Design and Surface Modification of Wind Turbine Blade Using Analytical as Well as Virtual Method

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***Abstract*: Designing horizontal-axis wind turbine (HAWT) blades to achieve satisfactory levels of performance starts with knowledge of the aerodynamic forces acting on the blades. In this paper, HAWT blade design is studied from the aspect of aerodynamic view and the basic principles of the aerodynamic behaviours of HAWTs are investigated. Firstly, blade designs procedure for an optimum rotor according to CFD analysis as well as analytical calculations. Then designed blade shape is modified such that modified blade will be lightly loaded regarding the highly loaded of the designed blade and power prediction of modified blade is analysed. When the designed blade shape is modified, it is seen that the power extracted from the wind is reduced about 10% and the length of modified blade is increased about 5% for the same required power.**

***Keywords:* Horizontal-Axis Wind Turbine Blades, Wind energy, Aerodynamics, Airfoil.**

1. Introduction:

Lower production from a wind turbine is a function of wind speed. The relationship between wind speed and power is defined by a power curve, which is unique to each turbine model and, in some cases, unique to site-specific settings. In general, most wind turbines begin to produce power at wind speeds of about 4 m/s (9 mph), achieve rated power at approximately 13 m/s (29 mph), and stop power production at 25 m/s (56 mph). Variability in the wind resource results in the turbine operating at continually changing power levels. At good wind energy sites, this variability results in the turbine operating at approximately 35% of its total possible capacity when averaged over a year. The amount of electricity produced from a wind turbine depends on three factors:

1) Wind speed: The power available from the wind is a function of the cube of the wind speed. Therefore if the wind blows at twice the speed, its energy content will increase eight-fold. Turbines at a site where the wind speed averages 8 m/s produce around 75-100% more electricity than those where the average wind speed is 6 m/s.

2) Wind turbine availability: This is the capability to operate when the wind is blowing, i.e. when the wind turbine is not undergoing maintenance. This is typically 98% or above for modern European machines.

3) The way wind turbines are arranged: Wind farms are laid out so that one turbine does not take the wind away from another. However other factors such as environmental considerations, visibility and grid connection requirements often take precedence over the optimum wind capture layout.

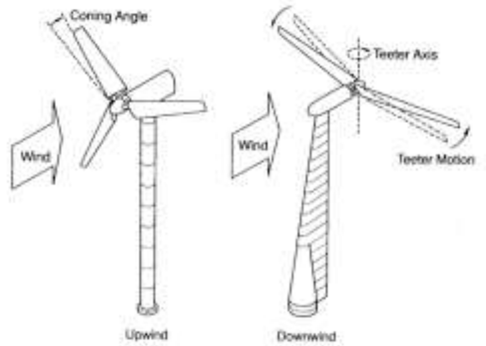


Fig: Schematic of the two common configurations. Upwind, rigid hub, three-bladed

A wind turbine uses rotor blades to extract and convert kinetic energy of wind into electrical energy. Therefore, a rotor blade requires optimal aerodynamic shape to maximize its efficiency and to improve power performance. To make optimum aerodynamic design of wind turbine blades, blade element momentum theory (BEMT) is widely used due to its effectiveness in design and rapid calculation. Aerodynamically, the evaluated values such as electrical power, powercoefficient, axial thrust force, annual energy production (AEP) are concerned to secure design effectiveness of rotor blades. A typical design process starts with determining blade length and rated rotating speed according to design class and specification, and then design parameters such as blade chord length, twist angle and airfoil distribution are obtained by using BEMT to construct a blade plan form for baseline blade. The pitch and torque control schedule map should be determined to maximize the efficiency and to maintain the target power ofblade with completed design.

Therefore, there have been various researches using CFD to identify the blade performance and flow characteristics. As CFD analysis utilizes the three-dimensional Navier-Stokes equation as the governing equation, it has the advantage of providing more accurate result of analysis compared to previous aero-elastic code. On the contrary, to acquire reliable result from computational method, a vast amount of computational grids are required and advanced turbulence model needs to be applied. The computational method is very useful for understanding the aerodynamic characteristics of rotor blades, but it consumes too much time and resources; thus it is generally applied at the final performance evaluation stage after all the design process is completed.

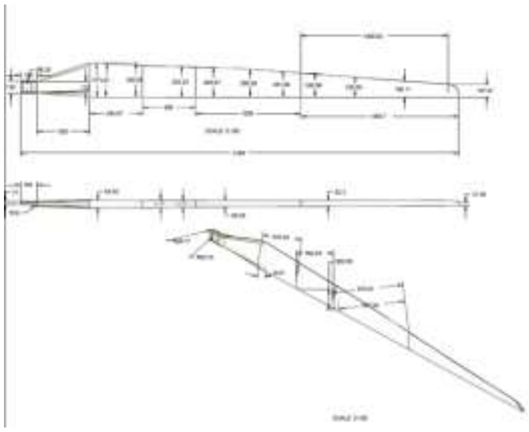


Fig: Detailing and Drafting of blade

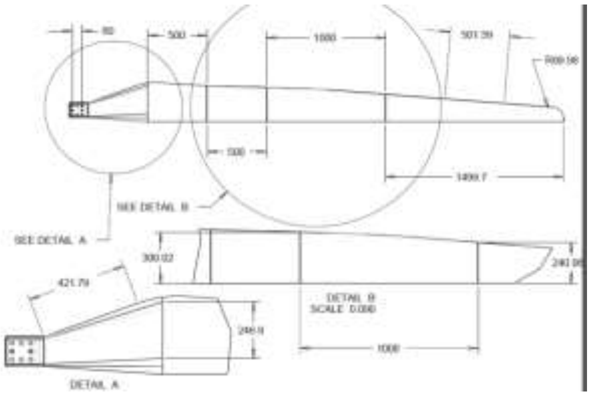
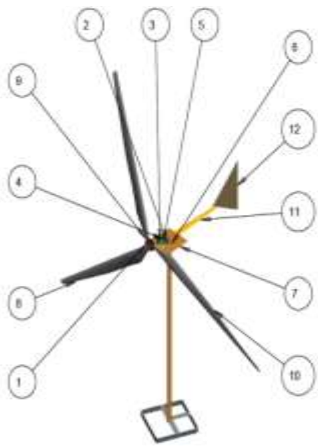


Fig: Detailing and Drafting of Wing blade

2. CAD MODELLING BY USING CREO-PARAMETRIC 2.0 SOFTWARE.

Methodology:



1	11	1
2	BOTTOM	1
3	DYNAMO	1
4	DYNAMOCOVER	1
5	NUT_WING_BOLT	1
6	NUT_WINGS	7
7	PLYWOOD	1
8	PRT0002	1
9	PRT0003	1
10	PRT0004	1
11	RUDDER	1
12	RUDDER1	1

Fig: Bill of material

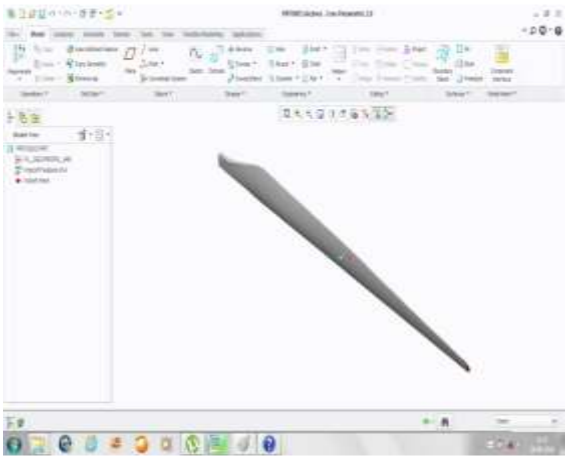


Fig: 3D Model

3. Lift Force Calucualtion

$F_l = \frac{1}{2} \rho V_0^2 c C_l$

c- Length of aerofoil

V_0 – Velocity of air

P- Density of air= 1.23Kg/mm^3

C_l – Coefficient of lift

F_l = 0.5*1.23*4*4*8.6*0.143
= 12.101N

F_l = 0.5*1.23*4*4*8.6*0.2
= 13.99N

F_l = 0.5*1.23*4*4*8.6*0.105
= 4.19N

Table: Coefficient of lift and lift force for original shape

AEROFOIL SECTION	C	C_l	F_l
1st cross section	8.6	0.143	12.101
2nd cross section	7.11	0.20	13.99
3rd cross section	4.06	0.105	4.19

Modified section of Aerofoil

F_l = 0.5*1.23*4*4*8.6*0.120
= 11.75N
F_l = 0.5*1.23*4*4*8.6*0.0873
= 6.10N
F_l = 0.5*1.23*4*4*8.6*0.075
= 2.99N

Table: Coefficient of lift and lift force for modified shape

AEROFOIL SECTION	C	C_l	F_l
1st cross section	8.6	0.120	11.75
2nd cross section	7.11	0.0873	6.10
3rd cross section	4.06	0.075	2.99

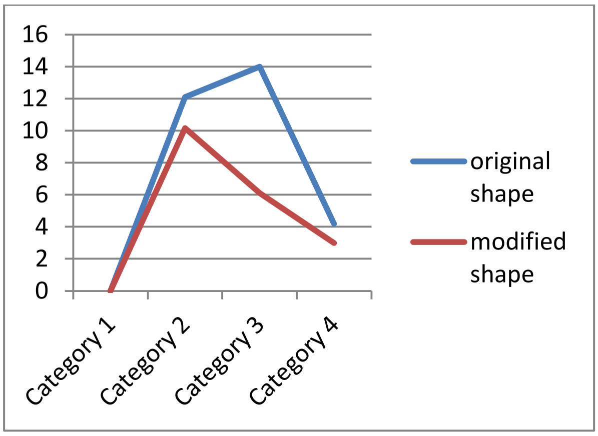


Fig: Graph for original and modified shape(LIFT)

4. Drag Force

$F_d = \frac{1}{2} \rho V_0^2 c C_d$
c- Length of aerofoil
V_0 – Velocity of air
P- Density of air= 1.23Kg/mm^3
C_d – Coefficient of drag
F_d = 0.5*1.23*4*4*8.6*0.474
= 40.111N
F_d = 0.5*1.23*4*4*8.6*0.252
= 17.63N
F_d = 0.5*1.23*4*4*8.6*0.169
= 6.75N

Table: Coefficient of drag and drag force for original shape

AEROFOIL SECTION	C	C_d	F_d
1st cross section	8.6	0.474	40.111
2nd cross section	7.11	0.252	17.63
3rd cross section	4.06	0.169	6.75

Modified section of Aerofoil
F_d = 0.5*1.23*4*4*8.6*0.479
= 41.53N
F_d = 0.5*1.23*4*4*8.6*0.368
= 25.746N
F_d = 0.5*1.23*4*4*8.6*0.268
= 10.706N

Table: Coefficient of drag and drag force for original shape

AEROFOIL SECTION	C	C_d	F_d
1st cross section	8.6	0.479	44.53
2nd cross section	7.11	0.368	25.746
3rd cross section	4.06	0.268	10.706

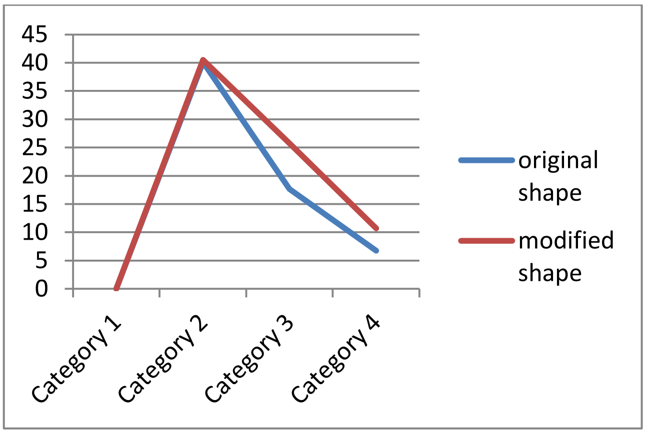


Fig: Graph for original and modified shape(DRAG)

Resultant force
F = $\sqrt{F_l^2 + F_d^2}$
=$\sqrt{12.101^2 + 40.111^2}$
= 41.89N
Torque = F*distance
= 41.89*100
=4189Nm
Power = ω T/60
0.796*41.89/60
55.57Kw
Modified aerofoil
F = $\sqrt{F_l^2 + F_d^2}$
=$\sqrt{11.75^2 + 41.53^2}$
= 43.16
Torque = F*distance
= 42.198*100
=4316Nm
Power = ω T/60
0.796*4316/60
57.25Kw

5. Analysis By Using Ansys 14.0 Software:

Computational grid and calculation conditionsComputational grid domain is divided into rotational part and stationary part. Rotational part is configured with domainwhich surrounds the blade and the rest. To generate numerical grid, ANSYS ICEMCFD V14.0 is used and hexagonal grid is applied for the purpose of improving the accuracy and convergence of the solution. About 5.0 million nodes are generated for a single blade domain that rotates, and 1.5 million nodes are used for stationary domain. A numerical grid on the blade surface and surroundings are shown in Fig.

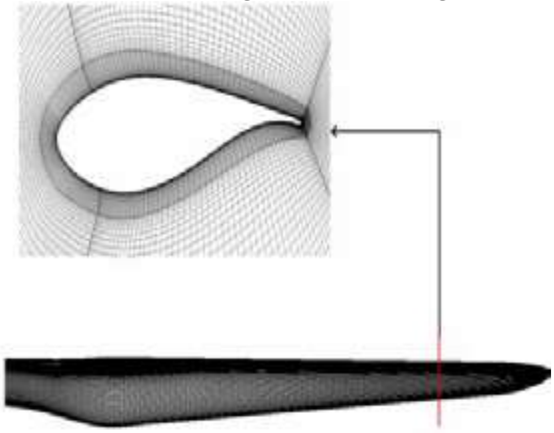


Fig: Computational grids.

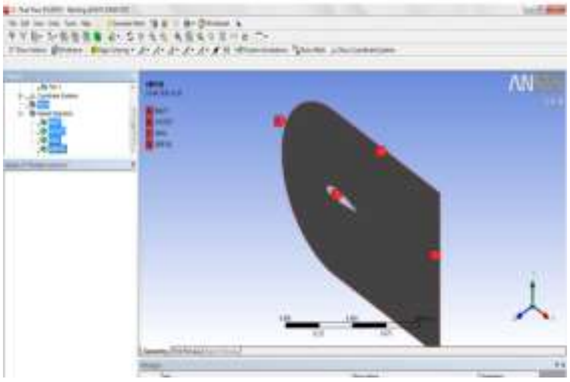


Fig: Boundary Condition

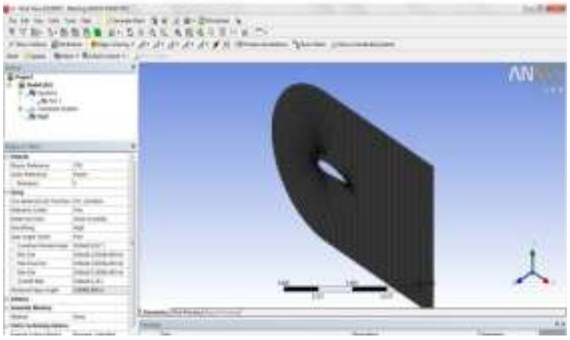


Fig: Meshing

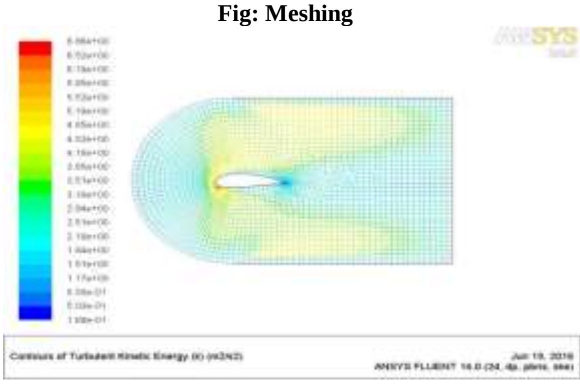


Fig: Contour plot for Turbulent Kinetic Energy

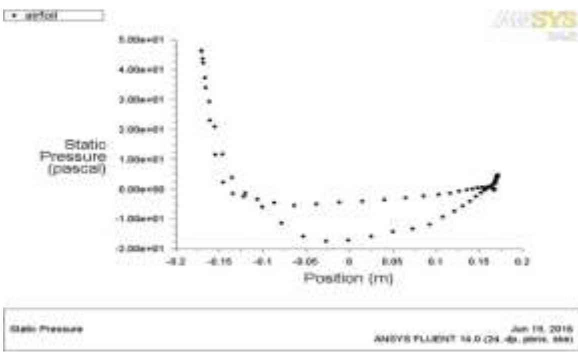


Fig: Graph for Static Pressure

6. Performance Analysis

The compared result of blade power output analysis is shown in Fig. Result of CFD analysis was compared directly with the result of GH-Bladed. It shows that the CFD result is relatively in good agreement with the result of GH- Bladed both qualitatively and quantitatively throughout thewind speed range. However, the result of CFD analysis at wind speed of 20 m/s shows higher value compared to that of GH-Bladed and those discrepancies have effects on power coefficients. At the rated wind speed of 20 m/s, of mechanical power output is predicted by CFD analysis. Fig. 17 shows the result of predicted power coefficient comparison between CFD and GH-Bladed and it is not matched well at 5 ~ 8 m/s range. To confirm theaccuracy of two different analysis codes, reliable experiment data need to be compared, but it is almost impossible to ac- quire test data of self-designed large blade. Therefore, if the difference of analysis method is used for assessment, the result of Navier-Stokes equation based CFD analysis is more reliable than the result of analysis based on simplified BEMT. Maximum power coefficient of 56.15 KW blade is 0.479 for CFD analysis result and 0.462 for GH-Bladed analysis result. Fig. 18 shows the result of axial thrust force distribution. The result of GH-Bladed and the result of CFD analysis correspond fairly well, and the blade axial force gets bigger as wind speed increases.

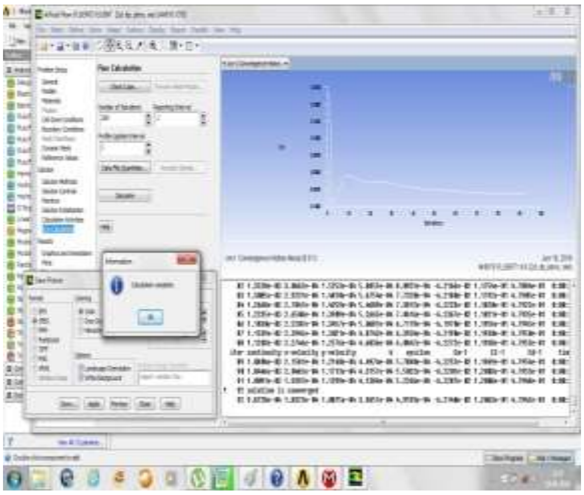


Fig: Graph for Cd

7. SHAPED CHANGED

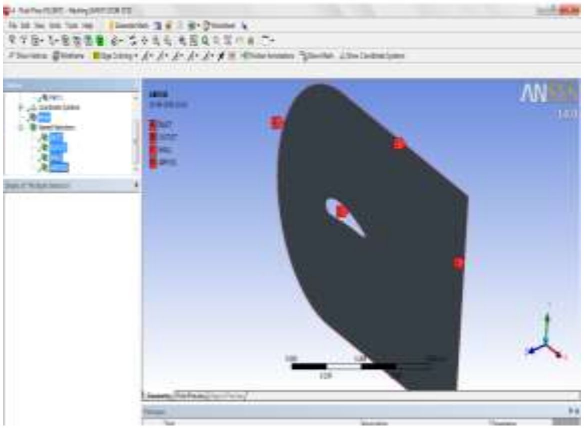


Fig: Boundary Condition

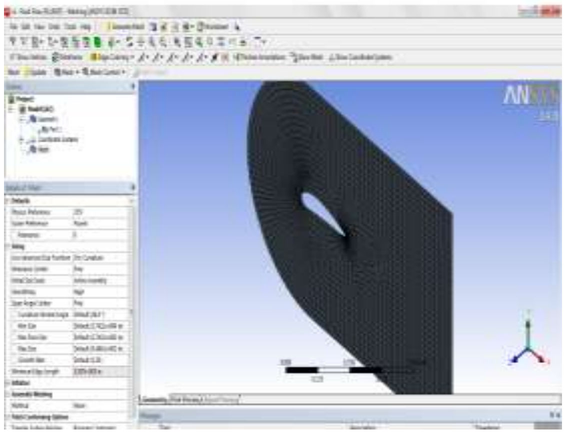


Fig: Meshing

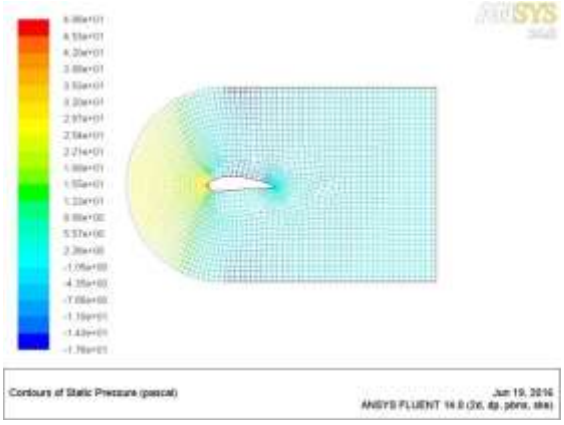


Fig: Contour plot for Turbulent Kinetic Energy

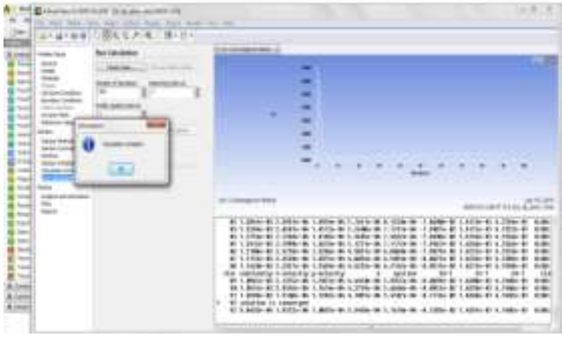


Fig: Graph for Cd

shape	Cd	Cd	Cd
original	1^{st} section	2^{nd} section	3^{rd} section
			
	0.474	0.252	0.169
modified	1^{st} section	2^{nd} section	3^{rd} section
			
	0.479	0.368	0.268

From the above table we concluded that the coefficient of drag value is increasing By changing the shaped of airfoil. And hence drag force also increases results in increasing total force. Power also increases since Cd value change.

8. Conclusion

Aerodynamic design of 55 KW wind turbine blade is carried out using, and performance analysis is performed by CFD code. An approach to the wind turbine design has been estimated in terms of analytical as well as virtual method. The value obtained from from CFD analysis through different section of the blade. For designing purpose creo parametric 2.0 software is implemented which gives perfect geometry for further analysis. On the basis of this analysis we concluded that if we changed shape aerodynamically then defiantly we get improved results. Bu t for optimization of the blade we have to take number of iteration. The multi-disciplinary design system has the ability for geometry creation and analysis for axial turbine. It is being adapted for wind turbines which have their own unique issues. The multi- disciplinary approach makes it easy to address a vast number of aerodynamic and structural issues. A parametric design tool for geometry has been developed that will help implement quick design changes from a command line input. The system developed was investigated with the in-house turbo machinery axisymmetric solver, as it was easy to change the source code to suit our needs for wind turbine design. For a conventional horizontal axis wind turbine, the analysis shows: The lower 25% of span should account for cascade effects. From 25% - 75% span, the wind turbine can be assumed 2D and isolated (wing theory applicable).From 25% - 75% span, the wind turbine can be assumed 2D and isolated (wing theory applicable).

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