Structural Design and Analysis of a Blade of a 2 MW Capacity Wind Turbine

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***Abstract*—Considering the limitation with the fossil fuels, the use of wind energy for producing power is increasing day by day. Wind Turbines have gained importance due to their usage in electricity production and water pumping applications. According to Betz Law, the ideal efficiency of the turbine is 59.6%. But due to losses, in practice, the wind turbine efficiency is restricted to 40%. One of the important factors which affect the performance of wind turbines is blade design. The focus is to optimize the design of blade by accounting the airfoil selection, variation of pitch angle (twist) along the length of blade and material selection. Structural analysis carried out validates the strength of the blade against bending and twisting failures**

***Keywords*— Airfoil, Wind turbine blades, twist angle, blade material.**

I. Introduction

Considering the limitations of the fossil fuels, the use of wind energy for producing electricity/power is increasing day by day. The overall efficiency of the wind turbines according to Betz Limit is 59.6% which is the ideal efficiency. The overall efficiency of the wind turbine is the product of aerodynamic, mechanical and generator/electrical efficiencies. In practice the efficiency that we get from wind turbines is around 40%. Due to the aerodynamic (drag), mechanical (friction) and electrical (motor) losses, the extracted energy from total is 40%.To utilize this available energy effectively it is necessary to design the components at each stage carefully. One of the important components to design is wind turbine blade which mainly focuses on aerodynamic efficiency. Aerodynamic performance depends upon factors such as blade profile and very importantly distribution of twist over the length of the blade. The different airfoil (blade profile) used are NACA series, MH-series, FFA-W series, etc. The selection of airfoil depends on maximum lift provided or lift to drag ratio by the airfoil. The blade at the same time must withstand failure due to bending stresses. The materials used commonly for blade are carbon fiber, aluminum, GRP, steel, wood etc. The selection of blade material is based on cost and fatigue strength of the material.

II. Basic Theory of Wind Turbine Blades

In wind turbine blades the relative velocity of the wind striking the blade or the angle of attack varies with the length of blade as the tangential speed of the turbine blades varies with the distance r from the root to the tip of the blade. But the coefficient of lift (C_L) to coefficient of drag (C_D) ratio is maximum for a particular angle of attack hence it is important to maintain the angle of attack constant throughout the blade length. This is done by changing the pitch angle or giving twist to the wind turbine blades. From Fig.1, Ø is the pitch angle, α is the angle of attack and γ is the angle of relative wind speed with the horizontal. V_t and V_1 are the tangential and the horizontal component of the wind velocity respectively. To maintain the angle of attack constant the pitch angle decreases from the root to the tip of the blade. Therefore twist is provided in blades to obtain maximum lift to drag ratio, thus increasing the torque on the blades.

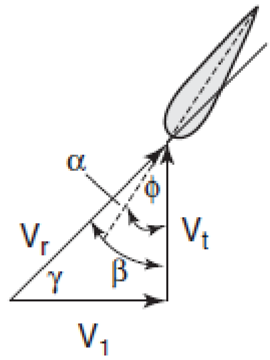

Figure 1: FBD of airfoil [Pramod Jain PhD, Wind Energy Engineering, "Relative Velocity Wind", Mcgraw Hill Publications]

The blade element theory determines the forces acting on the blades. The structural analysis is carried out on the basis of the theory.

$$C_N = \frac{F_N}{\frac{1}{2}\rho V_{rel}^{\ 2} c},$$

$$C_T = \frac{F_T}{\frac{1}{2}\rho V_{rel}^{\ 2} c}$$

$$C_N = C_L \cos\beta + C_D \sin\beta$$
$$C_T = C_L \sin\beta - C_D \cos\beta$$

$$\tan\beta = \frac{(1-a)V_1}{(1+a^{'})\omega r}$$

III. Blade Design

The most widely used wind turbine type for electricity generation application is horizontal axis wind turbine with three blades. The tip speed ratio for three blades turbine is 7. The design includes following steps like selection of airfoil shape, optimizing the twist according to the Betz's Law for the blade and selection of proper blade material. The aim is to optimize the angle of twist to be given to the wind turbine blades. The capacity of wind turbine chosen for design is 2MW. The speed of the wind striking is 10m/s The height of the wind turbine tower is 100m and length of the blade is 42m calculated for the given capacity.

A. *Selection of blade.*

The various airfoils used for wind turbine blades are of NACA-series, NREL-series, and MH-series. The important parameter while selecting the airfoil is lift to drag ratio. The torque to the wind turbine blades should be more which is ensured by maximum lift to drag ratio (C_L/C_D). The Table.1 shows the C_L/C_D ratio for NACA and MH airfoils taken into consideration for design.

Table.1

Airfoil	C_L/C_D	Angle of attack (°)
MH102	186.54	9
MH104	151.12	10.5
MH106	142.893	10.5
MH108	146.91	11.5
MH110	146.172	11.5
NACA 63418	156	12.5
NACA 63415	151	11.5
NACA 64442	152	12.5
NACA 64415	152	12

From the above table, the C_L/C_D ratio is maximum for MH102 airfoil at an angle of attack of 9°.Hence MH102 airfoil is chosen. The C_L/C_D ratio vs. angle of attack is shown in Fig.2, it depicts that the ratio is 186.4 at alpha=9°.

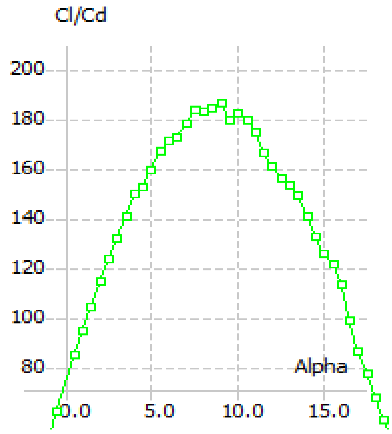

Figure 2: The C_L/C_D ratio vs. angle of attack

B. *Distribution of twist over the blade length*

The twist or pitch angle with distance from root to tip of the blade is shown in Table.2

TABLE.2 Optimized twist angle

Radial distance (m)	Chord length (m)	Optimized Twist angle (°)
0	-	-
1	-	-
3	3.512	24.6338
5	3.3519	14.5119
7	3.1918	7.98437
9	3.0318	3.5321
11	2.8717	0.336671
13	2.7117	-2.0546
15	2.55169	-3.90541
17	2.3916	-5.37753
19	2.23159	-6.57494
21	2.07154	-7.56715
23	1.91148	-8.40229
25	1.7514	-9.11463
27	1.5913	-9.72922
29	1.4313	-10.2648
31	1.2712	-10.7355
33	1.11	-11.1525
35	0.9511	-11.5245
37	0.7911	-11.8582
39	0.63	-12.1594
41	0.471026	-12.4325
42	0.391	-12.5597

The twist obtained is optimized as per the Betz's Law. At radial distance up to 1m i.e. at root the airfoil shape is circular. After 1m onwards the airfoil shape is of MH102 airfoil. The CAD view of the blade is shown in Fig.3

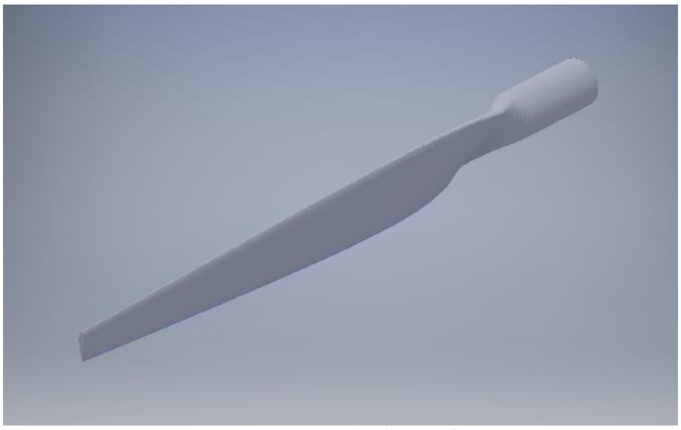

Figure 3: Cad view of the airfoil

C. Structural analysis of blade and material selection

According to the Blade element theory, the normal and the tangential forces acting on the blade is shown in Table.3. The tangential force is responsible for tangential bending moment at the root of the blade. The normal force causes the flap wise bending at the root.

V_n = ? = (1-a) V_1 = 6.67 m /s is common to all values of r

α = ? =9, is common to all values of r

TABLE.3 Forces acting on the MH102 blade

r	Chord Length	V_n/V_t	C_N	β (radian)	C_T	F_N	F_T
3	3.500	1.331	0.817	0.9264	1.075	122.16	159.84
7	3.192	0.570	1.176	0.5183	0.663	416.23	233.15
11	2.872	0.363	1.271	0.3481	0.454	853.70	302.95
15	2.552	0.266	1.306	0.2601	0.340	1371.43	355.10
19	2.232	0.210	1.323	0.2071	0.271	1899.45	386.31
23	1.911	0.174	1.331	0.1719	0.224	2366.96	395.66
27	1.591	0.148	1.337	0.1467	0.190	2706.49	382.98
31	1.271	0.129	1.340	0.1281	0.165	2840.54	348.41
35	0.951	0.114	1.342	0.1135	0.146	2705.55	292.14
39	0.631	0.102	1.344	0.102	0.130	2226.60	214.49
42	0.400	0.095	1.345	0.0947	0.121	1598.10	142.40

The blade materials used for wind turbine blades are shown in Table 4. To withstand the heavy wind force, the blade should have high endurance and fatigue strength. The important parameters while selecting the blade material are the stiffness, fatigue strength and cost of material. The fatigue strength of CFRP is highest among the given materials. Since 2MW capacity wind turbine comes under the category of the larger wind turbines, stiffness is one of the important design parameters to be considered as compared to cost of the material. The structural analysis done on the blade Fig.4 shows that the maximum stress induced in the blade is 77.48 Mpa which is less than the strength of the CFRP.

TABLE.4 Materials used commonly for blades

Material	Stiffness (Gpa)	Strength (Mpa)
Aluminum	70	300
Steel	210	275
GRP	40	300
CFRP	125	900

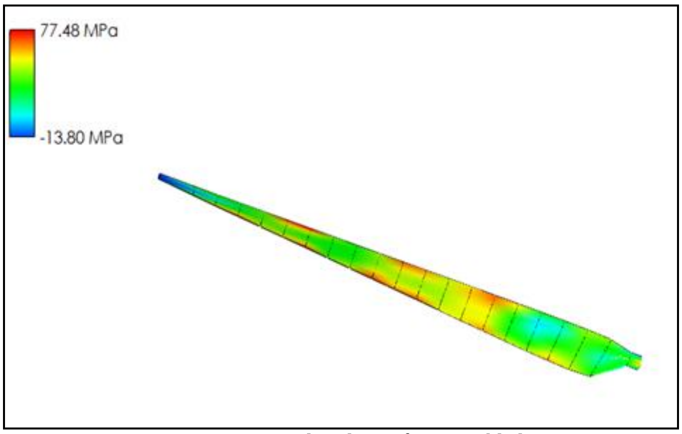

Figure 4: Structural analysis of MH102 blade

Conclusion

The paper reviews the steps for designing the wind turbine blade. The designed blade satisfies the strength criterion and is able to withstand the bending failure caused by the tangential and the normal forces acting on the blades. The points to be considered while selecting the parameters like airfoil shape and material are well discussed in this paper. The twist of the blades is optimized which ensures an aerodynamic design. The overall designing of the blades is highlighted in this paper.

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