CFD ANALYSIS ON VERTICAL AXIS WIND TURBINE ROTORS-REVIEW

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Abstract:

The detailed investigation has been done on Vertical Axis Wind Turbine (VAWT) rotor blades especially on Savonius and Darrieus rotors. Many of the studies on the geometry of the rotor blades were carried out by the researchers during the years. In this paper, various aspects like velocity of the wind, temperature, pressure and required dimensions of the rotor are used. The main intention of this paper is to gather the information about the rotors of different geometry and bring into the discussion about the factors that influence the performance of the different rotor blades depending on their geometry for future studies.

Key words: Vertical Axis Wind Turbine(VAWT),Savonius Rotor, Darrieus Rotor.

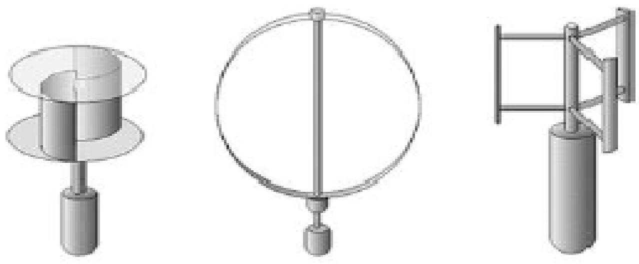
1. Introduction

Fossil fuels are conventional energy source which are limited. Intensive use for energy generation from fossil fuel will diminish in several upcoming decades. By burning fossil fuels like natural gas, crude oil, coal etc. generate heat energy which will utilize for power to vehicle, generation of electricity for domestic & industrial purpose. Burning of fuel causes environmental pollution which is harmful for eco-system day by day. It is necessary to use renewable energy source such as wind. A device which converts kinetic energy of wind into electricity is known as wind turbine.

Wind turbines are two types such as horizontal axis wind turbine & vertical axis wind turbine. Horizontal axis wind turbines are not suitable for mounting on roof of house & building. Because it generates vibration, noise also harmful for birds due to high speed rotation of blades.

Vertical axis turbine has two categories such as Darriues vertical axis turbine (D-VAWT) & Savonius vertical axis turbine. The savonius wind turbine has suffering from poor efficiency. Many of researchers had proposed different savonius configuration to increase the performance. D-VAWT is lift- drive which has more efficiency than savonius VAWT, but savonius turbine has some advantages over darriues vertical axis turbine like self-starting capacity at low speed wind, simple in construction, independent on wind direction, reduced wear & tear of moving parts.

The concept of conventional savonius turbine was cutting a cylinder into two halves along the central plane & then moving the two-half cylinder sideways along the cutting plane so that the cross-section of seems like 'S' letter. Savonius wind turbine, which has concave and convex section. In concave section wind strike and get trapped into it, the wind has some kinetic energy which exert pressure on concave section of blade exactly at a same time wind get deflect on convex section of blade, so that pressure difference arise between concave & convex section from upstream to downstream due to that turbine get rotates about its central axis of the shaft [7].



(a) (b) (c)

Fig. 1. VAWT turbines: (a) Savonius rotor; (b) Darrieus rotor; (c) H- Darrieus rotor [1]

Early assessments of the CFD technology for Darrieus rotor aerodynamics aiming at thoroughly investigating the complex fluid mechanics of these machines, made use mainly of a two-dimensional approach. A 2D simulation of H Darrieus can provide quite accurate estimations of both the overall performance and the flow field description around the rotor with reasonable computational cost, on condition that proper settings are applied. In case of the medium-size rotor and low tip-speed ratios, the use of a transitional model for turbulence closure is suggested by Alessandro Bianchini.

2.Theory and Design of Rotors

Savonius Rotor:

Wind power is defined as the multiplication of mass flow rate and K.E per unit mass. The wind power, P_w is denoted by the mathematical equation given below.

$$P_w = \frac{1}{2} mv^2 = \frac{1}{2} (\rho av)\, v^2 = \frac{1}{2} \rho av^3$$

Where mass flow rate m= ρ.a.v

$$\text{Kinetic Energy K.E.} = \frac{1}{2} NV^2 [2]$$

Swept area is calculated by using the given formula

$$A = D \times H$$

where D= Rotor diameter

H= Rotor height

Power output will depend on the swept area. Large swept area gives large power output.

The wind power equation represents the ideal power of Savonius wind turbine, as in case of no losses during the conversion process i.e. at the time of mechanical energy is converted into electrical energy but there is no possible for converting all energy in to useful work. There is only 45% of energy is converted into useful work some energy is may lose in gear box, transmission, bearingsetc. [1]

Table 1: Design parameters used in Savonius wind turbine [3]

Parameter	Value
Power generated	2.5 kW
Swept area	8 m^2
Rated wind speed	10.5 m/s
Aspect ratio	2
Solidity	2.16
Diameter-Height	2 m – 4 m
Number of blades	2

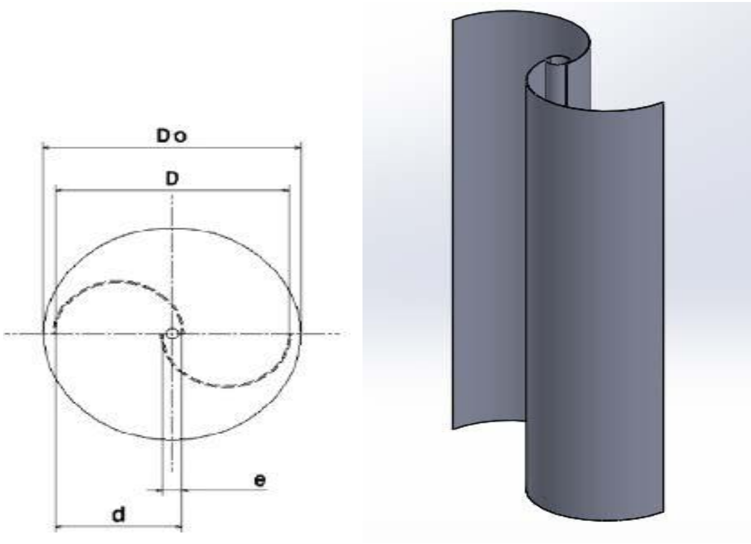


Fig. 2. Design model of Savonius rotor blade in SolidWorks [3]

Darrieus Rotor:

When the Darrieus rotor is spinning, the aerofoils are moving forward through the air in a circular path. Relative to the blade, this oncoming airflow is added vectorially to the wind, so that the resultant airflow creates a varying small positive angle of attack to the blade. This generates a net force pointing obliquely forwards along a certain 'line-of-action'. This force can be projected inwards past the turbine axis at a certain distance, giving a positive torque to the shaft, thus helping it to rotate in the direction it is already travelling in. The aerodynamic principles which rotate the rotor are equivalent to that in autogiros, and normal helicopters in autorotation.

As the aerofoil moves around the back of the apparatus, the angle of attack changes to the opposite sign, but the generated force is still obliquely in the direction of rotation, because the wings are symmetrical and the rigging angle is zero. The rotor spins at a rate unrelated to the windspeed, and usually many times faster. The energy arising from the torque and speed may be extracted and converted into useful power by using an electrical generator. The aeronautical terms lift and drag are, strictly speaking, forces across and along the approaching net relative airflow respectively, so they are not useful here. To know the tangential force pulling the blade around, and the radial force acting against the bearings [6].

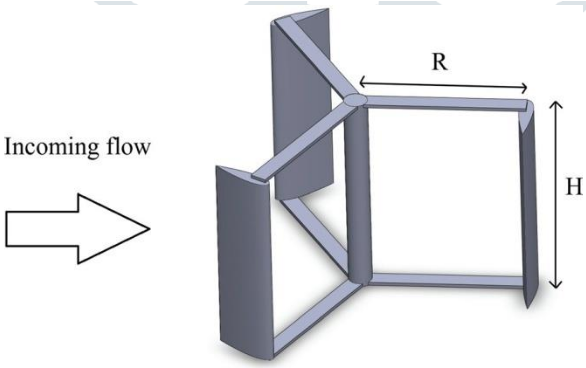


Fig.3 Darrieus Rotor Model [4]

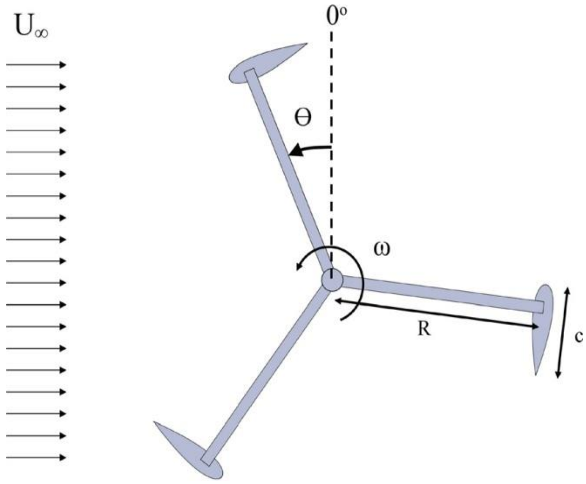


Fig.4.Various Geometric Parameters of a Darrieus Rotor [4]

3.Simulation and Analysis:

Savonius Rotor:

The flow type of Savonius rotor blade is considered in this paper as external flow since it involves a solid model which is fully surrounded by the flow. The fluid flow is not bounded by any outer surface the flow is bounded by the computational domain boundaries. The computational domain is non uniform is defined to 3m that means the Savonius rotor is enclosed by this region and volume is fixed in this region as shown in Fig. 5.

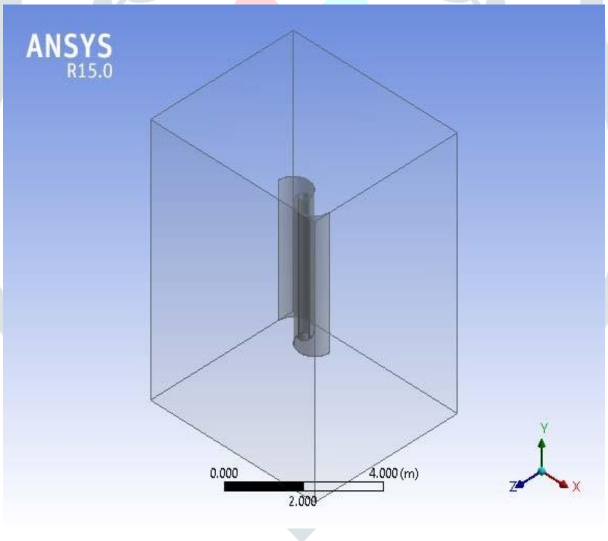


Fig. 5. Creating Enclosure for given model in ANSYS [3]

After completed the input data, the model is entering to the meshing process. The meshing is viewed through a wire frame as shown in Fig. 6. The fluid is separation when it passes through the Savonius rotor blade and this region is considered as high-gradient flow region.

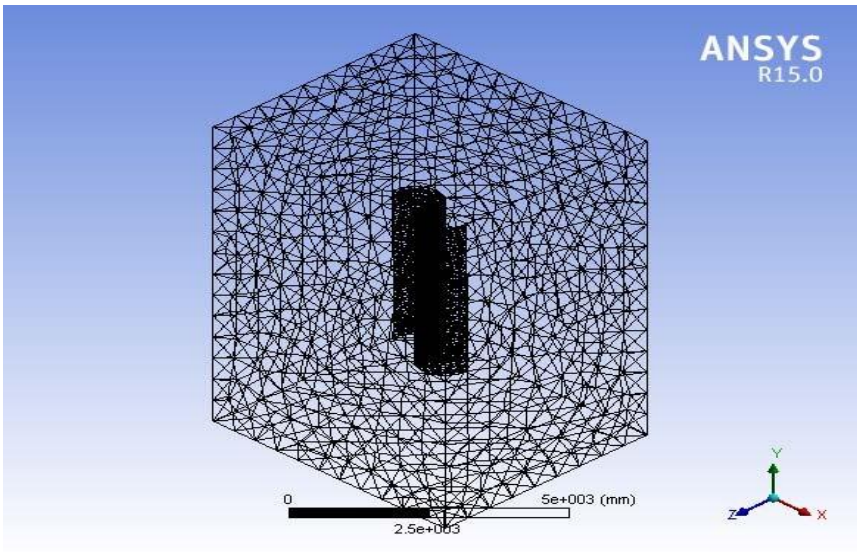


Fig. 6. Meshing process for given model [3]

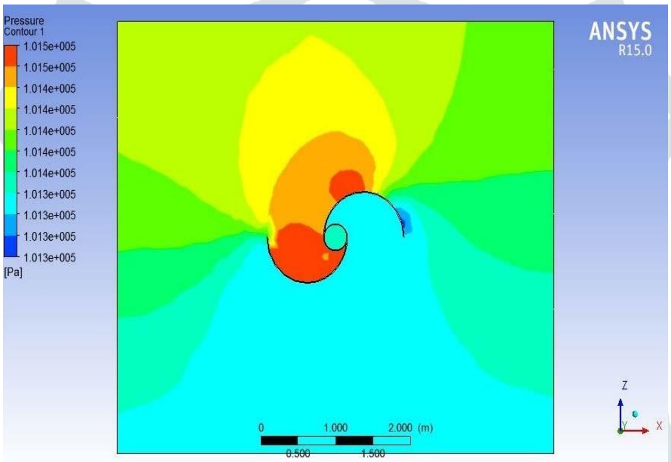


Fig. 7. Pressure distribution over turbine blades [3]

The pressure distribution around the Savonius rotor is viewed by a contour cut plot from top view. The above Fig.7 shows the contour cut plot display. The high-pressure region as red and lower pressure region as blue colour respectively. The pressure is high near the concave surface and is low near the convex surface is observed from the above figure. The maximum and minimum pressures are 101.496 pa and 101.264 pa respectively.

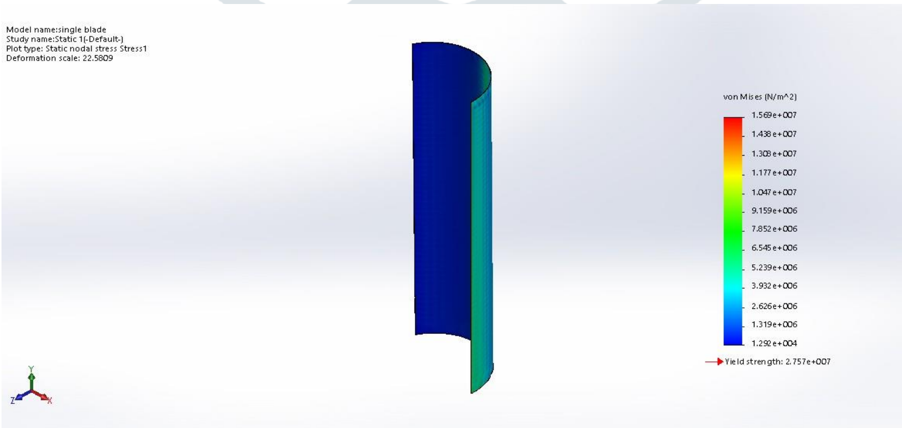


Fig.8.Distribution of stress over the rotor blade [3]

Fig.8 shows the stress distribution of rotor blade. The maximum and minimum Von Mises stress for the rotor blade are 15691100 Pa and 12922 Pa respectively. The outcome is satisfactory in light of the fact that the maximum Von Mises stress is much lower than the Yield strength of the material applied for the rotor blade.

Darrieus Rotor:

Mesh generation was based on generating a high grade spatially discretized grid for the entire domain.Fig.9 shows the setup done to create this quadrangular mesh around the air foil wall.

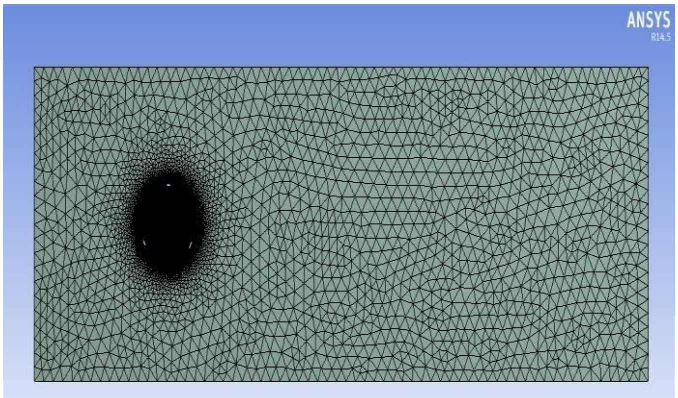


Fig.9. Meshing of the surroundings around the model [5]

The boundary conditions for inlet and outlet were fixed by defining designed values for the rotor assembly. Moreover, by following few relevant literatures, the turbulent intensity and turbulent viscosity ratio were fixedat 0.1 percent and 10 for both inlet and outlet.

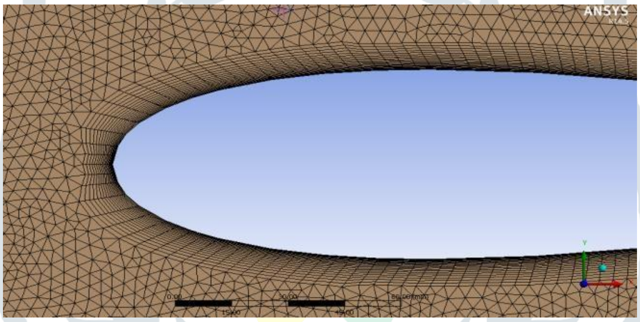


Fig.10. Meshing around the blade/Air foil. [5]

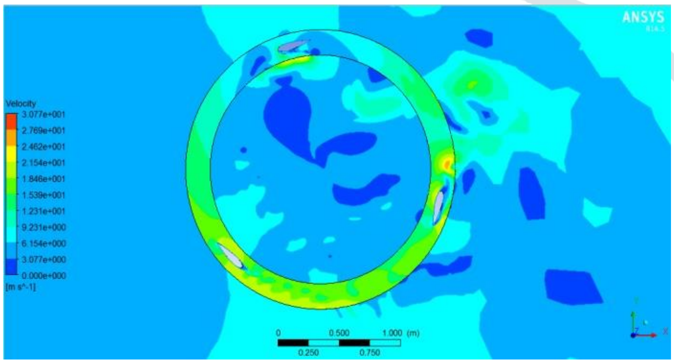


Fig.11. Velocity Contour at 0.5 sec[5]

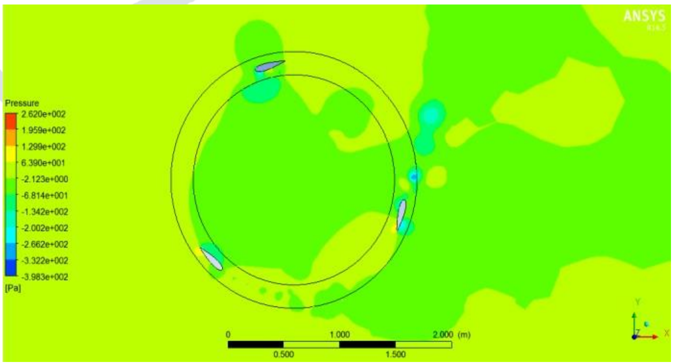


Fig. 12. Pressure Contour at 0.5 sec [5]

To take into account the unsteady effects, particularly dynamic stall and interactions between blades motion and wake, it was necessary to use the Fluent solver in a transient version.

The boundary conditions in inlet and outlet were defined by fixing he windspeed in inlet at on-design value for each rotor so that the calculated torque is function of rotational speed only and thus it was simple to obtain a Cp versus λ Comparison. The simulation is carried out in such a way that one degree o the VAWT rotation can be captured and results may be viewed for the entire VAWT rotation.

4.Results and Discussion

This paper investigates the design and analysis of Savonius rotor blade. The rotor blade was designed by utilizing Solid Works software. Computational fluid dynamics (CFD) analysis was performed to obtain the pressure difference between the convex and concave surface of Savonius rotor blade. While FEA analysis was performed to obtain the stress experienced. The below graph was plot with wind speed vs power output. In this paper average wind speed is considered as 7 m/s. The rated wind speed used in this paper is 10.5 m/s.

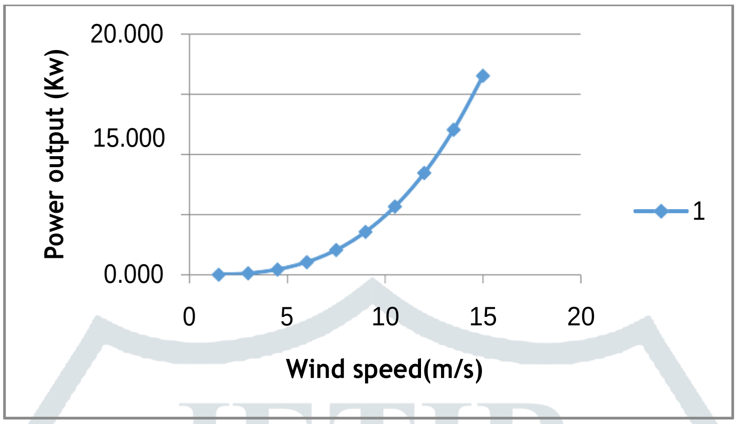
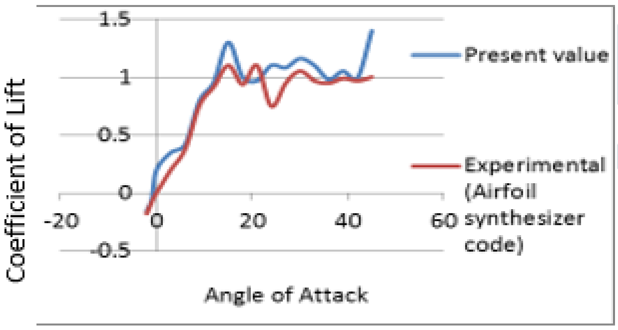


Fig. 13. Variation of power output with wind speed [3]

In order to calibrate the SST Transitional model for wind turbine applications, a long process of optimizing the local correlation variables was carried out.

The coefficient of Drag predicted by the Fluent Solver shows under fitting with respect to the experimental data for most of the angle of attack values and thus makes the assumption pretty complicated. However, the error percentage in this case is also not large and thus the model can be considered stable for these angle of attack(AoA) values.



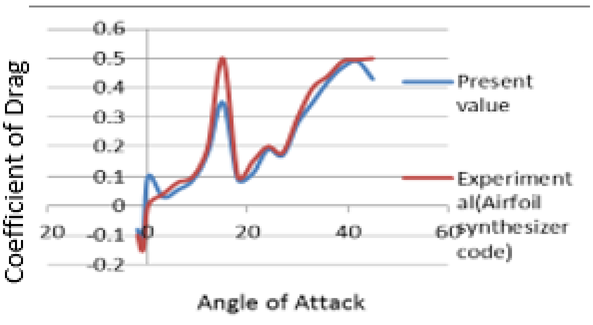


Fig.14.Variation of Lift coefficient with AoA [5]

Fig.15.Variation of Drag coefficient with AoA [5]

Conclusion:

From the results obtained, it can be concluded that both the type of VAWT depends on the application, wind characteristics, etc. Savonius works under drag forces. Darrieus operates because of lift forces. Savonius is able to self-start but darrieus cannot start.

A Darrieus is a high speed, low torque machine suitable for generating alternating current electricity. Darrieus type requires a manual push, therefore, some external power source is required to start turning as the starting torque is very low. The Savonius uses drag and therefore cannot rotate faster than the approaching wind speed. An area that has strong and gusting winds or when you need a unit that self-starts, this is the best type

A steady-state two-dimensional CFD analysis using FLUENT 6.2 software was performed to simulate the flow over a twisted three-bladed H-Darrieus rotor. Future study could entail three-dimensional wake modelling of the rotor to study the dynamic nature of the separated vortices with its effect on the performance of the rotor. Also, a study on wake minimization of the rotor could be made by selecting unequal radii of rotation for the rotor.

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