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Optimization of lift to drag ratio in a horizontal axis wind turbine Blade profile using CFD

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ABSTRACT

Computational Fluid Dynamics (CFD) software is used to compare the performance of a handmade wind turbine blade with conventional factory made model. This work deals with CFD analysis of three wind turbine blade profiles with different angles of attack (AOA) at a constant wind velocity. From the CFD analysis, the optimized wind turbine blade which gives the high performance in all the aerodynamic aspects is considered. The effect of add-on parts on wind turbine blade is studied. The simulated wind turbine model is useful to find out the torque and power.

KEY WORDS: L/D ratio, winglet, angle of attack, wind turbine blade profile.

1. INTRODUCTION

Depending on the layout and wind conditions of a wind farm the power loss of a downstream turbine can easily reach 40% in full-wake conditions. When studying power losses and blade loading, wind-turbine wakes are typically divided into a near and a far wake. Lift and drag coefficients are non-dimensional numbers used to quantify the amount of lift or drag on a given aerofoil under a given set of flow conditions, e.g. Reynolds’s number or AOA. Rajakumar and Ravindran (2010) determined lift and drag forces of NACA 4420 at different sections for AOA from 0° to 12° for low Reynolds number. The angle of attack of 5° has high Lift/Drag ratio. High L/D ratio was obtained for AOA of 3-8° by Sayed (Mohamed, 2012). Chen (2013), investigated NACA 63-415 wind turbine for tidal wind current low head turbine. Blade Element Momentum theory (BEM) was used to design a HAWT (Bhaskar Upadhyay Aryal, 2014). Samuel and Malloy (2009) constructed a straight edge blade prototype with optimal on coming wind and rotation speeds were 7 m/s and 20 rpm. The blade has a length of 20m and uses a constant airfoil cross section NACA 4412. NACA 4420 was analyzed by Master (2014) and the maximum L/D ratio was obtained for AOA of 6°. Genetic Algorithm was used to design the wind turbine systems (Pankaj Jain, 2012). In the literature, the AOA and L/D ratio of wind turbine blades are analyzed by several researchers. The effect of winglet, an added mass on the L/D ratio was analyzed and the simulation results are reported.

2. COMPUTATIONAL METHODOLOGY

CAD Model: Three different blade profiles (GEO-426, S-823 and NACA-4411-63) are selected for the computational analysis. The CAD models of these profiles are created using CATIA. The co-ordinates are imported into the CAD tool and the profile is generated. Then the profile is extruded along the length and twist. The blade profiles with different shapes are imported in CAD tool as co-ordinates and the profile is dragged for a length of 3400 mm. The connector which connects the root of the blade to the rotor is with a diameter of 180 mm and a length of 200 mm. Figure 1 shows the three dimensional CAD models of GEO series, S- Series and NACA series blades which are used for present CFD investigation.AOA and L/D ratio were studied.

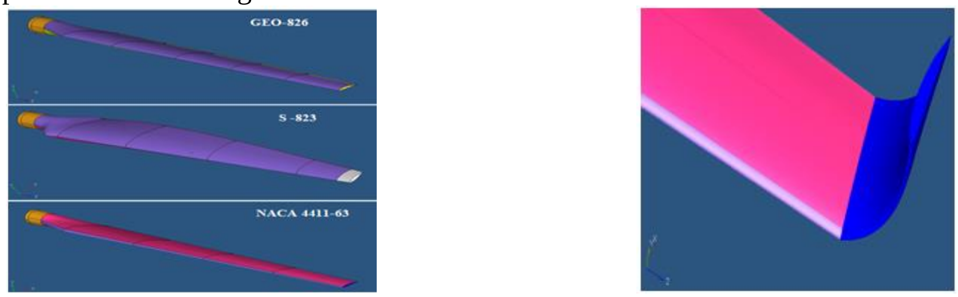

Figure.1.(a) CAD models with various blade profiles (b) Winglet added to the tip of the blade

An add-on part winglet which improves the aerodynamic performance of the blade profile is added to the optimised blade configuration and the CFD analysis is carried out to identify the lift enhancement. Figure 2 shows the CAD model of the blade with winglet.A hypothetical domain is considered for the external flow analysis of the blade configurations. The domain size are chosen proportional to the blade length. The wind turbine blade model which is optimized using CFD is assembled along with hub, rotor, generator and pillar components in order to simulate the static analysis of the HAWT assembly. Figure 3 shows the wind turbine assembly along with optimized blade and winglet.

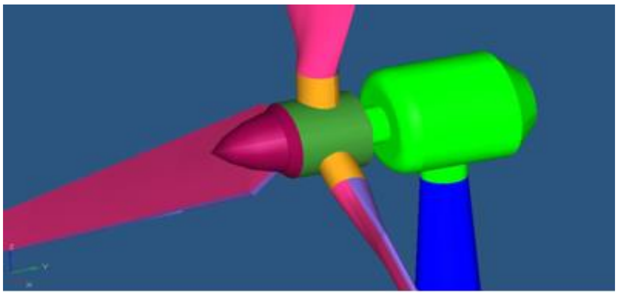

Figure.3.HAWT assembly used for final CFD investigation

Mesh Details: The second process in CFD methodology is to discretize the CAD model into elements in order to carry out the numerical calculations. The meshing is carried out using Hyper mesh. The surface meshing is done with triangular elements and the volume meshing is carried out with tetra elements. Boundary layers are formed around the blade in order to capture the near wall shear effects. Mesh refinement has been carried out near the tip surface in order to capture the profile properly. There are 10 layers of boundary layer mesh formed with a growth rate of 1.2. The first layer height is kept with 0.05 mm. The sectional view of the volume mesh with tetra elements. Total volume elements created for the computations are around 28 Lacks. The tetra growth near the blade surface is shown in the zoomed view. The tetra growth ratio is also same as the boundary layer growth. The total nodes considered for computations are around 6.6 Lacks.

Boundary Conditions and Solver Settings: The volume mesh generated in the hyper mesh is exported as mesh file for fluent solver using CFD input/output option. The boundary mesh is kept in different components like blade surface, leading surface, trailing surface, tip, root, etc. The surface mesh quality is kept within 60 degrees of triangular elements and the volume mesh quality is checked for tetra skewness. Highly skewed elements are adjusted to improve the quality of mesh. The solver settings are given in Table 1. The third process in CFD methodology is setting up the boundary conditions (BC) in the solver. The BC is given in Table 2.

Table.1.The boundary conditions and solver settings consolidated.

Type	Description
Flow	Steady & Incompressible
Energy	Isothermal
Equations	Continuity, Momentum, Turbulence
Turbulence	k- epsilon (2 Equation Model)
Fluid	Air @ 27° C
Solver	Pressure Based Navier Stokes (PBNS)

Table.2. Boundary Conditions applied for present Investigation

Boundary	Type	Value
Domain Inlet	Velocity Inlet	10 m/s
Domain Outlet	Pressure Outlet	0 Pa (gauge)
Turbine Blades, Winglet, Root Shaft	Wall	No Slip
Domain	Reference Pressure	101325 Pa

3. RESULTS AND DISCUSSION

Effect of Winglet: Adding a winglet at the tip of the blade significantly improves the lift and reduces the drag. NACA-4411-63 series produces better aerodynamic performance and hence higher lift. So a winglet is added to this profile and the CFD analysis is carried out with the same wind speed.

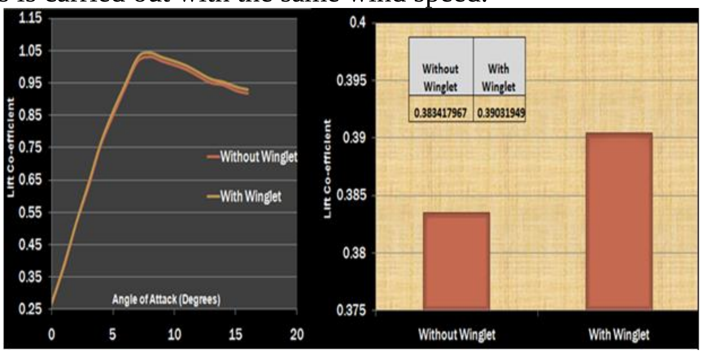

Figure.4. Pressure Distribution on NACA 4411 series with winglet

A cut plane just above the wind turbine blade is considered to show the effect of winglet. A significant pressure reduction is observed just above the suction side which in turn creates higher lift. Figure 5 depicts the variation of C_L / C_D with respect to various angles of attack. It can be observed that the maximum L/D ratio is obtained within an angle of attack of 5 degrees. Later it suddenly drops down with a negative slope.

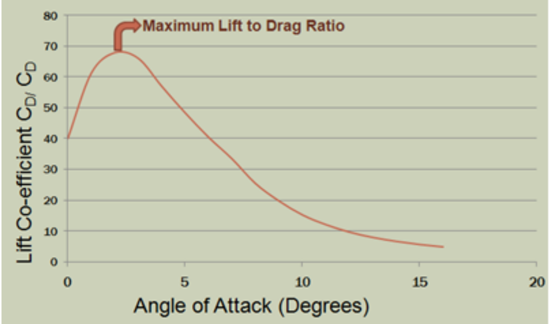

Figure.5. Variations of C_L / C_D with AOA

From Fig. 5, it is noted that adding an Add-on Part (Winglet) leads to increment in lift co-efficient at high angle of attack. At lower angle of attack (Within 5 degrees) the winglet is not much effective.

4. CONCLUSION

Computational codes reasonably predict the flow around the wind turbine blades. It is observed that among the three blade configurations (GEO - 426, S-823 and NACA-4411-63). From the analysis NACA-4411 gives the better performance and produces high lift at an angle of attack of around 3-4 degrees. The effect of add-on part has also been studied using CFD adding a winglet at the tip of the blades. The lift co-efficient increased significantly due to the presence of winglet. At lower angle of attack, the C_L/C_D ratio reaches the maximum value. The entire assembly of the wind turbine is considered to plot the pressure and velocity distribution to identify the wake formation and recirculation zones around the components.

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