DESIGN ANALYSIS OF WINGLET FOR SMALL WIND TURBINES: -A COMPUTATIONAL APROCH.

1Avijit Nayak, 1S.S. Singh, 1S.K. Satapathy, 1S.K. Pattnaik, 1T.K. Barik,1 S. Dalei,2Aryan dalai

1Asst. Prof. Department of Mechanical Engineering, , Gandhi Institute of Technology & Management, Bhubaneswar

2 Student of Department of Mechanical Engineering GITAM, BHUBANESWAR ODISHA

ABSTRACT

Increase the effectiveness of the wind turbine blades reduces the noise of the wind turbine blades during the running period. Wind turbine, a blade plays a vital role as it consumes a large amount of energy and it is the main part of the energy absorption system According to the design configuration, the blade must be design to absorb the energy with a highest efficiency. For the design of the wind turbine blades effectively, ANSYS and CFD software are used in this project work. Here for the analysis of the blades, NACA 63-215 aerofoil is considered. For increasing the efficiency of the wind turbine blades, passive methods of modification is made in the wind turbine blade with winglet from the root to tip of the blade. For reducing the noise of the wind turbine blades during the working period winglet is required to introduce in the tip portion of the blade that is also increase the efficiency of wind turbine blade. The modified blade with winglet and the exiting wind turbine blade were compared.

Keywords-Blades, winglet, aerofoil, tower, hub, efficiency, wind speed, CFD, ANSYS

1. INTRODUCTION

The main purpose of adding a winglet to a wind turbine rotor is to decrease the total drag from the blades and thereby increase the aerodynamic efficiency of the turbine. The need of electricity for our generation is the prime importance due to the luxurious lifestyle of mankind. According to our needs and priorities one alternative natural resource is Wind from which we can draw power. Wind is a natural resource which blows everywhere from large area to a small area. This power of wind turbines has increased 100 times as compared to the old wind mills used before couple of decades. The largest wind turbine found till date is the 'Siemens SWT-6.0' which produces an excess of 6.0 MW of power producing about 20 million KWh per year, which is shown in Figure 1. There are two types of bladed rotors i.e. two bladed rotor and three bladed rotors. The aerodynamic efficiency is lower as compared to the three bladed rotors. Usually, the two bladed and single bladed rotors are needing a hinged hub for rotation and it should be in balance conditions so that it will not hit the tower and make the blades bent. Three blade rotors area having more effective because it uses the yawing mechanism. A survey has been done for small and medium scale wind turbine blades and most of all the literatures follow the classical blade element theory for designing the turbine blades and optimizing the forces acting on the rotor blade. Some works which

has been followed for this work as follows. Jackson, et.al prepared a preliminary. Design of a 50 meters long turbine blade, in order to improve the structural efficiency, there are two versions of material are tested. One of fiber glass and one with carbon composite was tested looking to the cost and thickness of cross sections. The aerodynamic performance was made by using computational techniques and the computations were predicted using clean and soiled surface. In the article [1] modifies the tip of the rotors to winglet to improve the aerodynamic performance of turbine rotors and to make them less sensitive to wind gusts. The variables are cross section area, radius of gyration and the chord length, the optimal design for the maximum natural frequency. The optimization is done using multi-dimensional search techniques. The results had shown an efficient technique [2].

The effect of winglets tip in the wind blade decreases the induced drag of the blade by changing the downwash distribution, hence increasing the power production [3] and [4]. The BEM theory used to design applications and ANSYS for calculation of natural frequencies. It found that shape of the blades by using the Timoshenko twisted tapered beam element theory. The genetic algorithm was used to minimize blade vibration, maximize output, minimize blade cost and increase stability [5]. Blade geometry optimization for the design of wind turbine rotors, pre- programmed software was used to optimize structures and cost model [6]. 1.5 MW turbine rotor of 35 meters blade length were developed using Matlab programming for designing and concluded the feasibility of Matlab for designing large wind turbines, further they had also compared with CFD results and the found out Matlab was economical in artificial design and optimizing for efficiency [7]. Three different wind turbine sizes in order to optimize the cost based on maximizing the annual energy production for particular turbines at a general site. In their research using a refined BEM theory, an optimization model for wind turbines based on structural dynamics of blades and minimizes the cost of energy. Effective reduction of the optimization was documented [8]. Dynamic stresses on a blade were estimated using the blade element theory. The rotor diameter was 10 meters and the dynamic analysis was made using the beam theory and the modal analysis is made using the finite element modelling and also using the blade motion equation [9]. Wind turbine blade designed for 38 meters for a 1.5MW power using the BEM theory, and had suggested in his future work the chord distribution formula which I have implemented. Since his blade design formula was close to my design I choose the same airfoil profile[10].

Figure 1 Siemens SWT-6.0

This present work is done in designing a wind turbine blade using the Blade Element Theory for a length of 1.5 meters which is suitable for 2.0 KW small wind turbine. The chord lengths are calculated and the chord distributions, flow angles, the differential power, thrust and torque are all at discrete intervals of the blade are plotted. The blade is then assumed to be a tapered hollow beam. The natural frequency is found out by solving the Eigen value problem. The blade efficiency can be increased by attaching a winglet to the end of the blade. The winglets are normally used in the aerospace vehicle sign.

2. DESIGN OF WINGLET GEOMETRY

Blade Pitch Angle

A critical part of the rotor design includes the selection of either a variable speed ratio or a fixed speed ratio, and this is determined by either implementing a variable blade pitch system or selecting a fixed blade pitch angle. For the purpose of this project, a fixed blade pitch angle is chosen. Recalling previous definitions, the tip speed ratio is defined as the ratio between the blade tip speed and the wind speed. Since the wind speed in a regular environment is a variable phenomenon, it is physically right to say that having a fixed blade pitch angle produces a variable tip speed ratio. An optimal blade pitch angle is attained by means of BEM and later optimized through $\varphi = (2/3)\tan 1(1/\lambda r)$ …..(1)The distribution of the chord length is given in the proposed design.

2.3 Proposed Initial Design

The design of the blade has been preliminarily performed using Q-blade, available wind turbine blade design software which works together with X-foil in order to design and analyze a blade with different airfoils for each cross section as well as twist angle along the length of the blade as shown in Figure (2-9). The parameters for the design of the blade were taken from a student design optimization in which a wind turbine blade was optimized using several methodologies including design of experiments (DOE), gradient-based sequential quadratic programming optimization and a multi objective genetic algorithm. The objective functions of this optimization project are to maximize the power output while minimizing the blade volume and structural stress. The chosen blade radius is 1.6 m, and in the airfoil used is 63 series especially 63-215, 63-215 (Modified), 63- 415. Given that the purpose of this B.E. thesis is The local speed ratio - The blade twist angle

The distribution of the twist angle is given in the proposed design, and it is equal to φ minus the angle of attackα.

NACA airfoil family was used for the blade geometry. Unlike typical airfoils used in aeronautics, these airfoils have been specifically designed for wind turbines. The camber in these airfoils is higher than others the thickness of the blade is higher at its root, and decreases along its length, until the thinnest airfoil is used at thetip.

2.4 Sizing and Parameters

There are several sizing aspects involved in the design of a wind turbine, specifically a wind turbine blade. Based on previous designs and research, an optimal blade design has been used in this project, involving airfoils, twisting, setup and scaling factors. The rotor diameter for the wind turbine is 3.0 meters, and the winglet configuration selected will add approximately 0.2 meter to this dimension depending on the configuration used. This dimension could be altered by changes in one or more characteristics of the winglet. The design parameters of the winglet that this project involves are height, radius and can't angle.

Can't Angle, Radius and Height

The cant angle of a winglet has been previously defined in this report. The range of variation for the cant angle for the purpose of this project is from 10° to 90°.

The radius between the turbine blade and the winglet varies as a function of the winglet height; therefore the parameter setup for this case is a multiple of the height. The radius varies from 10% to 100% of the height of the winglet.

The height of the winglet fluctuates in relation with the turbine rotor radius, varying from 1% to 2% of the rotor radius. This parameter is setup to change in the range of 0.16 to 0.32 meters.

3. NUMERICAL METHODOLOGY

The computing for the performance of blade is completed in FLUENT. Based on the tridimensional N-S equation (the fluid is incompressible and steady). We adopt segregated implied formulation, absolute velocity and k- SST turbulence model. All of the variable and viscosity parameters are set with second order discretization for better accuracy

Boundary Conditions

The setting of the Boundary Conditions (BCs) is a very important step. Therefore, BCs have to be properly applied. Below is a list of the used boundary conditions:

Velocity-Inlet

When dealing with incompressible flows, the velocity must be specified at the inlet of the mesh. It can be specified as both constant and variable, either normal to the surface or acting with a specified angle (as would be in a yaw-study case). In this case it was specified as constant and perpendicular to the boundary. Turbulence conditions also have to be defined here and the default turbulence parameters of the NASA Ames Wind Tunnel were used, that is, inlet turbulence intensity of 0.5 % and viscosity ratio set to10.

Pressure-Outlet

This boundary condition was applied at the outlet of the domain and sets the pressure at the boundary at a specific static pressure value. In this study, the obvious choice was to put the value equal to zero so that the pressure at the outlet would be equal to the atmospheric operating pressure (standard pressure at sea level was used. i.e. 101,325Pa).

No-Slip Wall

This condition is applied to the solid surface of the blade, and implies the velocity of the fluid particle to be zero at the wall.

Periodic Condition

Since the wind turbine rotor rotates at a constant angular velocity thus presenting a periodically repeating nature; the software allows applying periodic boundary conditions to specific surfaces giving the great advantage of reducing the size of the domain.

Solution Method

As we already introduced before the pressure-based discretization scheme is being applied and since computing hardware permitted, the coupled algorithm, which solves in one step the system of Momentum and pressure-based continuity equation, could also be used, thus reducing computational times. With FVM, scalar quantities are defined at the centre of cells whereas convection terms are stored at the face of the cells. These last terms can only be found by means of interpolation from the centre of the control volume, namely upwind scheme. In the software, there are different methods that can be used such as first- or second-order upwind scheme.

According to the FLUENT Theory Guide, the latter is in most cases preferable as error margins are decreased. However, as recommended by FLUENT, the solution should be initialized with first-order upwind scheme and when some convergence is achieved, it can be switched to second order.

This is done in order to limit divergence problems. The mesh file of the wind turbine blade assembly is shown in the Figure 2 and Figure 3.

Figure 2 Design of winglet

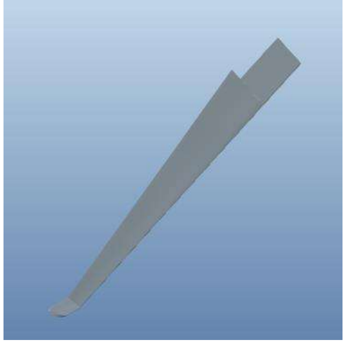

Figure 3 isometric view with Winglet

4. RESULT ANALYSIS OF WINGLET

Numerical simulation has been carried out for the wind turbine with winglet at edge of the blade for various Velocities. The graphical representation of velocity magnitude and iteration the winglet for wind velocities of 2.5 m/s and 3.5 m/s is shown in Figure 6 to Figure 7.

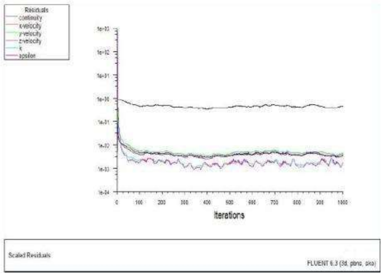

Figure 4 Wind speed 2.5 m/s

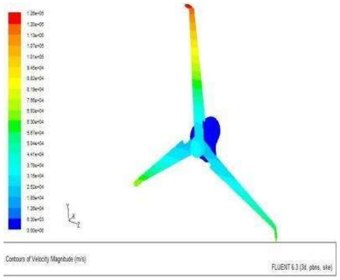

Figure 5 Velocity magnitude at wind speed 2.5 m/s

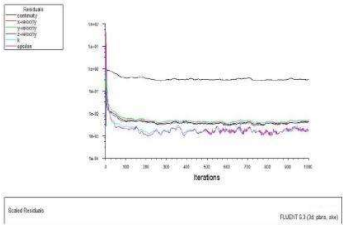

Figure 6 Wind speed 3.5 m/s

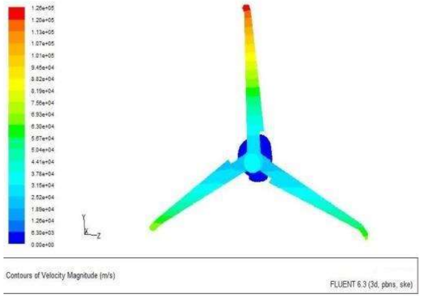

Figure 7 Velocity Magnitude at Wind Speed 3.5 m/s

5. CONCLUSION

The winglet design process must come after an implementation of final airfoil design that will be used to compare the improvement of a system with winglets and without winglet. The blade design of a wind turbine differs from an airplane wing design. Airplane wings usually have one airfoil design through all the length of the wing, in the case of wind turbines, around three or four different airfoil of winglet profiles are used in the wind turbine blade varying from the root to the tip of the free stream. Also, another important difference can be found in the twist angle of a wind turbine blade. The blade is twisted in a special and optimized manner through the length of the blade. Various differences made in the numerical analysis of a wind turbine blade with winglet were more complicated than normal wind turbine blade. Hyper Works for meshing and simulation was carried out using ANSIS Fluent 6.3. The blade design process was very time consuming, methods and techniques are being refined in order to produce fastest and more reliable designs. The implementation of the mentioned software packages reduces largely the load of the design process, and several other packages are in way to be implemented to improve the blade design and the calculations as much as possible. It has been shown that winglets can effectively improve the performance of a conventional tip wind turbine blade. The noise level in the wind turbine is also certainly reduced after the implementation of the winglet the CFD analysis also shows the better result over the present blade structure.

6. REFERENCES

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