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DESIGN AND ANALYSIS OF VERTICAL AXIS SAVONIUS WIND TURBINE

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Abstract:- *This paper presents the design and analysis of vertical axis Savonius wind turbine to generate electrical energy from wind energy. The Savonius rotor was designed with the rotor diameter of 2 m and the rotor height of 4 m. The 3D model of Savonius rotor blade was made by utilizing SolidWorks software. Computational Fluid Dynamics (CFD) analysis and structural Finite Element Analysis are presented in this paper. CFD analysis was done to obtain the pressure difference between concave and convex surface of the rotor blade and structural FEA was done to obtain the structural response of blade.*

Keywords-*Vertical axis wind turbine, Savonius, Rotor blade, Rated wind speed, Aspect ratio, Solidity*

I. INTRODUCTION

The improvements of renewable energy particularly wind energy become widely since 1973 because of the oil crisis issues. At present, almost ninety percent of the world's energy originated from the burning of fossil fuels, i.e. coal, normal gas, petroleum oils, etc. Almost every people use fossil fuels to meet all their energy needs, for example, fuelling vehicles, producing electricity for house hold purpose and running industries. The population development will make the need of energy sources gets to be higher and also the cost of fossil fuels.

At the same time there is an issue with the world wide environmental change as a consequence of carbon-dioxide and sulphur-dioxide emissions from the burning of fossil fuels. By using renewable energy to reduce the carbon emissions coming out from vehicles and industries. It is also a cost effective. Renewable energy is eco-friendly energy source due to the absence of carbon emissions [1]. The international energy agency reported that just a little extent of the energy comes from hydro-power and nuclear power, and a much little part from renewable energy source, for example, wind energy, solar energy, bio mass, geo thermal energy and tidal waves.

Wind energy is an environmental friendly energy source and also to alleviate the environmental changes from greenhouse gasses emitted by the burning of fossil fuels. It was evaluated that approximately 10 million MW of energy available in the worlds wind energy [2].

Wind turbine is a device is used to convert wind energy to generate electrical power. Wind turbines are classified into two categories, horizontal axis wind turbine and vertical axis wind turbine. Savonius wind turbine is simple in construction and it is operated on drag concept. It has good starting torque. Savonius rotor is 'S' in shape [3].

II. ADVANTAGES

1. It is independent of wind direction no additional force is required to drive mechanism.
2. Savonius wind turbine has good starting torque.
3. It is simple in construction and also maintenance is easy.
4. It has low noise and emissions. [4]

III. THEORY AND DESIGN

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

$$Pw = m \qquad \text{.......(1)}$$

Swept area is calculated by using the given formula
Where D= Rotor diameter
H= Rotor height

1. SELECTION OF BEARING

Here we select 6004 number bearing which is suitable for our application in which each no. specifies some features as follows.
6 = Deep groove ball bearing
0 = extra light series
04 = 20 mm bore diameter.

2. SELECTION OF BEARING FOR MAIN SHAFT

As load acting on bearing consist of two components Radial & Thrust. So we have used single row deep groove bearing. This bearing has high load carrying capacity & suitable for

Shaft diameter = 20 mm

Radial load, Fr = 54.936 N

L_{10h}=20000 (Amitabha Ghosh) (reference 11)

Bearing life in million revolution,

$L10 = (60*n*L_{10h})/10^6$

$= (60*100*20000)/10^6$

= 120 million of revolutions

Dynamic load calculations

Load, P= (xFr+yFa) S

= (1*54.936+0)1.1

= 60.4296 N

Where C=P (L_{10})1/p

= 60.4296 (120) ^1/3

= 298.06 N

We select bearing no. 6004 for diameter 20 mm.

Type of bearing is ball deep groove bearing, for easy mounting.

3. SPECIFICATIONS:

Rotor radius = R = 150 mm

Length of blade = L = 460 mm

No. Of blades = N = 3 blades

Initial angle of attack = αo = 0º

Blade camber = c = 20 mm = 0.020 m

Swept area:

$$S = 2\,R\,L$$

where S is the swept area [mm2], R is the rotor radius [mm], and L is the blade length [mm].

$$S = 2 * 150 * 460$$

$$S = 138000 \text{ mm}^2 = 0.138 \text{ m}^2$$

A. POWER AND POWER COEFFICIENT

The power available from wind for a vertical axis wind turbine can be found from the following formula:

$$Pw= 1/2\, \rho\, S \, [V_o]^3$$

Where, Vo is the velocity of the wind [m/s] and ρ is the air density [kg/m3], the reference density used its standard sea level value (1.225 kg/m^3 at 15ºC),

$$V_o=66 \text{ kmph} = 18.333 \text{ m/s}$$

$$Pw= 1/2×1.225×0.138[(18.333]^3$$

$$Pw=521.415 \text{ Watts}$$

The power the turbine takes from wind is calculated using the power coefficient:

Cp= Power captured by blades/ Incident Power

Cp value represents the part of the total available power that is actually taken from wind, which can be understood as its efficiency. 16 There is a theoretical limit in the efficiency of a wind turbine determined by the deceleration the wind suffers when going across the turbine. For HAWT, the limit is 19/27 (59.3%) and is called Lanchester-Betz limit (Tong, 2010, p. 22). For VAWT, the limit is 16/25 (64%) (Paraschivoiu I. , 2002, p. 148). These limits come from the actuator disk momentum theory which assumes steady, inviscid and without swirl flow. Making an analysis of data from market small VAWT, the value of maximum power coefficient has been found to be usually ranging between 0.15 and 0.22. This power coefficient only considers the mechanical energy converted directly from wind energy; it does not consider the mechanical-into-electrical energy conversion, which involves other parameters like the generator efficiency. (ref 2)

Tip Speed Ratio:

$$TSR = (\text{Tangential speed at the blade tip})/V_o = (R\,\omega)/V_o \quad \text{(reference 9)}$$

$$\omega = V/R = 18.333/0.150=122.22 \text{ m/s}^2$$

$$TSR= (R\,\omega)/V_o =(0.150 ×122.22)/18.333$$

$$TSR=1$$

Solidity

$$\sigma = (N\times c)/R = (4 \times 0.020)/0.150 = 0.5333$$

B. DESIGN OF BLADES/AEROFOIL:

For the blade design of VAWT the chosen aerofoil is NACA0018. At the frontal side of the rotor the blade has a positive angle of attack and at the back side a negative angle of attack. So symmetrical aero foils must be used. These airfoils have lower maximum lift coefficients when they are compared to asymmetrical aero foils of the same thickness. (Ref 6)

C. Number of blades:

As the number of blades in the wind turbine increases aerodynamic efficiency increases, but in a diminishing manner. When we move from 2 blades to 3 blades design efficiency gain is about 3%. But as we move from 3 blades to 4 blades design, efficiency gain is marginal. The number of blades has a direct effect in the smoothness of rotor operation as they can compensate cycled aerodynamic loads. For easiness of building, four and three blades have been contemplated. Most VAWT used 3 blades

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, bearings etc.

The maximum power coefficient for Savonius wind turbine is 0.45. So in this project we use maximum power coefficient value is 0.45. Finally wind power equation can be return by considering losses is shown in given bellow [1].

Wind velocity is the major significant component that influence the power output. The wind speed parameters include in this project is cut-in speed, rated wind speed, cut-out speed. Jain (2011) expressed that the three wind speed parameters related to power performance as follows [6].

Vcut – in = 0.5 Vavg ….. (4)

Vrated = 1.5 Vavg ….. (5)

Vcut-out = 3.0 Vavg …..(6)

IV. PROBLEM STATEMENT:

The increase in the use of energy during the 20th century has been enormous. In the early part of the century, coal was the dominant source of energy. The main competitor was oil because of its higher energy density. After the World War II, a shift from coal to oil has occurred, and oil is now the main energy source. The supply of cheap energy has spurred both economic and population growth. Almost 40 per cent of the total energy consumption in the world derives from oil. Different estimations have been presented on when the oil will start to deplete or become too expensive to extract. However, the most acute problem with the large oil consumption in the world is not the end of the resource but rather the environmental concerns associated with oil, i.e. the greenhouse effect. The greenhouse effect and the climate threat have been discussed substantially during the last years and the discussions were stimulated by the report by the International Panel on Climate Change (IPCC) from 2007, they describe that the climate change noticed in the last 50 years, it is due to increased emissions caused by human activity.

Many climate indicators are already moving above the patterns of natural variability. These indicators include global mean surface temperature, sea level rise, global ocean temperature, Arctic sea ice extent, ocean acidification, and extreme climatic events. More energy needs to be produced as the electricity consumption in the world increases. The wind as a fuel for producing electricity is inexhaustible, free and always available somewhere, and there is enough of it. The Potential for wind power generation for grid interaction has been estimated at about 1,02,788 MW taking sites having wind power density greater than 200 W/sq. m at 80 m hub-height with 2% land availability in potential areas for setting up wind farms at 9 MW/sq. km. Currently, horizontal axis wind turbines (HAWT) dominate the wind energy market. However, the power that a turbine can produce is proportional to the swept area. As a result, HAWT designs are continuously getting bigger to produce more power, which means that the blades must be made continuously larger. Increasing blade size adds extra weight to the blades, leading to higher centrifugal and inertial forces that the blade must be able to resist. Also, increased blade size leads to large bending moments on the blades at high rotational speeds. For these reasons, it has been suggested that HAWT technology will probably reach its peak in the next few years, making way for the vertical axis wind turbines (VAWT)

All there wind parameters depended up on average wind speed value, V_{avg} was found at 7 m/s

TABLE I. Shows the all values of three wind speed parameters

Wind speed parameter	Equation	Calculation
Cut-in speed, V_{cut-in}	Vcut-in = 0.5 Vavg	3.5 m/s
Rated wind speed, V_{rated}	Vrated = 1.5 Vavg	10.5 m/s
Cut-out speed, $V_{cut-out}$	Vcut-out = 3.0 Vavg	21 m/s

Aspect ratio is important criteria to calculate aerodynamic performance of Savonius rotor. Johnson (1998) recommends the Savonius rotor is designed with rotor height twice of rotor diameter. The expression for aspect ratio is given bellow [7].

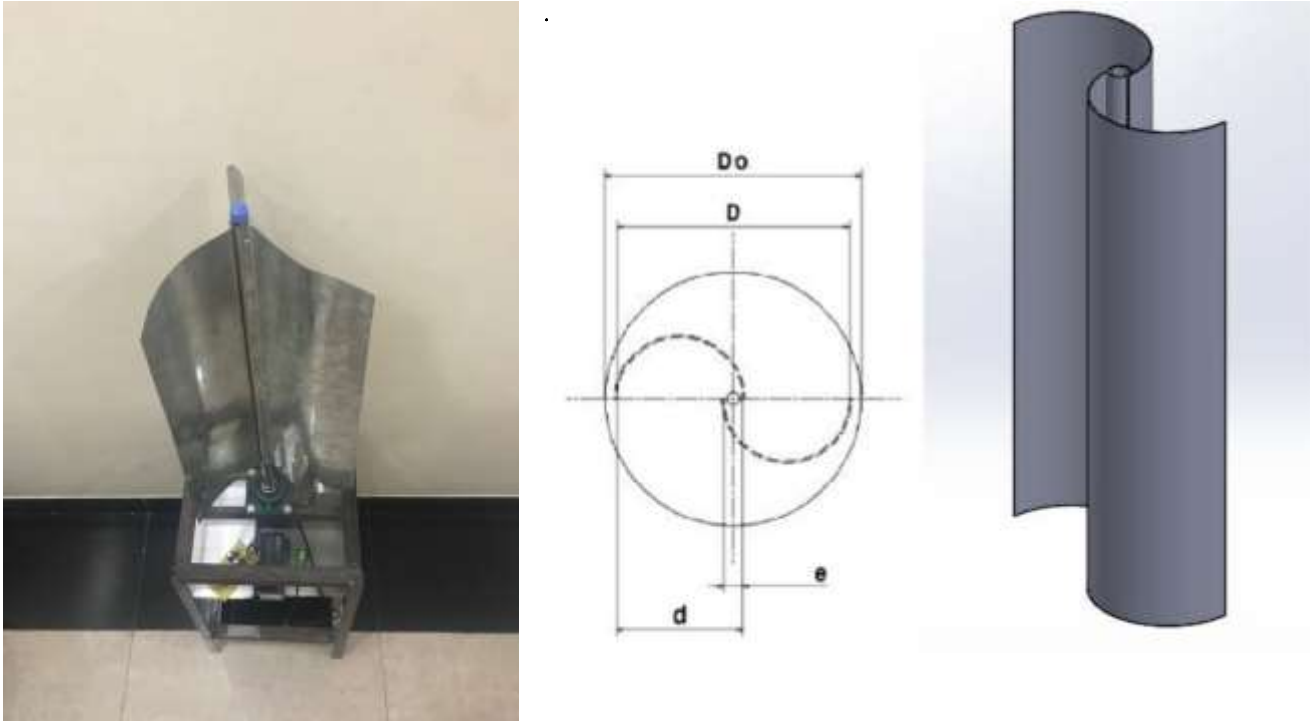


Fig. 1. **Angle of blades between the Turbines**

Tip speed ratio, λ is defined as the ratio of linear speed of rotor blade ω.R to the undistributed wind speed V.

Manwell et al., (2009) write that the high tip speed ratio, λ improves the performance of Savonius wind turbine and expanding the rotational rate of rotor.

Where

ω = angular velocity

R = radius revolving part of turbine

Musgrove (2010) says solidity, σ defined as the ratio of blade area to the turbine rotor swept area. According to Manwell et al., (2009). It is related to tip speed ratio.

Where n = number of blade

d = chord length (diameter of each of cylinder)

R = radius of wind turbine

TABLE 2. Shows the design parameters used in this paper

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

TABLE 3.Design model of Savonius rotor blade in SolidWorks

Parameter	Value
Swept area, A	8 m^2
Rotor Diameter, D	2000 mm
Rotor Height, H	4000 mm
Chord length, d	1080 mm
Overlap distance, e	162 mm
Blade thickness, t	10 mm
Mass density	2700 kg/m^3
Tensile strength	68935600 N/m^2
Yield strength	27574200 N/m^2
Poisson's ratio	0.33

IV. SIMULATION AND ANALYSIS

There are two kinds of simulation and analysis were done in this paper i.e. computational fluid dynamics (CFD) analysis by using ANSYS 15.0 and structural analysis by using solidworks structural simulation.

A. Computational fluid dynamics (CFD) analysis

The purpose of this analysis is to obtain the pressure difference between the convex and concave surface. The pressure difference between the convex and concave surface of the rotor induced drag force the drag force turns the blade. The pressure difference was obtained by using computational fluid dynamics (CFD) analysis by using ANSYS 15.0 software. The flow type in this paper were external flow analysis. External flow analysis were static analysis.

B. External flow analysis

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. 3.

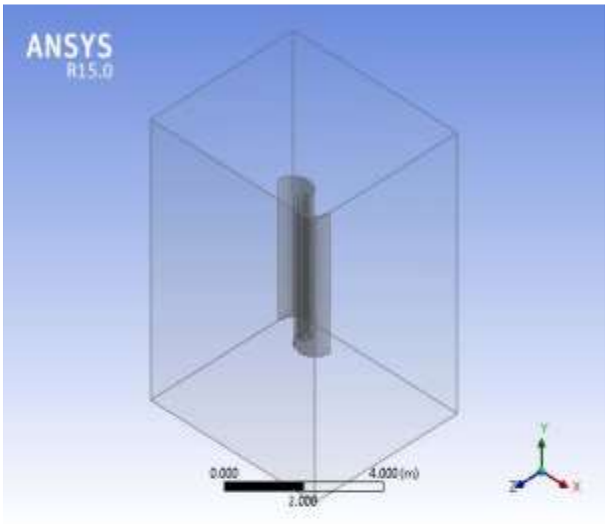


Fig. 2. Creating Enclosure for given model in ANSYS

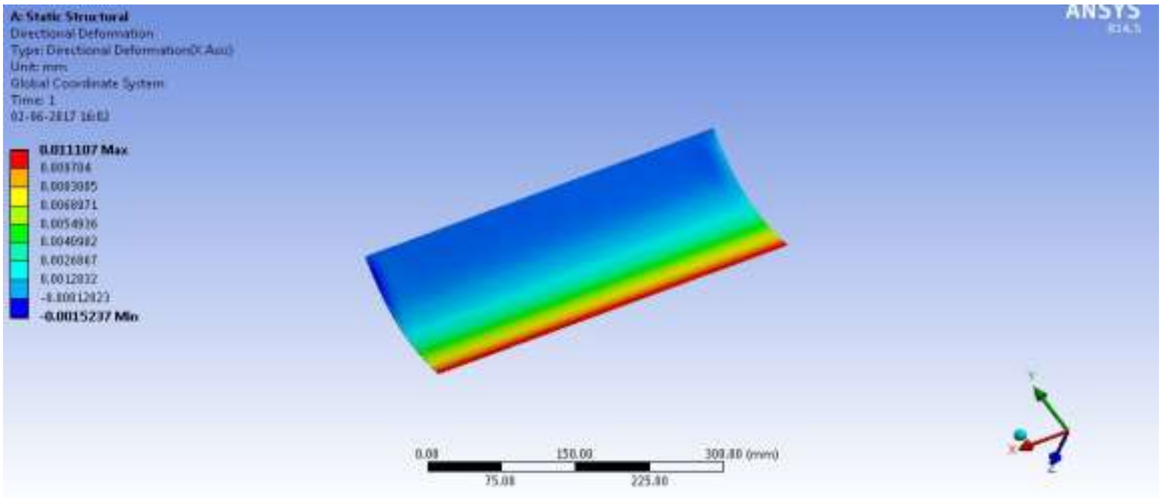
After completed the input data, the model is entering to the meshing process. The meshing is viewed through a wire frame as shown in Fig. 4. The fluid is separation when it passes through the Savonius rotor blade and this region is considered as high-gradient flow region

The pressure distribution around the Savonius rotor is viewed by a contour cut plot from top view. The above Fig.5 shows the contour cut plot display. The high pressure region as red and lower pressure region as blue color 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.

C. Structural analysis

The structure of rotor blade is analyzed utilizing Finite Element Analysis (FEA) static method by SolidWorks simulation software. The FEA analysis is performed on only one blade because the two rotor blades are symmetry. The static FEA result is translated in two criteria: stress distribution and deformation. Initial step of FEA analysis is allotted material to the rotor blade model where aluminum 1060 alloy was the material chosen. Then the fixed constrains are applied on the top, centre and bottom of the blade edge (where the blade is connected to shaft) as shown in Fig. 6.

The blade is stay in a static position only. The load applied for this analysis is Force with 600 N is obtained from the aerodynamic analysis. And the force is equally distributed on the concave blade region.



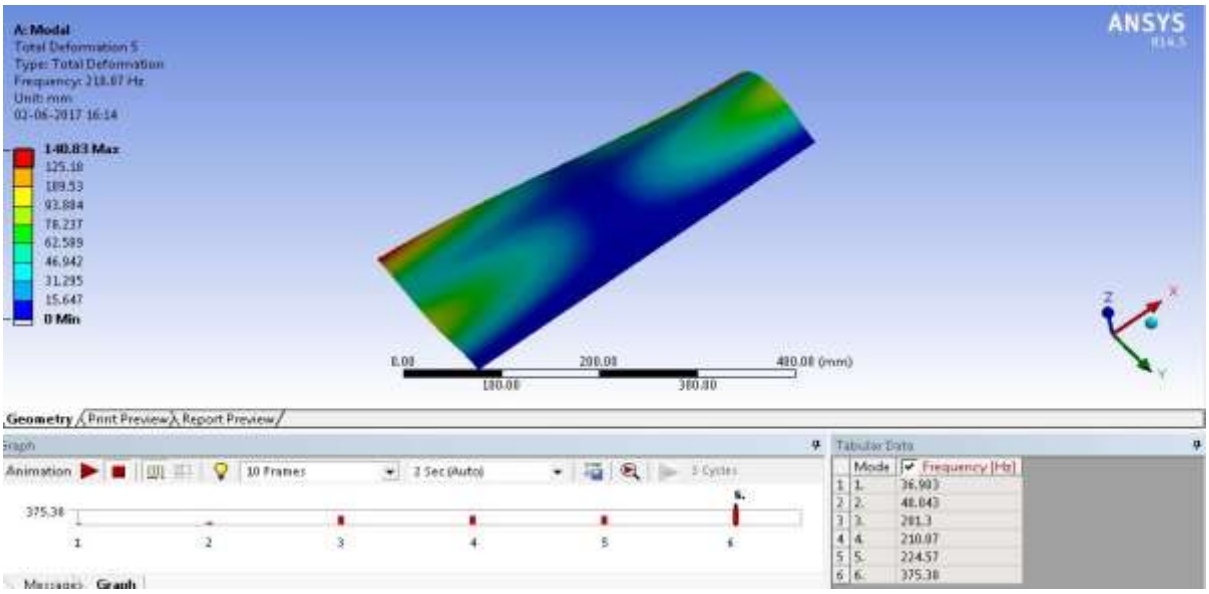


Fig. 3. Boundary condition of the Rotor blade 1

Fig. 7 shows the meshing of the blade model by using tetrahedral shape mesh elements and also shows the FEA result of the blade model which presents the stress distribution over the blade structure.

Fig. 4. Meshing of rotor blade in SolidWorks

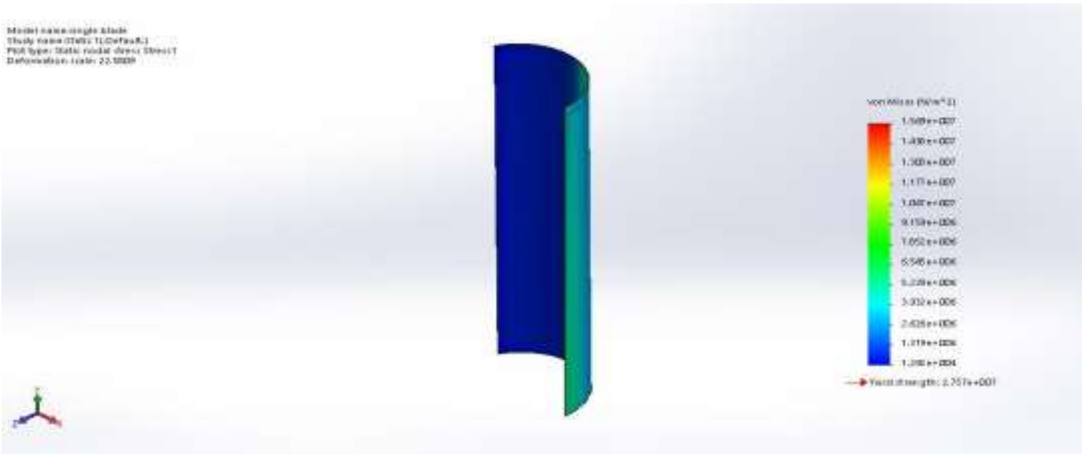


Fig. 5. Stress distribution of Rotor blade 2

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. Fig.9 shows the deformation of the rotor blade under the given load. And the maximum Displacement is 19.0711 mm at the edge of the rotor blade. The rotor blade is acceptable because it is small in relation to the general size of the rotor blade

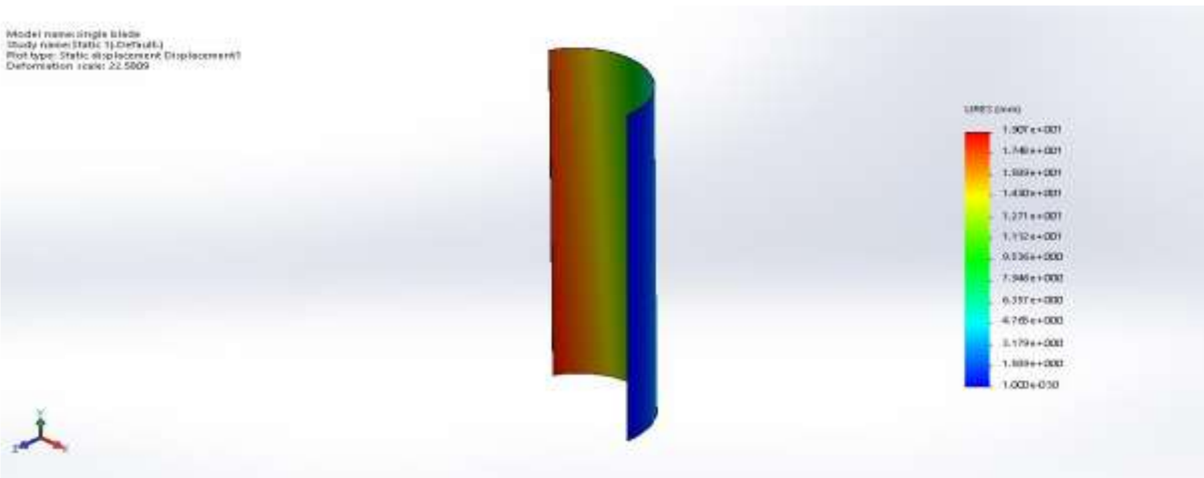


Fig. 6. Stress distribution of Rotor blade 3

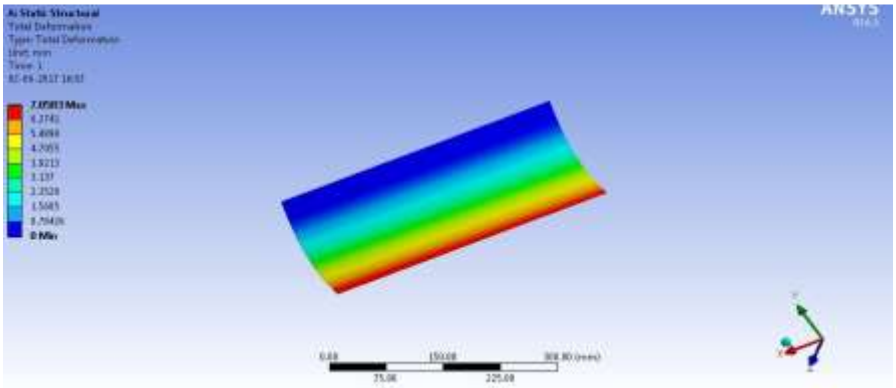


Fig. 7. Stress distribution of Rotor blade 1-2

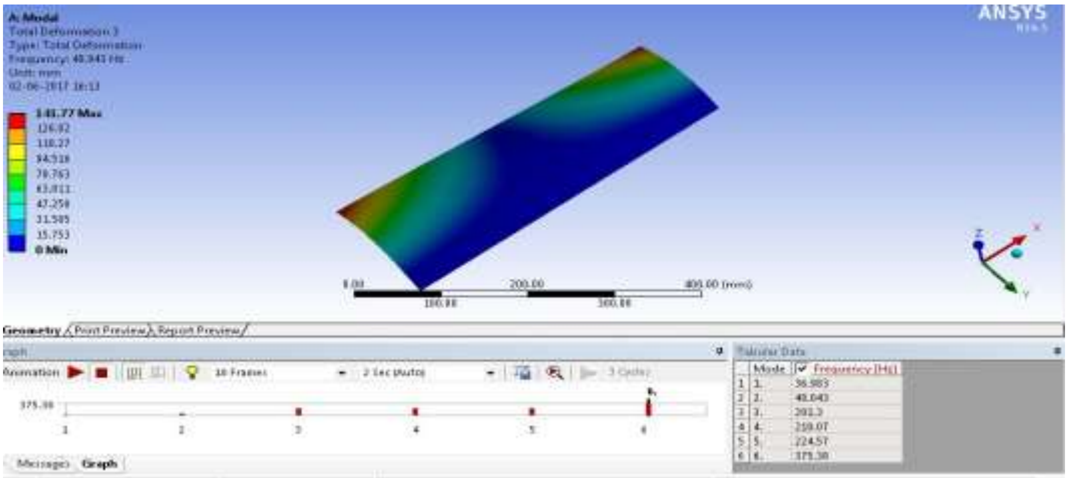


Fig. 8. Stress distribution of Rotor blade 2-3

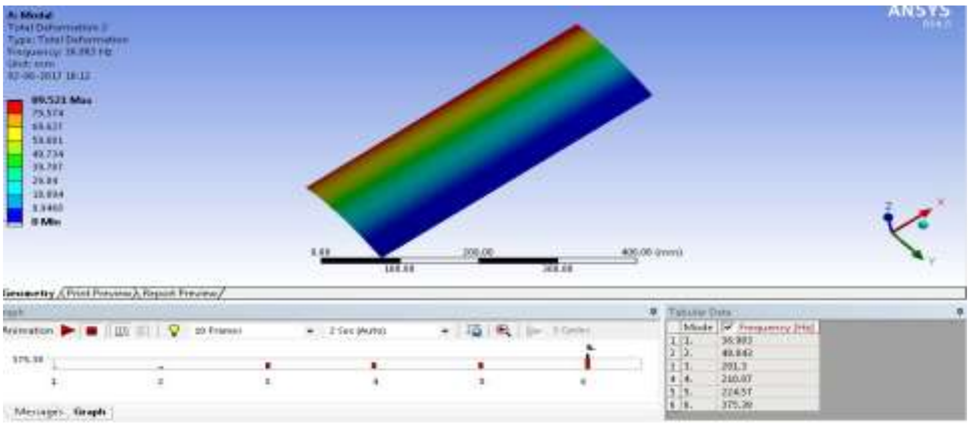


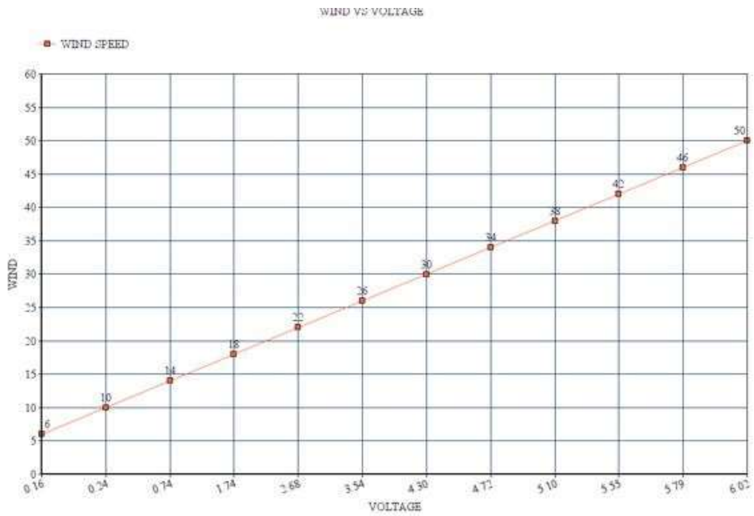
Fig. 9. Stress distribution of Rotor blade 3-1

V. RESULTS AND DISCUSSION

Results of this paper investigate the components that add to the design and analysis of Savonius rotor blade. The rotor blade was designed by utilizing SolidWorks 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 and maximum deformation of the rotor blade. 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.

From the computational fluid dynamics analysis, it is found that the concave blade region experience high pressure while the convex region experience low pressure for the two blades Savonius. The maximum and minimum pressure from external flow analysis were 101.496 Pa and 101.296 Pa respectively. The high pressure region produces drag force that turns the Savonius wind turbine.

Output Graph:
We plot the graph for wind speed vs voltage. As we can see they are linearly related. Therefore voltage is directly proportional to the wind speed.



From the finite element analysis the maximum deformation of the Savonius rotor blade was 19.0711mm. The deformation is acceptable because it is small in relation to the general size of the rotor blade. The maximum Von Mises stress obtained from FEA was 15691100 Pa.

VI. CONCLUSION

The following conclusions on Savonius type wind turbine model designed in SolidWorks and simulation using ANSYS 15.0 are

1. From CFD analysis, it is found that the concave blade region have high pressure and convex region have low pressure for the two blade Savonius rotor.
2. The maximum and minimum pressure from external flow analysis were 101.496 Pa and 101.296 Pa respectively.
3. From FEA, the maximum Von Mises stress are 15691100 Pa. 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.

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