International Journal of Research in Advent Technology, Special Issue, August 2018
E-ISSN: 2321-9637
International Conference on "Topical Transcends in Science, Technology and Management"
(ICTTSTM-2018)
Available online at www.ijrat.org

Modeling and Static Analysis of Small Scalewind Turbine Blades

SUKRUTH SAGAR B P
Dept. of Mechanical Engineering
P.E.S. College of Engineering, PESCE
Mandya, India
sukruthsagar1991@gmail.com

RAVIKUMAR T R
Dept. of Mechanical Engineering
S.J.C. Institute of Technology, SJCIT
Chickballapur, India
ravikumartr85@gmail.com

DODDASWAMY V
Dept. of Mechanical Engineering
P.E.S. College of Engineering, PESCE
Mandya, India
doddaswamy.1801@gmail.com

AKSHAY R N
Dept. of Mechanical Engineering
P.E.S. College of Engineering, PESCE
Mandya, India
akshaynataraju@gmail.com

ABSTRACT

The wind turbine blade is a very important part of the rotor, extraction of energy from wind depends on the design of blade. Development of small wind power systems is very attractive and useful to the energy demand of local residence and small business personals where establishment of large wind power systems is costly. Hence a research is carried out on it in the present work. In this work three wind turbine blades of three separate aerofoils are considered for analysis. A blade for horizontal axis wind turbine is modelled using CATIA V5R20 software. The dimensions (Twist, chord and length) are taken from a reference journal and the aerofoils considered for analysis are NACA0015, NACA4412 and NACA4418. The aerofoil taken is same from root to tip for each blade. The analysis of designed blade is done in flap-wise loading. The Finite element analysis of designed blade is carried out in ANSYS V13 software. Three different aerofoils are analyzed to determine which one has the best static behavior considering deformations,stresses and strains. The Results obtained from ANSYS V13 software is compared with the theoretical results obtained using standard equations. The results show that the NACA4418 aerofoil has the better static properties as compared to NACA0015 and NACA4412 aerofoils.

Keywords—Static, Modeling, Deformation, Stress, Analysis, Wind Turbine Blade

I. INTRODUCTION

A wind turbine in a wind power system extracts the energy from the wind and converts it into electrical energy and hence serves the purpose of utilizing wind energy. Large wind power systems are much economical compared to the small wind power systems since it produces large amount of energy in terms of megawatts. However, large wind turbines are usually located in remote areas and few specific locations where it requires permissions from the government and environment board. Hence small wind power systems are the best choice considering the energy demand in small businesses, residential areas and for the developing countries which are facing the problems with shortage for electrical power supply.

In the past, many researchers have developed the model and analyzed it by considering various factors so that it yields optimum performance. Prediction of the pitch angle along the blade radius and the chord line profile distribution by using blade element theory, conservation of axial and angular momentum equations and also the optimization process were considered. Aerodynamic design was the prime factor considered for the optimum design of the blade. The blade designed using the studies and analysis obtained considerable lift required for an optimal design. The blade used in their study had aerodynamic shapes which were in the acceptable range of low power wind turbine. Various designs were compared and analysis was performed using theories of physics to design an optimal and efficient blade considering geometric and aerodynamic factors [1].The finite element method was used to analyze dynamic characteristics of wind turbine blade under the rotational and irrotational conditions. The first five mode shapes of every condition were similar with each other. The first and third order mode shape were flapping, the second one was the shimmy. Besides, the fourth and the fifth order modes were both the coupled vibration of flapping and shimmy. Because of the frequencies of flapping and shimmy was lower than the torsional vibration whose frequencies were all high order. High order ones had little effects on the blade [2].

II. MODELLING AND ANALYSIS OF WIND TURBINE BLADES

A. Theoretical Modelling and Analysis

The values of Deformation and Maximum stress of the wind turbine blades are determined using theoretical equations [10] considering some of the assumptions which are as follows,

- The blade is uniform and continuous.
- The blade has a rectangular cross-section.
- The load is uniformly distributed.
- The blade is a cantilever beam.

The theoretical model can be represented as shown in figure 1, which can be considered as a cantilever beam of length(l), breadth(b) and depth(d) with one end fixed and a uniformly distributed load(W) acting on it as shown in Fig. 2,

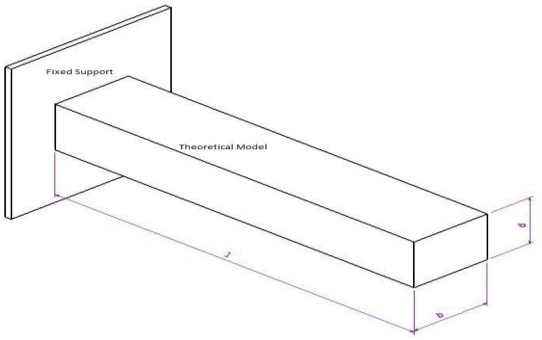

Figure 1: Theoretical 3D model.

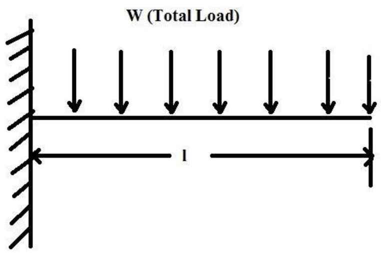

Figure 2: Load acting on the cantilever beam.

The theoretical model was assumed as a cantilever beam with specifications as shown in Table 1 and the respective equations were used in the calculations and the results obtained are as shown below,

Table 1: Specifications of wind turbine blade

Length, l	1.2 m
Breadth, b	0.15 m
Depth, d	0.02 m
Cut-in wind speed	3 m/s
Cut-out wind speed	20 m/s
Material	Glass fibre
Young's Modulus, E	74×10^9 N/m^2
Density, ρ	2540 kg/m^3

1) Load applied on the wind turbine blade.

$$W = F = C_D \, 0.5 \, \rho \, U^2 A \text{ in (N)}$$

Where,
C_D = Drag Co-efficient = 2.05
ρ = Density of air at 20^0 C = 1.21 kg/m^3
U = Wind velocity in m/s
A = Surface Area in m^2

2) Maximum deformation of the wind turbine blade.

$$y_{max} = \frac{Wl^4}{8EI} \text{ in (m)}$$

Where,
W = Load acting on the wind turbine blade in (N).
l = Length of the wind turbine blade in (m).
E = Young's Modulus of the material of the blade in N/m^2.
I = Area moment of inertia in m^4.

3) Maximum stress acting on the wind turbine blade or stress at the support.

$$\sigma_{max} = \frac{Wl}{2Z} = \frac{3Wl}{bd^2} \text{ in } (N/m^2)$$

Table 2: Theoretical results

Parameters	Theoretical results
Load applied in (N)	89.29 ≈ 90
Maximum Deformation(y_{max}) in (m)	3.152×10^{-3}
Maximum Stress(σ_{max}) in N/m^2	0.540×10^{7}

B. **FE Modelling and Analysis**

1) Collection of wind turbine blade geometry data required for 3D Modelling.

The co-ordinates were obtained from an online aerofoil plotting site www.aerofoiltools.com at various sections along the length of the blade,

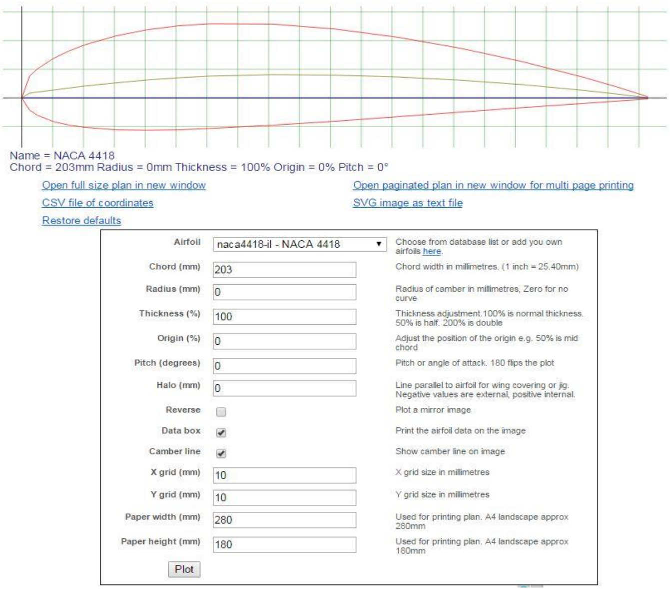

Figure 3: Online aerofoil plotter tool.

Table 3: Aerofoil coordinates of NACA4418

Aerofoil coordinates	
X(mm)	Y(mm)
203	0
192.85	3.8367
182.7	7.0238
162.4	12.6266
142.1	17.3565
121.8	21.1932
101.5	24.0555
81.2	25.781
60.9	25.9028
50.75	25.172
40.6	23.7916
30.45	21.6398
20.3	18.4933
15.225	16.3618
10.15	13.7025
5.075	10.15
2.5375	7.6328
0	0
2.5375	-4.2833
5.075	-6.0697
10.15	-8.2418
15.225	-9.4801
20.3	-10.2718
30.45	-11.1447
40.6	-11.2868
50.75	-11.1447
60.9	-10.6778
81.2	-9.541
101.5	-8.1606
121.8	-6.5772
142.1	-4.9735
162.4	-3.3901
182.7	-1.8879
192.85	-1.1165
203	0

Similarly, the co-ordinate points of the aerofoils at various sections of the blade were determined and used for 3D modelling of the wind turbine blades.

2) Creating 3D geometrical model of wind turbine blade using CATIA V5R20 software.

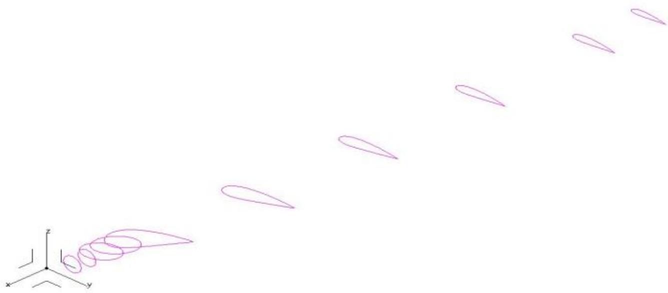

Figure 4: Aerofoils generated at different sections of the wind turbine blade.

Figure 5: Solid model generated using the aerofoils at different sections

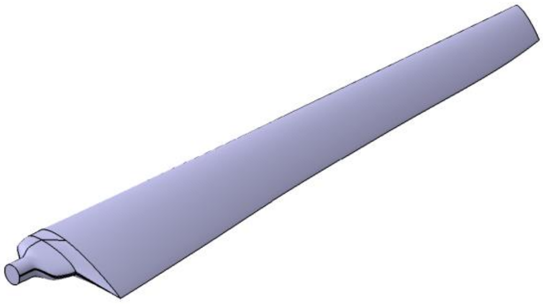

Figure 6:3D Geometrical model using CATIA V5R20 software.

3) Meshing and applying boundary conditions using Hypermesh11.0 software.

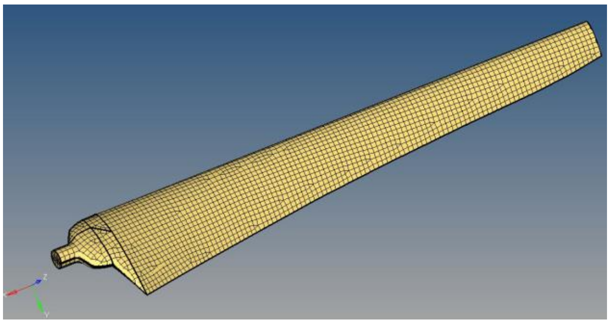

Figure 7: Meshed model using Hypermesh11.0 software.

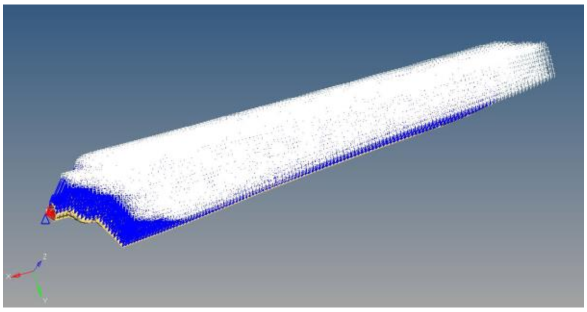

Figure 8: Load and fixed support applied on the meshed model.

The boundary conditions such as fixed support at root and load acting on the upper surface of wind turbine blade are shown in Fig. 8,

Table 4: FE model details

Element type	SOLID45
Number of Elements	3555
Number of Nodes	3502

III. RESULTS AND DISCUSSION

A. **Results of Static Analysis**

1. Deformation of the wind turbine blade with Aerofoil NACA0015.

The results for deformation of wind turbine blade analysed in the ANSYS software is as shown in Fig.9,

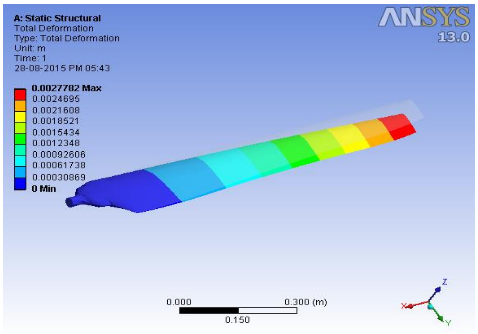

Figure 9: Deformation of wind turbine blade with aerofoil NACA0015.

Since one end is fixed and a uniformly distributed load is applied on it the maximum deformation is observed to be at the free end, therefore from Fig. 9 the maximum deformation of the blade can be noted as,

$$y_{max} = 2.778 \times 10^{-3}\ m$$

2. Maximum stress acting or stress at the support for wind turbine blade with Aerofoil NACA0015.

The results for stress acting on wind turbine blade analysed in the ANSYS software is as shown in Fig.10,

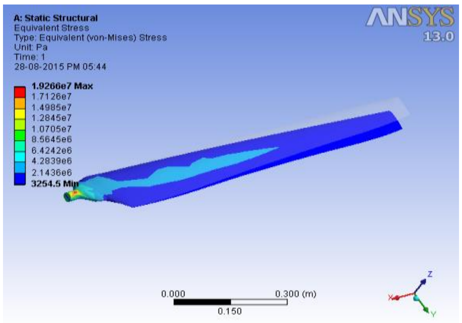

Figure 10: Stress acting on wind turbine blade with aerofoil NACA0015.

Since one end is fixed and an uniformly distributed load is applied on it the maximum stress is observed to be at the outer surface of fixed end, therefore Fig. 10 the maximum stress at support can be noted as,

$$\sigma_{max} = 1.926 \times 10^{7}\ N/m^2$$

3. Maximum strain acting or strain at the support for wind turbine blade with Aerofoil NACA0015.

The results for strain acting on wind turbine blade analysed in the ANSYS software is as shown in Fig.11,

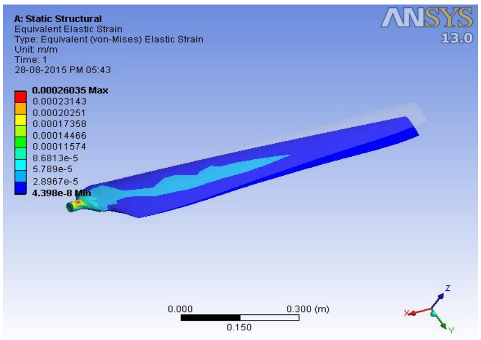

Figure 11: Strain acting on wind turbine blade with aerofoil NACA0015.

Therefore from Fig. 11 the maximum strain is at support and can be noted as,

$$\epsilon_{max} = 2.604 \times 10^{-4} \text{ m/m}$$

Similarly the NACA4412 and NACA4418 aerofoil shape wind turbine blades were modeled and analyzed and the respective test results were tabulated as shown in Table 5.

Table 5: Theoretical and Numerical results for three aerofoils

Parameters	Theoretical results	Numerical or ANSYS results for Different Aerofoil shapes		
		NACA0015	NACA4412	NACA4418
Maximum Deformation(y_{max}) in Meters(m)	3.152×10^{-3}	2.778×10^{-3}	5.101×10^{-3}	1.667×10^{-3}
Maximum Stress(σ_{max}) in N/m^2	0.540×10^{7}	1.926×10^{7}	3.525×10^{7}	1.198×10^{7}

B. **Discussions**

The Table 5 shows theoretical and numerical results for three wind turbine blades with aerofoils NACA0015, NACA4412 and NACA4418. The parameters considered are Deformations, Stresses and Strains of the wind turbine blades. Comparing the results obtained the following observations can be drawn,

- The theoretical and numerical results are comparative to each other and the variations are due to the fact that Numerical analysis was carried for exact geometry in the ANSYS V13.0 software while Theoretical analysis was carried out using assumptions and approximations of the theoretical 3-D model in the Theoretical Equations.
- Considering the Maximum deformation (y_{max}) it can be noted that, among the three aerofoil shapes NACA4418 has the least deformation. Hence NACA4418 has better strength and is the best choice considering maximum deformation.
- The Maximum stress (σ_{max}) for NACA4418 has the least value among the three aerofoil shapes and hence NACA4418 has best ability to withstand stress acting on it.

From the analysis NACA 4418 has a better Structural property and Dynamic property compared to the other two aerofoil shape wind turbine blades.

IV. CONCLUSIONS AND SCOPE OF FUTURE WORK

A. **Conclusions**

The significant conclusions of the studies conducted on wind turbine blades with aerofoil shapes NACA0015, NACA 4412 and NACA4418 are presented in the following sections.

- The theoretical validation of the numerical results showed satisfactory outcomes since theoretical analysis involved some of the assumptions and approximations but both the results were comparable to each other.
- NACA4418 aerofoil gives better Structural properties considering maximum deformations and stresses compared to NACA0015 and NACA4412 aerofoil shape wind turbine blades.

B. **Scope of Future Work**

The scope for future work that can be carried out on wind turbine blades are as follows,

- The blade can be made of different aerofoils for different sections of blades such as blade root, mid span and the tip which we have considered to be same throughout.
- The angle of twist of the blade can be varied for optimization.
- The material of the blades can be varied.
- Similar studies can be made on large wind turbines with different geometries.

REFERENCES

[1] Jesus Vega Fuentes, Jose M. Carlos Perez Aguirreand Eloy Cruz Machicado, "Design of wind turbine blades of a power of 1000 watts for domestic use,"Maestro en Ciencias con especialidad en Electronica, (IEEE : 978-1-61284-1325-5/12), 2012.

[2] Shun-zhang Chen and Lu-ping L, "3D Modelling and Finite Element analysis of Dynamic Characteristics for Blades of Wind Turbine," College of power and energy Engineering, Changsha University of Science & Technology, Changsha, China. (IEEE : 978-1-4244-4813-5/10), 2010.

[3] S.O. Ani, H. Polinder and J.A. Ferreira, "Energy yield of small wind turbines in low wind speed areas,"Electrical Power Processing, Delft University of Technology Mekelweg 4, 2628 CD Delft, Netherlands. (IEEE : 978-1-4673-0759-8/11), 2011.
[4] Fei-Bin Hsiao, Chi-Jeng Bai and Wen-Tong Chong, "The Performance Test of Three Different Horizontal Axis Wind Turbine (HAWT) Blade Shapes Using Experimental and Numerical Methods,". (ISSN 1996-1073), Energies 2013, 6, 2784-2803, 2013.
[5] Qiyue Song, "Design, Fabrication, and Testing of a New Small Wind Turbine Blade,". Master of Applied Science in Engineering, University of Guelph, Guelph, Ontario, Canada. April 2012.
[6] Yuqiao ZHEN, Rong zhen ZHAO and Hong LIU, "Mode Analysis of Horizontal Axis Wind Turbine Blades,". Key Laboratory of Digital Manufacturing Technology and Application, The Ministry of Education, Lanzhou Univ. of Tech., Lanzhou 730050, China. (ISSN : 2302-4046), TELKOMNIKA Indonesian Journal of Electrical Engineering, Vol.12 No.2,pp. 1212-1216, February 2014.
[7] Nitin Tenguria, Mittal.N.D and Siraj Ahmed, "Design and Finite Element Analysis of Horizontal Axis Wind Turbine blade,". Department of Applied Mechanics, Maulana Azad National Institute of Technology, Bhopal, India. (ISSN : 0976-4259), International Journal of Applied Engineering Research, Dindigul, Volume 1, No 3, 2010.
[8] Han Cao, "Aerodynamics Analysis of Small Horizontal Axis Wind Turbine Blades by Using 2D and 3D CFD Modelling,". MSc (by Research), University of Central Lancashire, Preston, England, May 2011.
[9] Sikandar Khan, Afzal Khan, Muhammad Irfan and Shah Hussain, "Aerodynamic Analysis and Dynamic Modeling of Small Horizontal Axis Wind Turbine,". Mechanical Department, N.W.F.P University of Engineering and Technology, Peshawar, Pakistan. (IEEE : 978-1-4673-4886-7/12), 2012.
[10] Mr. Josua Kirsch, "Design of a small wind turbine for electric power generation (1-5kW),". Department of Mechanical Engineering, University of Southern Queensland, November 2009.
[11] Jin Xu, Zhenqian Lu, "Application of Fiber-Reinforced composites in Wind turbine blades,". College of textiles and clothing, Yancheng Institute of Technology, Yancheng, Jiangsu, China. (IEEE : 978-1-4244-8921-3/10), 2010.
[12] "Introductory course on Theory and Practice of Mechanical Vibrations" By J.S.Rao, K.Gupta Revised second edition, New Age International (P) Limited, Publishers.
[13] www.revolvy.com
[14] www.aerofoiltools.com