Numerical analysis of Darrieus vertical axis wind turbine using omni-direction guide vane

K Sathiyamoorthy*, N Nandha Sri Varma, M Showrinath

Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur – 603 203, Tamil Nadu, India

*Corresponding author email: sathiyak@srmist.edu.in

Abstract. The performance of Darrieus turbine is studied in this paper with the attachment of ODGV to enhance its performance. The angles of guided vanes are chosen from the literature as α=20◦, beta=55◦. According to this hypothesis the airfoil section of S1046 chosen for performance analysis. The K-ε SST 2 equation model is used for generating the moment for 5 blades turbine with the radius of 0.25m in the 2D configuration. The Chord length is chosen as 78mm and Air velocity is considered as 6m/s for the entire transient simulation. The study of performance and operational parameters have been done on turbine with presence and absence of ODGV.

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 below along with the dimensions of the specimen.
2.1 Geometry of the ODGV

The ODGV is modelled using CATIA V5 and the specifications are given in the table 1. The top view of the ODGV integrated around the turbine along with the guide vane angles is shown in Fig 2.

2.2 Turbine Geometry

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

| Symbol | Description               | Symbol | Description               |
|--------|---------------------------|--------|---------------------------|
| A      | Swept turbine area (sq. m)| i      | thickness of the blade (mm)|
| C      | Blade chord length (mm)   | R      | radius of the wind turbine (mm)|
| CFD    | Computational fluid dynamics| TSR   | Tip speed ratio |
| Cm     | Torque coefficient        | P      | Power (W) |
| Cp     | Power coefficient         | Greek  | second angle of ODGV (°) |
| D      | Turbine diameter          | α      | first angle of ODGV () |
| HAWT   | Horizontal axis wind turbine| β     | azimuth angle () |
| VAWT   | Vertical axis wind turbine | θ     | air flow speed (m/s) |
| ODGV   | Omni-direction-guide vane | ψ     | number of blades |
| N      | Number of blades          | ω      | turbine angular velocity |
| L      | Length of the blade       |        |                           |

Figure 1. Nomenclature

Table 1. Geometry of ODGV.

| Geometry of ODGV | Dimensions |
|------------------|------------|
| Number of Guide Vanes | 8          |
| Inner radius      | 350 mm     |
| Outer radius      | 636.5 mm   |

Figure 2. Comparison of HAWT and VAAWT.
Table 2. Geometry of turbine.

| Geometry of turbine                  | Dimensions |
|--------------------------------------|------------|
| Airfoil blade selected               | S1046      |
| Chord length (C)                     | 78mm       |
| Turbine radius (R)                   | 250mm      |
| Number of blades (N)                 | 5          |
| Smaller circle diameter              | 120mm      |
| Rotor diameter with boundary layer   | 660mm      |

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

2.3 Principles of operation and performance parameters

2.3.1. 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.

\[
\text{TSR} = \frac{\omega R}{U} \tag{1}
\]

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. Cp and Cm, which are formulated in the equations below, are commonly used to calculate the results.

\[
\text{Cp} = \lambda \text{Cm} \tag{2}
\]

\[
\text{Cm} = \frac{\text{Moment}}{0.5 \rho V^2 A_s R} \tag{3}
\]

Where \( \rho \), \( A_s \) and \( V \) represents the air density, swept area of the turbine and the inlet velocity.
2.4 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.

Table 3. Boundary conditions in domain.

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

Table 4. Various zones and taken conditions.

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

2.4.1. 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.](image)
2.5 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.

Figure 5. Meshing of the domain without ODGV

Figure 6. Meshing of domain with ODGV
Table 5. Mesh Details

| Parameter         | Value            |
|-------------------|------------------|
| Nodes             | 64858            |
| Elements          | 94021            |
| Mesh Metric       | Orthogonal Quality |
| Min               | 0.252172816296278 |
| Max               | 0.999999977924907 |
| Average           | 0.957078103032203 |
| Standard Deviation| 6.29475591158929E-02 |

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 and pressure contours are shown here for TSR value 1.

Figure 7. TSR vs Cp graph without ODGV (set 4)
3.2. In the presence of ODGV:
The addition of ODGV has shown some good amount of increase in Cp value when plotted against TSR. The peak Cp value is found to be near to 0.45.
3.2.1. Velocity and Pressure contours for profile in the presence of ODGV:
From the contours it can be found that the maximum pressure is found to be 86.4 pascal and the minimum pressure is -21.9 pascal. The maximum pressure is found to be near the blades of the odgv whereas the minimum pressure is found in the path behind the turbine.

From the figure 11. it can be seen that the maximum velocity is 16.5 m/s whereas the minimum velocity is 0 m/s. The maximum velocity is found to be near the turbine blades whereas the least velocity is seen around the odgv and other parts of the turbine. There is a moderate amount of velocity found throughout the domain.
Figure 12. Velocity contour in presence of ODGV.

4. Conclusion:
The following conclusions were drawn from the experimental CFD simulations done in Ansys for the S1046 profile in the presence and absence of ODGV. Cp for the profile containing odgv has been found to be 0.45 (+- 0.01) in between the TSR values 2.5 and 3. Cp for the profile in the absence of ODGV has been found to be 0.391-0.392 between the TSR values 2.5-3. It can be seen that the peak Cp values can be obtained in between TSR values 2.5 and 3. The mesh parameters have significant effect in results. There has been an increase in the Cp when ODGV has been added to the domain. Fabrication has of the model S1046 has been done with the help of 3D printing and the blades have been assembled. Also, future work on this project can be done. The future work can be focused on the experimental analysis of this turbine under highway conditions. These experimental results can be used to validate the simulation results obtained from Ansys.

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