Numerical and structural investigation of flow past a helical axis wind turbine

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Abstract. The present work is about designing a helical axis wind turbine and testing its performance of both numerical and static structural analysis. NACA 0018 symmetric aerofoil is used as a turbine blade to modelling the vertical 3 bladed axis wind turbine rotor is tilted to an angle of 60 degrees, so as to get better performance of turbine. This paper deals, Numerical investigation of Helical Axis Wind Turbine (HAWT) with three blades has been carried out by means of both the numerical simulation and static structural analysis. The turbine performance can be observed by the span wise pressure distribution and velocity distribution, stress distribution and also observed that HAWT generated a power, which is an average power output incremental of 6.75 percent than precedes.

Keywords: Renewable energy, Helical Axis wind turbines (HAWT), Tip Speed Ratio, Pressure coefficient, Torque, Computational fluid dynamics (CFD), Von-Mises stress.

1. Introduction

A wind turbine is a rotating machine which extracts power from the airstream and converts this wind energy into mechanical energy. For proper deployment of wind energy, it is necessary to revise the performance of the wind turbines subjected to aerodynamic and ambient conditions [1]. Wind turbines are classified into Horizontal and Vertical, these two are by dissimilar rotor shaft which are used mainly for production of electricity, VAWTs have intrinsic advantages, the principal advantages of the VAWT are their capability to admit wind from any direction without yawing and the ability to provide direct rotary drive to a fixed load. Compares with HAWTs, VAWTs have strong resisting wind ability [2]. However, VAWTs are typically complex rotating systems that correspond to a great challenge to researchers and engineers. Many efforts have been devoted to their study using simplified mathematical methods[2].

The main objective of the present work is to design, structural and flow analysis of a HAWT to generate renewable energy which decreases the pollution as well as to reduce the cost of electricity particularly on highways and remote areas. Decrease the demand factor for the entire area. Also permits the HAWT to be cost effective, make it accessible. The model was designed in CATIA and was imported in ANSYS-FLUENT for CFD and structural analysis of a helical axis wind turbine rotor has been undertaken.
2. Design methodology

2.1. Geometrical Introduction
The HAWT consists of three blade with NACA0018 symmetric profile, and a blade segment is twisted to an angle of 60 degrees. The shaft and blades are linked as one by a number of welded joints, thus the energy can easily transferred from the blades to a generator. In present investigation supporting frames are cut down to facilitate focus on the behaviour of the blades as well as to simplify the meshing complexity and computational demands. Some of the key geometrical parameters are given in Table 1.

| S.No | Parameters       | Specifications |
|------|------------------|----------------|
| 1.   | Blade Height     | 1 meter        |
| 2.   | Rotor Diameter   | 0.7 meter      |
| 3.   | Chord length     | 0.1 meter      |
| 4.   | Blade Type       | Twisted        |
| 5.   | Twist Angle      | 60°            |
| 6.   | No. of Blades    | 3              |
| 7.   | Blade Material   | Aluminium      |
| 8.   | Wind velocity    | 10 m/sec       |
| 9.   | Rated Blade RPM  | 150            |

Table 1. Specifications of HWAT

“Albert Betz was a German physicist who calculated that no wind turbine could convert more than 59.3% of the kinetic energy of the wind into mechanical energy turning a rotor. This is known as the Betz Limit, and is the theoretical maximum coefficient of power ($C_p$) for any wind turbine” [1]. for this reason, we considered $C_p$ value approximately 0.55, the tip speed ratios of HAWT is found to the range from 2 to 2.5, this can be used to forecast angular velocities for HAWT using the relationship as given below [2]

$$\lambda = \frac{r \omega}{V}$$

(1)

$\lambda$: Tip speed ratio, $r$: Turbine radius, $\omega$: Angular velocity, $V$: Average air velocity, rewriting equation (1) as $\omega = \frac{\lambda \times V}{r}$ (Mentioned in Table 1). $r = 0.7 / 2 = 0.35$ m, $V = 10$ m/s ; $\lambda_{average} = (2.5 + 2) / 2 = 2.25$. Thus, the equation (1) becomes: $\omega = 2.25105 / 0.35 = 64.28$ rad/s .

The torque of the turbine can be calculated using the following equation:

$$T = \frac{0.5 \times C_p \times \rho \times A \times V^3}{\omega}$$

(2)

Where, $A$: Area $= L \times d = 1 \times 0.7 = 0.7$ m$^2$, $C_p$: Coefficient of power, $\rho$: density of air. Then the torque becomes: $T = (0.5 \times 0.55 \times 1.18 \times 0.7 \times 10^3) / 32.14 = 7.06 \text{ N-m}$

The power of the HAWT can be calculated using equation (2):

$$P_{flow} = 0.5 \times \rho \times A \times V^3$$

(3)
\[ P_{flow} = 0.5 \times 1.18 \times 0.7 \times 10^3 = 413 \, W \]

\[ P_{turbine} = P_{flow} \times C_p \]

\[ P_{turbine} = 413 \times 0.55 = 227.15 \, W \]  \hspace{1cm} (4)

**Table 2.** The power of HAWT at various wind speeds

| S.No | Velocity(m/s) | Km/h | Area(m²) | \( P_{turbine}(W) \) |
|------|---------------|------|----------|----------------------|
| 1.   | 5             | 18   | 0.7      | 28.39                |
| 2.   | 6             | 21.6 | 0.7      | 46.9                 |
| 3.   | 8             | 28.8 | 0.7      | 111.4                |
| 4.   | 10            | 36   | 0.7      | 227.15               |
| 5.   | 12            | 43.2 | 0.7      | 375.9                |
| 6.   | 14            | 50.4 | 0.7      | 596.9                |
| 7.   | 16            | 57.6 | 0.7      | 890.9                |

**Figure 1.** Power Vs Wind velocity

By following all the above parameters and design constraints, we designed a turbine model in CATIA V5 as shown in figure 2.
3. Numerical simulation & Static structural Analysis

3.1. Boundary Condition and Meshing

The flow field or domain in front and behind the HAWT is extended 1.7*1.7*3.6 meter respectively as shown in figure 3.a. Tetrahedral mesh is used for meshing the both flow field and HAWT and it consists of 525593 nodes and 2847273 elements. Meshing parameters for turbine are shown in figure 3.b.

| Object Name | Geometry |
|--------------|----------|
| **Bounding Box** |          |
| Length X     | 1.726 m  |
| Length Y     | 1.7248 m |
| Length Z     | 3.6 m    |
| **Statistics** |          |
| Nodes        | 525593   |
| Elements     | 2847273  |
Figure 4. Velocity contours at inlet and outlet of the HAWT

The figure 4.a shows the velocity distribution at inlet of the flow field which is arbitrarily assigned at 10 m/s. The figure 4.b shows the velocity distribution at the outlet of the flow field, the velocity is maximum far from the HAWT and velocity is minimum adjacent to the HAWT.

Figure 5. Pressure contours at outlet and along the plane of HAWT

The figure 5.a shows the pressure distribution at the outlet of flow field, these contours that there is a pressure drop far from the flow field. The figure 5.b shows the pressure distribution of flow along the plane.
Figure 6. Stream lines around the HAWT with variation of velocities

The figure 6.a. shows the flow visualization around the HAWT and variation of velocity across the flow field. The figure 6.b. explains about range of velocity distribution of all the stream lines when passing through the HAWT.

Figure 7. Stream lines around the HAWT at outlet pressure and along the plane

The figure 7.a. shows the pressure stream lines around HAWT and at outlet of the flow field as we can see the pressure variation. It is observed that the utmost imported pressure is 4370 Pa taking place at CFD analysis at 10 m/s. The figure 7.b. shows the pressure distribution of flow across the HAWT along the plane. It is observed that the highest imported pressure along the plane is 7650 Pa taking place at CFD analysis at 10 m/s.
Figure 8. Velocity vectors at inlet and outlet of HAWT

The figure 8.a describes formation of inlet and outlet velocity vectors of HAWT and velocity distribution ranges along the HAWT. Figure 8.b explains visualization of flow with a range of velocity distribution when the fluid is passing through the HAWT.

Figure 9. Pressure coefficient and velocity magnitude at inlet and outlet of HAWT

The figure 9.a describes the pressure coefficient at inlet and outlet of HAWT, it can observed the variation of pressure coefficient with increase the velocity. The figure 9.b explains the velocity magnitude at inlet and outlet of HAWT, it can observed that velocity increases with wind speed the maximum velocity occurs at far from the flow field.

3.2. Boundary Condition and Meshing

Tetrahedral mesh is used for meshing the HAWT and it consists of 21387 nodes and 7639 elements. Meshing parameters for turbine are shown in figure 10.b
Figure 10. Meshing of HAWT in Ansys

Table 5. Boundary conditions & Meshing

| Object Name | Geometry |
|-------------|----------|
|              | Bounding Box |
|              | Length X  | 0.72601 m |
|              | Length Y  | 0.72481 m |
|              | Length Z  | 1.6 m     |

|              | Statistics |
|-------------|------------|
|              | Nodes      | 21387     |
|              | Elements   | 7639      |

Figure 11. Von-Mises stress and Strain energy of HAWT in Ansys

The figure 11.a the von-mises stresses distribution on HAWT at 10 m/s wind velocity, the turbine can with stand maximum load of 5.9 Mpa and 11.b represents the strain energy of HAWT at 10 m/s wind velocity, the maximum strain energy is 0.4708 Mpa.
4. Results

The various performance parameters like power, torque, lift, drag and movements developed by the HAWT at different wind velocities are studied in both theoretical and analytical, and we also studied how velocity and pressure distributed along the turbine blade. We have drawn the following results.

• The designed HAWT can generate a Torque of 7.6 N-m, and a power of 217.5 W at a speed of 36 Km/hr.

• It has been noted that the velocity magnitude improved with raise in speed and the pressure coefficient increases with increase in wind velocity.

• It has been observed that HAWT can withstand maximum load of 5.9 Mpa when the wind velocity is 10 m/s.

5. Conclusion

In this study, NACA 0018 airfoil is used as a turbine blade, through numerous design calculations, flow and structural analysis of the HAWT, we have drawn different conclusions on their effectiveness and significance growth of uncontaminated energy in India.

Three-dimensional HAWT was designed based on many design parameters, structural and flow analysis at a velocity of 36 kmph have been carried out at a configuration of 60 degrees. It has been observed that HAWT generated at a power of 227.15 W, which is an average power output incremental of 6.75 percent than precedes. This lead the HAWT toward a low speed of start-up and after that to a higher number of operational hours in similar environmental circumstances.

References

[1] History of wind turbines. (November 21, Renewable Energy World, 2014).From:www.renewableenergyworld.com/ugc/articles/2014/11/history-of-wind-turbines
[2] Rajagopalan, R.G.; Fanucci, J.B. Finite difference model for vertical axis wind turbines. J. Propul. Power 1985, 432–436.
[3] Price, Trevor J (3 May 2005). "James Blyth - Britain's First Modern Wind Power Engineer". Wind Engineering. 29 (3): 191–200.
[4] Alajmi, Jelowi, Alsayed & Tareq (2014) Design of Airfoils for Wind Turbine Rotors. American University, Sharqa, UAE
[5] Casini, M., (2016). Small vertical axis wind turbines for energy efficiency of buildings. JOCE Vol. 14/254
[6] Rishmany, Daaboul, Tawk‡ & Saba (2017). Optimization of a Vertical Axis Wind Turbine Using FEA, Multibody Dynamics and Wind Tunnel Testing. Athens Journal of Technology & Engineering X Y 1
[7] V.Guru shanker, V.Siva rama krishna, & K.Chandrashekar, (2015). Simulation of flow over a NACA 23012 airfoil in incompressible and compressible subsonic regimes. by International Journal of Dynamics of Fluids. ISSN 0973-1784 volume 11.
[8] Weigel R., Spichtinger, P., Mahnke, C., Klingebiel, M., Afchine, A., Petzold, A., & Szakáll.M. (2016). Thermodynamic correction of particle concentrations measured by under wing probes on fast-flying aircraft. Atmospheric Measurement Techniques, 9(10), 5135.