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DESIGN OPTIMIZATION AND ANALYSIS OF VERTICAL AXIS WIND TURBINE BLADE

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Wind Energy is clean and renewable source of energy and is also the world's fastest growing energy resource. Keeping in view power shortages and growing cost of energy, the low cost wind energy has become a primary solution. It is imperative that economies and individuals begin to conserve energy and focus on the production of energy from renewable sources. Present study describes a wind turbine blade designed with enhanced aerodynamic properties. Vertical axis turbine is chosen because of its easy installment, less noisy and having environmental friendly characteristics. Vertical axis wind turbines are thought to be ideal for installations where wind conditions are not consistent. The presented turbine blade is best suitable for roadsides where the rated speed due to vehicles is most often 8 ms^{-1}.To get an optimal shape design symmetrical profile NACA0025 has been considered which is then analyzed for stability and aerodynamic characteristics at optimal conditions using analysis tools ANSYS and CFD tools.

Keywords: Aerofoil**,** Vertical axis wind turbine (VAWT), Pro Engineer, ANSYS, CFD tools

Nomenclature: C_p = Coefficient of performance, η_g = efficiency of the generator, ρ = air density, η_b = bearings efficiency, tsr =tip speed ratio, a= Axial Flow Induction factor, R=Rotor radius ,**v=**Free stream air velocity, **B** =Number of Blades , N=Revolutions per minute , $v_{r=}$ Rated speed, V_f **=** fluttering speed, μ = absolute viscosity of air, Re = Reynold number and υ= kinematics' viscosity.

1. Introduction

Renewable energy is energy from natural resources such as sunlight, wind, rain, tides and geothermal. Renewability means it is not depleted when used. Renewable energy is of various forms such as solar, hydro, biomass, bio-fuel, geothermal and wind. Major advantages of renewable energy include the following; it is more environmental friendly than conventional forms of power and is inexhaustible, and is appropriate for remote areas where electricity from national grid is expensive to provide. Renewable energy facilities generally require less maintenance. Wind power systems are a capital intensive technology. It requires a considerable initial investment, however, the high initial costs are offset by the lower operating and maintenance cost of the plants. One time the system builds it provides energy free of cost [1, 2].

The focus of this research work was laid on wind energy as wind power is the most productive among the renewable energy resources. Wind energy can be captured by the use of wind turbine. Wind turbines are used to convert wind energy into electric power with the use of electric generator. There are two types of wind turbines namely horizontal axis and vertical axis wind turbines. Vertical axis turbines are powered by wind coming from all 360 degrees, and even some turbines are powered when the wind blows from top to bottom. Because of this versatility, vertical axis wind turbines are thought to be ideal for installations where wind conditions are not consistent, or due to public ordinances the turbine cannot be placed high enough to benefit from steady wind. Because of this, VAWT preferred over horizontal axis turbines in areas where a tall tower is not feasible [3].

Vertical wind turbines were specifically designed to resolve the unique issue associated with electricity production in urban or suburban settings where horizontal winds become vertical when encountering the face of a building. The helical shaped blades of the vertical wind turbine can make use of horizontal or vertical wind bursts blowing in from any direction [4,5]. Vertical axis wind turbines are different from traditional wind turbines in that their main axis is perpendicular to the ground. Their arrangement makes them

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suitable for both rural and urban settings and offers the owner an opportunity to offset the rising cost of electricity [6].

2. Blade Profile

Lenz type vertical axis wind turbine was selected. The blade profile selection is done from NACA series of symmetrical aero foils. By evaluating several symmetrical blade profiles with an aerodynamic multi-criteria shape optimization, reference considered the NACA0025 to have an optimal shape design because of its symmetry. The symmetrical air foil performs better performance under those alternating conditions. Other benefits are lower cost and easy fabrication as compared to the non-symmetrical air foil. The thicker blades like NACA0025 show a better performance of self-start and is closer to a self-start capacity nature. Thicker the blade, higher the pressure coefficient contribution to the forward movement of the wind turbine blades. In the NACA0025 the drag forces contributing to the tangential force are 110% higher than in NACA0012 and it operates at low Reynolds number.

Various referred NACA profiles have been shown in Figure 1. By using profile and XFLR software we get coordinates of NACA0025. With the help of these coordinates we designed blade profile which is shown in Figure 2.

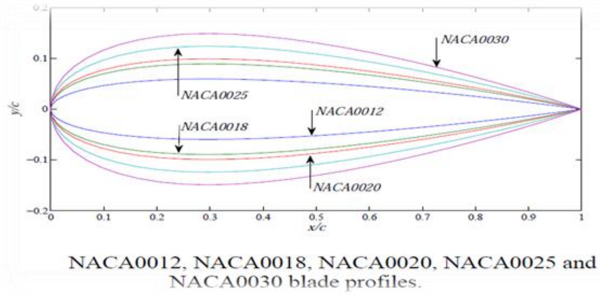


Figure 1. Various NACA profiles [7].

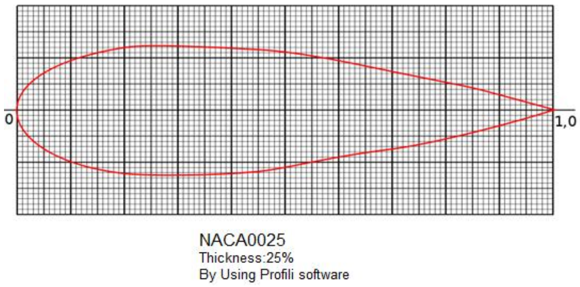


Figure 2. NACA0025, blade profile.

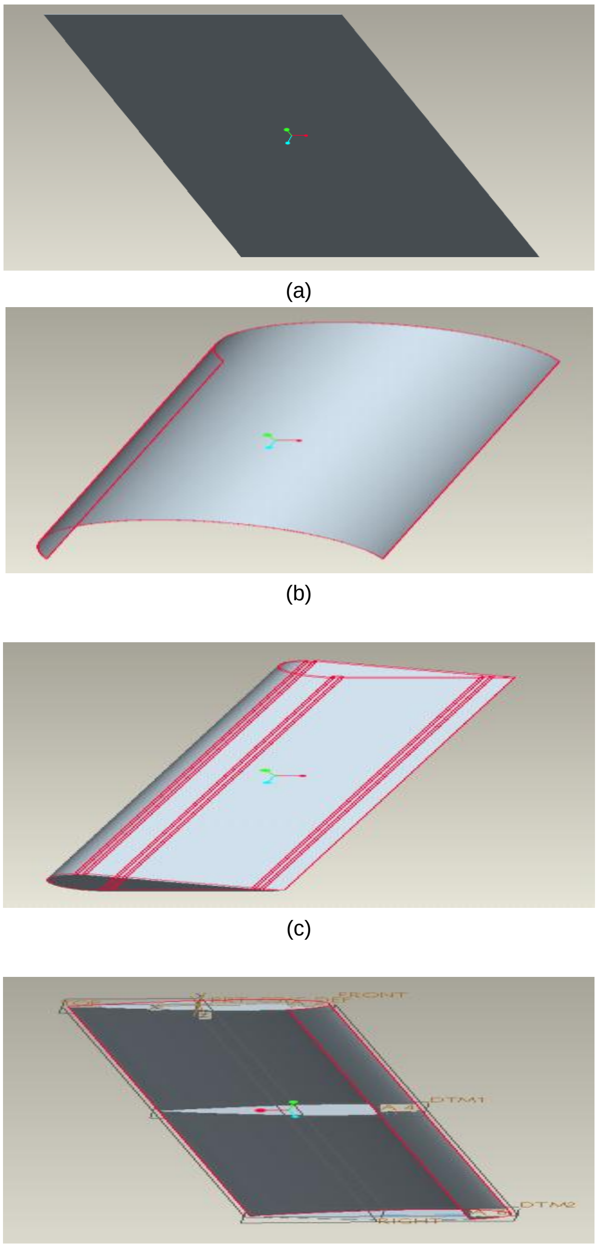
With the help of XFLR and profilli software coordinates of proposed profile are acquired and tabulated in Table 1.

Table 1. Coordinates of NACA0025.

S. No.	X	Y Upper	Y Lower
1	0	0.000	0.000
2	1.25	3.946	-3.946
3	2.5	5.447	-5.447
4	5.0	7.406	-7.406
5	7.5	8.750	-8.750
6	10	9.756	-9.756
7	15	11.136	-11.136
8	20	11.953	-11.953
9	30	12.504	-12.504
10	40	12.090	-12.090
11	50	11.029	-11.029
12	60	9.507	-9.507
13	70	7.633	-7.633
14	80	5.465	-5.465
15	90	3.016	-3.016
16	95	1.680	-1.680
17	100	0.262	-0.262

3. Design of Turbine and Analysis

The process of designing a wind turbine blade involves the conceptual assembling of a large number of mechanical and electrical components into a machine which can convert the power of wind into a useful form. By considering power in wind, betz law, actual coefficient of performance, power coefficient and other losses; design calculations resulted in the following.



(a)

(b)

(c)

(d)

Figure 3. Different designs of Fig 3: Different designs of blades used in vertical axis wind turbine and their corresponding types (a) Straight blade Giromill type design (b) Semicircular Savonius type design (c) Solid blade Lenz type design (d) Slotted aerodynamic design.

4. Designing of Blade and Analysis

The first type of design as shown in Figure 3a is a straight blade Giromill design. Through this type of design less lift can be attainable whereas due to its shape high drag is there. Low lift coefficient and high drag coefficient make it a less efficient design with minimum capability of capturing air. The turbine could not mostly start by itself and some starting mechanism is necessary to be imparted. Another type of design which is mostly used in home application is semicircular Savonius type design as shown in Figure 3b. This shape has also a less efficient design with low lift and high drag coefficient. Its self starting and air capturing capability is better than Giromill design but it also needs a starting mechanism, its air capturing capability is higher but high drag make it very less efficient. The above designs are easily manufacturable from the construction point of view. Both of the above designs could not be used for commercial purposes and less efficiency makes their use restricted. The type of designs which may be used for commercial purposes are the solid Lenz type design as shown in Figure 3c and aerofoil aerodynamic type design as shown in Figure 3d both of these designs have aerodynamic advantage with high lift and controlled drag characteristics.

This high lift coefficient and low drag coefficient make their efficiency reasonably high compared to the other designs. There are some drawbacks associated with LENZ type design. As the shape corresponds the design has less capability of capturing air therefore, no self starting capability is achievable

Also the Lenz type design due to its construction is more heavy can give high torque but adds in lower starting capability. Thus the design requires a starting mechanism. Through all the analysis we come across a conclusion that the designed Slotted aerodynamic design is the most efficient design. The design has higher air capturing capability. The design is self starting thus no starting mechanism is required. We can harvest a greater amount of energy from the manufacturing point of both Lenz and Aerodynamic types require high precision and more developed construction site.

5. Design Calculations

Power from wind turbine is calculated as follows:

$$P = 0.5 \text{ x } \rho \text{ x } A \text{ x } C_p \text{ x } V^3 \text{ x } \eta_g \text{ x } \eta_b$$

Where following data used :

Table 2. Power output at different operating speed.

Air velocity(m/s)	Power from wind(W)	Turbine power (W)	Rpm (for tsr=1)
1.5	4.15125	1.868063	17.90489
2	9.84	4.428	23.87319
2.5	19.21875	8.648438	29.84148
3	33.21	14.9445	35.80978
3.5	52.73625	23.73131	41.77807
4	78.72	35.424	47.74637
4.5	112.0838	50.43769	53.71467
5	153.75	69.1875	59.68296
5.5	204.6413	92.08856	65.65126
6	265.68	119.556	71.61956
6.5	337.7888	152.0049	77.58785
7	421.89	189.8505	83.55615
7.5	518.9063	233.5078	89.52445
8	629.76	283.392	95.49274
8.5	755.3738	339.9182	101.461
9	896.67	403.5015	107.4293
9.5	1054.571	474.5571	113.3976
10	1230	553.5	119.3659

a = 0.55 (assumed), **R** = 800mm , **v** = 5m/s, **B** = 3, **ρ** = 1.23 kg/m^3

Using Equation, we have

$C_P = 4a(1-a)^2$ or $C_P = 4*0.55(1-0.55)^2$ or $C_P = 0.45$

To calculate the power generated by the rotor, we use Equation:

$$P = \frac{1}{2} C_P \rho A U^3$$

Putting all the values, we get at normal operating velocity

$P_{available}$ = 70 watts

Revolutions per minute (N) is given for three velocities

As cut in speed =1.5 m/s, Speed at which charging should start= v_c =3m/s,Normal operating speed=5m/s, v_r =10m/s, Cut out speed= fluttering speed= $V_{f=}$ 25m/s.

Reynold number calculated is

Re = ρvL/μ

L is the plate length=0.7m, υ =1.4065e-5 m^2/s and μ =1.73e-5kg/ms

υ=μ/ρ

Re = vL/υ =248844.65≈250000

Thus from Table 2 we can see that at normal Power at operating speed of 5m/s =70 W and Rated power at 10 m/s is ≈550W

This graph depicted in Figure 4 shows the behavior of power output; higher the velocity of wind, higher is the power output by turbine and vice versa.

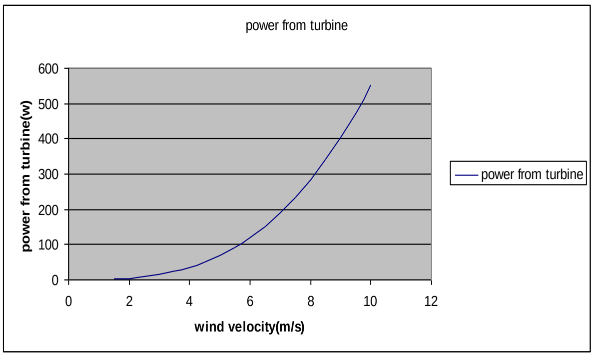


Figure 4. Curve between Power Available From Turbine and Wind Velocity.

6. CFD Analysis

A computational fluid dynamic analysis was done to analyze the flow of air around the profile for the blades of the fabricated model. Through this problem solution we were able to define the various characteristics of NACA 0025 at our specified velocity such as pressure differential, lift coefficient, drag coefficient etc. In this we consider the flow around a NACA 0025 airfoil at an angle of attack 10 degree, free stream velocity of 5m/s and Chord length of 1cm.

We done this by

- Convergence was checked through
- Using XY plots to check plot contours and vectors
- Plotting the C_l and C_d at our specified angle of attack

Three steps were followed in the analysis pre processing, solver and postprocessor geometry was formed in gambit and imported in fluid for analysis the geometry formed and results are as shown in the following:

Firstly, imported all points of selected profile in gambit and performed meshing there. By plotting pressure coefficient we obtained that the lower curve is the upper surface of the airfoil and has a negative pressure coefficient as the pressure is lower than the reference pressure. From the contour of pressure coefficient, we see that there is a region of high pressure at the leading edge (stagnation point) and region of low pressure on the upper surface of airfoil. This is of what we expected from analysis of velocity vector plot. From Bernoulli equation, we know that whenever there is high velocity, we have low pressure and vice versa. From the validation of results, it is concluded that our model is inviscid; $(C_l)_{\text{skin friction}}$ is zero. The lift and drag coefficient resulted were C_l= 0.73 C_d=0.025.

In Figures 5 and 6 Pressure coefficient, Velocity vectors and contours of pressure obtained are given which show behavior of NACA0025 (Figures 7,.8 and 9).

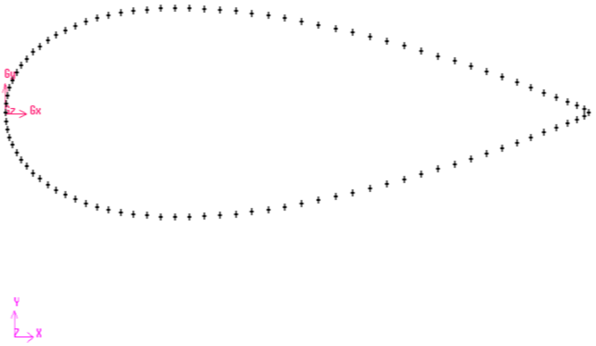


Figure 5. NACA0025 points imported in gambit.

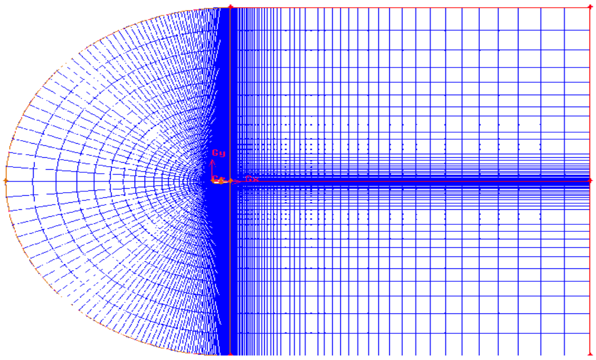
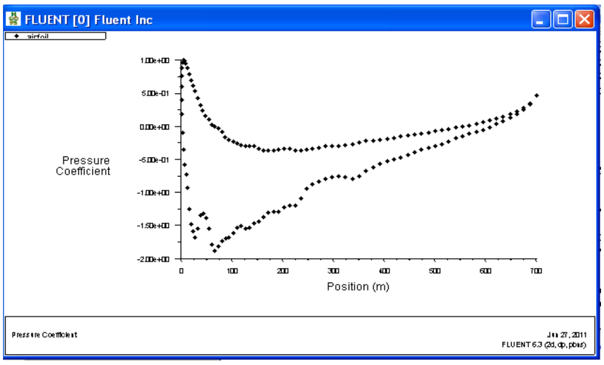


Figure 6. Meshing with small mesh size near the profile.



Pressure Coefficient

Jun 27, 2011
FLUENT 6.3 (2d, dp, pbns)

Figure 7. Pressure coefficient.

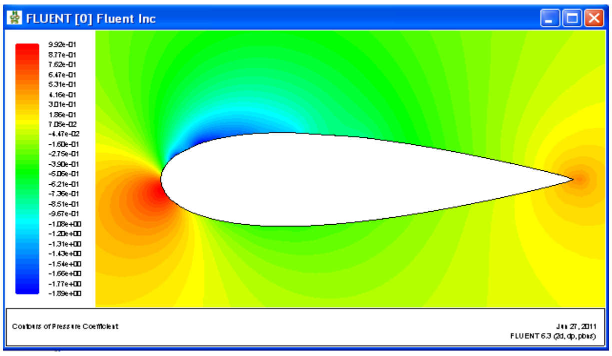


Figure 8. Contours of pressure.

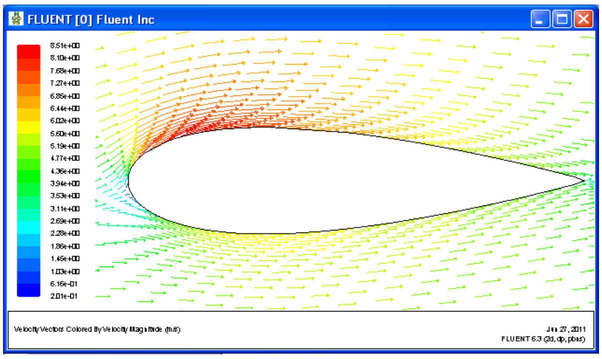


Figure 9. Velocity vectors.

7. Conclusion

Optimized blade design by using most suitable NACA profile and changing its characteristics according to the turbine leads to the development of optimized turbine .The main objective behind this idea was to develop a turbine which can generate electrical energy,focusing on objective we come across a conclusion that VAWT is most suited for commercially manufacturing for urban areas due to the various advantages like less noisy, less dangerous to human beings and birds for areas where the air speeds are not constant and turbulence of air as in such circumstances horizontal axis can't work which is the case of many urban areas.NACA0025 airfoil is selected because it has good lift-drag properties and also it is relatively easy to fabricate as compared with other airfoils. Airfoil selection was made on multiple criteria. As with vertical axis wind turbine, we see that one of the drawbacks of vertical axis wind turbine is that it do not start easily and sometimes a starter motor is used to start it by changing the profile somewhat and a bucket type structure is made. This structure provides it starting characteristics to it enhancing starting characteristics of turbine blade by capturing air the blade pitch controlled so as to optimize the aerodynamic angle of attack on the blade aerofoil on both the upwind and downwind blade passes.

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