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An Investigative Study on Design And Thermodynamic Aspects Of A Light Duty Vertical Axis Wind Turbine

Prof. S A Mohan Krishna[1]

[1]Department of Mechanical Engineering, Vidyavardhaka College of Engineering,
Mysore-570002, Karnataka, India

Abstract

With the recent surge in fossil fuels prices, demand for cleaner energy sources, and government funding incentives, wind turbines have become a viable technology for power generation. Currently, horizontal axis wind turbines (HAWT) dominate the wind energy market due to their large size and high power generation characteristics. However, vertical axis wind turbines (VAWT) are capable of producing a lot of power, and offer many advantages. The mechanical power generation equipment can be located at ground level, which makes for easy maintenance. The drag-based Savonius Vertical Axis Wind Turbine (VAWT) has shown promising applications for use on the tops of buildings, enabling clean energy production at the site of its use, virtually eliminating transportation losses. Also, VAWT are omni-directional, meaning they do not need to be pointed in the direction of the wind to produce power. Finally, there is potential for large power generation with VAWT because their size can be increased greatly. However, there are also downfalls to the VAWT. Firstly, boundary layer affects from the ground influence the air stream incident on theVAWT, which in some cases leads to inconsistent wind patterns. Secondly, VAWT arenot self-starting; currently, an outside power source is required to start turbine rotationuntil a certain rotational speed is reached.The main objective of this project is to design and build a self-starting vertical axis windturbine. This report outlines the first term efforts in the design of our small-scale VAWT.

Keywords: *Angle of Attack, Darrieus, Drag, H-Rotor, VAWT, Leading Edge, Trailing Edge, Yaw.*

1. INTRODUCTION

Energy is the primary and most universal measure of all kinds work by human beings and nature. Everything what happens the world is the expression of flow of energy in one of its forms. Energy is subject to the “law of conservation of energy”. With the recent surge in fossil fuels prices, demand for cleaner energy sources, andvgovernment funding incentives, wind turbines are becoming a more viable technology forelectrical power generation. Wind energy is the kinetic energy associated with the movement of atmospheric air. It is used for hundreds of years for sailing, grinding grain, and for irrigation. Wind Energy Systems convert this kinetic energy to more useful forms of power. Fortunately there is an abundance of wind energy to be harnessed. Currently, Horizontal Axis Wind Turbines (HAWT) dominates commercially over Vertical Axis Wind Turbines (VAWT). However, VAWT do have some advantages over HAWT.

Vertical axis wind turbines or VAWT can be divided into two major classifications

1. Savonius Vertical Axis Wind Turbine
2. Darrieus type turbines

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1. Savonius vertical Axis Wind Turbine is drag based like the simple wind anemometer.

2. Darrieus type turbines are based on Bernoulli's principle that faster moving air is relatively lower in pressure. These turbines have airfoil-like blades.

Each turbine has its respective advantages and disadvantages. Savonius type turbines work well with low-speed wind and are self starting. Darrieus type turbines, on the other hand, have great difficulty starting and operate better under high-speed wind conditions. We chose to investigate Savonius turbines mainly because of their ability to self-start, an attribute that would be useful in situation such as one where a rapid response to changing wind conditions is necessary.

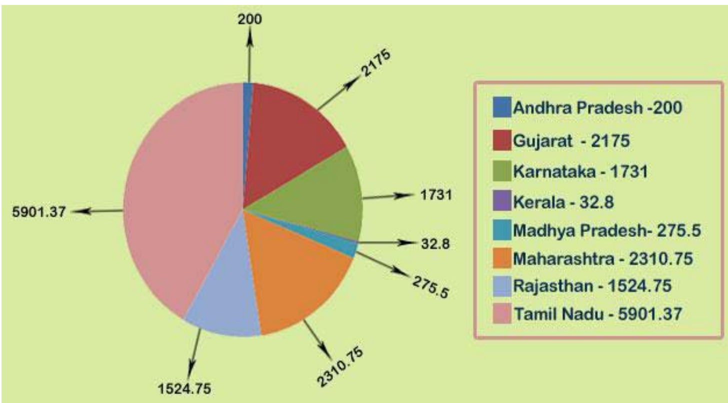

Fig 1: Wind power installed capacity state wise

2. LITERATURE SURVEY

Wind tunnel tests were conducted to assess the aerodynamic performance of single, two-and three-stage Savonius rotor by U.K. Saha, S. Thotla, D. Maity systems of Department of Mechanical Engineering, Indian Institute of Technology Guwahati, India. Experiments were carried out to optimize the different parameters like number of stages, number of blades (two and three) and geometry of the blade.

The Test facility is as follows: To study the performance of Savonius wind turbine a low speed wind tunnel with an open test section facility has been designed, developed, fabricated (Grinspan, 2002; Grispan et al., 2003 . The rotor axis is placed at a distance of 205 mm from the tunnel exit having a cross section area of 375 mm × 375 mm. By changing the input voltage, the wind tunnel exit air velocity can be changed. The entire tests have been conducted in the range of air velocity of 6–11 m/s. A thermal velocity probe anemometer was used to measure the airspeed with an accuracy of 70.1 m/s, while the rotational speed (RPM) of the rotor was measured with a digital tachometer. A brake dynamometer measures the static and the dynamic torques. Experiments have been conducted with four different types of blades viz., (a) Curved blade (b) Straight blade (c) Aerofoil blade and (d) Twisted blade. In the present work, both straight and curved blades have been redesigned and tested. From this investigation, an aerofoil shaped blade and a twisted blade have been designed, fabricated and tested in the same set-up.

3. EXPERIMENTAL SETUP

A model has been built and installed at a selected site. The investigative study produces an investigational exploration of a Savonius rotor wind turbine adapted for household electricity generation. The turbine collects wind energy and converts it into electricity, which in turn produces 12 V output which is used to charge one heavy duty battery. A small electricity generator has been designed for household installation. The generator (alternator) is driven by a modified Savonius rotor. This type of rotor (which is of the vertical axis variety) is chosen instead of a horizontal axis machine due to its simplicity and reliability. The S-rotor has been designed using an analytical method and confirmed by natural wind testing. The Savonius generator relies solely on drag to produce a force that turns the turbine shaft. It consists of three simple scoops, where one side catches the moving air more than the other causing the turbine to spin. This design does not allow the turbine to spin faster than the oncoming wind. This type of turbine is simple to build, and because it is vertical there is no need to have a mechanism to keep it turned into the wind. The turbine frame stands 1000 mm tall, and produces power from a direct drive, single phase brushless permanent magnet alternator.

Fig 3.1 Fabrication of a Vertical Axis Wind Turbine

The rotor blades are constructed from Acrylic plates bent to form semi circular blades. These Blades are mounted between two end plates made from M.S 100 mm long × 40 mm wide × 3 mm thick. The ends of the blades are simply bolted to the M.S pieces with M6 bolts, washers and locking nuts. The main shaft through the centre of the rotor is a ½ inch (27.5 mm) diameter hallows mild steel which is vertical in alignment. The frame consists of horizontal and vertical supports. Horizontal Supports: 2 pieces of 750 mm × 100 mm × 25 mm, 2 mm thick hallow M.S. plates Vertical Supports: 2 square 25 mm hollow pipes. The joints are securely attached with arc welding, and angle plate 2 mm thick to hold the bearing housing is supported to horizontal supports by M8 bolts. The lower cross member is 200 mm above the ground and the turbine height is 500 mm. A car alternator is used as the generator for this wind turbine. The most suitable car alternator was found to be the Lucas 17ACR. It is a 36 amp alternator and starts to charge at 900 rpm. It is most important to match the size of generator as closely as possible to the rotor. The alternator is connected to the left hand side of the main frame by two M10 bolts, locking nuts and washers. To keep the voltage drop to a minimum the wiring from the alternator to the battery was rated at 30 amps, and a fuse of 10 amps was placed in the battery circuit near the positive battery terminal for protection.

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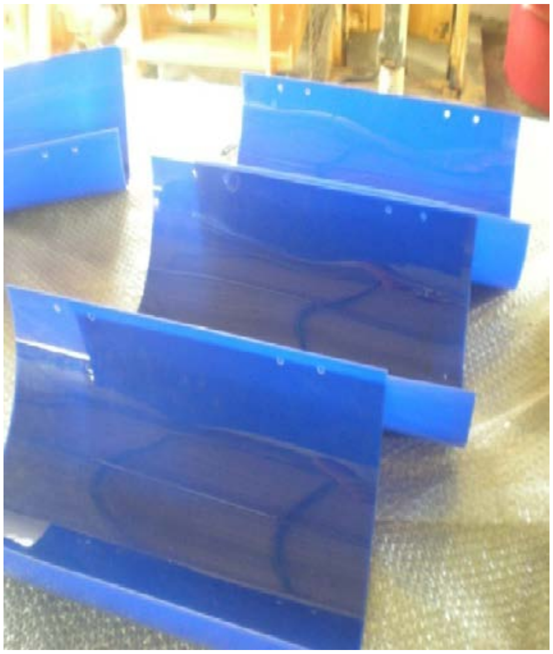

Fig.3.2 Rotor blades (acrylic material)

Fig.3.3 Lucas 17ACR alternator

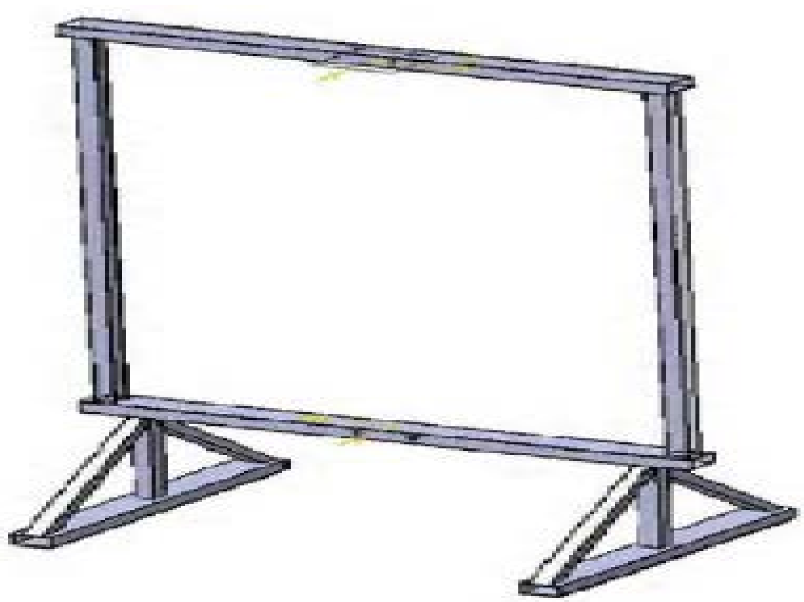

Fig.3.4-3D view of the support stand created using CATIA

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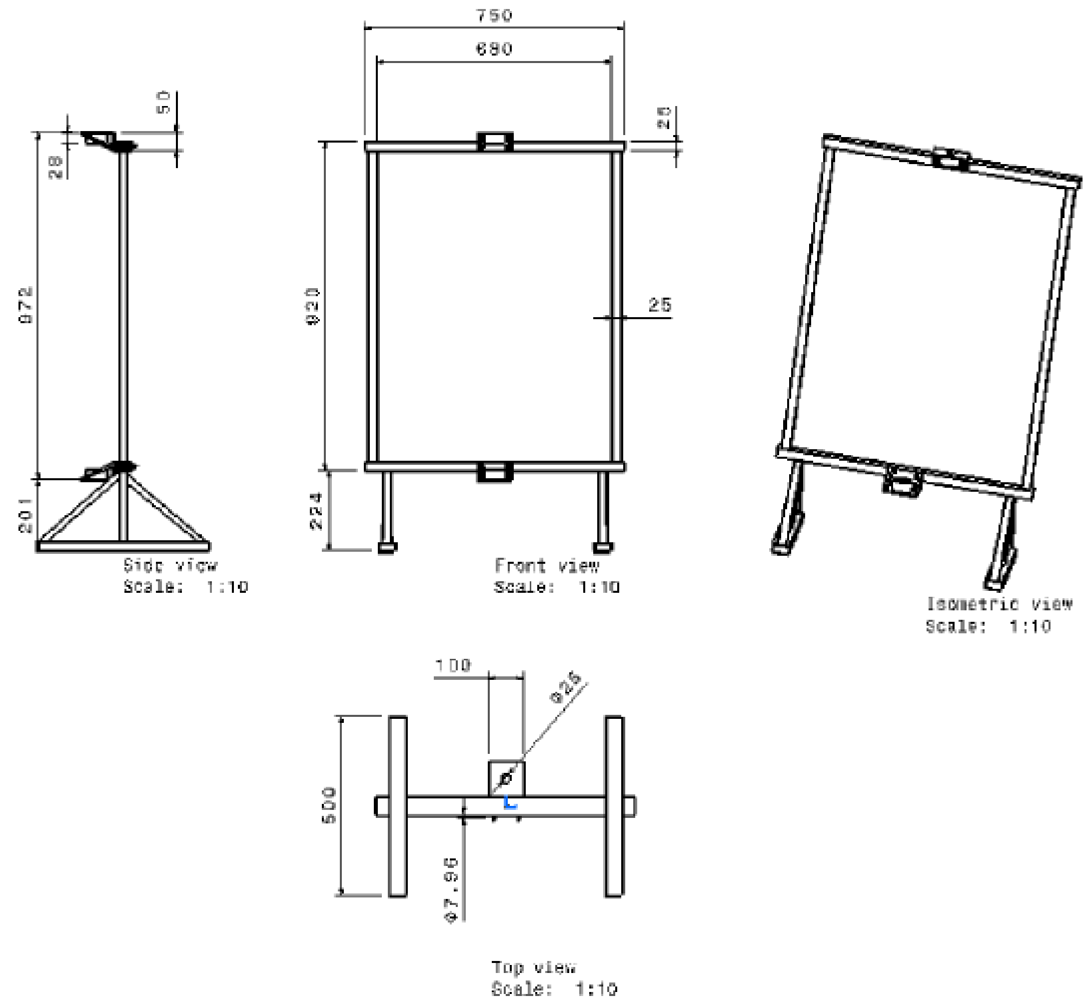


Fig.3.5 Frame Construction

4. RESULTS AND DISCUSSIONS

Design Calculations

i. Design specifications and limitations Minimum power to be extracted from the wind
P =20 W

ii. Minimum wind speed to extract that power =3.5 m/s

iii. For stability, diameter to height ratio fixed at D /H=1.1 -> D=1.1×H

iv. From the selected concept, the turbine is semi circular shaped, hence the swept area is
A swept =D×H=1.1×H2

Performance Calculations

Height H**=0.5m** and Chord Length of each blade= 0.240 m

Hence, Rotor Diameter **D=0.537m** (240+27.5+15mm)

Then swept area

A swept=D×H=0.537×0.5

A swept =0.2685 m^2

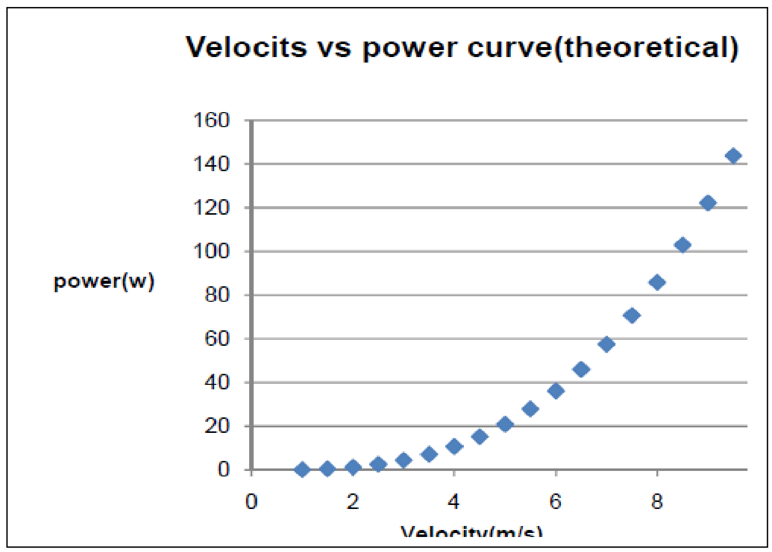
Power from this swept area, Pw = 0.625×0.2685× v3

Pw = 7.19 W

Based on the design and performance calculations expected power output at various wind speeds maintaining the turbine swept area constant are tabulated below:

Table.4.1. Power Calculation for Various Wind Speeds

Slno	V(m/s)	P(W)
1	1	0.167813
2	1.5	0.566367
3	2	1.3425
4	2.5	2.62207
5	3	4.530938
6	3.5	7.194961
7	4	10.74
8	4.5	15.29191
9	5	20.97656
10	5.5	27.9198
11	6	36.2475
12	6.5	46.08551
13	7	57.55969
14	7.5	70.7959
15	8	85.92
16	8.5	103.0579
17	9	122.3353
18	9.5	143.8782
19	10	167.8125



PARTICULARS	FORMULA	VALUE OBTAINED
Power available from air at maximum wind speed	P=0.5×ρ×Aswept×V3	155.42 W
Maximum speed of rotor	$\frac{V \times \lambda \times 60}{2\pi R}$	1273 rpm
Angular speed	$\frac{2\pi N}{60}$	133 rad/sec
Required shear stress for M.S pipe	$\frac{T}{J} = \frac{\tau}{R}$	0.6118 N/mm^2
Centrifugal force on bearing	$me\omega^2$,	5.33 kN

After carrying out the design calculations, the following were finalized

1. The hollow shaft chosen was medium carbon steel (C40 of 27.5mm OD and 23.5mm ID).

2. SKF 6305 bearing was selected.

3. M8 bolts were used.

5. CONCLUSION

One can foresee some future where each human dwelling in the world is equipped with a wind machine as global peak oil is reached making them indispensable for human well being. They are well suited for green buildings architectural projects as well as futuristic aquaponics; where vertical farming in a skyscraper uses automated farming technologies converting urban sewage into agricultural products. Their cost will come down appreciably once they are mass produced on a production line scale equivalent to the automobile industry. The economic development and viable use of horizontal axis wind turbines would, in the future be limited, partly due to the high stress loads on the large blades. It is recognized that, although less efficient, vertical axis wind turbines do not suffer so much from the constantly varying gravitational loads that limit the size of horizontal axis turbines. Economies of scale dictate that if a vertical axis wind turbine with a rated power output of 10 MW could be developed, with at least the same availability as a modern horizontal axis turbine, but at a lower cost per unit of rated power, then it would not matter if its blade efficiency was slightly lower from 56 to about 19-40 percent. The initial goal of the project was accomplished, as this is a solution to low wind speed areas. The potential of the concept has been proven to function. This design fills the functions required of a self-starting vertical axis wind turbine for use in low wind areas. It represents a new breed of VAWT suitable even for the urban environment. The higher the solidity, the higher the power produced and therefore the higher the torque produced. It is therefore desirable to have as high a solidity as possible so it can operate in as low a wind speed as possible.

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