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EFFECT OF BLADE SHAPE ON PERFORMANCE OF SAVONIUS VAWT FOR ACCESSING POWER PERFORMANCE

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Abstract
Non-renewable reserves are continuously depleting and are potentially major sources of harmful local and global emissions. On the other hand, renewable sources of energy are not only environmentally-benign. Present technology, dominated by the megawatt-scale Horizontal Axis Wind Turbines (HAWT), has demonstrated the viability of large-scale systems capable of supplying a substantial part of the electric energy supply. But louder noise at the location, collision of bird species with blades and more deaths due to installation are the drawbacks of HAWT which can be overcome by vertical axis wind turbine while fulfilling the energy needs. So, the main objective of the project revolves around the design of Savonius type vertical axis wind turbine and its comparative analysis for four different blade shapes to improve the performance and starting characteristics.
Keywords: Vertical axis wind turbine, Savonius wind rotor, rotor blade shape, coefficient of performance, starting characteristics.

1. Introduction

The vertical axis wind turbine is a turbine whose axis of rotation is pointed in vertical direction and the flow of the wind is perpendicular to rotor and main components such as shaft, gear box, generator unit etc. are located at the base of the turbine. The VAWT are omnidirectional in nature that is it can work for any direction of wind flow. The VAWT has advantages over Horizontal axis wind turbine are ability to generate power at relatively low wind speed, Simple installation and maintenance, Low risk of damage to birds, no need of yaw mechanism, silent, aesthetic and ergonomic operation, small shadow flickering, less aesthetic visual disturbance, small scale and can be installed in remote rural areas.
Also, it is capable of producing electricity in remote rural areas where access to the electric grid is not achievable. Louder noise at the location, collision of bird species with blades and more deaths due to installation and high initial cost and high transportation cost etc. are the drawbacks of HAWT which can be overcome by vertical axis wind turbine while fulfilling the energy needs.
Furthermore, Vertical Axis Wind Turbine has been predicted as a potential solution for the implementation of wind turbines in urban and semi-urban areas. The VAWTs have a relatively low environmental impact and better adaptable characteristics to the unsteady wind of urban terrains. These turbines can produce electricity from any direction with low cut in wind speed and are relatively simple in design to integrate with urban infrastructure.

Table 1. comparison between HAWT and VAWT

Parameters	HAWT	VAWT
Overall Construction	Complex	Simple
General location	On ground	Not on ground
Height for installation	High	Low
Noise produced	Relatively high	Low
Wind direction	Dependent	Independent
Location of main components	At top	At base

1.1. Types of Vertical axis wind turbine:

The VAWT are mainly classified on basis of drag and lift type forces acting on the turbine blades. These two types are as follows-
1. Savonius Vertical Axis Wind Turbine: - It works on drag force. A drag-type turbine performs better at the initial start-up wind speed. On the other hand, drag-type shows

lower power generation efficiency than a lift-type turbine. Some of the most appealing benefits of the Savonius design are it simple and cheap to construct, it has low noise and angular velocity when in use, and it can accept wind from any direction and can withstand extreme weather conditions without significant damage. In addition, there are multiple variations to the design that change the performance of the turbine depending on blade configuration.

2. Darrieus Vertical Axis Wind Turbine: - It works on lift force. The lift based Darrieus turbine has higher coefficient of performance than Savonius, has reduced sensitivity to oncoming turbulent wind. But these turbines have poor self-starting properties as compared to Savonius. Also, the aero foil problems more complicated than the HAWT.

2. Literature Review:

The content of this paper is an overview of the available literature and information on wind turbine design that will be ultimately used as a foundation for this case study

Kumar R. *et al.* [8] Research paper concluded that power and torque coefficient increase with increase in overlap ratio giving maximum value of overlap as 16.8% and Tip speed ratio 0.604.

Colmenero J. *et al.* [4] research paper shows the behavior of the turbine has been analyzed by varying the angle of rotation for section of its buckets. Using a rotation angle of 45 degrees the power coefficients values improve by 32% compared to the values obtained using angle of 0 degree. Research paper also states that by twisting the bucket the efficiency of the VAWT has been improved. Two bucket Savonius design has 34% higher coefficient of performance than other types of turbine. Paper also suggested that bucket angle=124 degree and aspect ratio 0.7 is best suitable for better performance of the S-shaped Savonius VAWT. For maximum Cp value of aspect ratio is 0.7 and overlap ratio= 0.15. As the number bucket increases starting torque increases but Cp value goes on decreasing. The use of end plate improves efficiency and diameter of end plate should be 10% greater than bucket diameter.

Menet J. *et al.* [10] has discussed that two-stage rotor is superior over single stage in both torque and power parameters. Also starting torque coefficient of two stage is never negative, whatever the direction of the wind. Two bladed Savonius rotor are the best performer. The best efficiencies obtained for value of overlap ratio are 20 to 30%. This paper gives the design of Savonius prototype for nominal wind speed 10 m/s with complete electromechanical system. This paper explains the advantages and application of VAWT over HAWT.

Kacprazak K. *et.al.* [6] introduces new blade shapes for Savonius VAWT that are Bach type, Elliptical shape. The performance is examined by means of quasi-2D flow predictions executed in ANSYS-CFX. This paper gives the comparison between conventional and new geometries for coefficient of performance and coefficient of torque at different tip speed ratios. It also gives the torque analysis and velocity distribution at different tip speed ratios. Paper concludes that the Bach type and the Elliptical blades have better performance than the conventional in terms of coefficient of performance.

Bhayo B. et.al. [1] published the paper named 'Experimental characterization and comparison of performance parameters of S-rotors for standalone wind power systems. In this paper, an on-wind flow test of seven Savonius model was conducted to explore the influence of design parameters on the performance and starting characteristics. Some of the models were single stage and some of 2 stages. Number of blades were varied from 2 to 5. The shapes were modified for different shape factor and with or without overlap ratios. The paper includes the graph of static torque analysis for different azimuthal angle at Reynolds number 1.5x 10^5 and 1.2x 10^5. The paper also discusses about the fabrication procedures of different models and the experimental setup. The experimental setup includes generator, belt and pulley, anemometer, wind tunnel section, static torque meter etc. Performance parameters are maximum, minimum and average torque coefficients for different models.

Longanathan B. *et al*. [9] published a paper named 'Effect of sizing on s-type VAWT'. This paper mainly focuses on effect of larger size and large number of blades on performance of s-type VAWT. The base model of 8,16,24 blades with rotor diameter 600mm and scaled up diameter of blade. The performance was increased by 80% but not proportionally.

3. Design Calculations:

3.1 Blade Design:

Iteration 1:
Material selected for the blade is Galvanized Iron
Assuming the power output at shaft 10-Watt, coefficient of performance as 0.35.
Coefficient of performance is given by,

$C_p = \frac{P_m}{P_t}$………………………………………… (1) [10]

Where P_m = Mechanical or Actual power, taking P_m = 10 Watt.
Theoretical power is given by,

$P_t = \frac{1}{2}\rho A v^3$…………………………………..….. (2) [10]

Assuming ρ= 1.225 kg/m3, Velocity of Air, v= 8 m/s
Substituting in equation (2),
A=0.0911 m^2
Where A is swept area of rotor

$A = \frac{\pi}{4} D_O{}^2$ ……………………….....................(3)

D_O= 341 mm.
Theoretical power is given by,

$P_t = \frac{1}{2}\rho D_O H v^3$……………………………..….. (4)

H= 0.267 m.
As aspect ratio is very less, going for the second iteration.

Iteration 2:
Assuming, $D_O = 0.5$ m
D_O=1.1D………………………....................... (5) [10]
D= 0.4545 m
A= 0.1963 m2
P_t= 61.56 W
Actual Cp is given by,
Cp= $\frac{10}{61.56}$ = 0.1624
Using equation (4),
H= 0.4 m
Taking Rotor height = H= 0.6 m for the aspect ratio greater than 1
The height of the rotor is divided into two stages.

Thickness of the blade as well as rotor is assumed 1.5 mm
Density of the Galvanized Iron = 7850 kg/m^3
Area of rotor =$\frac{\pi}{4}$[$D_o{}^2 - d^2$]…………… (6)
Area of rotor = 0.1963 m^2
Volume of rotor = A*t
Volume $= 2.944 * 10^{(-4)}$
$Mass = \rho * v$
Mass= 2.311 kg
Weight of 3 rotor plate = 68 N

Area of blade $= \pi * R * H$……………… (7)
Area of blade = 0.2141
Volume of blade = $3.21 * 10^{(-4)}$
Mass = 2.52 kg
Weight of rotor blade = 49.48 N

3.2 Shaft Design:

Power output at the shaft is given by,

$P_s = \frac{1}{2}\rho A v^3 C_p$……………………………… (8) [10]

$\omega = \lambda \frac{v}{r}$…………………………………… (9) [10]

Assuming $\lambda = 1$

$\omega = \frac{2v}{D_0}$……………………………………… (10)

Substituting values, angular speed is,

$\omega = 35.2$ rad/s

$P_s = \omega * T$ …………….. ………………… (11) [7]

Substituting ω, P_s in equation (11), torque is,
T= 0.4 Nm.
For shaft, selecting material 40C8, having tensile strength, S_{ut} = 580 N/mm^2 and yield strength, S_{yt} = 380 N/mm^2.
τ_{max}= 0.3S_{yt}…………………………… [14]
τ_{max}= 0.18S_{ut}………………………… [14]
Taking minimum value of the two,
τ_{max} = 105 N/mm^2.

$\tau_{max} = \frac{16T}{\pi d^3}$…………………...………… (12) [14]

Substituting the values in equation (12)
d = 3 mm
considering factor of safety 2,
d = 6 mm

3.3 Bearing Design:

Radial force is given by,

$F_r = \frac{1}{2}\rho A v^2$……………………….…… (13)

$F_r = 1.9\ N$
Selecting single row deep groove ball bearing, assuming L_{10h}= 50000 hrs.
N= 337 rpm
L_{10}= 1011 million revolutions
Dynamic capacity is given by,

$C = P^* (L_{10})^{\wedge(1/3)}$ ………………………. (14) [14]

C= 1779.316 N

Selecting bearing of diameter 10 mm
C= 4620 N, C_0= 1960 N, OD =26 mm
Designation = 6000

As the inner diameter of the bearing comes as 10 mm, selecting the diameter of the shaft as 10 mm.

4. Modelling of the Designed VAWT:

Modelling of VAWT is done using Solidworks Software. Modelling is done for four different blade shapes including conventional semicircular shape for the same aspect ratio.

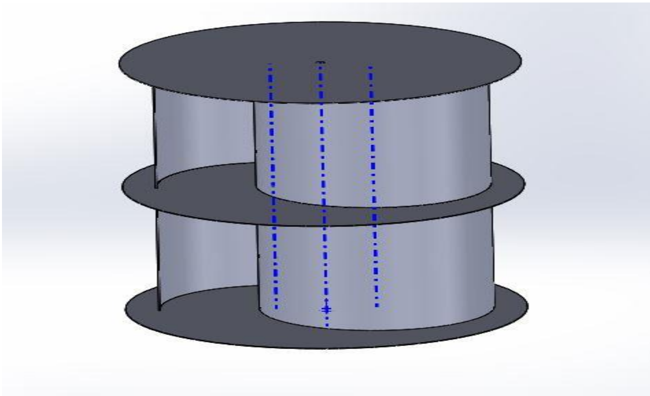

Fig 1. Conventional type VAWT. Model 1

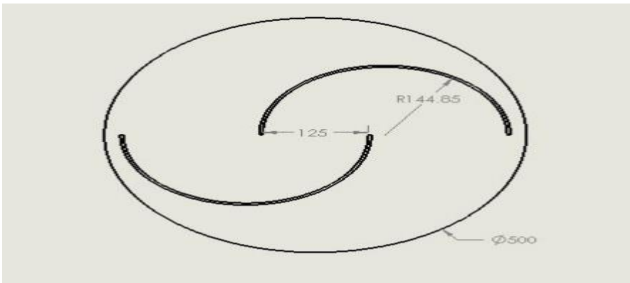

Fig 2. Conventional blade, model 1.

Model 1 is conventional semi-circular shape with blade arc angle 180°.

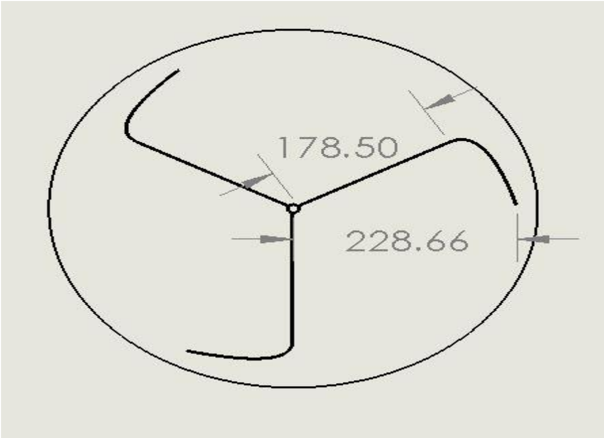

Fig 3. Model 2

For model 2, the ratio of the rotor radius to the maximum depth distance is set to 2.5 and the ratio of maximum depth location from the center to radius of rotor is set to 0.75. Other parameters are same as conventional.

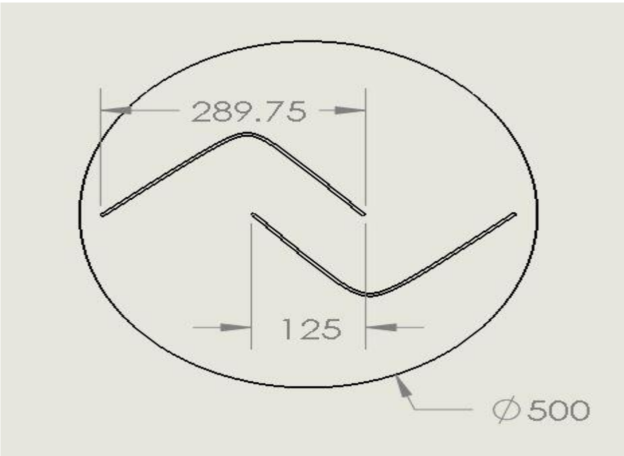

Fig 4. Elliptical type VAWT. Model 3

For model 3, radius of the blade is 289.75 mm and the distance from center to radius is 164.75 mm.

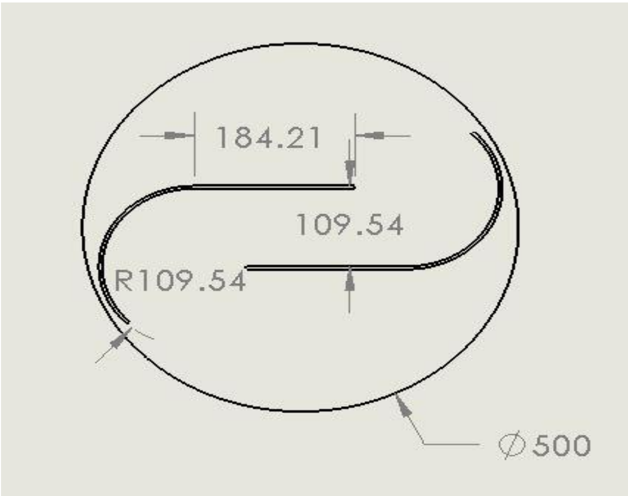

Fig 5. Bach type, Model 4

For model 4, ratio of straight part of blade to curvature i.e. shape factor is kept 0.48. Blade arc angle is set 135° and overlap raio is 125 mm.

5. Theoretical analysis and comparison of blade shapes:

In terms of the power coefficient the Bach-type rotor is superior to the other tested geometries and at the same time the Elliptical Savonius turbine exhibits better power characteristics than the Classical one. In the range of tip speed ratios between 0.2 and 0.4 the Elliptical Savonius rotor performs better than the Bach-type and the Classical Savonius rotor [6].

Table 2. comparison of different models [1]

Model		TSR	C_{pmax}	C_{Td}
Model 1	a	0.28	0.231	0.81
	b	0.42	0.260	0.62
	c	0.62	0.197	0.32
Model 2	a	0.21	0.118	0.56
	b	0.39	0.167	0.43
	c	0.47	0.141	0.30
Model 3	a	0.14	0.079	0.58
	b	0.46	0.184	0.4
	c	0.56	0.165	0.3

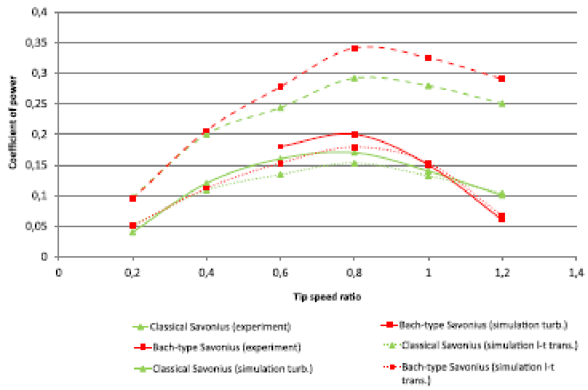

Fig 6. Comparison of average coefficient of performance Vs TSR [6]

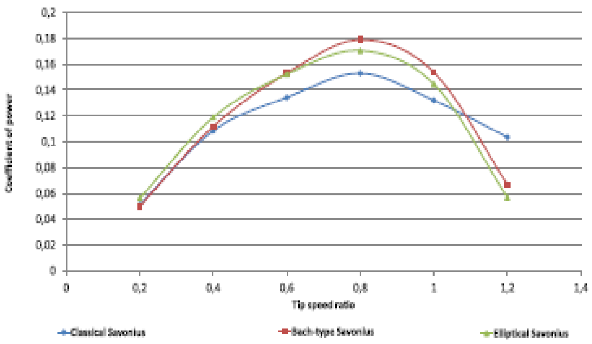

Fig 7. Comparison of average coefficient of performance Vs TSR [6]

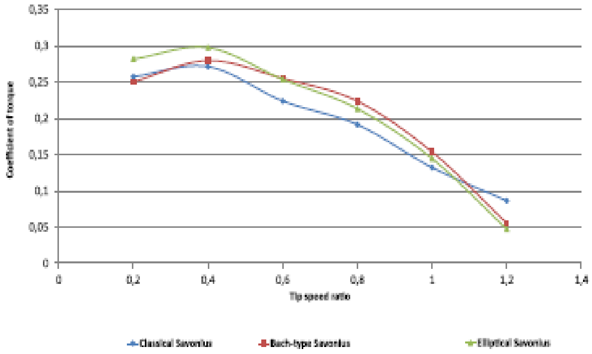

Fig 8. comparison of average coefficient of torque Vs TSR [6]

Fig 6 and Fig 7 shows the comparison between the conventional, Bach type and the elliptical type of rotor for coefficient of performance Vs different tip speed ratio. Fig 8 shows the comparison for coefficient of torque Vs different tip speed ratio.

6.Conclusion:

From the review study of blades, it is concluded that,
1) Bach type i.e. model 4, for maximum TSR of 0.8 for all the geometries, has better coefficient of performance than the conventional rotor.
2) For similar angular positions, Bach type exhibits characteristics better than the conventional and elliptical rotor.
3) The elliptical turbine i.e. Model 3 exhibits better characteristics at all angular positions than the conventional rotor for similar angular positions.
4) At the smaller values of TSR, elliptical turbine has biggest torque coefficients.

7. Future Work:

Future work of the project includes the analysis of the modelled four blade shapes for different tip speed ratios, coefficient of performance, coefficient of torque. Starting characteristics will be found for different angular positions of rotor and different tip speed ratio. Analysis will be mainly structural analysis and the flow analysis.

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