Two blade vertical axis wind turbine: Investigations on the torque generation at different rotational velocities

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Abstract. Among renewable energy technologies after solar energy, wind turbines are widely used. The most common types of wind turbines are Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbines (HAWT). VAWT’s have the higher output energy potentials than to the commonly used HAWT’s. In this paper, a study has been considered to develop the two blade VAWT and estimate the torque generation possibility in it. This study includes the selection of airfoil by comparing lift and drag generated by airfoils NACA 0012, NACA 0015, NACA 0018, and NACA 0021. CFD analysis of various rotation angles and speeds of the 2-blade Vertical Wind Axis Turbine having chord 0.5m and radius 1.25m were performed. Forces generated by the turbine over one complete cycle were estimated.

1. Introduction
Among renewable energy technologies, solar energy is the predominant one \([1,2]\). After solar power, wind turbines are quite popular and widely used in the locations where the wind resource is available. Wind energy harvesters are those generating electricity from the wind’s kinetic energy using wind turbines coupled with electrical alternators \([2]\). The most common types of wind turbines are Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbines (HAWT) \([3]\). VAWT’s have the higher output energy potentials than to the commonly used HAWT’s \([3]\). In VAWT, the main rotor placed transverse to the wind and other main components set at the base of the turbine, thereby facilitating easy service and repair, see Figure 1 \([4]\). They are used primarily in small wind projects and residential applications. The airfoils of this wind turbine are placed in such a way that it is lift driven and have zero rigging angle. This arrangement makes it valid irrespective of the wind direction, thus removing the need for wind-sensing and orientation mechanisms. The difference between VAWT and HAWT is the position of blades. The blades are at the top and spinning in the air for HAWT whereas in VAWT the blades are wrapped around the shaft. The spin of the Darrieus rotor places the airfoils in a circular path. Incoming airflow is added vectorially relative to the blades, creating a small varying positive angle of attack to the blade. A force is generated obliquely along a certain line of action which is projected inwards giving a positive torque to the turbine shaft helping it to rotate in the direction it is already traveling in \([5]\). The objective of the paper is to design 2-blade VAWT with appropriate airfoil selection. The airfoil is selected by considering a condition of maximum attainable force concerning various rotational velocities. 2-blade VAWT is modeled and analyzed computationally to access the amount of torque generation concerning selected velocities.
2. Materials and Methodology

For analysis, symmetric airfoils are selected so that the airfoil characteristics does not change in case of inversion of the airfoil. The airfoil should have a higher lift to drag ratio owing to the lift being the main driving force. The airfoils should also generate the maximum tangential forces in one complete cycle. Forces acting on the turbine blades is shown in Figure 2. The airfoils considered are NACA 0012, NACA 0015, NACA 0018, and NACA 0021. Characteristics of these airfoils at an angle of attack from 0° to 180° were taken from the literature [8-12].

2.1. Calculation of Forces

The arrangements of the airfoil are placed according to the turbine configuration. Forces generated at each angle of attack of the airfoil is calculated, which is then added to get the total force generated and is compared with those generated by other airfoil types. CL and CD forces from 0° to 180° are obtained.
to calculate tangential forces for each blade with the help of horizontal and vertical component of the force [8-12].

\[
F = F_x^1 - F_y^1
F = [(F_y \times (\cos \theta)) - (F_x \times (\sin \theta))]
\]

Where, \( F_x \) = Horizontal Component of Force, \( F_y \) = Vertical Component of Force, \( F_x^1 \) = Tangential component of \( F_x \), and \( F_y^1 \) = Tangential component of \( F_y \).

2.2. Selection of Airfoil

Tangential forces generated by both the blades were plotted into figures comparing with rotation angles were shown in Figure. 3. The four results were analyzed in Figures. 4, wherein the curve for NACA 0015 covers the higher graphical area. This ultimately depicts what NACA 0015 would produce maximum average tangential force over one complete cycle. Thus, NACA 0015 airfoil is selected for further analysis, and the cross-section of the airfoil chosen is shown in Figure. 5.

![Figure 4. Force vs. rotational angle](image1)

![Figure 5. Cross section of NACA 0015 airfoil](image2)

2.3. Modeling in SolidWorks and ANSYS Workbench

The geometry for the selected airfoil is generated with a chord length of 0.5m. The grid is divided into different cell zones for the addition of rotational velocity so that the analysis of rotational effect can be done on the wind turbine. The cell zones are generated separately in Solid Works and then meshed in ANSYS Workbench. Since the forces act in the plane of the airfoil except for the end of the blade, 2-D analysis has been carried out. Triangular meshing is used for the geometry. Edge sizing of the blades are given regarding some divisions, and the mesh grows by a factor of 1.015. Three meshes of different grid sizes with a different number of elements (see Table 1) and forces on the blades were analyzed, see in Table 2. In comparison the results of Case-2 and Case-3 are reasonably close, see in Table 1. Thus, the grid sizing in Case-2 is used for further analysis. Since the flow speed is Mach 0.03 thus flow can be treated as incompressible. The two-dimensional pressure-based solver is used. Taking the air density to be 1.21 kg/m³ and viscosity to be 1.81 x 10^-5 kg/m-s and wind speed of 10 m/s Reynolds number of the flow is calculated as 3.34x10^5 indicating it as laminar flow.

| Blade Number | Case-1 | Case-2 | Case-3 |
|--------------|--------|--------|--------|
| x-force      | 50.50  | 50.59  | 50.59  |
| y-force      | 4.35   | 4.36   | 4.36   |

| Blade Number | Case-1 | Case-2 | Case-3 |
|--------------|--------|--------|--------|
| x-force      | -13.21 | -13.22 | -13.22 |
| y-force      | 0.11   | 0.09   | 0.09   |
Nevertheless, in the practical scenario, the interaction of the flow over one turbine blade and its wake with angle blade is likely to create turbulence. Therefore, flow is treated as turbulent for simulation. K-epsilon model of solution iteration is used.

3. Computational Results
Analysis was carried out for wind velocity of 10m/s and the following rotational velocity: 4 rad/sec (38 RPM), 6 rad/sec (56RPM), 8 rad/sec (76RPM). The tangential forces produced by the blades and the total torque produced by turbine were calculated for different rotational velocities and rotation angles. For every 10° angle of rotation, separate meshes were generated. The analysis was performed from 0° to 170° and was iterated twice to complete one cycle.

Blades are tested at a zero-degree angle of attack for rotational velocity of 4rad/sec with stagnation point at approximately 90°. Due to flow separation, the leading edge of blade 1 has the highest flow velocity. The blade 2 is in the wake of blade one experiences comparatively lesser force. Figure. 6. Shows the velocity contours at 4 rad/sec for the two blade VAWT and Figure. 7 shows the respective total torque produced by the blades for the various angle of rotation. There will be a certain point where the turbine rotational speed neutralizes the flow velocity. Thus, the net torque at that instant will be zero due to the absence of tangential force.

The results are analyzed for rotational velocity 6 rad/sec and 8rad/sec and were shown as velocity contour in Figure. 8, and Figure. 10 respectively. The generated torque in the 2-blade VAWT for 6 rad/sec and 8 rad/sec rotational velocities were shown in Figure. 9, and Figure. 11 respectively. Upon calculating the area under the curve, it is found that the turbine would probably have the maximum
efficiency for rotation velocity of 8 rad/sec. This depicts that the VAWT works better at higher RPM. However, the rotational speed will be governed by the torque produced, a moment of inertia of blade assembly and friction at the axis of rotation.

![Total Torque](image)

**Figure. 12.** Comparison of torque generated at different rotational velocities

The comparison is made to identify the effect of different rotational velocities in the torque produced. It is observed from the Figure. 12. that for the rotational velocity of 8 rad/sec has a greater area under the curve compared to the other rotational velocity. This area is the measure of power generation by the wind turbine. The performance of the turbine is dependent on RPM of the turbine shaft. The lift and hence, the torque generated depends on two primary factors: Relative velocity of the wind concerning the moving blades, Change of the relative angle of attack due to the rotation of the turbine.

4. Conclusion

The results show that there are acceleration and deceleration in the rotation speed of the turbine. For maximum power to be generated the acceleration must be constant. The analysis of 2-blade VAWT is not efficient enough for optimal performance. It can be perceived that increasing the number of blades can improve the performance of the wind turbine. From the analysis, it is observed that VAWT seems to generate power for higher rotational speeds. The irregular peaks and dips in the production of torque are because the dynamic stall of the blade varies rapidly with changes in the angle of attack, which in turn affects the torque generation. The effect is more prominent when the rotation velocity of the turbine increases. These types of turbines work better for higher rotational velocities.

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