CONSTRUCTION AND PERFORMANCE ANALYSIS OF SAVONIUS VERTICAL AXIS WIND TURBINE

This thesis paper is submitted to Department of Mechanical Engineering, Sonargaon University of partial fulfillment in requirements for the degree of Bachelor of Science in Mechanical Engineering

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DECLARATION OF AUTHORSHIP

We, Md Atikur Rahman, Md. Bellal Sharif, Md. Rubel Hossain And Sabrina Akter Sumi declare that this thesis titled, “**CONSTRUCTION AND PERFORMANCE ANALYSIS SAVONIUS VERTICAL AXIS WIND TURBINE**” and the work presented in it are our own and has been generated by us as the result of my own original research.

We confirm that:

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2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
3. Where we have consulted the published work of others, this is always clearly attributed.
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5. We have acknowledged all main sources of help.
6. None of the part of this work has been published before submission.

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ABSTRACT

In the current age of global energy crisis, the production of energy through alternate energy resources has gained a significant attention. Wind as a source of energy is a very attractive due to the fact that fuel is free of cost in this case. This research is about the design of a VAWT blade using the analytical and CFD (Computational Fluid Dynamics) techniques for a small scale vertical axis wind turbine (VAWT), aiming 04 Volt power output which may be use for domestic purposes to power a single room. The blade design parameters and dimensions are taken aiming the required power output and analytical models are developed to evaluate the aerodynamic forces like lift and drag over the surface of the blade. These forces which are very helpful for the evaluation of the structural integrity of the VAWT blade are then found to be in a close agreement with CFD results which are simulated using commercial software, solid works. The static CFD model is developed at a selected pitch angle during a complete 360° where the aerodynamic forces evaluated are comparable with the analytical values at the similar location.

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NOMENCLATURE

Symbol	Description	Unit
A	Swept area	m^2
C_d	Coefficient of drag	
C_p	Coefficient of power	
C_t	Coefficient of torque	
D	Rotor diameter	m
F	Force	N
F_w	Wind force	N
H	Rotor height	m
I	Current	A
P_a	Power available	watt
u_∞	Free steam velocity	m/s
U	Wind speed	m/s
n	Number of blades	
P_{active}	Active electrical power generated	watt
P_t	Turbine power	watt
P_{total}	Total electrical power	watt
P_w	Wind power	watt
r	The radius of semi-circular section of rotor	m
T	Torque	N-m
R	Rotor radius	m
R_l	Load resistance	Ohm
R_s	Stator resistance	Ohm
W	Weight of blade	Kg
T_{Base}	Rated Torque	N-m
T_p	End plate thickness	m
t_t	Blade thickness	m
V_{rotor}	Velocity of rotor	m/s
α	Angle of attack	rad
ρ	Free stream density	kg/m^3
λ	Tip speed ratio, m	
λ_r	Rotor flux linkage	
τ	Maximum shear stress	N/mm^2

CHAPTER-I
INTRODUCTION

1.1 Wind Turbine:

A wind turbine, or alternatively referred to as a wind energy converter, is a device that converts the wind's kinetic energy into electrical energy.

Wind turbines are manufactured in a wide range of vertical and horizontal axis. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels. One assessment claimed that, as of 2009, wind had the "lowest relative greenhouse gas emissions, the least water consumption demands and... the most favorable social impacts" compared to photovoltaic, hydro, geothermal, coal and gas.[1]

1.2 Types of Wind Turbine:

1.2.1 Horizontal axis Wind Turbine (HAWT): [2]

Large three-bladed horizontal-axis wind turbines (HAWT) with the blades upwind of the tower produce the overwhelming majority of wind power in the world today. These turbines have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a yaw system. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

Fig. 1.1: Horizontal axis Wind Turbine

Some turbines use a different type of generator suited to slower rotational speed input. These don't need a gearbox and are called direct-drive, meaning they couple the rotor directly to the generator with no gearbox in between. While permanent magnet direct-drive generators can be more costly due to the rare earth materials required, these gearless turbines are sometimes preferred over gearbox generators because they "eliminate the gear-speed increaser, which is susceptible to significant accumulated fatigue torque loading, related reliability issues, and maintenance costs." There is also the pseudo direct drive mechanism, which has some advantages over the permanent magnet direct drive mechanism. The rotor of a gear less wind turbine is being set. This particular turbine was prefabricated in Germany, before being shipped to the U.S. for assembly. Most horizontal axis turbines have their rotors upwind of the supporting tower.

1.2.2 Vertical axis Wind Turbine (VAWT): [3]

A vertical-axis wind turbine (VAWT) is a type of wind turbine where the main rotor shaft is set transverse to the wind (but not necessarily vertically) while the main components are located at the base of the turbine. This arrangement allows the generator and gearbox to be located close to the ground, facilitating service and repair. VAWTs do not need to be pointed into the wind,[1][2] which removes the need for wind-sensing and orientation mechanisms. Major drawbacks for the early designs (Savonius, Darrieus and giromill) included the significant torque variation or "ripple" during each revolution, and the large bending moments on the blades. Later designs addressed the torque ripple issue by sweeping the blades helically (Gorlov type).

Fig. 1.2: Vertical axis Wind Turbine

A vertical axis wind turbine has its axis perpendicular to the wind streamlines and vertical to the ground. A more general term that includes this option is "transverse axis wind turbine" or "cross-flow wind turbine." For example, the original Darrieus patent, US Patent 1835018, includes both options.

Drag-type VAWTs such as the Savonius rotor typically operate at lower tip speed ratios than lift-based VAWTs such as Darrieus rotors and cyclo-turbines.

1.2.3 Darrieus wind turbine:

"Eggbeater" turbines, or Darrieus turbines, were named after the French inventor, Georges Darrieus. They have good efficiency, but produce large torque ripple and cyclical stress on the tower, which contributes to poor reliability. They also generally require some external power source, or an additional Savonius rotor to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades, which results in greater solidity of the rotor. Solidity is measured by blade area divided by the rotor area. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing.

1.2.4 Giromill:

A sub-type of Darrieus turbine with straight, as opposed to curved, blades. The cyclo-turbine variety has variable pitch to reduce the torque pulsation and is self-starting. The advantages of variable pitch are: high starting torque; a wide, relatively flat torque curve; a higher coefficient of performance; more efficient operation in turbulent winds; and a lower blade speed ratio which lowers blade bending stresses. Straight, V, or curved blades may be used.

1.2.5 Savonius Wind Turbine:

Savonius wind turbines are a type of vertical-axis wind turbine (VAWT), used for converting the force of the wind into torque on a rotating shaft. The turbine consists of a number of aerofoil’s, usually—but not always—vertically mounted on a rotating shaft or framework, either ground stationed or tethered in airborne systems.

The Savonius wind turbine was invented by the Finnish engineer Sigurd Johannes Savonius in 1922.

Fig. 1.3: Savonius Wind Turbine

However, Europeans had been experimenting with curved blades on vertical wind turbines for many decades before this. The earliest mention is by the Italian Bishop of Czanad, Fausto Veranzio, who was also an engineer.

These are drag-type devices with two (or more) scoops that are used in anemometers, Flettner vents (commonly seen on bus and van roofs), and in some high-reliability low-efficiency power turbines. They are always self-starting if there are at least three scoops.
Twisted Savonius is a modified savonius, with long helical scoops to provide smooth torque. This is often used as a rooftop wind turbine and has even been adapted for ships.

1.3 Advantages of VAWT:

VAWTs offer a number of advantages over traditional horizontal-axis wind turbines (HAWTs):

- Being Omni-directional, some forms do not need to track the wind. This means they don't require a complex mechanism and motors to yaw the rotor and pitch the blades.
- VAWTs generally function better than HAWTs in turbulent and gusty winds. HAWTs cannot efficiently harvest such winds, which also cause accelerated fatigue.
- The gearbox of a VAWT takes much less fatigue than that of a HAWT.
- In VAWTs, gearbox replacement and maintenance are simpler and more efficient, as the gearbox is accessible at ground level, so that that no cranes or other large equipment are needed on-site. This reduces costs and impact on the environment. Motor and gearbox failures generally are significant considerations in the operation and maintenance of HAWTs both on and offshore.
- Some designs of VAWTs in suitable situations can use screw pile foundations, which hugely reduces the road transport of concrete and the carbon cost of installation. Screw piles can be fully recycled at the end of their life.
- Wings of the Darrieus type have a constant chord and so are easier to manufacture than the blades of a HAWT, which have a much more complex shape and structure.
- VAWTs can be grouped more closely in wind farms, increasing the generated power per unit of land area.
- VAWTs can be installed on HAWT wind farm below the existing HAWTs; this can supplement the power output of the existing farm.
- Research at Caltech has also shown that a carefully designed wind farm using VAWTs can have an output power ten times that of a HAWT wind farm of the same size.
- Cheaper to produce than horizontal axis turbines.
- More easily installed compared to other wind turbine types.
- Transportable from one location to another.
- Equipped with low-speed blades, lessening the risk to people and birds.

1.4 Disadvantages of VAWT:

- Rotors are generally near ground where wind is poorer.
- Poor self-starting capabilities.
- Requires support at top of turbine rotor sturdy construction.
- Overall poor performance and reliability.

1.5 Application:

- Marine Industry Power supply.
- Electricity for Housing Residential.
- Telecommunication
- Electricity on Agriculture & Fishery Industry.
- Rural (off-grid) areas.
- Billboard
- Street lighting.

1.6 Maintenance:

Wind turbines need regular maintenance to stay reliable and available. In the best case turbines are available to generate energy 98% of the time. Modern turbines usually have a small onboard crane for hoisting maintenance tools and minor components. However, large, heavy components like generator, gearbox, blades, and so on are rarely replaced, and a heavy lift external crane is needed in those cases. If the turbine has a difficult access road, a containerized crane can be lifted up by the internal crane to provide heavier lifting.

1.7 Objectives:

- To study the design, process and methodology of a vertical axis wind turbine.
- To build up a small scale vertical axis wind turbine by using PVC pipes and sheet metal.
- To utilize wind energy for the generation of electricity.
- To test the performance of the VAWT experimentally.
- To generate power at low cost.

CHAPTER-II

LITERATURE REVIEW

In this portion of the article, the main studies related to modeling and comparative performance analysis of different bladed VAWT are summarized and discussed.

Savonius type wind turbine has been experimentally studied by Mahmound N.H et. al. by considering its different geometries to determine the parameters that are most effective. The two blades rotor is highly efficient than three and four ones in his study. [4]

Alexander and Holownia [5] tested the effect of various parameters and the wind tunnel was used for carrying test on several different Savonius rotor geometries. It was concluded that, the tests for two blades rotor gave appreciably higher values of efficiency than three and four bladed.

Saha et. al., [6] made the comparison of different geometries of the Savonius rotor. It was concluded that for Savonius rotor the optimal number of blades is two. And also, two-stages of Savonius rotor proved better coefficient of power in comparison to the single- and three-stage rotors.

Bhutta, M.M.A., et. al., [7] studied the average wind velocity in Sindh is 5.1 to 5.6 m/s. As in the beginning VAWT first ever used to harness wind energy but these days HAWT is being installed at large scale because it was a perception that VAWT could not generate much electricity. VAWT is economical and useful for remote areas

Sai, S.J.V. and Rao, T.V., concluded that carbon emission by vehicles and industries could be reduced by using renewable energy and it would be cost efficient too. There is no need of additional force and it is also not dependent on wind direction to drive mechanism. Savonius wind turbine possesses outstanding starting torque Its construction is simple and is easy to maintain. And, it has low noise and emission. Only 45% of energy is utilized in useful work [8]

Wenehenubun, F., et. al., [9] described that when the difference of forces puts its pressure on each blade, Savonius turbine starts working as blades rotate around its central vertical shaft. Otherwise, the convex part hits the air wind to defect the blade. Since the curvature of the blade has less drag force, when it moves against the wind or Convex than blades move with the wind or Concave. Rotation of the rotor depends upon the number of blades. Three blades produce faster rotational speed and tip speed ratio than that two and four blades. Highest tip ratio is 0.555 with 7 m/s wind speed. Four blade turbines contain high torque as compared with two or three blades wind rotor. Four blade turbines possess good performance at lower tip speed ratio, but three blades has the best performance at higher tip speed ratio.

Ali, M.H., [10] from his experiments and calculations, it was seen that the two blade Savonius wind turbines are more efficient that three bladed turbines. And, it has higher co efficient power under the same test conditions. Because, if we increase the number of blades, drag surfaces will increase against the wind air flow and cause to increase the reverse torque and guides to decrease in the net torque working on the blades.

CHAPTER-III

MATHEMATICAL MODELING

3.1 Experimental Study:

In experimental study the experiments carried out on proposed dimensional savonius wind turbine in open or closed wind tunnel for testing the performance. In wind tunnel axial flow fan was mounted & encased in a circular mouth casing, when the wind tunnel starts then anemometer measures the velocity of wind, when wind is produced by fan it pushes the blade of turbine, then turbine will rotate. Rotation will measured by tachometer & torque of turbine measured by torque meter corresponding wind speed. This method gives accurate results but it is costly and time consuming method.

Coefficient of performance (C_p):- it is ratio of maximum power (P_t) obtained from wind and total power available (P_a) from wind. C_p can be calculated-

$$C_P = \frac{Pt}{Pa} = \frac{\mathrm{Pt}}{\frac{1}{2}\rho A V^3}$$

Where ρ is air density (1.225kg/m³), U is wind speed (m/s), A is swept area of rotor (m²).

Maximum power (P_t = watt) of wind turbine can be calculate.

$$P_t = T\,w \text{ (Watt)}$$

Swept area (A):- it is product of height and rotor diameter.

$$A = H \times D$$

Tip speed ratio (λ):- it is ratio of speed of tip blade (V_{rotor}) and wind speed through blade. It is calculated by-

$$TSR = \lambda = \frac{.V_{rotor}}{V}$$

Where, V_{rotor} is the tip speed.

Coefficient of torque (C_t):- It is ratio actual torque of rotor to theoretical torque of wind (T_w)

$$C_t = \frac{T}{Tw} = \frac{4T}{\rho A d V^2}$$

3.2 Torque Calculation for Savonius Rotor:

A mathematical model for the torque acting on the Savonius rotor is derived using the formula,

Torque = Force × Distance.

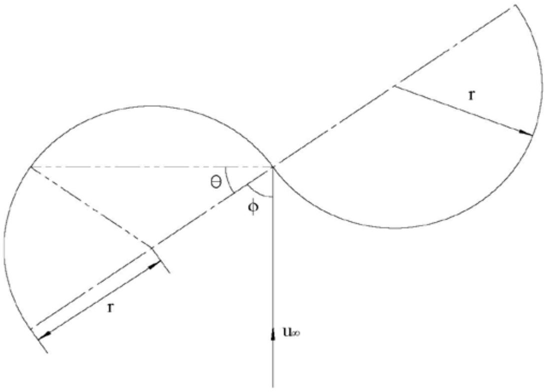

Fig. 3.1: Savonius Rotor Schematic

In **Fig.** 3.1, α is the angle of attack, θ is the angle subtended by the point of impact at the center of the rotor, r is the radius of the semi-circular section of the rotor, and u_∞ is the free stream velocity.

Given: r, θ, α, A (area of rotor), ρ (free stream density), C_d (Coefficient of drag), u_∞, and F (wind force).

Wind Force, $F = \frac{1}{2} \rho A u_\infty^2 C_d$.. (1)

According to the definition of Torque = Force × Distance

We can deduce that, from **Fig.** 3.2;

T= OA × F = OA.F.sin (∠OAC)... (2)

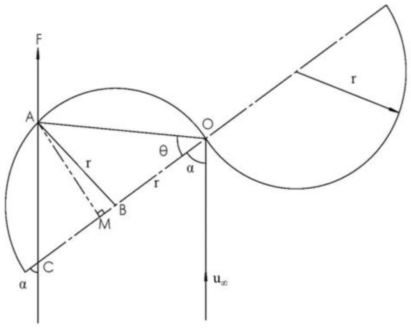

Fig. 3.2: Savonius Rotor with Angles and Forces

In, ΔAMB;

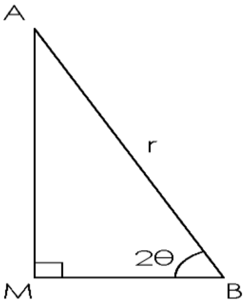

Fig. 3.3: Calculating the length, MB

Case- I: (when $2\theta < \pi/2$)

Then, $-\cos(2\theta) = MB/r$.. (3)

So, $MB = -r\cos(2\theta)$.. (4)

Case-II: (when $2\theta > \pi/2$)

Then, $-\cos(2\theta) = MB/r$.. (5)

So, $MB = -r\cos(2\theta)$.. (6)

In ΔAMO and ΔABO,

Case I:

$OM = OB + BM$.. (7)

$OM = r + r\cos(2\theta) = r(1+\cos(2\theta))$ .... (8)

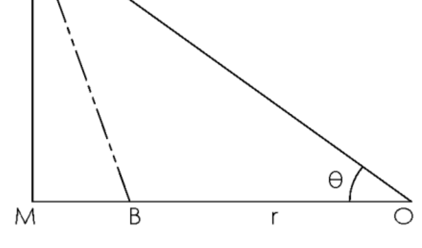

Fig. 3.4: Calculating the length, OM

Case II:

OM = OB – BM... (9)

OM = r + r cos (2θ) = r (1+ cos (2θ)).............. (10)

Also, cos (θ) = OM÷OA................................... (11)

OA= OM ÷ cos (θ)   ....12)

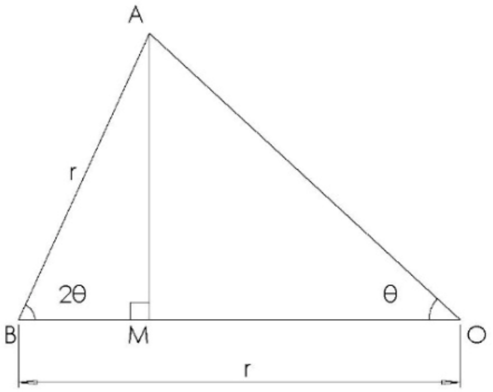

Fig. 3.5: Calculating the length, OA

OA = r (1+ cos (2θ)) ÷ cos (θ).. (13)

= r (1 + 2 cos² θ –1) ÷ cos (θ)

=   2 r cos (θ)

In ΔOAC,

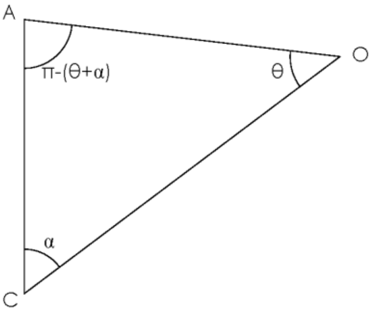

Fig.3.6: Calculating the Angle, OAC.

$\angle OAC = (\pi - (\theta + \alpha))$.. (14)

Substituting the unknowns into the equation of torque gives;

$T = OA.F.\sin(\angle OAC)$.. (15)

$T = 2r\cos\theta\,(\frac{1}{2}A\rho u_\infty^2 C_d)\sin(\pi-(\theta+\alpha))$.. (16)

$T = 2r\cos\theta\,(\frac{1}{2}A\rho u_\infty^2 C_d)\sin(\theta+\alpha)$..(17)

Net torque on the rotor is given by

$T_{net} = \int_0^{\pi/2}\{2r\cos\theta(\frac{1}{2}A\rho u_\infty^2 C_d)\sin(\theta+\alpha)\}d\theta$..(18)

$T_{net} = (A\rho u_\infty^2 C_d)\int_0^{\pi/2}\{r\cos\theta.\sin(\theta+\alpha)\}d\theta$...(19)

Where, α varies from 0 to 2π.

3.3 Summarizes the different aspects of our project:

3.3.1 Social:

- Provide small-scale clean energy generation for people with no access and no Connection to the grid (remote and rural areas).

- Increase awareness of issues of energy and the environment by making the use of Renewable sources easy and widespread.

3.3.2 Technological:

- Design and build an innovative Vertical Axis Wind Turbine, and experimentally test the performance of Savonius rotors.

- Take part in the efforts to develop renewable energy technologies to solve our energy problems.

3.3.3 Environmental:

- Provide a clean alternative for fossil fuel based generation, and reduce our environmental footprint.

- Make use of a renewable and inexhaustible energy source instead of basing our generation on limited and polluting sources.

3.3.4 Economical:

- Provide a cheaper way to utilize the energy of the wind by building a cheaper vertical rotor.

- Investigate consumer attitude towards Vertical Axis Wind Turbines.

3.3.5 Political:

- Reduce our country's energy dependence.

- Help in pushing political action to promote the use and integration of renewable energies.

3.3.6 Legal:

- Help achieve the commitments to the recommendations of the COP 22 in generating more green energy.

- Allow for small scale generation according the 13.09 Moroccan laws.

3.3.7 Ethical:

- Help reduce and undo the vast damage we caused to our environmental systems.
- Take part in the global action to protect the environment.
- Test the claims of the Ice wind company in an objective scientific manner.
- Provide people with a clean alternative energy source and empower people with no access to conventional energy sources.

CHAPTER-IV

PROPOSED DESIGN

4.1 The design of the blade of self-pitch:

The blades of self-pitch VAWT are designed in straight wing shape without bends or variable cross section; they are easy to manufacture with low-cost. Arm design is based on aerodynamic principles and triangular vector connections, which reduce the threat of opposite wind pressure on the blades. Therefore, the new design improves deformation resistance and reduces blade cost. The blades of the self-pitch VAWT are uniformly distributed along the circumference. Since fewer blades may lead to low power output and too many blades may adversely affect the Aerodynamic characteristic, a VAWT with straight wing blades in general have 3 to 6 blades. In order for self-pitch adjustment, the blade is designed with nose CG located before the maximum thickness position. This ensures that the lift force acting point is behind or after the CG. Therefore, the blade pitch angles will be kept in the best range under the centrifugal force and lift torque. Furthermore, the rapid development of blade material and unique structure for typhoon resistance provides a potential opportunity to increase the power capacity of VAWT.

4.2 Description of Components and materials:

4.2.1 Material list:

- 4-inch dia PVC pipe 30 cm length
- ACP sheet 30 cm length.
- Dynamo 12 volt
- PVC Fittings 3T’s and 4 elbows.
- L-clamp steel 6 pieces.
- Plate washer 3-inch dia.
- Connecting wires
- Cycle screws as required.

4.3 Tools Need:

- Grinder
- Drilling Machine
- Drill bit
- Welding Machine
- Multi-meter
- Anemometer
- Other necessary equipment

4.4 Working Procedures:

Step-1:

- Take PVC pipe having 4-inch diameter and 30 cm length.
- Axially divide it into 6 equal parts using an angle grinder.
- Carefully use grinder.
- Make hole on one side of the PVC using 6mm drill bit.

Fig. 4.1: PVC pipe

Step 2:

- Cut 6 pieces of ACP Sheet having 30 cm in length and 6 cm in width.
- Mark hole on ACP from PVC pieces and make holes using 6mm drill bit.

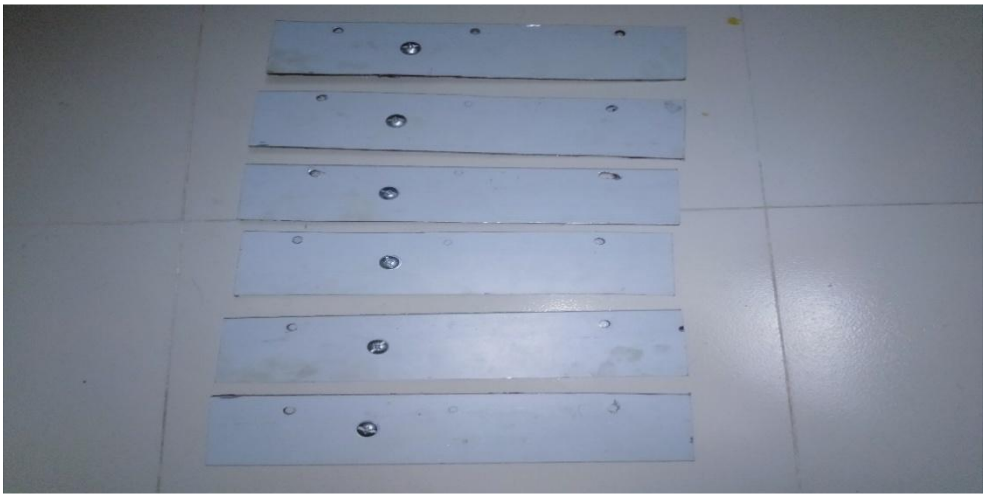

Fig. 4.2: ACP sheet 6 pieces

Step 3

- Buy 6 steel L-clamps and cut it into required length using an angular grinder.
- Take care and wear glasses while using a grinder.

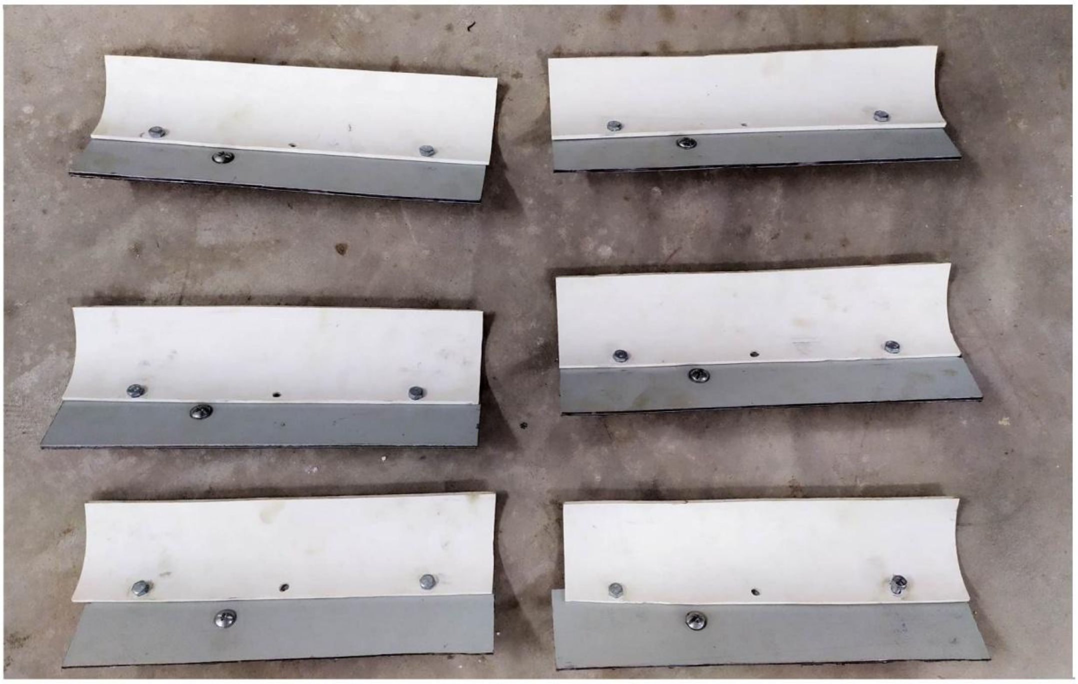

Fig. 4.3: PVC pipe 6 pieces and ACP sheet 6 pieces

Step 4

- Take GI plate washer 3 inch in diameter.
- Take GI nut that suits dynamo pulley.
- Take GI pulley and GI bolt that connected with GI plate washer.
- Then weld all 6 L-clamps on the plate washer.

Fig. 4.4: Weld all 6 L-clamps on the plate washer

Step 5:

- Connect ACP Sheet and PVC pieces together using cycle screws.
- Use a spanner to tighten it.
- Then connect these propeller blades on propeller frame.

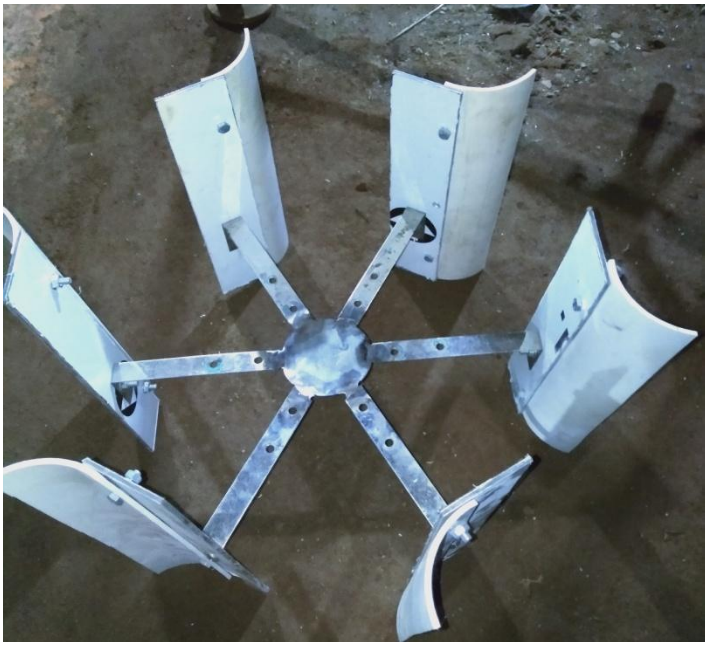

Fig. 4.5: Connect these Impeller blades on propeller frame.

Step 6:

- ➢ Buy PVC fittings 4 elbows and 3 T's.
- ➢Join these components together to make turbine base.
- ➢Connect the wire to the dynamo and fix it on wind turbine base.

Fig. 4.6: PVC fittings

Step 7:

- ➢ Place propeller on the wind turbine base.
- ➢ Vertical axis wind turbine is ready.
- ➢ Place the wind turbine in front of a fan.
- ➢ Yeah. It is working fine.
- ➢Check the output voltage using a multi-meter

Fig. 4.7: Propeller on the wind turbine base

Fig. 4.8: A VWAT Turbine

4.5 Design Calculations for shaft:

Torque is the most important fact while dealing with shaft where,

Torque, $T = W \times r$

W = Sum of weights of the 6 blades;

$= W_1+W_2+W_3 + W_4 + W_5 + W_6$

$= 6W$

$= 6 \times 0.2$ ……….. (Since mass of 1 blade is 0.2 kg)

$= 1.2$ kg

$\therefore W=1.2\times9.81 =11.77$ N

Radius of radial arm is found to be 0.2 cm.

$T=W \times r = 11.77 \times 2$

$= 23.54$ N-mm = 0.023 N-m

Torsion Equation is given by

$T/J= \tau/r$

$T = \pi/16\ \tau d^3$

$\tau = 0.023\times 16/(\pi\times0.012^3)$

$\tau =67788.11$ N/m²

Dimension of Shaft:

Based on the calculations the shaft diameter is determined as 2 mm. To reduce the weight of the shaft, the material was selected as aluminum due to its low weight and sufficient strength.

Table. 4.1: Dimensions of the shaft

SL.No	Description	Dimension(mm)
1	Diameter of shaft	4
2	Length of shaft	40

CHAPTER-V

RESULT & DISCUSSION

5.1 Calculation:

The following tables show the observations at various wind velocities and different rigging values-

Table. 5.1: Wind velocities and different rigging values

Sl No	Air Velocity (m/s)	Voltage (V)	Current (I) (mA)	Power (Watt)
1	3	2	3.1	0.0062
2	5	2.6	3.8	0.00988
3	6	4	5.1	0.0204

Here, Power = Voltage × Current

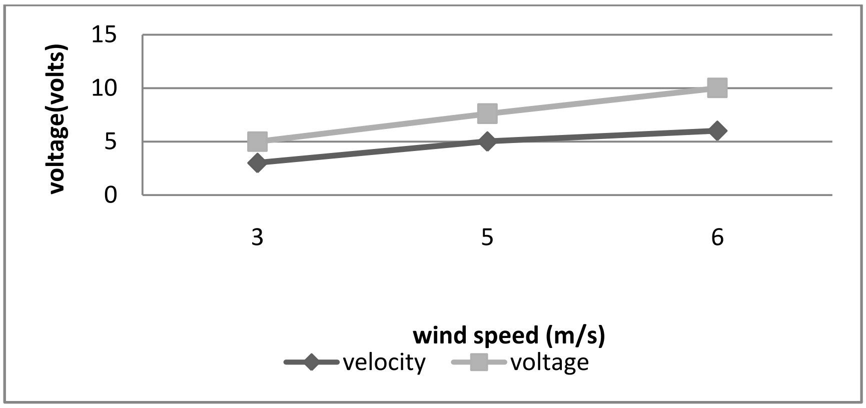

Fig. 5.1: Graph at wind speed (velocity) and voltage

When velocity increases at that time voltage increase that shown the graph. when velocity 3 m/s at that time voltage 2 volts similarly when velocity 5 m/s at that time voltage 2.6 volts and when velocity6 m/s at that time voltage 4 volts.

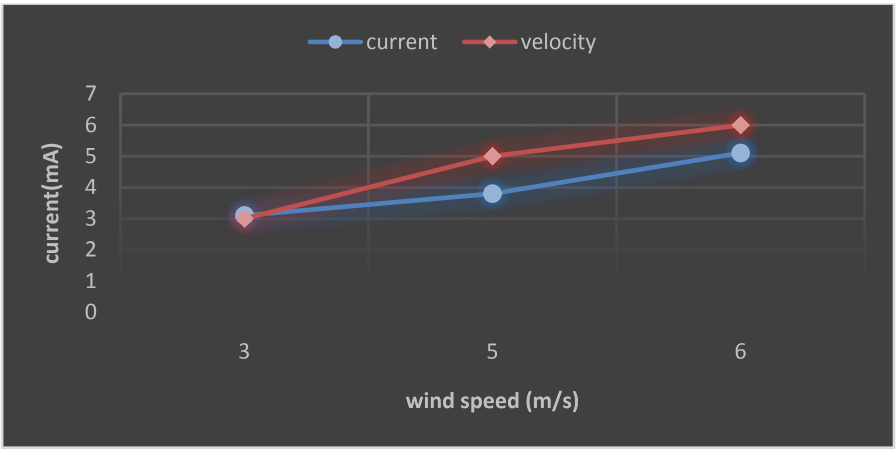

Fig. 5.2: Graph at wind speed (velocity) and current

When velocity increases at that time current increase that shown the graph. When velocity 3 m/s at that time current 3.1 mA. Similarly when velocity 5 m/s at that time current 3.8 mA and when velocity 6 m/s at that time current 5.1 mA.

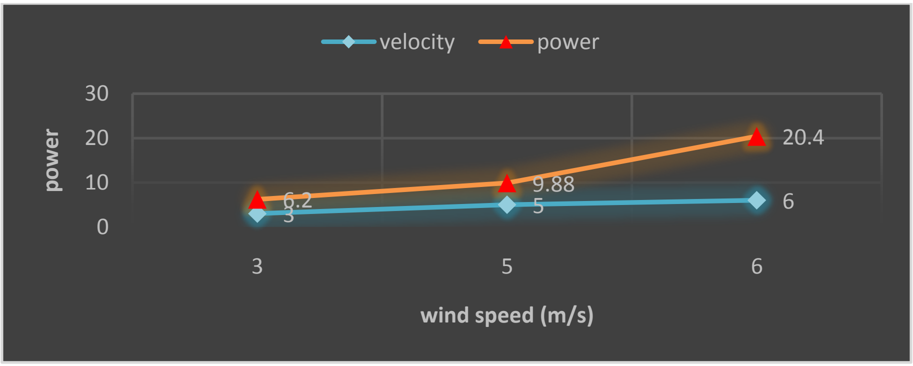

Fig. 5.3: Graph at wind speed (velocity) and power

When velocity increases at that time current increase that shown the graph. When velocity 3 m/s at that time power 6.2. Similarly when velocity 5 m/s at that time power 9.88 and when velocity 6 m/s at that time power 20.4. The graphs were plotted between Blade angles and Power Output for various air velocities. First of all, a common inference could be drawn after observing all the graphs that higher the wind Velocity more is the power output. Now, concentration was made on trends of low air velocities such as 3 m/s, 5 m/s, 6m/s. It is observed that power output is goes on decreasing 6m/s to 3m/s. This is because more amount of air energy goes in drag and fewer amounts causes' action of lift force over the blades. But, it can be seen from plots that the power output sharply increases as the rigging velocity approaches to 6m/s . Reason behind this is that maximum amount of wind energy is utilized in application of lift force, with a positive angle of attack. Drag is at its minimum. This is the most favorable condition for a lift type VAWT. Hence, the power output in this case maximum for all the air velocities.

CHAPTER-VI

CONCLUSION AND SCOPE

6.1 Conclusion:

The work in this thesis presents a complete model of a Savonius wind turbine. An approximate Lumped parameter model for the wind turbine system was developed using the mathematical equations for the torque acting on the Savonius rotor There are a number of assumptions made in the torque calculations i.e. the wind force acting on the rotor surface remains constant the entire time, the coefficient of drag does not vary with the rotation, and the rotor area exposed to the wind remains constant. Also, the three dimensional fluid effects are ignored to further simplify the formulation of torque formula. The PMSG model is developed using the simplified equations in the d-q synchronous rotating reference frame. The entire wind turbine system is implemented in the MATLAB environment to study the system response under different wind speeds. A comparison of the experimental and numerical results shows some differences which may be attributed to the fact that the mathematical model developed for torque acting on the Savonius rotor. An approximate model for the torque has been developed as per the model does not account for the three-dimensional fluid effects and environmental effects. Also, an assumption has been made for the PMSG parameters used in the simulation because the PMSG parameters are unknown for the experimental system. Considering the size of the Experimental Savonius wind turbine, the electrical power generated is very low. There are a number of reasons for the low electrical power generation. First, the thickness of the aluminum sheet used for the rotor buckets is large and results in high system inertia. Also, the wooden end plates further add to the inertia of the system. Second, the misalignment of the rotor buckets attached to the shaft leads to instability of the turbine rotor. Third, the protective wire mesh around the frame of the turbine reduces the effective wind force acting on the wind turbine rotor. The frame for the purpose of mobility of the wind turbine; reduce the stability of the system. All of the above reasons reduce the rotor speed, therefore reducing the power generated by the wind turbine.

6.2 Recommendation:

Further improvement is needed to facilitate the power output. It is recommended that

- To improve its structural stability research is needed.
- The testing is supposed to be repeated using wind tunnel to predict the performance of the turbine under different wind speeds.
- The selection and fabrication method need to be optimized.

6.3 Scope for future work:

- VAWT can be installed on green buildings.
- Can be used in place of Horizontal Axis Wind turbine (HWAT).
- Can be used in rural areas to produce electricity.
- It can also be used in areas where wind speed is as low as 4 mph.

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