Computational Fluid Dynamics Analysis to find the Efficient Blade Angle of a Typical Spiral Wind Turbine

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Abstract. Spiral wind turbine is designed to capture wind coming in from different directions at different times because of its inherent ability to catch the wind irrespective wind direction. Spiral wind turbine operates efficiently at lower speeds. In the present work an attempt is made to identify effective blade angle of the turbine. Computational fluid dynamics (CFD) analysis is adopted with various blade angles such as 45°, 60° and 70°. Boundary conditions were set including velocity flow in X and Y directions to imitate real world environment. The streamline flow analysis yielded a velocity of 7.36m/s. The key parameters extracted are torque output by blades, residual and area around which fluid flow occurs. The power coefficient (C_p) was calculated which is the measure of the capability of the wind turbine to convert kinetic energy of wind into rotational energy of the turbine. The maximum power coefficient is found to be 0.205 in a turbine with 60° blade angle. Hence, the turbine with 60° blade angle is found to be the most effective one.

Keywords: Wind turbine, torque, blade angle, power coefficient

INTRODUCTION

Archimedes wind turbine is designed to capture wind flowing from different directions at different durations. It has the ability to catch the wind irrespective of wind direction. It can automatically adjust itself in the optimum wind position.

Archimedes screw pump is a helix patterned pipe with blade that comes out from front to back in the shape of a cone like spiral. This spiral shape allows it to swivel and collect gusts of wind entering at an angle from axis. The traditional horizontal axis wind turbine uses the lift force to take power from wind energy, whereas the spiral wind turbine uses both the lift and drag force for extracting power from wind energy. Spiral wind turbine utilizes the kinetic energy of the wind more efficiently and effectively than horizontal axis wind turbine.

The advantage of such wind turbine is that in urban environment the wind direction changes continuously and this turbine follows the wind direction automatically and operates efficiently at lower speeds. Other advantages includes low cost, low maintenance, light weight, less noise, lower vibrations. It ensures a more consistent energy output compared to traditional turbines, making them highly reliable for residential use. These turbines operate quietly, addressing concerns about noise pollution commonly associated with conventional wind turbines. Their silent operation makes them suitable for residential neighborhoods where noise ordinances may be a concern. They can also help in reducing carbon foot print which helps in negating climate change. Also there can be drastic reduction in electricity bills as well.

Aerodynamic analysis and experimental investigations are important for finding the efficiency and performance of spiral wind turbine blades. Factors such as the power coefficient, swept area, and directional sensitivity play noteworthy roles in determining how effectively the turbine converts wind energy into usable electricity. Through detailed aerodynamic simulations researchers can compare the performance of spiral turbine blades against conventional designs. This comparative analysis provides valuable insights into the advantages and limitations of spiral turbines.

The power coefficient can be calculated by using the equation $C_p = \frac{2\ w}{3}$ where C_p is power coefficient, T is torque output by blades, w is angular velocity of turbine, ρ is density of air, A is swept area of turbine, v is free stream velocity of air.

In the present work an attempt is made to investigate through finite element analysis the torque output of a spiral wind turbine and power coefficient. Also the effective blade angle of the turbine needs to be identified. Feasibility of installing such an energy generator in house hold applications may be studied

LITERATURE REVIEW

Q.Lu et al [1] presented a detailed study on the performance of spiral wind turbine using computational fluid dynamics with 60° blade angle. They discuss about aerodynamics principles behind spiral turbines and its efficiency in comparison with horizontal axis turbines.

H Cao et al [2] worked on performance comparison of spiral wind turbines with blade angles varying from 30° to 90°. Simulation technique is adopted to analyze power output, efficiency and aerodynamic characteristics.

N.J. Choi et al [3] explored the comprehensively into turbine efficiency and power generation capabilities by using numerical techniques.

Ankit kushreshta [4] showed that as the inflow velocity increases the pressure differences become higher. This pressure difference is large at blade tip which means that a lot of energy can be extracted near the blade tip. They proved that the wind turbine have high efficiency even under velocity of 2m/s which is low. The blade was so designed that they can utilize the maximum potential of the air. Author's objective was to provide basic information on automatic yawing system and give compact design of the wind turbine which would be suitable to be used in households.

Arman Safdari et al [5] worked on aerodynamic characteristics of a small scale Archimedes spiral wind turbine. Aerodynamic performance of the blade of different configurations was studied by applying numerical simulation technique. The technique was based on lattice Boltzmann method. To verify the numerical analysis velocity behavior around the blade and the same are compared with experimental results. They found that the analysis results are in good agreement with that of the experimental results.

Kanchan D Ganvir et al [6] carried out work on size and dimensions required while designing spiral wind turbine. They intended to make more energy efficient turbine and also to overcome the deficiencies of the conventional turbines.

In the context of the literature review carried out the authors desired to carry out CFD analysis of a typical spiral wind turbine to arrive at a standard and efficient blade angle required for the turbine.

OBJECTIVES

The following objectives are set based on the extensive literature review

- To design a spiral wind turbine blade to enhance energy efficiency using helical design
- To carry out detailed aerodynamic analysis since power coefficient, swept area and directional sensitivity play an important role converting wind energy into electrical energy
- To optimize blade shape and profile to minimize fatigue and stress concentrations.
- To compare the performance against conventional turbine

METHODOLOGY

To carry out set objectives, a detailed design of 3D model is developed using CREO software. The design of the blade is going to have different blade angles such as 45°, 60° and 70° are chosen. the CFD analysis is employed to simulate airflow around the turbine blades allowing for iterative adjustments to optimize aerodynamic performance. For the 3D model blade length of 3m and width of 3m were chosen. Necessary blade angles and pitch diameters are also selected. Three specific angles as said above are chosen for analysis and comparison. Utilizing the helical sweep option a precise representation of the turbine structure was done. It is as shown in Figure 1

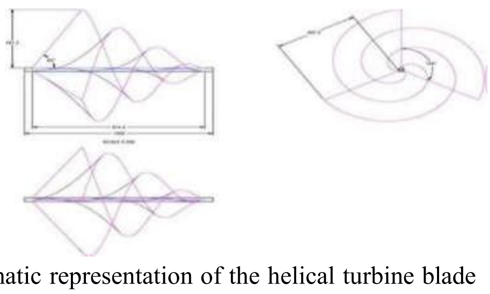

Figure 1: Schematic representation of the helical turbine blade

To create a 3D model of the blade, various diverse tools are utilized. Necessary blade angles are incorporated..The 3D model of the blade is as shown in Figure 2

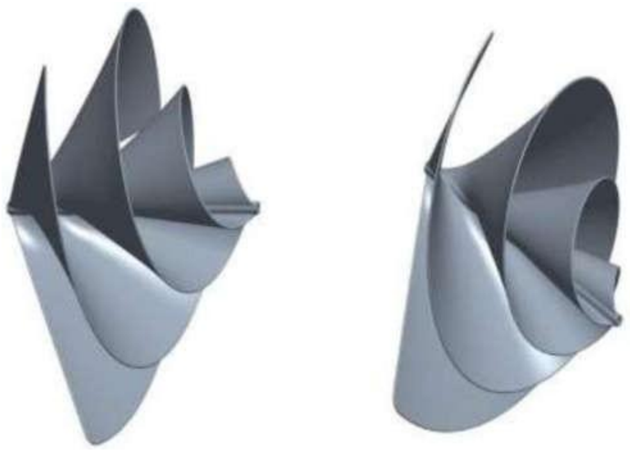

Figure 2: 3D model of the blade

Supporting stand for the turbine is also developed using the software. It is as shown in Figure 3

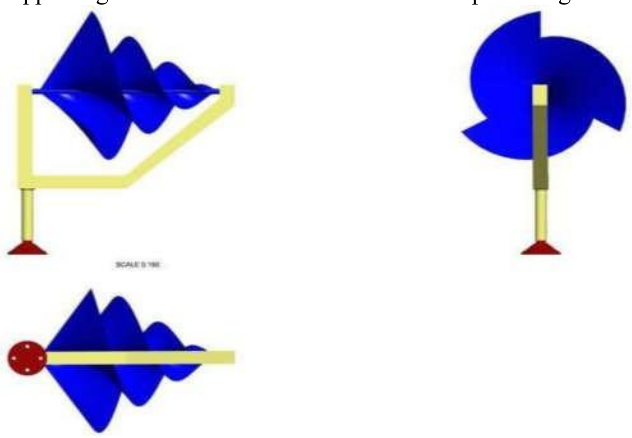

Figure 3: 3D model of the blade with the support stand

A boundary was defined for fluid flow with an inlet velocity at 5m/s and outlet pressure set at atmospheric level. Standard air was selected as fluid medium with a turbulent flow model. This is to simulate the real world conditions.

Through the analysis, the torque output by blades at earlier said blade angles was noted. This gives us the insight into the performance of the turbine. Later on, power output were calculated and compared among blades which helped in identifying the effective blade angle that enhances efficiency. The inlet boundary condition was set with specified velocity of 5m/s and outlet boundary condition set at atmospheric level. Element size employed is 20 resulting with a mesh consisting of 270299 edges and 384420 faces. This would ensure detailed representation of turbine's geometry. Analysis was conducted with varied pitch of the blades such as 1, 1.5 and 2 units to assess performance under different configurations and conditions.

RESULTS AND DISCUSSIONS

After analysis the performance parameters namely torque, residual were plotted to visualize turbine's behavior and efficiency. Figure 4, Figure 5, Figure 6, Figure 7, Figure 8 and Figure 9 will show the plots for torque output and residual for different blade angles as discussed earlier.

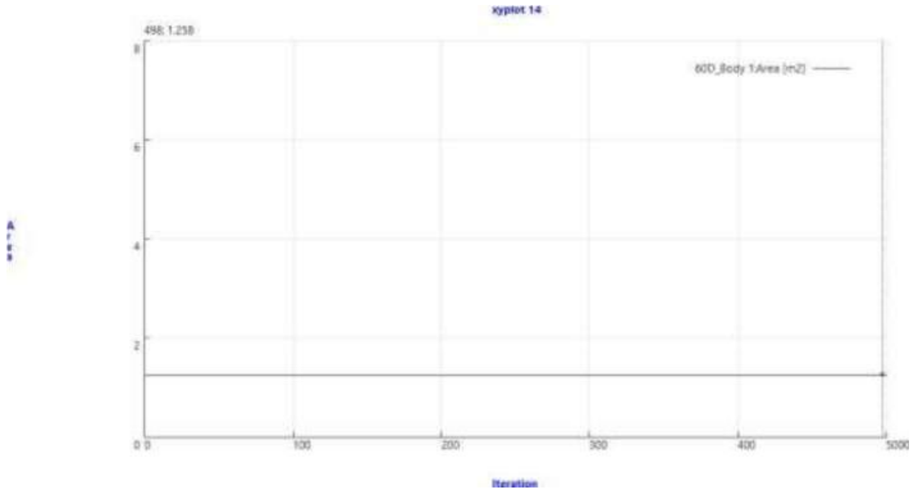

Figure 4: Torque output for 45°blade angle

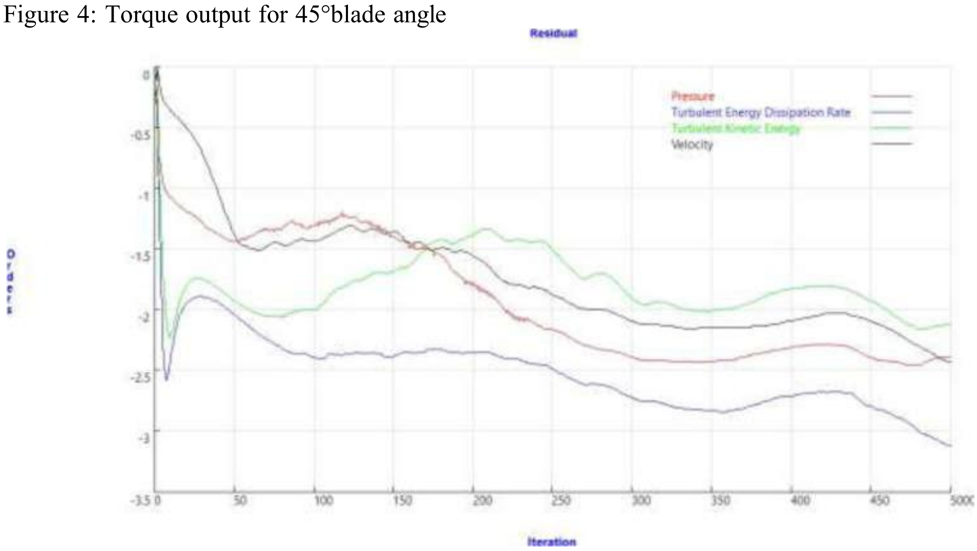

Figure 5: Residual for 45°blade angle

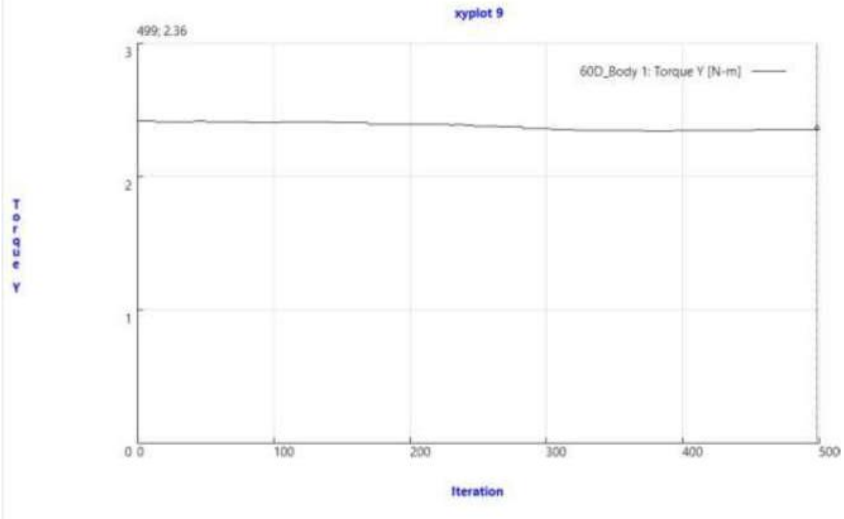

Figure 6: Torque output for 60°blade angle

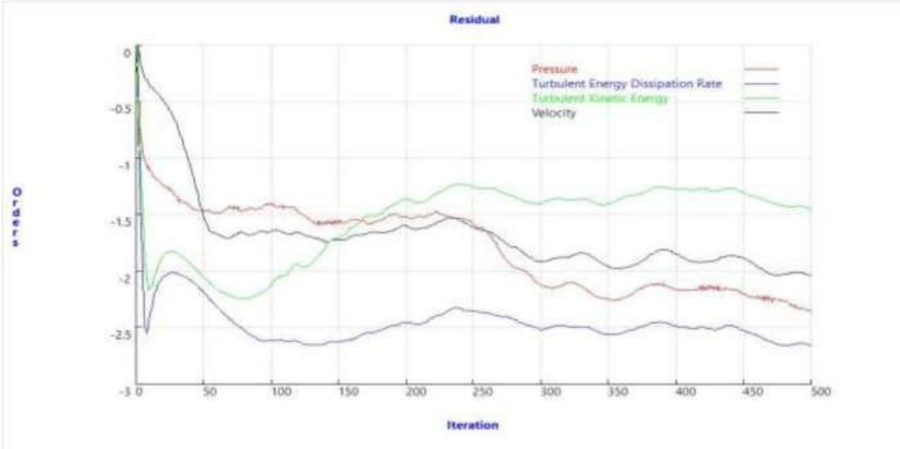

Figure 7: Residual for 60°blade angle

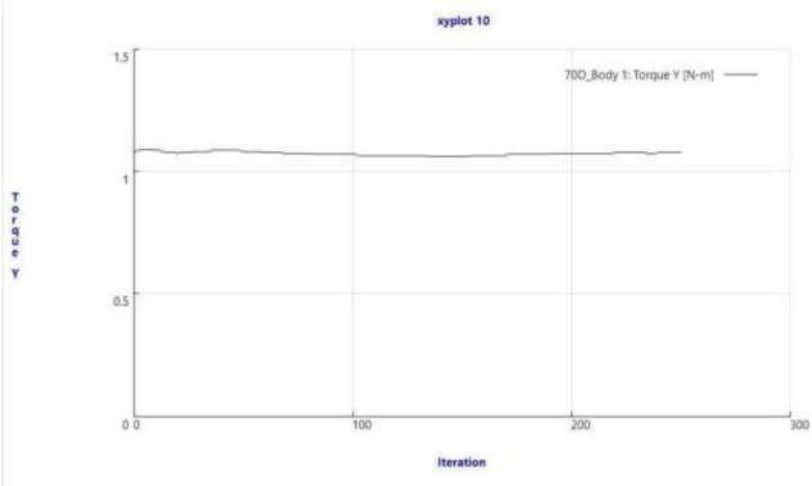

Figure 8: Torque output for 70°blade angle

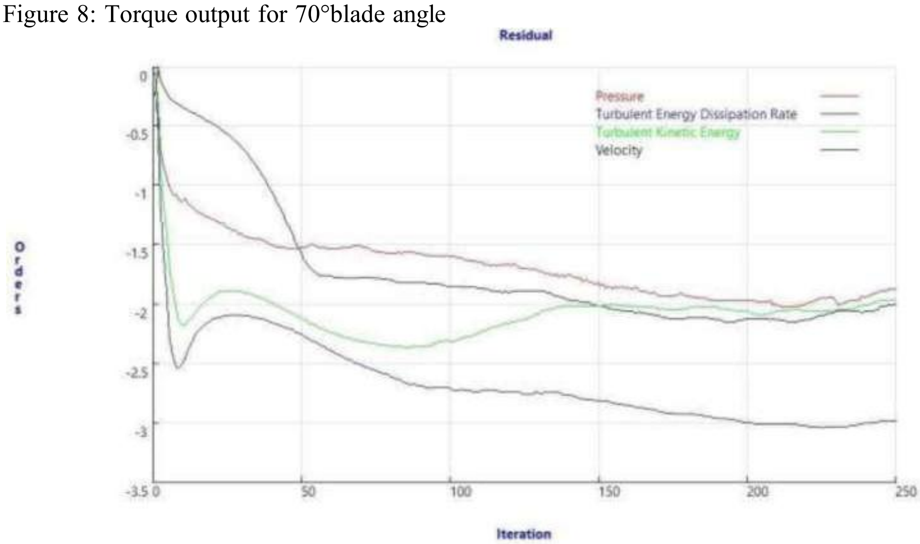

Figure 9: Residual for 70°blade angle

From the above figures it could be seen that the blade with 60° blade angle has higher output torque compared to other two blade angles. The power coefficient is calculated based on the torque output for all the blade angles with a pitch of 2 and the values are tabulated in Table 1.

Table 1: values of power coefficients of various blade angles

Sl no	Blade angle	Pitch	Power coefficient
1	45°	2	0.165
2	60°	2	0.205
3	70°	2	0.094

From Table 1 it can be observed that the power coefficient is higher in 60° blade angle.

CONCLUSIONS

The primary objective of the present work was to carry out CFD analysis to find out the efficient blade angle for a spiral wind turbine blade. For a 3D model a 3m length and 3m wide sheet was formed into helical turbine through CREO software. Analysis was carried out for different blade angles 45°, 60° and 70° were chosen for analysis. Torque and residual are the output parameters. Power coefficient is calculated. The torque output of 60° is found to be 2.5N-m where as in other two blade angles it is found to be around 1.2N-m. The parameters such as pressure, turbulent energy dissipation rate, turbulent kinetic energy and velocity are found to be superior in blade with 60° angle. The power coefficient is calculated and is 0.205 which is higher than the other blades for the pitch 2. Hence, from the above findings it can be concluded that the spiral wind turbine with a blade angle of 60° is found to be useful for household applications.

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