Experimental analysis of wind turbine of high-speed air available from industrial exhaust of rectangular flat blade

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Abstract:

Wind energy is contributing to the majority of the energy production in the renewable energy sectors. Currently more research work is being carried out in the Vertical Axis Wind Turbine technology. It is a turbine in which the axis of rotation of rotor is perpendicular to the ground and also perpendicular to the wind direction. Literature is available for the wind blades which have the special curves such as NACA profile etc., the drawback of aerodynamics blades is the manufacturing difficulties due to the complex profile which leads to the high cost of blade manufacturing. The best choice of the profile to provide a better solution is flat rectangular blade. The dimensions of the rectangular blade are: blade height- 176mm, rotor diameter- 110mm, blade width- 12mm, blade side width- 4mm and has a cross section of 12*4mm This paper deals with the study on the effect of the rectangular flat plate under the high wind velocity. A 2D model was developed using Solid works software, CFD Analysis was performed to determine the wind velocity which gives a better performance. A Prototype was built to perform the experimental analysis, and to correlate the results obtained in the CFD analysis for validation and verification. The results show that the maximum coefficient performance of 0.3 is achieved with Tip Speed Ratio (TSR) ranging from 2 to 4. This study on the dynamics of the wind blade may lead to the advancement of the blade structure and thereby generating more power. This type of flat blade can be used in the heat recovery system in the industrial exhaust where high speed wind is available. The another new thing is discussed here using the IoT techniques to measure the torque for every azimuth angle in real time experiment.
1. Introduction

Wind turbines convert mechanical power to generate electric power. Wind is a sensible and feasible force source, and has less impact on nature as compared to other essential sources. There are 2 classifications of wind turbines specifically Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). VAWTs are classified into two types namely "drag-type" and "lift-type". Savonius turbines are characterized by their high torque, low speed and low viability [1]. The Darrieus turbines are illustrated by their quick and high efficiency [2]. From time to time, the smoothed out parameter "tip-speed extent" is used to depict wind turbines and for this circumstance, they are arranged into "lowspeed machines" and "quick machines" [3]. Small turbines are used for applications such as battery charging for vessels or troops or to control traffic signals [4]. As VAWTs spin about a vertically situated pivot that is at right edges to the breeze course.

H-Rotor VAWTs are huge three-bladed vertical-hub wind turbines with the cutting edges being situated corresponding to the rotor pivot to deliver wind power[5]. These turbines have the primary rotor and electric generator at the base of the turbine. VAWT shown in figure 1 have thequalities of straightforwardness, simple structure, mechanical lodging, no yaw frameworks, gearboxes, and generators, and mechanical and electrical components [6]. There are different inconveniences challenging this breeze rotor like low productivity, inability and inadequacy to self-beginning, and no capacity to control the rotor power yield [8]. The turbines control speed by utilizing variable pitch points like different types of sharp edges.

Darrieus rotors (with H-formed cutting edge) are organized rather than traditional bend edges called egg-molded blades. Scaled down turbines can be defined by a clear breeze vane, on the other hand immense turbines generally use a breeze sensor joined with a yaw structure [9]. These are called as direct-drive, asthe rotor are coupledto the generator without gearbox. For Computational Fluid Dynamics (CFD) analysis, K-epsilon (k-ε) roughness model is the most common turbulence model. It is used to reproduce mean stream parameters for breezy stream circumstances.

Figure. 1.1 Schematic diagram of H-Rotor VAWTs [1]

2. Methodology

The main objective of the work is to design, analyse and fabricate a rectangular flat blade. The steps involved are
1. Design and Modeling of the Darrieus Wind Turbine using solid works
2. CFD Analysis using ANSYS Fluent software.
3. Fabrication of the 3D model using 3D Printer.

The aerodynamic performance assessment will be carried out for this aerofoil in order to compare with the final output of the numerical analysis.

3. Design and Modelling of VAWT

Initially the 2D modeling of the rectangular flat blade was performed using solid works as shown in Fig 2 and 3.

![Figure 2: Model of Flat blade.](image)

CAD geometry of the profile –rectangular flat blade was created using CATIA. The mesh and the stimulations followed by post processing were carried out using ANSYS fluent. Moment coefficients were selected to be monitored after all the necessary and required conditions are entered and the stimulation is performed.

4. CFD Analysis using ANSYS Fluent software

Flow conditions: -

Both Steady state and transient state conditions are used.

Boundary Conditions:
Inlet: - Velocity = 3m/s.
Turbulence Intensity = 5%
Turbulent Viscosity ratio = 10%
Outlet: - Pressure =0 Pascal.
Turbulence Intensity = 5% Turbulent Viscosity ratio = 10%
Solution method: -
- Scheme – Coupled.
• Gradient – Least square cell based.
• Pressure – Standard.
• Momentum – Second order upwind.

5. Fabrication and Testing

The 3D model (Prototype) is generated with the help of Creo 3D modeling software. The rotor has been constructed separately with the diameter of 55.113mm. The modeling has been performed on Creo 3.0 modeling software. The Aerofoil and the rotor are to be assembled together. After the model is completed, it is then forwarded it to a 3D printer for the fabrication of the prototype. After the model is completed, it is then forwarded it to a 3D printer for the fabrication of the prototype. WOL 3D Creality Ender printing machine was used to generate the required prototype. Weight: 8 Kg. PLA filament white was the raw material used for the prototype. The chips that are required for those measurements are: HX711 Load cell amplifier and Photo interrupter. The HX711 Load cell amplifier is used to measure the torque generated by the setup and the photo interrupter is used to measure the RPM generated by the setup shown in figure 8 and 9.
The centrifugal blower for the purpose of floor testing. A blower is an equipment which increases the velocity of air when it is passed through equipped impellers. It is used to rotate the model at high speeds. For testing the wind, we used an anemometer. An anemometer is an instrument used for measuring wind speed and direction. It is also a common weather station instrument. The tachometer is used to measure the RPM of the rectangular flat blade. Torque produced by the turbine needs to be measured in order to find torque we need to setup Arduino board in such a way that it generates average torque digitally. Photo interrupter, Mini load cell, LCD keyboard shield for Arduino, Photo interrupter breakout board, Resistor 220 ohm, Load cell amplifier and Cables jumper shown in figure 10 are required to design and fabricating the torque measuring system based on the IoT based measuring systems are available in the following picture.

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The formulae used for determining the experimental output are given as follows.

1) Tip Speed Ratio, \( \text{TSR} = (\omega \times r) \div v \)

where \( r = \text{radius} \)

\( \omega = \text{Angular Velocity (rad/sec)} \)

\( \text{Circumference of a circle} = 2\pi r \)

1 rad = 2\pi

2) Angular velocity, \( = (2\pi N) \div 60 \)

3) \( \text{Pshaft} = (2\pi NT) \div 60 \)

where \( N = \text{RPM} \)

\( T = \text{Torque} \)
4) Torque = F×d

\[ P_{\text{wind}} = \frac{1}{2} m v^2 \omega \]
\[ = \frac{1}{2} (\rho A v) v^2 \]
\[ = \frac{1}{2} \rho A v^3 \omega \]
\[ = \frac{1}{2} \times 1.18 \times 0.0176 \times v^3 \]
\[ = 0.010384 \times v^3 \omega \]

Figure 5: IoT based torque acquiring system

where \( \rho \) = Air density at 25 °C = 1.18 (from HMT data book)
\( A \) = Swept Area = Diameter x Height = 0.11 x 0.16 = 0.0176m²
\( V \) = Velocity

6. Results and Discussion

After the simulation based on the above mentioned setup the following graph is obtained between azimuth angle and the coefficient of torque. Firstly, the stimulations are run for mesh validations. Aerodynamics characteristics parameters such as coefficient of moment are obtained from post processing. The following is the plot for Azimuth angle Vs Coefficient of moment. For every azimuth angle the coefficient of moment will flow like in a sine wave shown in figure 7.
After the experimental test has been performed the results generated are listed in following table 1 and 2 corresponding graphs are plotted in the following figure 12 and 13 which shows TSR 0.3 is the optimum for operating the wind turbine, it shows clearly less noise when it operates with high efficiency of around 0.35.

Table 1: Velocity of air from the blower

| Distance from the fan | V1  | V2  | V3  | Vavg |
|----------------------|-----|-----|-----|------|
| 0.5                  | 20  | 22  | 21  | 21   |
| 0.8                  | 19  | 14.5| 18.5| 19   |
| 1                    | 18  | 18.7| 17.7| 18.1 |
| 1.5                  | 14  | 16  | 15  | 15   |
| 2                    | 13  | 18  | 17  | 16   |

Table 2: Measured data

| Vanemo | N   | \(\omega\) (2\Pi N)/60 | TSR = (\omega \times N)/V | Torque | \(P_{\text{shaft}} = (2\Pi N T)/60\) | \(P_{\text{wind}} = 0.0104 \times 10^3\) | \(C_p = (P_{\text{shaft}}/P_{\text{wind}}) \times 100\) |
|--------|-----|------------------------|--------------------------|--------|----------------------------------|---------------------------------|----------------------------------|
| m/s    | rpm | rad/s                  | ---                      | Nm     | W                               | W                              | ---                              |
| 21     | 920 | 96.342                 | 0.2523                   | 0.3    | 28.9                            | 96.3144                         | 30.0059                          |
| 19     | 780 | 81.681                 | 0.4729                   | 0.234  | 19.11                           | 71.3336                         | 26.99                            |
| 17     | 550 | 87.595                 | 0.3727                   | 0.1774 | 10.21                           | 51.0952                         | 19.9                             |
| 17.5   | 480 | 50.265                 | 0.316                    | 0.2774 | 13.94                           | 55.7375                         | 25                               |
| 20     | 600 | 62.831                 | 0.3456                   | 0.3708 | 23.29                           | 83.2                            | 28                               |
The result we have plotted in the figure 7 which showing the average error between the experimental and numerical are less than 10 % for both the TSR and $C_P$. The simulation results are verified with grid independency method.

7. Conclusion

Comparing the performance of wind turbine of the rectangular flat blade. Flat blades are very cheap and we can easily fabricate without 3D machine itself it is easy to fabricate the Rectangular Flat Blade. The material cost can be reduced for flat blade. When we do NACA profile there will be much wastage when cutting. But the wastage is less for flat blade compared to other blades. For high speed application torque is not a problem. So, it can rotate automatically. The performance does not differ much for high speed application $C_P$ value we got is 0.3 this is the maximum value. If we use NACA Profile we can get values up to 36% but in this till 30% we can obtain. In future we can do comparison study for Flat profile, NACA Profile. We can do cost comparison so we can get knowledge through special flat blades. The maximum $C_P$ value is 0.3 at TSR between 2 to 3.5. In future, we can try flat blade wind turbine with low cost for high-speed wind application. In feature the same system can be implemented in the exhaust and may do some thermal analysis for measuring the with stand ability of the blade high temperature and velocity environment.

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