Abstract—Wind energy is the most abundantly available clean form of renewable energy in the earth crust. Wind turbines produce electricity by using the power of wind to drive an electric generator. There are two kinds of wind turbines according to the axis of rotation to the ground, horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). VAWTs include both a drag type configuration like Savonius wind turbine and a lift-type configuration like Darrieus wind turbine. Savonius wind rotor has many advantages over others in that its construction is simpler and cheaper. It is independent of the wind direction and has a good starting torque at lower wind speeds. The experimental study conducted in this paper aims to investigate the effect of number of blades on the performance of the model of Savonius type wind turbine. The experiments used to compare 2, 3, and 4 blades wind turbines to show tip speed ratio, torque and power coefficient related with wind speed. A simulation using ANSYS 13.0 software will show pressure distribution of wind turbine. The results of study showed that number of blades influence the performance of wind turbine. Savonius model with three blades has the best performance at high tip speed ratio. The highest tip speed ratio is 0.555 for wind speed of 7 m/s.

Key words: Wind Turbine, Wind Energy

I. INTRODUCTION

Wind turbines are generally divided into two categories, horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs), based on the relative position between their rotation axis and the wind direction. VAWTs are more favored in small-scale power generations because they respond to flow from any direction and allow generating equipment to be located on the ground shaft, and the maintenance costs can be reduced. Savonius wind turbine is a common VAWT which generates torque through the combined effects of drag and inside forces and typically comprises two or three arc-type blades.1 Savonius turbine has the following advantages over other types of wind turbines: (1) ability to operate under complex turbulent flows; (2) low rotation speed and noise emission; (3) simple structure, low cost. However, the Savonius turbine has a relatively lower power efficiency, with a maximum efficiency of 0.25,4 compared with the lift-type wind turbines, such as HAWTs and Darrieus wind turbines. In order to increase the efficiency.

In addition, some researchers worked to enhance the Savonius turbine performance by changing the structure of the turbine.

II. PROBLEM STATEMENT

To study the power developed by turbine by natural and forced means and convert the mechanical energy into electrical energy.

III. OBJECTIVES

The objective of this project is to design and build a self-staring vertical axis wind turbine that is capable of producing power in real world situations. The design of the turbine will include exploration of various self-starting options, as well as construction of both model and full-scale turbines. The full-scale turbine will be designed such that it can be connected to a generator and a torque transducer to measure the output power, torque, and rotational speed of the turbine. The design will also allow for data collection regarding the effects of blade pitch angles. With these applications, it is hoped that Dalhousie University’s Department of Mechanical Engineering will conduct future research involving vertical axis wind turbines.

IV. EXPERIMENTATION

A. Mohammed Hadi Ali [1]

Savonius turbines are one of the simplest turbines. Aerodynamically, they are drag-type devices, consisting of two or three blades (vertical – half cylinders). A two blades savonius wind turbine would look like an "S" letter shape in cross section (figure 1). The savonius wind turbine works due to the difference in forces exert on each blade. The lower blade (the concave half to the wind direction) caught the air wind and forces the blade to rotate around its central vertical shaft. Whereas, the upper blade (the convex half to wind direction) hits the blade and causes the air wind to be deflected sideways around it.

![Fig. 1: Schematic drawing showing the drag forces exert on two blade Savonius.](image)

Because of the blades curvature, the blades experience less drag force (F convex) when moving against the wind than the blades when moving with the wind (F concave). Hence, the half cylinder with concave side facing the wind will experience more drag force than the other cylinder, thus forcing the rotor to rotate. The differential drag causes the Savonius turbine to spin. For this

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reason, Savonius turbines extract much less of the wind’s power than other similarly sized lift type turbines because much of the power that might be captured has used up pushing the convex half, so savonius wind turbine has a lower efficiency. Similarly, the three blade savonius wind turbine is constructed from three half cylinders, they are arranged at (120°) relative to each other as shown in figure (2).

Fig. 2: Schematic drawing showing the drag forces exert on three blade Savonius.

The goal of this research is to carry out a study and make a comparison in performance between two and three blades savonius wind turbine at low wind speed, the reasons to study them at low speed are:

1) In many areas in the world apart from coastal region, the average wind speed is relatively low and varies appreciably with seasons. It is around 20 km/h.
2) A Savonius rotor requires (30 times) more surface for the same power as a conventional rotor blade wind turbine. Therefore it is only useful and economical for small power requirements.
3) It has a high starting torque; a Savonius rotor can theoretically produce energy at low wind velocities.
4) It is difficult to protect them from extreme winds.
5) The peak power coefficient for any Savonius rotor occurs at a tip speed ratio (less than 1).
6) Lower wind speeds found at lower heights, thus VAWT like savonius can be installed close to the ground without an extended post with the generator and the driven train mounting at the base near the ground level which makes these components easier to service and repair.

B. S. Jagadish Venkata Sai*1, T. Venkateswara Rao2[2]

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.

1) 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. 3: 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.

Fig. 4: Pressure distribution over turbine blades

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 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.

C. Structural Analysis

The structure of rotor blade is analysed 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 aluminium 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. 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. 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.

As a simplest turbine, Savonius wind turbine works due to the difference of forces exert on each blade. The concave part to the wind direction caught the air wind and forces the blade to rotate around its central vertical shaft. Otherwise, the convex part hits the air wind and causes the blade to be deflected sideway around the shaft. The blades curvature has less drag force when moving against the wind or $F_{convex}$ than the blades moving with the wind or $F_{concave}$ as seen in Fig. 3 [11]. Hence, concave blades with more drag force than the other half cylinder will force the rotor to rotate.

The performance of Savonius wind turbine can be expressed in the form of torque coefficient ($C_t$) and the coefficient of power ($C_p$) in comparison with the tip speed ratio or $TSR (\lambda)$. $TSR$ is a parameter related with rated wind speed and rotor diameter. As the ratio between the speed of tip blade and wind speed through the blade, $TSR$ can be determined as.

$$TSR = \lambda = \frac{V_{rotor}}{v}$$

where $V_{rotor}$ is the tip speed or the peripheral velocity of rotor (m/s) ; $\omega$ is the angular velocity of rotor (1/s) ; $d$ is the diameter of the halves cylinder of rotor (m), and $V$ is the wind speed (m/s). The coefficient of torque or $C_t$ is defined as the ratio between the actual torque develop by the rotor ($T$) and the theoretical torque available in the wind ($Tw$) as,

$$C_t = \frac{T}{Tw}$$

where $\rho$ is the density of air ($= 1.225$ kg/m$^3$) ; $T$ is the torque (Nm), and $As$ is the swept area of blades = the rotor height x the rotor diameter (m$^2$). The coefficient of power of a wind turbine ($C_p$) is the ratio between the maximum power obtained from the wind ($P_t$) and the total power available from the wind ($Pa$) as,

$$C_p = \frac{P_t}{Pa}$$

where the maximum power of wind turbine is determined as

$$P_t = Tw \text{ (Watt)}$$

The relationship between the power coefficient $C_p$ and the tip speed ratio $TSR$ or $\lambda$ as an effect of solidity of the wind turbine performance is shown in Fig. 4 [13]. The curve shows that single blade of wind turbine has smaller solidity and the shape of curve $C_p$ relatively flat which caused by higher drag force. The three blades wind turbine gave optimal solidity with $C_p$ maximum and the result it produces more energy.

E. Exp set up

The experiment used a model of Savonius wind turbine with two, three and four blades as shown in Fig. 5. The model of wind turbine was built with overlap ratio ($e : d$) equal to 0.15 ; aspect ratio ($D : h$) equal to 1.0 and end plate parameter ($D_0 : D$) equal to 1.1 [14].

![Diagram of Savonius turbine model](image)

(a) the cross section of turbines with (b) two blades (c) three blades, and (d) four blades

Dimensions of the blades of Savonius wind turbine model are diameter of blades ($d$) = 200 mm ; gap ($e$) = 0.15x $d$ = 0.15 x 200 = 30 mm ; rotor diameter ($D$) = 200 + 200 – 30 = 370 mm ; rotor height ($h$) = 370 mm ; end plate diameter ($D_0$) = 1.1 x $D$ = 1.1 x 370 = 407 mm ; and thickness of blades and end plates ($t$) = 2 mm. The model of Savonius wind turbine were performed in a low speed open circuit wind turbine . The low speed wind tunnel was started to produce wind and an anemometer measured the
velocity of wind. When the wind produced by wind tunnel pushed the blades (halves of cylinder) of the model, the rotor of wind turbine will rotate. The rotation of rotor was measured by tachometer and noted three times of experiments. Each experiment with two, three and four blades respectively used the speed of wind from 1 to 10 m/s. The torque of wind turbine was also measured by a torque meter related with the speed of wind. The specified speed of wind from the wind tunnel (1 to 10 m/s) were determined based on the assumption that small wind turbine, like the model of Savonius wind turbine, will tend to split in angular motion if using high speed wind. High speed of wind exerts high pressure on blades causing the rotation of rotor may exceed its design limit and become difficult to measure.

F. Zhaoyong Mao and Wenlong Tian[4]

The two-dimensional schematic view and geometrical parameters of a two-bladed Savonius wind turbine are presented in Figure 1, where U is the wind velocity, \( \alpha \) is the azimuth angle of the blade, \( \beta \) is the blade arc angle, \( v \) is the rotation velocity of the turbine, \( r \) is the blade radius, and D is the turbine diameter. In order to investigate the effect of the blade arc angle, \( \alpha \), on the performance of the turbine, we performed simulations on turbines with \( \alpha \) varying from 150\(^\circ\) to 200\(^\circ\). The specific values of the turbine geometrical parameters for each case are shown in Table 1. Because the straight blades have the same cross section in the span direction, the blade span effect can be ignored and two-dimensional transient simulations are carried out with the aid of the commercial CFD code Fluent 13.0. A sliding mesh model was applied to realize the rotation motion of the rotor.

![Fig. 7: Computing domains and boundary conditions](image)

<table>
<thead>
<tr>
<th>Case</th>
<th>D</th>
<th>R</th>
<th>( \alpha )</th>
</tr>
</thead>
<tbody>
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<td>0.25</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>0.909</td>
<td>0.25</td>
<td>160</td>
</tr>
<tr>
<td>3</td>
<td>0.909</td>
<td>0.25</td>
<td>170</td>
</tr>
<tr>
<td>4</td>
<td>0.909</td>
<td>0.25</td>
<td>180</td>
</tr>
<tr>
<td>5</td>
<td>0.909</td>
<td>0.25</td>
<td>190</td>
</tr>
<tr>
<td>6</td>
<td>0.909</td>
<td>0.25</td>
<td>200</td>
</tr>
</tbody>
</table>

Computation domains and boundary settings-In order to allow a full development of the flow as well as decrease the blockage effect, the computational domain was a rectangle of 18D312D. The rotor was placed in the symmetry axis of the top and bottom boundary and at a distance of 6D from the left boundary (see Figure 2). The overall domain is split into two subdomains, including an external station domain and an internal rotation domain containing the rotor. In the simulations, the internal rotation domain rotates with the rotor angular velocity \( \omega \). The boundary conditions employed consist of a constant velocity inlet (7 m/s) on the left side, a pressure outlet on right, and two symmetry boundary conditions on top and bottom. No-slip boundary conditions were imposed at the surface of the blades. Siding interfaces exist between the external stationary domain and the internal rotational domain, allowing the transport of the flow properties.

G. Grids generation

The computation grids were generated using the MESH tool in ANSYS 13.0. Quadrilateral elements are less memory-occupying than triangular elements (the number of quadrilateral elements is only a half of the triangular elements considering the same grid nodes number) in two-dimensional simulations and more suitable for simulation of the boundary layers flow. The renormalization group (RNG) \( k \_ e \) turbulence model was employed. This model is known to give highly accurate predictions of rotating machinery because the effect of swirl on turbulence is included. Moreover, the RNG \( k \_ e \) model provides an analytic/derivative differential formula for effective viscosity that accounts for low-Reynolds-number effect. Besides, a standard wall treatment is applied to increase the solution accuracy under low Reynolds numbers. For each case listed in Table 1, several simulations were carried out with the tip speed ratio varying from 0.6 to 1.4. Tip speed ratio represents the ratio of the blade tip speed to the wind speed and has the following expression

\[
\text{tip speed ratio} = \frac{v}{U}
\]

Each simulation lasted for three revolutions. The time step used was set as \( 1/\Delta t \), that is, the rotor Therefore, the two subdomains were discretized with quadrilateral elements (see Figure 3(a)). As can be seen in Figure 3(b), grids closest to the profiles of the blades were refined with boundary layer elements to describe with sufficient precision the boundary layer flow. The Reynolds number was computed based on the wind speed and the blade chord length, resulting in a value of about 4.3310^5. The first element height of the mesh above the surface was set as 0.04 mm, and the y+ value for the first node from the wall was in the order of 10. There were eight layers in total, and a layer growth rate of 1.2 was chosen. Moreover, grid node density was higher in the rotational subdomain than in the stationary.

H. Subdomains:

As \( \lambda \) increases, the turbine rotates faster and the blade has a higher linear velocity. Therefore, the relative velocity between the wind and the blade on the downwind direction will reduce, decreasing the thrust force and the positive torque on the blade (the region of positive torque in Figure 7 gets smaller as \( \lambda \) increases), while the relative velocity between the wind and the blade on the upwind direction will go up, increasing the drag and the negative torque on the blade (the region of negative torque in Figure 7 gets larger as \( \lambda \) increases).

V. Conclusion

Some conclusions on the experimental study of Savonius type wind turbine model in wind tunnel and simulation using ANSYS 13.0 are:
- Number of blades will influence the rotation of rotor of wind turbine models. The three blades wind turbine produces higher rotational speed and tip speed ratio than that two and four blades. The highest tip speed ratio is 0.555 for wind speed of 7m/s.
- Wind turbine rotor with four blades has high torque compared with two or three blades wind rotor.
- Four blades wind turbine has good performance at lower tip speed ratio, but three blades wind turbine has the best performance at higher tip speed ratio.

REFERENCES