International Journal of Research in Advent Technology, Vol.3, No.3, March 2015
E-ISSN: 2321-9637

Design and Analysis of 100 Watts Savonius Rotor Blade

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Abstract -This paper explores about the design and analysis of the Savonius rotor blade for generation of 100 Watts power output. The relevant design parameters and theories were studied in this paper and it is used to determine related design geometry and requirements of the Savonius rotor blade. The Savonius rotor was designed with the rotor diameter of 70mm and the rotor height of 140mm. The 3D model of Savonius rotor blade was created by using PRO-E software. Computational Fluid Dynamics (CFD) analysis and structural Finite Element Analysis (FEA) are presented in this paper. CFD analysis was performed to obtain the pressure difference between concave and convex region of the blade while FEA was done to obtain the structural response of the blade due to the wind load applied in term of stresses and its displacements.
Keywords: Savonius, Rotor Blade, CFD, FEA.

1. INTRODUCTION

Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land. The effects on the environment are generally less problematic than those from other power sources. The effects ofthe change of the aerodynamic flow (in the steady and unsteady cases), the variation of parameters of the cinematic movement (angle of attack, pitch angle and yaw angle) and the definition of subsystems characteristics that makes the wind turbine (blade, nacelle and pylon) allow one to characterize the structural dynamic behavior of the wind turbine. It is therefore necessary to develop these items.The design of a wind turbine structure involves many considerations such as strength, stability, cost and vibration [1]. For wind energy to become competitive with respect to other sources of energy, the initial consideration must be to reduce the cost of energy from wind power. In modern wind power researches, how to minimize the cost of a wind turbine per unit of energy is an important task. The shape of the rotor blades play a decisive role [2]. In this research a step towards the development of savonius VAWT blade is taken into consideration, the blade is design for rated output on the available researcher theory.Islam (2005) explained that the feature of flow phenomena including high turbulence, unsteadiness and flow separation, also explained about the normal drag force (*FN)* which acts in perpendicular direction on the blade surface whereas tangential drag force, FT acts along tangential direction on each blade further he had given the both *FN* and *FT* equations as follow:

$$F_N = \Delta PS sin\emptyset \qquad (1)$$

$$F_T = \Delta PS cos\emptyset \qquad (2)$$

Where S-chord length and and ΔP-pressure difference.

2. THEORETICAL MAXIMUM EFFICIENCY

High rotor efficiency is desirable for increased wind energy extraction and should be maximized within the limits of affordable production. Energy (P) carried by moving air is expressed as a sum of its kinetic energy [Equation (1)]:

$$P = \frac{1}{2}\rho AV \rho = AirDensity, A = SweptArea, V = Velocityofair \qquad (3)$$

For the swept area for Savonius Wind Turbine blade is given by Widodo(2012), the swept area for Savonius blade is obtained by multiplication of rotor diameter, D and the rotor height, H. The power output of blade is improved with the swept area.

$$A = DH \qquad (4)$$

The energy extraction is maintained in a flow process through the reduction of kinetic energy and subsequent velocity of the wind. In wind turbine there is not possible to convert the all possible energy into the useful energy. The maximum energy that can be extracted from the wind turbine efficiency cannot exceed 59.3% [ ]. The maximum power coefficient, *Cp* for Savonius rotor is 0.30. Hence, the *Cp* value used in this project is 0.30 and the power output, P with considering the power efficiency is:

$$P = 0.15\, \rho AV \qquad (5)$$

The power output of the wind turbine is affected the speed of the turbine.Jain (2011) explain the three wind speed parameter, like cut-in speed, rated wind speed and cut-out speed.

$$Vcutin = 0.5\,Vavg \quad (6)$$

$$Vrated = 1.5Vavg \quad (7)$$

$$Vcut\text{-}out = 3.0\ Vavg \quad (8)$$

These all speed parameters are depending on the average wind speed. For design of the rotor the average speed of air is consider as 4 m/s. The details of cut-in speed, rated wind speed and cut-out speed as summarize in table below:

Table 1: Wind speed parameters calculation

Wind Speed Parameter	Equation	Calculation
cut-in speed	Vcut-in=0.5 Vavg	2 m/s
rated wind speed	Vrated= 1.5 Vavg	6 m/s
cut-out wind speed	Vcut-out = 3.0 Vavg	12 m/s

The aerodynamic performance of Savonius rotor can be evaluated by the aspect ratio. The aspect ratio for Savonius rotor is given by

$AR=H/D$

The tip speed ratio is defined as the ratio of the speed of the extremities of a windmill rotor to the speed of the free wind. Drag devices always have tip-speed ratios less than one and hence turn slowly, whereas lift devices can have high tip-speed ratios (up to 16:1) and hence turn quickly relative to the wind.Widodo (2012) write that high tip speed ratio improves the performance of wind turbine and this could be obtained by increasing the rotational rate of the rotor.

$\lambda = \omega.R/V$

Solidity is related to tip speed ratio. A high tip speed ratio will result in a low solidity. According to researchersolidity define as the ratio of blade area to the turbine rotor swept area;also solidityis usually defined as the percentage of the area of the rotor, which contains material rather than air. For VAWT, the solidity is defined as

$\sigma = nd/R$

Where$n$ numbers of blade, d is the chord length or diameter of concave and convex surfaces and R be the radius of turbine rotor. Many researchers explain different theory about the performance of wind turbine blade. The summary of design parameters of the savonius rotor are as follows:

Table 2: Summaries of rotor blade design

Parameter	Value
Power Generated	100 watts
Swept Area	980 mm^2
Rated Wind Speed	6 m/sec
Aspect Ratio	2
Tip Speed Ratio	1
Solidity	2.11
Diameter	70 mm
Height	140 mm
Number of Blade	2

3. MODELING OF SAVONIUS ROTOR BLADE

A 3- D model of savonius rotor blade with rated parameter was developed by using PRO-E software. The material proposed for savonius rotor blade in this research is E-glass fiber.

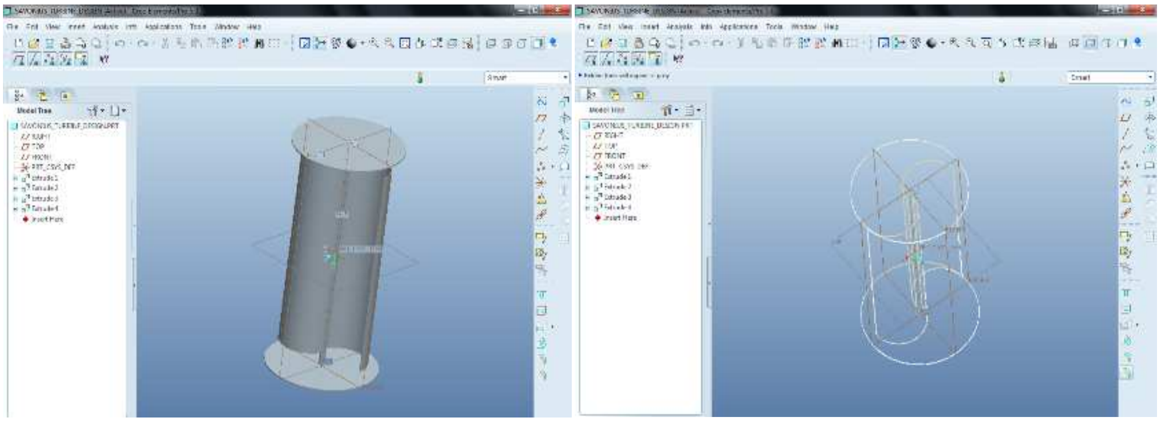


Fig :(1) (a) 3-D model & (b) wire frame of Savonius Rotor

Table 3: Summaries of rotor blade design and the material properties of E-glass fiber.

Parameter	**Value**
Swept Area (A)	980 mm^2
Rotor Diameter *(D)*	70mm
Rotor Height *(H)*	140 mm
End Plate Diameter*(Df)*	77 mm
Chord Length *(d)*	37 mm
Overlap Distance *(e)*	4 mm
Blade Thickness *(t)*	0.5 mm
End Plate Thickness *(tf)*	1mm
Density	1.85e9kg/m3
Young's modulus	3.33 e5GPa
Poisson's ratio	0.09
Tensile strength	217 – 520 Mpa
Compressive strength	276 – 460 MPa

3.0 SIMULATION AND ANALYSIS

In this paper, two kinds of simulation and analysis were done that is Computational Fluid Dynamics (CFD) Analysis and Structural Analysis.

3.1 Structural Analysis

The structure of the Savonius rotor blade is analyzed using ANSYS software. The FEA result is taking into three criteria by considering stress, deformation. For finite element analysis E-glass fiber material is taken into consideration. The model that was already created in Pro-E is imported in the ANSYS environment and fixed constraints.The load for this analysis is force with 2.93 *N* obtained from the aerodynamic analysis and equally distributed on the concave blade surface..

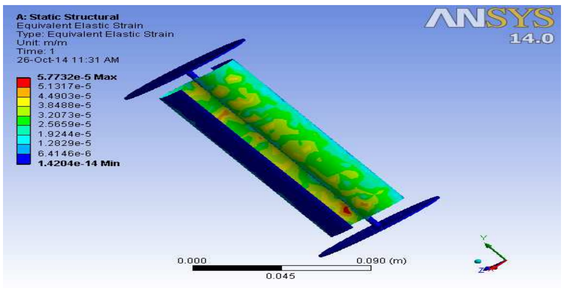


Fig:(2) Equivalent Elastic Strain

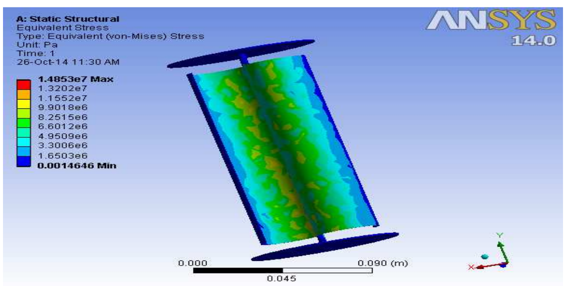


Fig:(3) VonMises stress

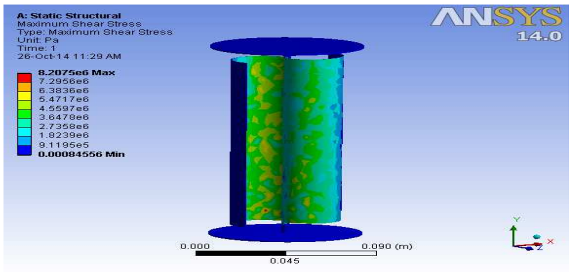


Fig:(4) Maximum Shear Stress

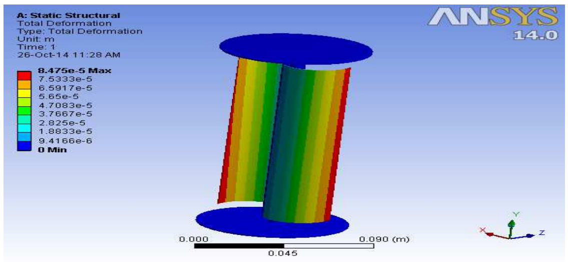


Fig:(5) Maximum Deformation

The maximum and minimum Von Mises stress for the Savonius rotor blade are 1.04853 x 10^{7} Pa and1.46 x 10^{-3} Pa respectively. Figure (5) shows the deformation of the model under the given load, the maximum displacement is 0.847 mm at the edge of the blade. The deformation is acceptable because it is small in relation to the overall size of the blade structure.

Table 3: Summaries of result for structural Analysis

Parameters	**Value**
Equivalent Elastic Strain	**5.7732e-5**
Von Mises stress	**1.48e7**
Maximum Shear Stress	**8.2057e6**
Maximum Displacement	**0.847 mm**

3.2. Computational Fluid Dynamics (CFD) Analysis

Computational Fluid Dynamics (CFD) analysis on ANSYS Simulation software is used for the purpose of obtaining the pressure difference between the concave and convex surface of rotor blade. The savonius rotor blade experienced drag force and this drag force turns the blade in the rotational motion. In this paper external flow and internal flow analysis for velocity, pressure and turbulence were analyzed.

3.2.1 Computational flow analysis

The blade of savonius rotor blade experience the drag force as the solid model is fully surrounded by the flow. This fluid flow is bounded by the Computational Domain boundaries. After the input data is ready, the model then is entering the meshing process. The meshing of savonius rotor blade in the computational domain shown in fig.(6) The fluid is experienced separation when it passes through the blade and this region is considered as high-gradient flow region. The mesh control is set to be finer in this region to obtain better solution accuracy.

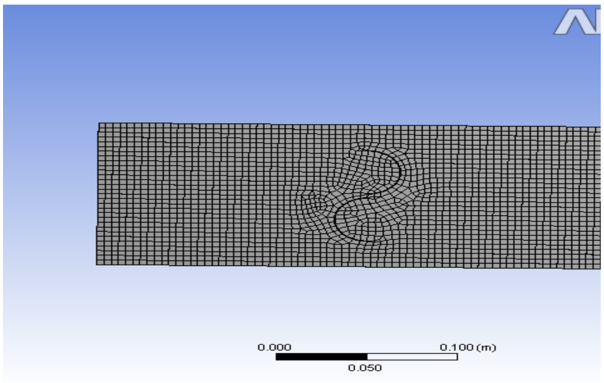


Fig: (6) Meshing in computational fluid Domain

The savonius rotor blade is surrounded by the flow of air on the concave and convex surfaces. The pressure distribution around the Savonius rotor is viewed by a contour cut plot from the topview. The contour cut plot display the higher pressure region and lower pressure region as red and blue color respectively as shown in fig.(7) The pressure is high near the concave surface and is low near the convex surface. The maximum pressure is found 112.02 kPa.The flow pattern is viewed by a flow trajectory is shown in fig.(7).

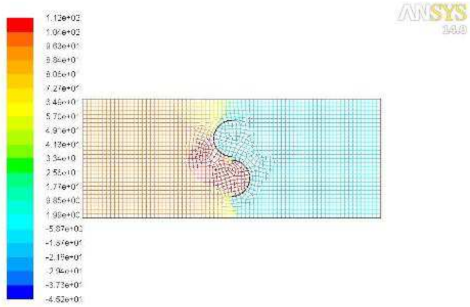


Fig.(7) Flow Distribution of Pressure on rotor blade

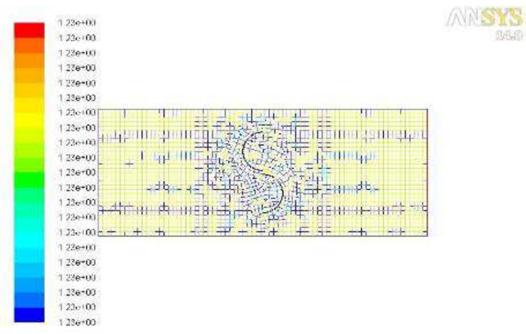


Fig.(8) Flow Distribution of Density

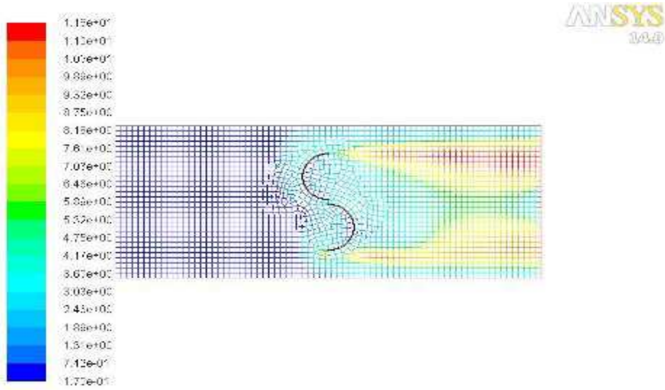
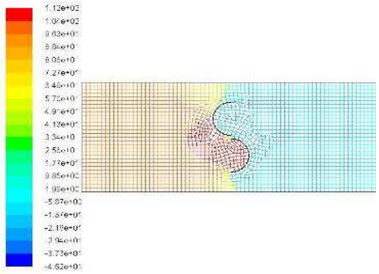


Fig. (9) Turbulence flow of air

The fig.(8) shows the flow distribution of density of air over the rotor blade. The density of air over the concave and convex surfaces is equally distributed. The red spotted region shows the maximum density of air.The maximum density of flow air found to be 1.23 kg/m^3.In the fig.(9) shows the turbulence of air flow over the surfaces of the blade. The concave surface of blade experience the maximum turbulence as compared with convex surface.

Table 3: Summaries of computational fluid dynamics results

Aspect	Flow Analysis
Maximum Pressure	112.03 KPa
High Pressure Region	Concave surface
Low Pressure Region	Convex surface
Vector Plot	
Flow Pattern	The wind flow is blocked by the Savonius rotor blades and it has bias from the wind direction. Since there is no wall boundary between it. The wind is not completely flow through the rotor blades.

4. CONCLUSION

The paper has explored the elements that contribute to the design and analysis of Savonius rotor blade. The blade was design by using Pro-E software. The structural feasibility was analyzed by Finite Element Analysis method to obtain the maximum deformation and stress experienced by the rotor blade. The computational fluid dynamics analysis was performed in order to obtain the pressure difference between the concave and convex surface of the rotor blade. The force induced to the blade was calculated from aerodynamic analysis. From the CFD analysis, it is found that the concave region of blade experience high pressure while the convex blade region experience low pressure for two blades Savonius rotor. The maximum pressure from flow analysis was 112.03kPa.The high pressure region produces 2.93 N of drag force that spinning the Savonius wind turbine.The maximum deformation of the Savonius rotor blade was 0.847mm. This deformation is acceptable because itis relatively small compared to the whole blade model. The maximum Von Mises stress obtained from the FEA was1.04853 x 10^{7} Pa.This concluded that the Savonius rotor blade was safe enough to withstand the aerodynamic force on the turbine.The study that was explored is limited by the software and computer capability.

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