Numerical analysis of vertical axis wind turbine with the wing profile of NACA0021

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Abstract. A model of Vertical Axis Wind Turbine (VAWT) with the wing profile of NACA0021 is created for testing purpose in the modeling software. The numerical test is conducted in the profile using two equation turbulence model. The result is presented here. The visualization part of blade is showing the detailed region of both velocity and pressure. The large number of simulation is performed for attaining the maximum performance of the blade with different tip speed ratio. The result shows the average co-efficient of performance of 0.27 at the tip speed ratio of 2.5. The flow visualization is studied at the simple level.

1. Introduction

Electricity consumption is increasing on a daily basis to meet people's needs while causing no or minimal environmental damage. As a result, there has been an increase in the number of wind farms in the developed and developing countries [1,2]. Now a days many researchers are finding a way to increase the energy that is transferred by the wind [3,4]. Wind turbines are used to convert the kinetic energy into mechanical energy at first and then to electrical energy [5-8]. Vertical axis and horizontal axis wind turbines are the two types of wind turbines [9,10]. The differences between those two are given in figure 1. In this paper, Vertical axis wind turbine is considered because of its low economic cost, less maintenance and less complicated design [11-13]. To overcome these drawbacks, Chong et al. [19] introduced the concept of The VAWT's efficiency and performance can be improved by using an omni-direction-guide-vane (ODGV). The ODGV could also be used in urban areas with low wind speeds and turbulent conditions. It can also accelerate with oncoming wind to increase energy output and improve the wind turbine's starting characteristics.

India has one of the top 5 largest road connectivity of the world. How-ever in the remotely located highways, the electricity is required to meet the basic needs such as guiding signals and traffic lights to avoid accidents [19]. So that the energy call to fulfill by means of wind energy from constantly high-speed vans, cars, and other heavy automobiles will be used by a wind turbine projected in the middle of a highway.

2. Model preparation

The different steps involved in preparing the model are listed here along with the dimensions of the specimen.
2.1. **Turbine Geometry**

The 2D model is prepared using CATIA V5. The specifications of the model are given in table 1.

**Table 1. Geometry of turbine.**

| Geometry of turbine | Dimensions |
|---------------------|------------|
| Airfoil blade selected | NACA0021 |
| Chord length (C) | 78mm |
| Turbine radius (R) | 250mm |
| Number of blades (N) | 3 |
The 3D model is created in the modeling software which it is given in the following figure. The pattern command is used to make the three blades from the single blade. The purpose of the 3D model is describing the geometrical characters of the blade. The another purpose of 3D turbine is confirming the top and front view, which very important for modeling the 2D blade for the tool of the numerical analysis.

![3D model of a turbine](image)

**Figure 3.** Top view of ODGV integrated in the rotor.

### 2.2. Principles of operation and performance parameters

#### 2.2.1 Key performance parameters.

The performance parameters are varied for different tip-speed ratios (TSR). Tip speed ratio is the ratio of speed of the wind to that of speed at the tips of the turbine blades.

\[
\text{TSR} = \frac{\omega R}{U}
\]

In this study, the tip-speed ratio (TSR) ranges from 0.5 to 4 for rotor angular velocity of 12 rad/s to 96 rad/s, respectively. The CP is a ratio of the wind rotor's generated power to the power available at a given wind speed. Cm and Cm, which are formulated in the equations below, are commonly used to calculate the results.

\[
\text{CP} = \lambda \text{Cm}
\]

\[
\text{Cm} = \frac{\text{Moment}}{0.5 \rho V^2 A s R}
\]

Where \(\rho\), \(A_s\) and \(V\) represents the air density, swept area of the turbine and the inlet velocity.

### 2.3 Domain and its boundary conditions

Table 3 lists the required boundary conditions for the CFD simulation in all cases (both VAWT and ODGV). In all cases, the inlet velocity remains constant at 6 m/s.

Two distinct zones have been chosen to distinguish between the fixed and rotating parts of the domain. The details are given in table 4.

To establish the continuity in the flow, an interface boundary condition had been introduced between the two zones. The zone of mesh is given here. Here rotating mesh technique is selected for the transient simulation.
Table 2. Boundary conditions in domain.

| Wall     | Boundary condition | Value  |
|----------|--------------------|--------|
| Inlet    | Velocity           | 6 m/s  |
| Outlet   | Pressure           | 0 Pa   |
| Turbine  | Wall               | No slip walls |

Table 3. Various zones and taken conditions.

| Zone     | Condition |
|----------|-----------|
| Turbine  | Rotating  |
| Domain   | Stationary|

2.3.1 **Size of domain and its location study**

The dimensions of the domain have been selected from the literature review. The schematic diagram has been given in fig 3. From the study it is found that in CFD simulation, a side wall with a distance of less than 12D causes a blockage effect, resulting in inaccurate results. For distance, there isn't much of a difference in simulation output between 12D and 15D. As a result, 12D is chosen as an appropriate length based on the simulation time. It has been discovered that a domain length of 30D to 40D produces better experimental results. At 10D from the inlet, there is a wind turbine.

Figure 4. Schematic representation of domain size.

2.4 **Study of mesh**

As it can be seen from the below figures 4 and 5. The mesh around the VAWT, especially near the blades, is much denser than it is elsewhere. This is done in order to capture the complex flow structure with the least amount of expected error. The mesh details are listed in table 5.

| Parameter    | Value     |
|--------------|-----------|
| Nodes        | 24858     |
| Elements     | 37653     |
| Mesh Metric  | Orthogonal Quality     |
| Min/Max      | 0.25/0.99 |
| Average      | 0.96      |
Figure 5. Meshing of the domain without ODGV

The structured mesh is made in the same design which is given in the following figure 6. It consumes lot of times. If we made further small element it produced the error. The meshing is obtained after the many process, the good quality mesh is obtained finally.

Figure 6. Blade model with structured mesh
3. Results and Discussion:
To analyze the results graphs were plotted for parameters TSR vs Cp. The graphs were plotted for all the experimental cases for the S1046 profile in the presence and absence of ODGV.

3.1. In the absence of ODGV:
Graphs have been plotted for TSR values 1, 2, 3 and 4. The graphs were plotted for TSR vs CP and TSR vs Azimuth angle (denoted by θ or theta). M is the moment.

Out of different parameter sets that have been used to carry out the simulations, the graphs shown below are for the one that has shown higher value of Cp compared to others. The peak value of Cp is found to be near 0.391-0.392 between the TSR values 2.5 and 3.

3.1.1. Velocity and Pressure contour for set 4:
The velocity profile is obtained for the different length of lade from 0 to 150 mm which it is given in the figure 7. The higher velocity is available in and around the leading edge of the blades.

![Figure 7. Velocity graph](image)

The velocity profile is obtained from the result of simulation which it is given in the figure 7. It shows the high velocity region is always around the blade walls, which validating the simulation results are trusted in the evidence of physics. The wall velocity is zero then it gradually increase to reach the free stream velocity. The changes of velocity is happened due to the transient flow of wind in and around the blades. The pressure contour is produced in the following figure 9, which showing the low pressure region is always existing in the frontal region of blades. It is the essential for the rotating object in the particular speed.
4. Conclusion

The proposed method is used to determine the velocity and pressure profile for the vertical axis wind turbine using NACA0021. The detailed view of meshing is given here after studying the various element size. The type of mesh is suitable of all the system is structured mesh, but it may cause to higher computational cost and error in simulation due to non-conversing nature. Here both structured and unstructured meshes are studied for the specific NACA profile of 2D design. It shows the best quality of mesh is obtained in the triangular type of element. The simulation is done for various tip-speed ratio, finally we have selected the velocity and pressure profile randomly, and In future it can be modified further to increasing the performance of wind turbine on the blade side.
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