Design, Fabrication and Testing of a Low Cost Vertical Axis Wind Mill for Low End Power Generation

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Abstract – *A vertical axis wind mill is designed, fabricated and tested to verify its suitability for low end power generation applicable for low voltage DC powered electronic equipment like mobile phones, smart phones, tablets and battery banks. Low cost material and easily available materials conforming to standards were used for the purpose to keep the overall cost minimal. The purpose of the wind mill is to meet the power requirements during natural disasters like earth quakes, cyclones and floods when the power supply from the grid is interrupted. It was observed that DC power of 90 mA at 0.2 volts could be generated with the wind mill. Use of lighter materials and better design could yield higher electrical parameters.*

Key Words: **Wind Mill, Wind Energy, Vertical Axis, Low Cost, CFD, Design, Fabrication**

1. INTRODUCTION

Wind power was first used long time ago by many civilizations during mankind history to produce mechanical energy or for navigation. Only with the use of coal and oil in the last two centuries its importance decreased, but during the last decades the interest on this topic grew as much as the possible business around it. Since the beginning, two types of windmills and turbines have been built to use this renewable source: some machines with horizontal axis of rotation (HAWT) and some other with vertical axis (VAWT). The first type is the most common today, but growing market asks for machines with different proprieties to fit different requests. VAWT design have been always mistreated by literature and market, but with some new or improved technologies and decreasing prices for valuable materials such as permanent magnet, together with the peculiarity of VAWT turbines to operate were other types have problems, this turbine can have a very important advantage in the actual market. We want to investigate some structural and very important characteristics of a new kind of VAWT, which is made by aluminium blades.

The motivation of this work is to develop a portable and low cost wind mill which can meet the low voltage power demands of electronic communication devices like smart phones and battery banks. This wind mill will be handy during natural calamities when grid power supply fails.

1.1 Vertical Axis Wind Mill

Vertical Axis Wind Turbines are designed to be economical and practical, as well as quiet. They are great for use in residential areas whereas the HAWT is best for use at a business location. There are two different styles of vertical wind turbines out there. One is the Savonius rotor, and the second is the Darrieus model. Most of the wind turbines being used today are the Savonius models. The advantages of a vertical axis wind mill are:

i. Independence on wind direction, no additional control mechanisms are required [1]
ii. Electrical equipment can be placed at ground level
iii. Low noise.
iv. Compact size and
v. Simple and cheap construction.

2. DESIGN APPROACH

The initial stage of the project involved software analysis of the proposed designs. ANSYS FLUENT was used for the simulation. SOLIDWORKS was used for modelling purposes. Minimum diameter for shaft was calculated, blade dimensions and the necessary motor required to convert the mechanical energy into electrical was procured. Further, a stress analysis and deformation analysis is done to determine the minimum deflection or deformity of the blade design, therefore a single material is chosen amongst other options.

2.1 Design Constraints

Economic constraints – the turbine is to be setup at minimal cost affordable to everyone.

Material constraints – the material used for turbine blades should be economical, light weight and have good mechanical properties.

2.2 Standards Used

- IEC 61400-1 Design requirements [2]
- IEC 61400-2 Small wind turbines
- IEC 61400-5 Wind turbine rotor blades
- IEC 61400-12 Wind turbine power performance testing [3]

2.3 Design Approach

$P = C_p \frac{1}{2} \rho A V^3$ …… eqn (1)
(Standard power equation based on kinetic energy)

P = Power Output = 10 Watts
C_p = Coefficient of Power = 0.24 [4]
ρ = Density of air = 1.225 kg/m^3
A = Swept area = D x H
V = Velocity of air = 5 m/s

For charging a mobile phone, 2-6 Watts is required. Hence, Power output is taken as 10 W including all the losses.

Substituting the values in eqn (1), value of **A** is obtained to be as 0.54m^2

Diameter (m)	Height (m)
0.54	1
0.6	0.9
0.7	0.77

A diameter of 0.54 m has been chosen to obtain higher rotations per minute.

2.3.1 Selection of an Optimized Blade Profile

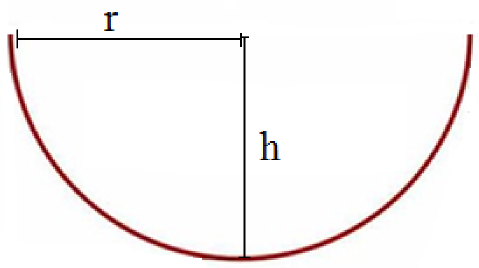

Fig. 1 – Blade Profile

As we can see in the above figure 1, height to radius ratio was varied and analyzed to select the optimum ratio between the two. The radius is constant for all the blade profiles and is equal to 15 cm.

Blade profile	H(cm)	R(cm)	H/R
I	3.75	15	0.25
II	7.5	15	0.5
III	15	15	1
IV	18.75	15	1.25
V	22.5	15	1.5

Table 1- Variations in blade profile

Table 1 shows the dimensions of different blade profiles. Figures 2 to 6 show different blade profiles used for simulations.

The different blade profiles are as follows:

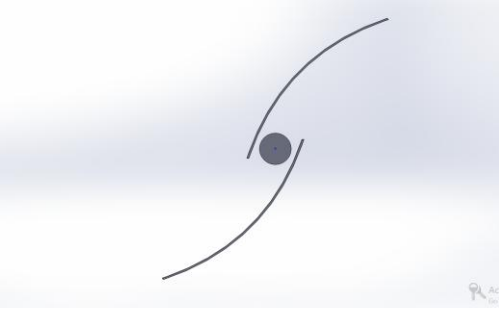

Fig. 2 – Blade profile I with H/R = 0.25

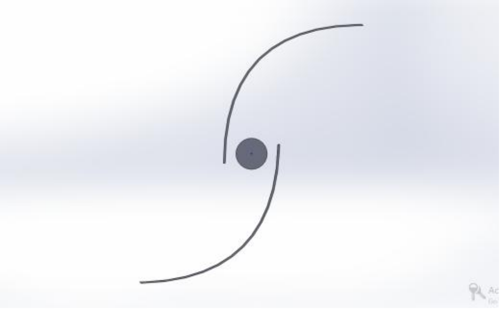

Fig. 3 – Blade profile II with H/R = 0.5

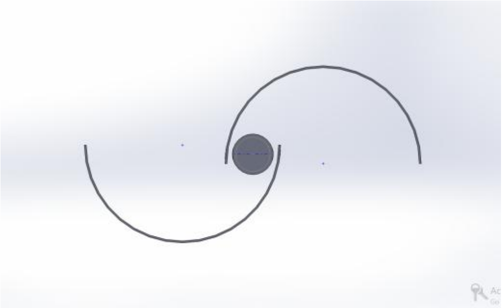

Fig. 4 – Blade profile III with H/R = 1

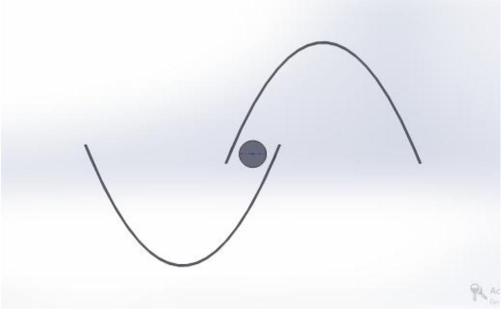

Fig. 5 – Blade profile IV with H/R = 1.25

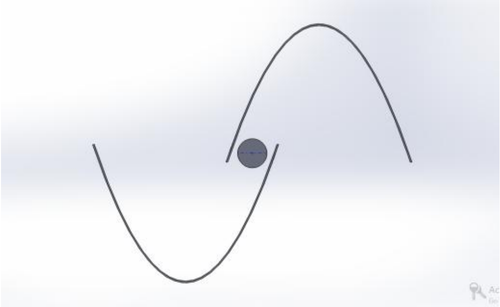

Fig. 6 – Blade profile V with H/R = 1.5

For each of the blade profiles, simulation was done at 3 different velocities of air i.e. 5m/s, 10m/s and 15 m/s and the drag force acting on the blades was found out in each case. Based on the drag force estimated, a total nodes of 19791 have been chosen for ease of CFD simulation.

The Table 2 shows the drag forces for various blade configurations.

H/R	Velocity (m/s)	Drag force (N)
0.25	5	9.19
	10	35.92
	15	80.37
0.5	5	9.06
	10	35.21
	15	76.28
1	5	**16.08**
	10	**63.31**
	15	**141.39**
1.25	5	15.71
	10	60.71
	15	136.24
1.5	5	15.18
	10	60.1
	15	135.23

Table 2 – variation of drag force

From Table 2, it can be concluded that the value of drag force is maximum at H/R=1 for all the velocity profiles. Hence, the blade profile III would generate maximum torque at a particular velocity. It can also be stated that the blade profile III would have better self-starting capacity even at a low speed as compared to other profiles.

Thus, blade profile III was chosen for further analysis with the dimensions as shown in Fig. 7.

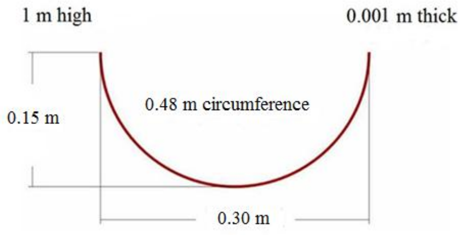

Fig. 7 – Dimensions of blade

2.3.2 Selection of Blade Material

Aluminium, Stainless Steel and Carbon Fiber [5] were used to study deformation and stress induced at different velocities. One material was selected out of the three for fabrication of the prototype after analysis.

Properties Materials	Density (kg/m^3)	Young's Modulus (GPa)	Yield Strength (MPa)	Cost (Rs./kg)
Aluminium	2719	69	276	170
Stainless Steel	7800	200	215	250
Carbon Fiber	1600	70	NA	1800

Table 3 – Material properties

Properties Materials	Density (kg/m^3)	Cost (Rs./kg)	Velocity (m/s)	Deformation (mm)	Stress induced (MPa)
Aluminium	**2719**	**170**	5	**0.8**	**3.47**
			10	**2.61**	**11.3**
			15	**5.23**	**22.6**
Stainless Steel	7800	250	5	0.3	3.49
			10	0.97	11.35
			15	1.95	22.7
Carbon Fiber	1600	1800	5	0.9	3.49
			10	2.95	11.35
			15	5.90	22.71

Table 4 – Cost, Deformation and stress induced

From Tables 3 and 4, it be found that the stress induced in all the materials is almost the same but the deformation is minimum in case of Stainless Steel. Also, the material of the blade should be light in weight and economical. Carbon Fiber is light in weight but is not economical and has poor mechanical properties as compared to aluminium and stainless steel. Stainless steel has better mechanical properties than aluminium but is very heavy and slightly costlier than aluminium. Considering all the above factors, **Aluminium** was chosen as the blade material.

The shaft was designed based on the factor of safety 3 as recommended by [6]. The shaft diameter is estimated as 20 mm.

The estimated power output of the wind mill for various wind speeds is shown below:

Velocity (m/s)	Power (Watts)
5	10
7.5	33.48
10	79.38
12.5	155
15	267

Table 5 – Theoretical power output

Table 5 shows the theoretical power output at different velocities calculated using eqn (1). Since the output of the turbine is less than 300 kW it is a small wind turbine. Hence, **IEC 61400-2 for small wind turbines.**

3. FABRICATION

The designed wind mill is fabricated in the university workshop with commonly available tools. The procedure is as follows:

- Measurements are taken and marked on the base plates.
- Drilling is done for the purpose of attaching motor, shaft and primary support.
- Shaft is machined along with the aluminium blades. Three holes are made in these in order to be fixed.
- Other end of the shaft is machined in order to be fixed into the coupler for mechanical support and better rotation.
- Assembly is done. Wires extending from motor are used to measure output.

The following figures 8 and 9 show the base plate and blade assembly.

Fig. 8 - Base Plate assembly

Fig. 8 shows the base plate assembly. It consists of three base plates welded together with the help of eight support rods. The DC motor is supported with screws. Two bearings are used to support the shaft since the shaft is long.

Fig.9 - Vertical Axis Wind Turbine

Fig. 9 shows the final assembly of the Vertical Axis Wind Turbine.

4. TESTING

The assembled set up was tested using a wind speed of 5 m/s which was measured using an anemometer. Electrical output was obtained from the motor and was measured with the help of multimeter. For an average wind speed of 5 m/s the maximum voltage was 0.2 V and maximum current was 90 mA.

5. COST ANALYSIS

The following Table 5 shows the cost involved.

Material	Length (cm)	Diameter (mm)	Quantity	Cost (Rs.)
MS Shaft	150	20	1	180
Bearing	-	20	2	300
Aluminium blades	92 x 46	300	2	350
MS Base plate	30 x 30	8 (thickness)	2	550
MS Support rod	20	18	4	150
Screws	12	4	4	20
Coupler	8	20	1	-
Nuts and Bolts	12	10	5	50
DC Motor	24 Volts 100 Watts			2700
			Total	4300

Table 5 – Cost analysis

6. CONCLUSIONS

Five different blade profiles were used to compare and analyze under the software proficiency considering variations in proportion, velocity and material of the blades. The blade profile with H/R ratio equal to 1 was obtained as the optimum profile since it generated maximum drag force amongst all other profiles. Higher value of drag force will correspond to higher torque and hence better self-starting capacity of the turbine even at low wind velocities.
Aluminium was chosen as the best material considering the factors like good strength, light weight, economical and minimum deformation as compared to other materials.

The optimized design was successfully fabricated and tested for results. Electrical output was generated and demonstrated. Output was measured by using multimeter.

Electrical output generated is as follows:
Maximum current – 90 mA
Maximum voltage – 0.2 V

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