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PERFORMANCE PREDICTION OF HORIZONTAL AXIS WIND TURBINE BLADE

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Abstract: India is a country of large population. As the population increases the demand for electricity is also increases. This demand of electricity is fulfilled by power plant. This power plant runs on the coal. This power plant produces the greenhouse gas. And this will affect the environment. Solution to this problem is renewable energy. In renewable energy wind is available free of cost. Wind is the problem of supply side management. Wind is the indirect form of solar energy. There are three methods of analysis (1) CFD analysis (2) analytical (3) experimentation. CFD analysis is the low cost method. There are mainly two types of turbine horizontal axis wind turbine and vertical axis wind turbine. Betz limit show that horizontal axis wind turbine produce more power than vertical axis wind turbine. If we carry out CFD analysis of wind turbine blade then it would be easy to determine different factors affecting the wind turbine blade while air is passing over it. From that we can find the value of $C_l$and C_d and determine the forces acting on blade. From that calculation we can determine the power produced by the turbine. And also determine the angle of attack at which maximum power developed.

Keywords:Wind energy, Aerofoils, CFD, Blade geometry

I. INTRODUCTION

Figure 1 shows the horizontal axis wind turbine with three blades.Horizontal axis wind turbines (HAWT) have their axis of rotation horizontal to the ground and almost parallel to the wind stream.Most of the commercial wind turbines fall under this category. Horizontal axis machines have some distinct advantages such as low cut-in wind speed and easy furling. In general, they show relatively high power coefficient.However, the generator and gearbox of these turbines are to be placed over the tower which makes its design more complex and expensive. Another disadvantage is the need for the tail or yaw drive to orient the turbine towards wind.

Figure 1 Horizontal axis wind turbine

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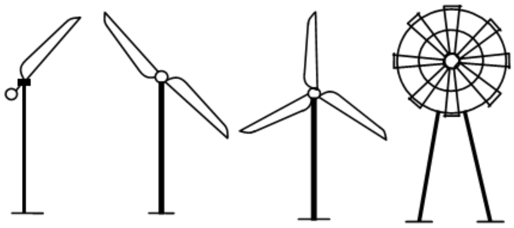

Figure 2 Types of horizontal axis wind turbine

Figure 2 shows the types of horizontal axis wind turbines. Depending on the number of blades, horizontal axis wind turbines are further classified as single bladed, two bladed, three bladed and multi bladed. Single bladed turbines are cheaper due to savings on blade materials. The drag losses are also minimum for these turbines. However, to balance the blade, a counter weight has to be placed opposite to the hub. Single bladed designs are not very popular due to problems in balancing and visual acceptability. Two bladed rotors also have these drawbacks, but to a lesser extent. Most of the present commercial turbines used for electricity generation have three blades.

II. Nomenclature

A	Swept area of rotor
α	Angle of attack
CD	Drag coefficient
CL	Lift coefficient
D	Drag force
L	Lift force
N	RPM of the rotor
P	Power developed by rotor
r	Radius of rotor
R	Resultant force acting on the airfoil
V	Free stream velocity
VT	Tangential velocity
VR	Resultant velocity
ω	Angular velocity

III. Airfoils

Major features of such an airfoil are shown in Figure 3.For the efficient energy extraction; blades of modern wind turbine are made with airfoil sections.The airfoils used for the earlier day's wind turbines were the aviation airfoils under the NACA (National Advisory Committee for Aeronautics) series. NACA specifies the features of the airfoil by numbers. For example, in a four digit specification, the first number denotes the maximum camber of the airfoil at the chord line (in per cent of chord), the second number gives the location of the point of maximum camber from the leading edge (in tenth of the chord) and the third and fourth numbers indicate the maximum thickness (in per cent of the chord). Thus a NACA 2415 air foil have maximum camber of 2 per cent, located at 0.4 times the chord length from the leading edge and the maximum thickness is 15 per cent of the chord.

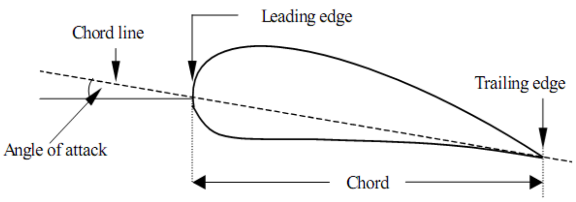

Figure 3 Important parameter of an Airfoil

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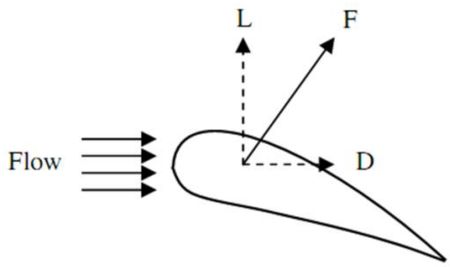

Figure 4 Airfoil lift and drag

Figure 4 shows the forces acting on airfoil when it is placed in airstream. When an airfoil is placed in a wind stream, air passes through both upper and lower surfaces of the blade. Due to the typical curvature of the blade, air passing over the upper side has to travel more distance per unit time than that passing through the lower side. Thus the air particles at the upper layer move faster. According to the Bernoulli's theorem, this should create a low-pressure region at the top of the airfoil. This pressure difference between the upper and lower surfaces of the airfoil will result in a force F. The component of this force perpendicular to the direction of the undisturbed flow is called the lift force L. The force in the direction of the undisturbed flow is called the drag force D.

The lift force is given by

$L = CL\ \frac{1}{2}\ \rho A V^2$

And the drag force (D) by

$D = \mathrm{CL}\frac{1}{2}\rho A V^2$

Where C_L and C_D are the lift and drag coefficients respectively.

Resultant force is given by

$R = \sqrt{L^2} + D\text{^}2$

And power is given by

$P = R \times r \times \omega$

And resultant velocity is given by equation

$$\mathrm{VR} = \sqrt{\mathrm{V}^2 + \mathrm{VT}^2}$$

Angular velocity is given by

$\omega = 2\pi N/60$

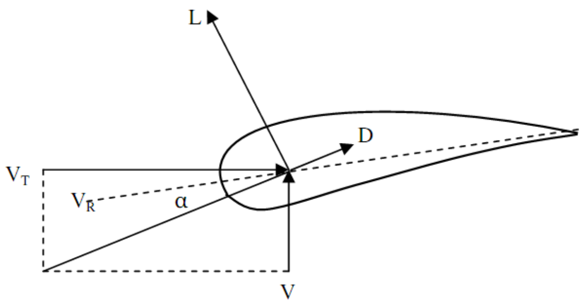

Figure 5 Section of rotating blade

Consider the cross section of the rotating blade of a wind turbine as in Figgure5. Apart from the wind velocity 'V', a point at the section is subjected to a velocity V_T due to rotation of rotor as shown in figure. Thus the velocity $V_R$experienced at this point of is the resultant of V and $V_{T.}$ V_R will have lift and drag component as shown in figure. Under this condition, the angle of attack V_R and the chord line of the airfoil. For the same rotational speed, V_T at different section of the blade varies with the distance from the hub. Hence, the angle at which the resultant velocity approaches the rotor would also be different along the blade section, being steeper at the root of the blade. As we have seen, the C_D/C_L ratio for an airfoil is minimum at particular angle of attack. To maintain this optimum attack angle throughout the blade sections, the blade may be twisted along its length.

IV. MODELLING, MESHING

First task in CFD analysis is preparation of geometry. First the type of airfoil is used is decided. Then find out the airfoil co-ordinate for drawing the airfoil shape. Here NACA 0018 selected for the analysis. Here the maximum thickness is 18% which indicate the maximum thickness (in per cent of the chord).In this analysis, the geometry is prepared in the pro-e software package and then after it is saved in iges format. Then import this geometry in the ansys 12.0.

Dimensions of the blade:

Chord length C= 240mm

Length of blade =500mm

Chord length at the 500mm distance= 40 mm

Computational conditions:

Airfoil	NACA0018
Simulation type	Steady simulation
Fluid material	Air
Temperature	288 K
Kinematic viscosity	1.4×10-5 m^2/s
Density	1.2 kg/m^3
Pressure	101325 pa
Wind speed	12 m/s to 24 m/s.
CFD algorithm	SIMPLE
Type of model	Spallart-allarmas model
Boundary condition	Velocity inlet & pressure outlet

The figure 6 shows the blade is made in the pro-e software. In pro-e software this is possible by using the blend tool.

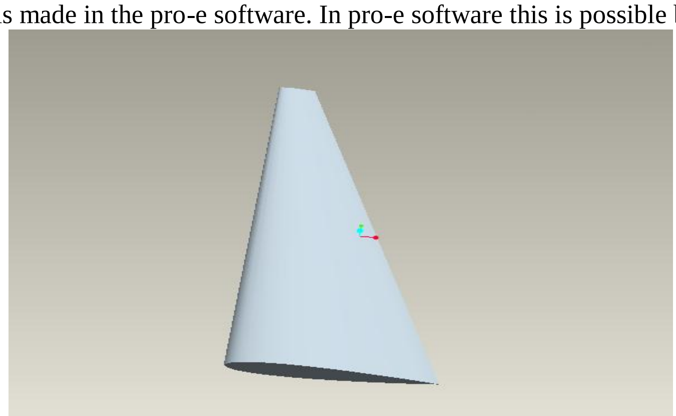

Figure 6 3d blade made in pro-e

Figure 7 shows the meshing of the blade in the ansys software

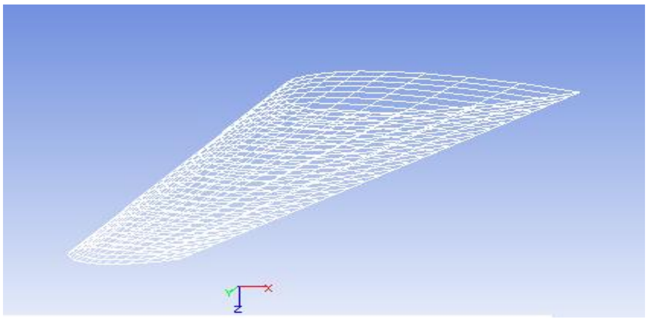

Figure 7 Meshing of the blade

V. RESULT AND CALCULATION

Calculations: The following procedure is used to calculate the numerical power developed by the wind turbine blade.

$\alpha = 6^0$; $V_0 = 22$ m/s : N = 51rpm; r =1.2m; $\rho = 1.225$ kg/m^3;

$V_T = r \times \omega = r. 2.\pi. 51/60$

V_T=6.40764 m/s

$V_R = (0.6.40764^2 + 22^2)^{1/2}$

$V_R = 22.91414$ m/s

From fluent software we get the value of

C_L =0.9559, C_D =0.001375
Therefore we get the value of
Lift force = L =0.5. ρ. V_R^2. C_L
L= 0.5 × 1.225 × (22)2 × 0.9559
L = 307.4155 N
Drag force = D = 0.5. ρ. V_R^2. C_D
D= 0.5 × 1.225 × (22)2 × 0.00147
D = 0.442326 N
Resultant force = R = $(L^2 +D^2)^{1/2}$
R = 307.4158
Numerical power = P = torque × ω
P = (R × V_R)
P= 1916.438 Watts

The table 1 is shown below is the numerical power produced by the wind turbine at different angle of attack and different wind velocity.

Table-1 Power produced by wind turbine

Sr.no	Rpm of the rotor	Wind speed	1	2	3	4	5	6	7	8
			PN (W)	PN (W)	PN (W)	PN (W)	PN (W)	PN (W)	PN (W)	PN (W)
1	19	12	105.0627	129.1391	111.6289	114.71	126.9622	142.2717	129.1391	65.66443
2	25	14	217.8328	277.2406	237.6352	253.4772	257.4621	277.2405	277.2406	225.7538
3	32	16	455.7491	509.365	462.4503	479.2055	479.2432	502.6627	509.365	368.6206
4	38	18	760.5923	816.3675	760.5915	770.7324	806.2261	811.2973	816.3675	623.6853
5	44	20	1180.884	1268.354	1202.752	1224.619	1239.197	1253.777	1268.354	947.623
6	51	22	1792.8	1969.81	1813.406	1834.012	1875.224	1916.438	1969.81	1576.426
7	57	24	2476.388	2627.719	2531.418	2558.932	2613.961	2613.961	2627.719	2201.232
8	62	26	3163.355	3374.239	3233.651	3268.797	3321.517	3374.239	3374.239	2987.611
9	70	28	2389.586	3015.962	2505.581	2551.975	2644.768	2783.967	3015.962	1739.998

To calculate the analytical power developed by the wind turbine, following method is used.

P=1/2 ρ. A . V^3
P= ½ 1.225*3.141*.6^2*12^3
1196.796 watt

The below table-2 shows the analytical power produced by blade at different wind velocity.

Table-2 Analytical power produced by wind turbine

Sr.no	Rpm of the rotor	Wind speed	Analytical power
1	19	12	1196.796384
2	25	14	1900.468332
3	32	16	2836.850688
4	38	18	4039.187796
5	44	20	5540.724
6	51	22	7374.703644
7	57	24	9574.371072
8	62	26	12172.97063
9	70	28	15203.74666

The below table-3 is obtained by comparing the numerical power with the analytical power. So we can obtain the coefficient of performance at different wind speed and different angle of attack. From the below table we also obtain the value maximum coefficient of performance.

Table-3 Coefficient of performance of wind turbine

Sr.no	Rpm of the rotor	Wind speed	1	2	3	4	5	6	7	8
			CP	CP	CP	CP	CP	CP	CP	CP
1	19	12	0.087787	0.107904	0.093273	0.095848	0.106085	0.118877	0.107904	0.054867
2	25	14	0.114621	0.14588	0.12504	0.133376	0.135473	0.14588	0.14588	0.118789
3	32	16	0.160653	0.179553	0.163015	0.168922	0.168935	0.17719	0.179553	0.12994
4	38	18	0.188303	0.202112	0.188303	0.190814	0.199601	0.200857	0.202112	0.154409
5	44	20	0.213128	0.228915	0.217075	0.221021	0.223652	0.226284	0.228915	0.171029
6	51	22	0.243101	0.267104	0.245895	0.24869	0.254278	0.259866	0.267104	0.213761
7	57	24	0.258648	0.274453	0.264395	0.267269	0.273016	0.273016	0.274453	0.229909
8	62	26	0.259867	0.277191	0.265642	0.268529	0.27286	0.277191	0.277191	0.24543
9	70	28	0.157171	0.19837	0.1648	0.167852	0.173955	0.183111	0.19837	0.114445

VI. CONCLUSIONS

(1)The maximum value of coefficient of performance (CP_{max} = 0.277191) was observed at angle of attack 6^0 and 7^0 and the velocity of 26 m/s.
(2) This blade can generate maximum power of 3374 w at maximum CP, at angle of attack 6^0 and velocity of air 26m/s.
(3) It was observed that value of numerical power increases as angle of attack increases from 1^0 to 7^0, after 7^0 the value of numerical power reduced. Hence critical angle of attack for this blade is 7^0.

REFERENCES

[1] H. V. Mahawadiwar, V.D. Dhopte, P.S.Thakare, Dr. R. D. Askhedkar"Cfd Analysis Of Wind Turbine Blade" Vol-2, Issue-3, pp-3188-3194, 2012
[2] R.S. Amano, R.J. Malloy "CFD Analysis on Aerodynamic Design Optimization of Wind Turbine Rotor Blade", pp 71-75 2009
[3] KENTARO HAYASHI, HIROSHI NISHINO, HIROYUKI HOSOYA, KOJI FUKAMI, TOORU MATSUO, TAKAO KUROIWA "Low-noise Design for Wind Turbine Blades", Vol-49, pp-74-772012
[4] Horia DUMITRESCU, Vladimir CARDOS Florin FRUNZULICA, Alexandru DUMITRACHE "Determination of angle of attack for rotating blades"Volume-4, Issue-2, 2012
[5] S. RAJAKUMAR, Dr.D.RAVINDRAN "COMPUTATIONAL FLUID DYNAMICSOF WINDTURBINE BLADE AT VARIOUSANGLES OF ATTACK AND LOW REYNOLDS NUMBER", Vol-2(11), 2010
[6] Horia DUMITRESCU, Vladimir CARDOŞ "THE TURBULENT BOUNDARY LAYER ON WIND TURBINE BLADES",Vol-11, pp-125-136, 2010
[7] Thomas D. Ashwill "Materials and Innovations for Large Blade Structures: Research Opportunities in Wind Energy Technology"2009
[8] Dr. S. P. Vendan, S. AravindLovelin, M. Manibharathi and C. Rajkumar"Analysis of a Wind Turbine Blade Profile for Tapping Wind Power at the Regions of Low Wind Speed"Vol-2, Issue-2
[9] Ryoichi Samuel Amano and Ryan Malloy "Horizontal Axis Wind Turbine Blade Design" 2010