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Research Article

Effect of Blade Design on Angular Velocity of Vertical Axis Wind Turbine – CFD Analysis

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Abstract. *Application of Vertical Axis Wind Turbine* (VAWT) for generation of power is gaining momentum. However no research has been done to increase the efficiency of blade design for bidirectional wind flow. In the present study the effect of blade profile and thickness for a Savonius wind turbine has been studied. Different blade profiles with thickness 2 mm, 4 mm and 6 mm were modelled. A numerical analysis was done for a bi-directional wind input. The model for the rotor was designed on Solidworks 2017 and a numerical analysis was carried outon commercial CFD software, Ansys Fluent. From the analysis, the angular velocity graphs were plotted with respect to time and compared. The effect of the blade profiles and thickness were studied. And it was observed that 2 mm blade with curved profile was most suitable for bidirectional wind flow as it gains stable velocity sooner which is an important factor for power generation.

Keywords. Vertical axis wind turbine; Blade design; Numerical analysis; Angular velocity; Bidirectional wind flow

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1. Introduction and Definitions

In recent decades, global concern over pollution, global warming and possible depletion of non-renewable sources of energy, such as oil has led to exploration of renewable and sustainable energy resources. Conventionally, wind energy is harnessed on large scale using *Horizontal Axis Wind Turbines* (HAWTs) spread over large area [7]. But, usage of HAWT is limited due to the requirement of large wind speeds, large area, high initial cost and more maintenance. Vertical axis wind turbine is one whose axis of rotation is vertical with respect to ground. This arrangement allows the generator and gearbox to be located close to the ground facilitating service and repair. A typical wind turbine focuses on utilising natural wind power. They face problems regarding lack or excess of wind speed and moreover natural wind blows in one direction. In this case a considerable amount of wind energy is produced due to the pressure difference created by the moving vehicles on the highways. We need a system to recycle otherwise wasted energy of highway traffic. Moreover in remote locations extending power supply would itself be a tiring task which can be solved by having this type of turbine which could generate power enough to illuminate the road cautions or indicators needed for the road users. By setting a *Vertical Axis Wind Turbine* (VAWT) in Highways, artificial wind can also be used to produce electricity. The other major advantage of this system is this is dependent only on the number of vehicles on the road and not on other resources such as Sunshine or wind which cannot be always relied upon or are seasonal or location specific.

There are two types of VAWT, Darrieus VAWT and Savonius VAWT. Out of these two, Savonius VAWT is known as quite wind power source because of its lowest tip speed ratio and compact size [8]. Savonius rotor was firstly developed and introduced by Finnish inventor S.J. Savonius [6]. Though Savonius rotor has low aerodynamic efficiency, it is preferably used because it runs at low wind speeds. A conventional Savonius rotor is a vertical axis wind turbine having good starting characteristics [3]. Moreover, the Savonius rotor is more resistant to mechanical stress and it runs at wind speeds as low as 2 m/s. Savonius VAWT is a drag type device, consisting of two scoops. Looking down on the rotor from above, a two scoop machine would look like an "*S*" shape in cross section. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the Savonius turbine to spin. Effect of various parameters on the performance of Savonius rotor were studied in the previous literature such as aspect ratio, use of end plates, use of deflecting plates, overlap ratio, and number of blades [1]. A model was made in Solidworks 2017 using appropriate dimensions with varying thickness. The Navier stokes equation was used as the governing equation and a 6 Degree Of Freedom (6DOF) solver was used. Subsequently analysis was carried out in Ansys Fluent.

2. CFD Model

The sequence of operations involved in the modelling and analysis are shown in the flow chart (Figure 1).

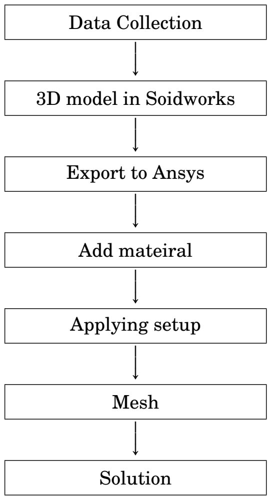


Figure 1. Steps involved in analysis of effective blade design for VAWT

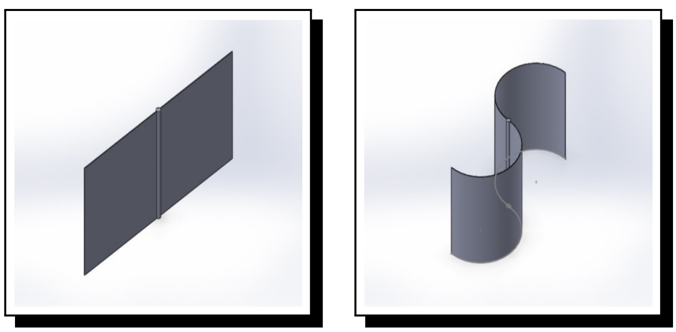
2.1 Model input

The model consists of a shaft on which two rotor blades are attached. A two blade design is noted to be efficient than three or four blade geometry [4]. A 3D model of Savonius model wind turbine was first established in Solidworks 2017 by comprehensively considering structural feature, processing requirements and solution calculation amount. For the purpose of reducing the number of elements and workload, when the finite model is establishing various reasonable simplifications were carried on, various petty features like fillet and chamfering were given up. A rotor diameter of 800 mm was used and a height of the rotor is 370 mm considering an optimum aspect ratio (< 0.5) and power coefficient [2, 5].

$$\text{Aspect ratio} = \frac{H}{D},$$

where H: Rotor height, D: Rotor diameter.

Through the Solidworks software the models of varying thickness viz. 2 mm, 4 mm, 6 mm for curved and flatblade design were established as shown in Figure 2. A radius of 200 mm was used for the curved blade profiles. The shaft radius used in all geometries is 10 mm.



(a) (b)

Figure 2. Profiles of rotor with (a) Curved blades (b) Flat blades

2.2 Governing Equations

The air flow speed is considered as 5 m/s. According to the Navier Stokes equation,

$$\underbrace{\rho\left(\frac{\partial \boldsymbol{u}}{\partial t}+\boldsymbol{u}\cdot\nabla\boldsymbol{u}\right)}_{(1)}=\underbrace{-\nabla p}_{(2)}+\underbrace{\nabla\cdot\left(\mu\left(\nabla\boldsymbol{u}+(\nabla\boldsymbol{u})^T\right)-\frac{2}{3}\mu(\nabla\cdot\boldsymbol{u})\boldsymbol{I}\right)}_{(3)}+\underbrace{\boldsymbol{F}}_{(4)}$$

where ρ = fluid density, $\boldsymbol{u}$= fluid velocity, p = fluid pressure, μ = fluid dynamic viscosity (1), pressure forces (2), viscous forces (3), and the external forces applied to the fluid (4).

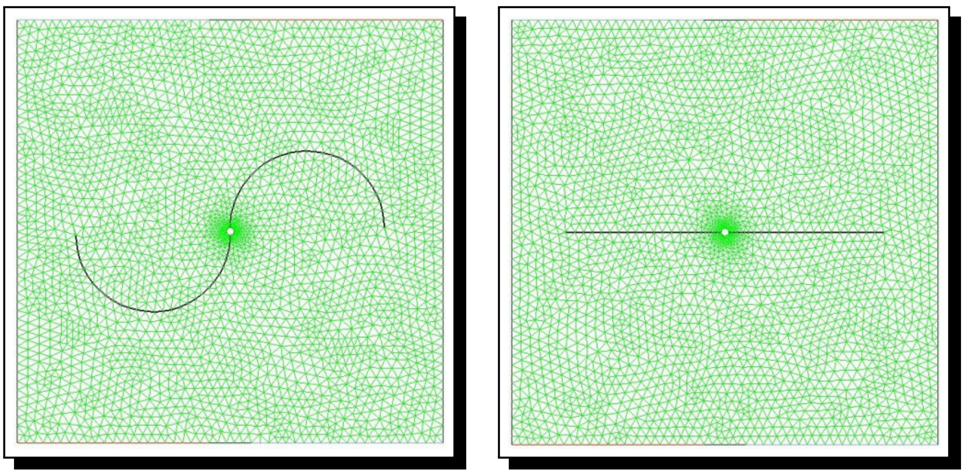
The six degree of freedom (6 DOF) solver used by the fluent software for analysis is given by

$$\dot{\vec{v}}_G=\frac{1}{m}\sum\vec{f}_G$$

where $\dot{\vec{v}}_G$ is the translational motion of the center of gravity, m is the mass, and $\vec{f}_G$ is the force vector due to gravity.

2.3 Analysis

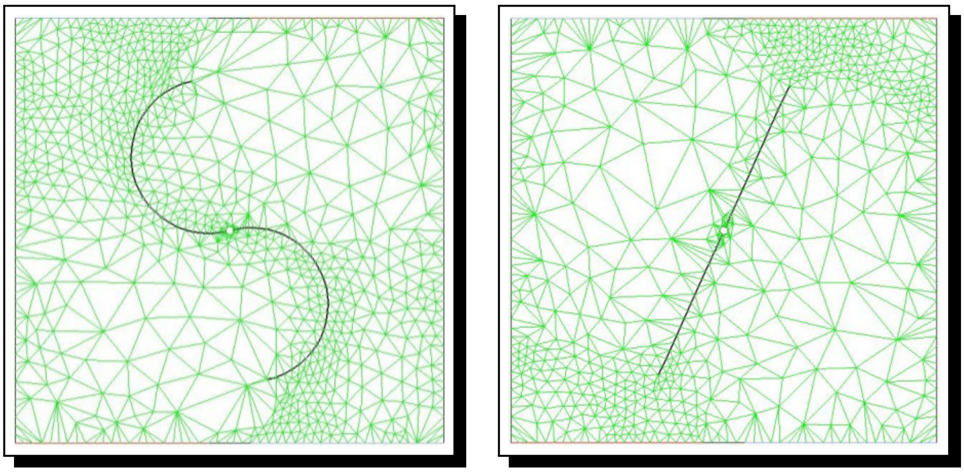
The profile of the rotor is symmetric and is an extrude of the 2D geometry. For the purpose of simplification and reduction of calculation time, also as there is no significant effect, the analysis is done in 2D. The analysis was done in Ansys Fluent as shown in Figure 3.



(a) (b)

Figure 3. Initial Mesh of VAWT with (a) Curved blades (b) Flat blades

The constraints of the body are given through a C program. The enclosure has 2 inlets and 2 outlets paired diagonally on opposite sides of a box enclosure. The adjacent inlet and outlet are separated by a small region of nil effect considering practical conditions of bidirectional fluid flow. Re-meshing (as shown in Figure 4) is carried out for each time step and smoothing is defined. The time steps are taken as 0.0025 seconds considering the accuracy and calculation time. Inlet air velocity is considered as 5 m/s. A dynamic mesh is defined for the fluid domain.



(a) (b)

Figure 4. Deformed mesh after analysis of VAWT (a) Curved blades (b) Flat blades

3. Results

For the curved and flat blade profiles of varying thicknesses of 2 mm, 4 mm and 6 mm the simulations are carried out and the study graphs are plotted (Figures 5 and 6).

Table 1. Comparison of flat blade rotor of varying thickness

	2 mm	4 mm	6 mm
Angular Velocity	120 RPM	110 RPM	100 RPM
Wave Distortion	High	High	Least
Stability Achievement	Very Fast	Fast	Slow
Angular Acceleration	Very High	High	Low

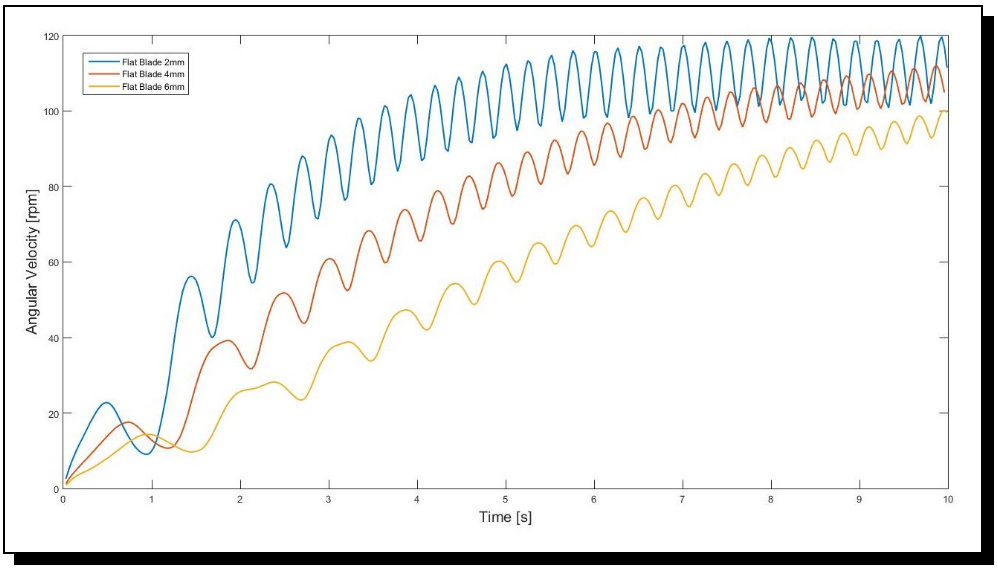
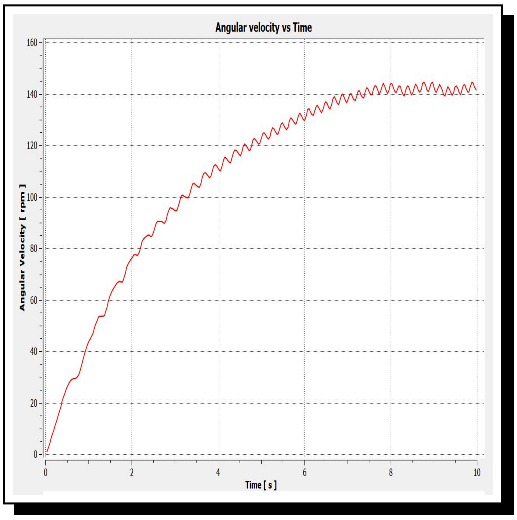


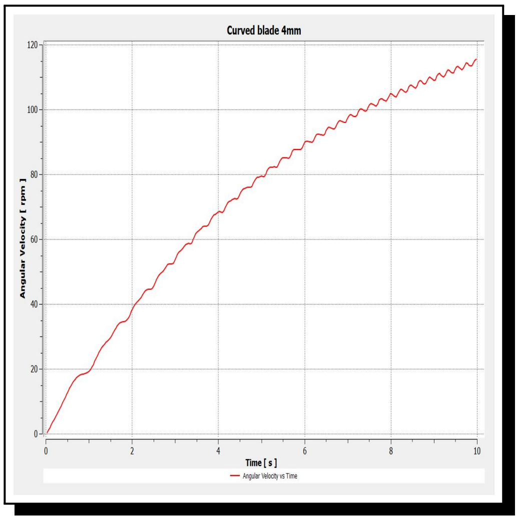
Figure 5. Angular velocity vs. time graph for flat blades

The variation of angular velocity with time is shown in Figure 5. It is observed that for a curved blade with 2 mm thickness (Figure 6a) it achieves the stability faster. Also it is observed that by 8 seconds an angular velocity of 160 RPM is achieved. However crest and troughs are observed more in this graph due to the fluctuation of angle of attack and the nil effect region.

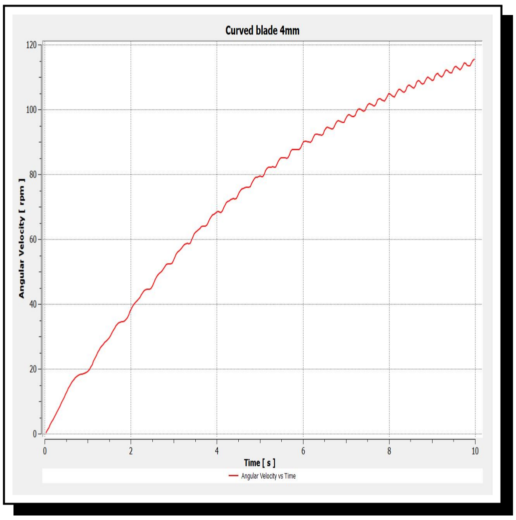
For a curved blade with 4 mm thickness (Figure 6b) it is observed that it is slower at the end of 10 seconds that its 2 mm counterpart. It also has not achieved stability in angular velocity. The variation in angular velocity in each revolution however is lesser, i.e., wave height is less. The Angular velocity at the end of 10 seconds is 140 RPM.



(a)



(b)



(c)

Figure 6. Angular velocity vs. time graph for curved blades with (a) 2 mm (b) 4 mm (c) 6 mm

A decreased angular velocity of less than 120 RPM is observed for the 6 mm curved blade (Figure 6c) in 10 seconds. The fluctuation of angle of attack however does not have a significant effect unlike the 2 mm and 4 mm blades.

4. Conclusion

This work looks at the numerical analysis of a curved blade and a flat blade Savonius rotor of varying thickness (viz. 2 mm, 4 mm and 6 mm) in conditions of a bidirectional wind flow. It can be concluded that the curved blade profiles attains a higher speed at a shorter duration which is preferable. Also, it is observed that when the blade is at $\Theta = 90^\circ$ air flows around it, and creates an adverse torque effect. This phenomenon is captured in the Angular Velocity vs. Time Graph as a wave curve. The highest wave height was observed in 2 mm blades of both rotors and on comparison it is noted that this disturbance decreases with increase in thickness. However, 2 mm curved blade rotor attains a stable state quicker which is an important factor in power generation. Also, a higher angular acceleration is noted. On the basis of these factors it can be concluded that in case of bidirectional wind flow, a Savonius rotor with curved blade of 2 mm thickness is preferred.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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