forces on the rotor of a conventional machine as the turbine tracks the wind. The vertical axis of rotation also permits mounting the generator and drive train at ground level [2]. The disadvantages of this type of rotors is that it is quite difficult to control power output by pitching the rotor blades, they are not self – starting and they have low tip-speed ratio [3]. Horizontal – axis wind turbines (HAWT) are conventional wind turbines and unlikely the VAWT are not omnidirectional. As the wind changes direction, HAWTs must change direction with it. They must have some means for orienting the rotor with respect to the wind.

2. LITERATURE SURVEY

2.1 Theoretical Maximum Efficiency [1]

High rotor efficiency is desirable for increased wind energy extraction and should be maximized within the limits of affordable production. Energy (P) carried by moving air is expressed as a sum of its kinetic energy [Equation (1)]:

\[ KE = \frac{1}{2} \rho AV^3 \]  

Where,

- \( V \) - Air Velocity
- \( A \) – Turbine Swept area
- \( \rho \) - Air Density

A physical limit exists to the quantity of energy that can be extracted, which is independent of design. The energy extraction is maintained in a flow process through the reduction of kinetic energy...
and subsequent velocity of the wind. The magnitude of energy harnessed is a function of the reduction in air speed over the turbine. 100% extraction would imply zero final velocity and therefore zero flow. The zero flow scenario cannot be achieved hence all the wind’s kinetic energy may not be utilised. This principle is widely accepted and indicates that wind turbine efficiency cannot exceed 59.3%. This parameter is commonly known as the power coefficient $C_p$, where max $C_p = 0.593$ referred to as the Betz limit. The Betz theory assumes constant linear velocity. Therefore, any rotational forces such as wake rotation, turbulence caused by drag or vortex shedding (tip losses) will further reduce the maximum efficiency.

2.2 Practical Efficiency
In practice rotor designs suffer from the accumulation of minor losses resulting from:

1. Tip losses
2. Wake effects
3. Drive train efficiency losses
4. Blade shape simplification losses

Comparison of Different Wind Turbines

<table>
<thead>
<tr>
<th>No.</th>
<th>Design</th>
<th>Orientation</th>
<th>Use</th>
<th>Propulsion</th>
<th>% Axis Efficiency</th>
<th>Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>J-type wind</td>
<td>VAWT</td>
<td>Drive</td>
<td>Drift</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Cup</td>
<td>VAWT</td>
<td>Nexon electric power</td>
<td>Drift</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>American wind</td>
<td>HAWT</td>
<td>18th century to present day, less use for pumping water, generating electricity</td>
<td>Lift</td>
<td>35%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Dutch Windmill</td>
<td>HAWT</td>
<td>16th Century, used for grinding wheat</td>
<td>Lift</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Bullock Rotor</td>
<td>VAWT</td>
<td>20th Century, electricity generation</td>
<td>Lift</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Modern Wind</td>
<td>HAWT</td>
<td>20th Century, electricity generation</td>
<td>Lift</td>
<td>50%</td>
<td></td>
</tr>
</tbody>
</table>

J- Type Vertical Axis Wind Turbine

J type wind turbine is basically a drag type wind turbine. Our aim was to produce electricity at low cost. The procedure for other turbines especially lift type turbines was too expensive and hence this led us to choose the drag type wind turbines with less complexities involved in construction.
Wind Turbine Design Parameters: [4]
The wind turbine parameters considered in the design process are:

i. Swept area
ii. Power and power coefficient
iii. Tip speed ratio
iv. Blade chord
v. Number of blades
vi. Solidity

3. DESIGN CALCULATIONS

3.1 Power calculations

The wind turbine works on the principle of converting kinetic energy of the wind to mechanical energy. The kinetic energy of any particle is equal to one half its mass times the square of its velocity,

\[ K.E = \frac{1}{2} m v^2 \] ........................ (1)

Where,
K.E = kinetic energy
m = mass
v = velocity,
M is equal to its Volume multiplied by its density \( \rho \) of air

\[ M = \rho A V \] ......................... (2)

Substituting eq. (2) in eq. (1)

We get,

\[ K E = \frac{1}{2} p A V \cdot V^2 \]
\[ K E = \frac{1}{2} p A V^3 \text{watts.} \]

Where,
A= swept area of turbine.
\( \rho \)= density of air (1.225 kg/m\(^3\))
V=wind velocity.
For 35 Watt power, calculate design parameters of turbine, P=35 watts.

Considering turbine efficiency as 25% and generator efficiency 85%,
\[ P = 35/ (0.25*0.85) \]
\[ P = 166 \text{ watts.} \]
\[ = \frac{1}{2} p A V^3 \]
For wind velocity 6.67 m/s (18mph)
Density of air (1.225 kg/m\(^3\))
\[ 166 = \frac{1}{2} \cdot 1.125 \cdot A \cdot (6.67)^3 \]
A= 1 Sq.m
\[ A = D \cdot H \text{ (Sq.m)} \]
D= diameter of the blade
Taking diameter as 1 meter, height of turbine can be calculated as
H = A/D = 1/1
H = 1m.
Diameter and height of wind turbine are 1m and 1m$^2$.

**Design of Turbine Blades [6]**

Wing width = diameter * 0.14
= 1 * 0.14
= 0.140m = 140 mm

Wing chord = circumference * 0.09
= π * 1 * 0.09
= 0.282m = 282mm

![Fig 3: Blade parameters](image)

**Block diagram**

![Fig. 4: Block Diagram](image)
4. CAD DESIGN

Wooden frame

Blades

Exploded view
5. DESIGN SPECIFICATIONS

Table 2: Turbine specifications

<table>
<thead>
<tr>
<th>Wind rotor</th>
<th>Rated power</th>
<th>35W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut in speed</td>
<td>3 m/s</td>
<td></td>
</tr>
<tr>
<td>Rated speed</td>
<td>6.67 m/s</td>
<td></td>
</tr>
<tr>
<td>Rotor diameter</td>
<td>1 m</td>
<td></td>
</tr>
<tr>
<td>Swept area</td>
<td>1 m^2(1 m*1 m)</td>
<td></td>
</tr>
<tr>
<td>Gear box type</td>
<td>None gear box, direct given to generator</td>
<td></td>
</tr>
<tr>
<td>Brake</td>
<td>Not required</td>
<td></td>
</tr>
<tr>
<td>Generator</td>
<td>Generator type</td>
<td>DC generator</td>
</tr>
<tr>
<td>Electric Transmission</td>
<td>Brushless</td>
<td></td>
</tr>
<tr>
<td>Turbine blade</td>
<td>Blade type</td>
<td>J-type(drag)</td>
</tr>
<tr>
<td>Blade number</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Blade material</td>
<td>GI sheet with Wooden frame</td>
<td></td>
</tr>
<tr>
<td>Hub material</td>
<td>MS</td>
<td></td>
</tr>
<tr>
<td>Blade dimension</td>
<td>Length</td>
<td>1m</td>
</tr>
<tr>
<td></td>
<td>Cup radius</td>
<td>0.126 m</td>
</tr>
<tr>
<td>Controller</td>
<td>PC16877A</td>
<td></td>
</tr>
</tbody>
</table>

Observation Table

Table 3: Observation table

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Speed (rpm)</th>
<th>Voltage (Volts)</th>
<th>Current (Ampere)</th>
<th>Power (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>4.39</td>
<td>1.86</td>
<td>8.16</td>
</tr>
<tr>
<td>2</td>
<td>39</td>
<td>4.64</td>
<td>2.28</td>
<td>10.61</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>5.73</td>
<td>2.28</td>
<td>13.06</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>6.14</td>
<td>2.98</td>
<td>17.78</td>
</tr>
<tr>
<td>5</td>
<td>97</td>
<td>7.16</td>
<td>3.64</td>
<td>26.39</td>
</tr>
</tbody>
</table>
6. RESULT DISCUSSION

The results obtain were up to expectations. While in theoretical design we considered the efficiency of turbine to be 25%, but we got efficiency as 23.3%. The efficiency was decreased due various manufacturing errors and friction losses.

7. CONCLUSION

Our work and the results obtained so far are very encouraging and reinforce the conviction that vertical axis wind energy conversion systems are practical and potentially very contributive to the production of clean renewable electricity from the wind even under less than ideal siting conditions this project will be helpful in rural areas where the electricity supply is scarce. Also in most cities, bridges are a faster route for everyday commute and in need of constant lighting makes this an efficient way to produce energy.

8. FUTURE SCOPE

The efficiency can be increased by precise fabrication of prototype and also by designing the blades of the turbine more aerodynamically and use simulation software like CFD. The development of effective alternators and dynamos can be used to harness wind energy from relatively small winds. The use of materials like Acrylic Plastic Sheets can be used to develop low cost VWAT.

REFERENCES

5. www.windgenkits.com
6. www.windstuffnow.com