FEA Modeling of HAWT WHISPER Model 200 through ANSYS

Raees Kha[1] and Dr. Uzma Qureshi[2]

[1]Research Scholar, Mechanical Engineering Department, SSSCE, RKDF University Bhopal
[2]Professor Mechanical Engineering Department, SSSCE, RKDF University Bhopal

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Abstract - *Our project is an attempt to study and analyze the wind turbine blades' software ANSYS has been used to analyze the stresses and loading condition of wind turbine blades. For the study the Horizontal Axis Wind Turbine of 1000Watts which was installed at SSSCE RKDF University Bhopal. The wind regime of the region for every month is found out with the help of wind charge controller integrated with the wind turbine. In this study, the finite element analysis software ANSYS was used to analyze the wind turbine blade. 1kW model of Whisper 200 which is having 3 blades in number is used for the study. The wind turbine blade is a structure, comprising Polypropylene/Carbon Reinforced material, and an extender is provided with the blades to connect the blade with the rotor. The material of blade is SS 304. The wind turbine is certified with ISO 9001-2008, CE, IEC 61400. It has been observed that the wind velocity or pressure is converted into the load on the blade structure. The stress analysis and failure of wind turbine blade due to deformation under the application of load in the form of wind velocity were obtained by taking into account different pitch angles and at different angles.*

Key Words*: *HAWT Whisper 200, Stress Concentration FEA Modeling, Power Coefficient, Pitch Angles

1.INTRODUCTION

Wind energy is a rich source of energy in comparison with other renewable energy resources. furthermore, distinct the solar energy, the use of wind energy could not be affected by the environment and weather conditions. Wind turbine was invented by the researcher in turn to take out energy from the current of air. Because the energy exist in the wind is transformed to electric energy, the machine which may be capable of converting wind energy into electrical energy is also called wind generator. Figure 1-1 shows the growth rate of wind generator capacities, which has increased significantly in the last ten years. The total installed capacity of wind power generators was 159,213 MW at the end of 2009 (World Wind Energy Report 2009). As of the end of 2016, the worldwide total cumulative installed electricity generation capacity from wind power is approximately 486,790 MW, an increase of 12.5% compared to the previous year which is really a big achievement. Installations increased by 54,642 MW, 63,330 MW, 51,675 MW and 36,023 MW in 2016, 2015, 2014 and 2013 respectively.

A wind turbine consists of the following parts:

- blades
- rotor,
-generator,
-driven chain,
-and Yaw system
-control system and so on.

The rotor is driven by the wind and rotates at particular wind speed, this wind speed is responsible for the generation of electricity as an output power of energy under the controlled atmosphere. Basically, the rotor blades are responsible for the maximum power generation that is why team of researchers and scientist are involved for the improvement of the efficiency and the performance of the turbine so that maximum amount of energy can be extracted from the wind. For the purpose many design modifications in the geometry of blades and the composition of blade materials have been carried out by them. Earlier similar blades as used in the helicopter airfoils are used for the design of blades, but nowadays, a lot of designs of blades are discovered and utilized in the blades of turbine generators. Furthermore, nowadays blade rotors became very complicated because they may have complex structure in terms of various sections of aerofoils to improve the efficiency in comparison with the earlier blade designs. Earlier the research on wind turbine was very tedious due to the lots of efforts for testing the performance of wind turbine and many resources are required so the study was restricted to the theoretical study. But nowadays system became computerized and addition of computer to the analysis and collection of data became easier so the design study and analysis of data, performance evaluation of wind turbine may be done easily.

Pressure, velocity performance flow study of wind turbine blades can be analyzed through a software known as CFD. For modeling through CFD algorithms are prepared and problems may be solved.

For the time being, finite element method (FEM) can be used for the blade structure analysis. Comparing to traditional theoretical and experimental methods, numerical method saves money and time for the performance analysis and optimal design of wind turbine blades.

1.1 Aims & Objectives

Aims

- The research aims to analyze the stresses at variable wind speed via loading conditions.

- horizontal-axis wind turbine blades through FEA analysis.

Objectives

The objectives of the research are to establish FEA models of wind turbine blade and rotor, so as

- To analyze the stresses under different loading conditions;

- To predict wind turbine power output at various wind speeds;

- To compare blade performance under varying loading condition;

- To predict the noise of wind turbine under operation.

A comprehensive study of the FEA modeling, the torque and thrust force acting on the blade can be calculated using ANSYS SOFTWARE. At different wind speeds, the optimum rotational speeds can be estimated in order to maintain constant power output at low wind speed or at high wind speed. This dissertation includes of five chapters. The aims and objectives are introduced in Chapter 1. In Chapter 2, consists of literature survey in which the theories of wind turbine aerodynamics are introduced. Simulation methods and theories relevant to the FEA are introduced in Chapter 3, In this chapter, different modeling approaches and governing equations are discussed so as to improve the simulation accuracy. Chapter 4 includes the methodology and expected outcomes. Simulation results are analysed in Chapter 5 under the headings of result and discussions, aerodynamic performance of different aerofoils are estimated in two-dimensional results section and a comprehensive analysis regarding wind turbine rotor performance is aerofoil behavior is implemented using FEA modeling through ANSYS. The conclusion is summarized in Chapter 6.

1.2 Scope of Work

- Three blades rotor is taken into consideration.
- Horizontal axis wind turbine blades with the extender.
- Stresses and deformation under different loading conditions.
- Performance evaluation under various wind velocity conditions.

2. LITERATURE REVIEW

Improvement and relevance of horizontal axis wind turbines and the interrelated issues like structural design, smooth aerodynamically design, and the selection of material as well as issues related with the manufacturing which includes failure due to fatigue load, power optimization, and stability for the aero elasticity have drawn the interest of various researchers, scientist and scholars'. Jureczko et al. [1] worked on the design and optimization of wind turbine blades and developed an ANSYS program and presented a model for the implementations of a modified genetic algorithm which optimizes of various objective functions which are subjective to various restraint likewise thicknesses and other dimensions of the blade model which is taken into considerations. Guo [2] considered wings of aircraft for the optimization of its weight, an analytical and numerical analysis has been carried out by the researchers and shown a comparison of the results with the experimental results. Veers et al. [3] carried out a detailed stress analysis of wind turbine blades by considering its design, manufacturing technology. Baumgart [4] compared the results of experimentation with the analytical data by preparing a mathematical model for an elastic wind turbine blades. Larsen and Nielsen [5] investigated a nonlinear rotor dynamic stimulation of wind turbine by parametric excitation of both linear and nonlinear terms caused by centrifugal and Coriolis forces.

Petrini et al. [6] worked with the offshore wind turbines and discussed its fundamental and the major aspects related to the design. They carried out a research for the evaluation of required performance related with the decomposition of the configuration systems, under the action of loads. By utilizing the active aerodynamic load control devices (trailing edge flaps), the load reduction of large wind turbine blades numerically investigated by Lee et al. [7]. Tenguria et al. [8] considered HAWT and NACA airfoils blade from root to tip for the study and design and analysis.

3. THEORY

3.1 Earlier Work of Wind Turbine

Wind turbine is really a design, whichever converts the kinetic energy with the wrap to AC electricity via an automatic rotor, a power train in addition to a dynamo. One of the previous generators was designed by Poul La Cour, who was a teacher at a night school centre in Denmark in 1891 Nowadays, Enercon E-126, the realm biggest wind turbine can achieve as much as 7 Megawatts of power below the appraised wind speed This strength can give the on a daily basis electrical energy for greater than 4500 homes. Following the mechanization issue of recent wind generators, they are able to now be reinforced either/or at the ground or at the sea bottom. A big offshore wind turbine of 10 megawatts would be initiated in 2011 by Enova SF in Norway. As the reduction of charcoal and petroleum, wind energy increasingly playing very important role during this century.

3.2 Wind Turbine Aerodynamics

According to the different rotational orientations, wind turbines can be categorized as vertical axis or horizontal-axis. The advantages of vertical-axis wind turbine (VAWT) are: 1. Simple structure: VAWT can work without yaw system and most of them have a blade with constant chord and no twist (Manwell, et al., 2002, p.259), which is easy to construct. 2. Easy to install: because the drive trains (gear box, brake and generator) can be located relative to the ground. Comparing to horizontal axis wind turbine (HAWT), stall control can only be used in VAWT as it is difficult to incorporate aerodynamics control such as variable pitch and aerodynamic brake, so the overall power efficiency is lower than HAWT.

3.3 Governing Equations

Generally, we consider two forces and one moment acting upon wind turbine blades; namely: lift, drag and diving moment respectively. Now all three being discussed here in this chapter.

Lift is the force that is used to prevail over gravitational force (Hansen, 2008, p. 8) and it will be vertical to the direction of the nearing wind velocity (Manwell, et al., 2002, p.96). It is formed as a result of the unequal pressure on the upper and lower blade surfaces.

The drag force is like a force which occurs in the direction of striking wind velocity. (Manwell, et al., 2002, p.96) The drag force is occurred because of two reasons one is the unequal pressure on the blade surface which is directed towards the oncoming wind and another is the viscous friction force at the surface of the blade. The lift force is the rising force that is required to prevail over gravity and higher the lift force then higher the mass that can be raised off the ground.

For a blade, Hansen (2008, p.8) explained that the lift to drag ratio be supposed to be maximized. Through which efficiency will be improved when wind turbine used to generate electricity.

Lift and drag coefficients C_L and C_D are described as follows:

$$\textbf{Lift Coefficient } C_L = \frac{F_L}{1/2\rho C V_0^2} \ldots\ldots.(\textbf{Eqn } 3.1)$$

$$\textbf{Drag Coeffici}C_D = \frac{F_D}{\frac{1}{2\rho C V_0^2}} \ldots\ldots\ldots.(\textbf{Eqn } 3.2)$$

Lift and drag is expressed in terms of force per unit length (N/m).

Where,

ρ - air density and

c - length of the blade, generally defined as the chord,

For the full description of both the forces it is must to find the value of pitching moment M. According to the researchers it is set up at ¼ chord length to get an approximate value and the pitching moment coefficient is expressed as follows:

$$\textbf{Moment Coefficient } C_M = \frac{M}{1/2\rho C^2 V_0^2} \ldots\ldots\ldots(\textbf{Eqn } 3.3)$$

Tip Speed Ratio
It can be defined as the ratio of speed of blade specifically tip speed to the wind speed. It has been shown is as follows:

$$R / v_0 \ldots\ldots\ldots\ldots (\text{Eqn } 3.4)$$

It can be also explained as the angular velocity of the wind turbine rotor,

R- radius of the rotor and

v_0- speed of wind.

As tip speed ratio is high then the efficiency of the system becomes too high but it increases the level of noise and vibrations. Tip speed ratio for the different cases are different it can be explained in terms of low speed wind turbine and high-speed wind turbine:

Low speed wind turbine: 1 to 4

High speed wind turbine: 5 to 9

For the best design consideration: around 7

It ensures that the wind turbine can run at approximately maximum power coefficient.

Tip speed and rotational speed is different a relationship between both can be expressed as:

$$\lambda = \frac{2\pi n r}{60 V_0} \ldots\ldots. (\text{Eqn } 3.5)$$

Where,

n - rotational speed of the rotor,

r -rotor radius and

V_0- wind speed.

In our case,

The tip speed ratio is 8,

the rotor radius is 1.375 m and

avg. wind speed for the location is 10m/s,

then the rotational speed of the rotor should be 85 rpm using Equation 3.6.

$n = \frac{60 v_0 \lambda}{2\pi r}$ .... (Eqn 3.6)

It can be clearly indicated that a blade with a big length has low rotational speed so, an inverse relationship between the blade span and rotational speed has been clearly shown in the above equation.

4. METHODOLOGY

This chapter includes the technical specifications of the HAWT models which was installed at SSSCE RKDF university, Bhopal Blade dimensions, Structural analysis, design analysis and FEA modeling to judge the failure criterion and its forecast.

4.1 Technical Specifications of Hawt (Whisper 200)

Table 4.1: Technical Specifications of Hawt (Whisper 200 Model)

PARAMETERS	SPECIFICATION
Rated Power	1000 watts at 11.6 m/s (26 mph)
Rotor Diameter	2.7 m (9 ft)
Turbine Controller	Whisper controller (Optional with all Units)
Blades (3)	Carbon reinforced fiberglass
Shipping Dimensions	1295 x 508 x 330 mm (51 x 20 x 13 in)
Monthly Energy	200 kWh/mo. at 5.4 m/s (12 mph)
Voltage	12, 24, 48 VDC*; HV Available at 120v, 230v
Mount 6.35 cm pipe	(2.5 in schedule 40)
Survival Wind Speed	55 m/s (120 mph)
Start-Up Wind Speed	3.1 m/s (7 mph)
Weight	30 kg (65 lb.) box :39.46 kg (87 lb.)
Overspeed Protection	Patented side-furling
Body	Cast aluminum with corrosion resistant finish
Warranty	5-year limited warranty

*Power ratings are normalized for sea level E

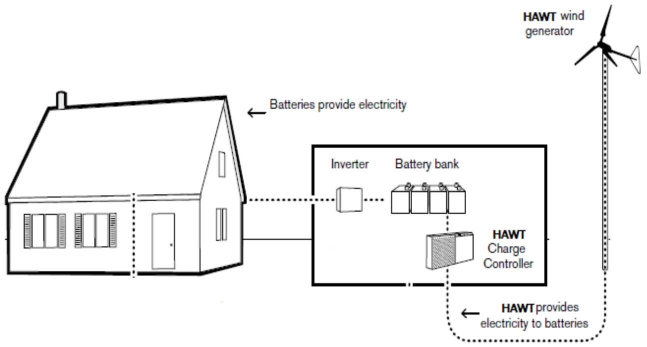


Fig.4.1 Schematic diagram of HAWT

Wind speed increases with height. Higher towers also raise generators above the air turbulence that can exist close to the ground.

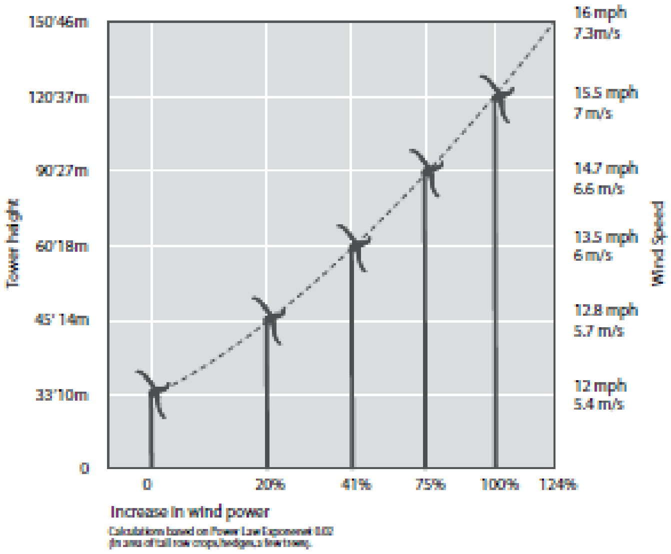
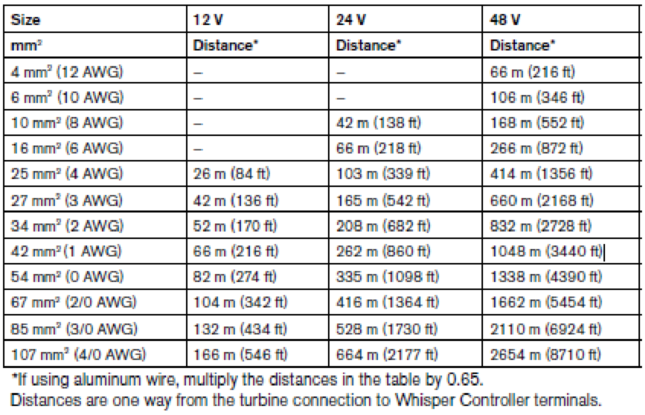


Fig.4.2 wind speed vs Tower height

Wire size from wind generator to controller based on voltage configuration and distance (Distance = A + B)

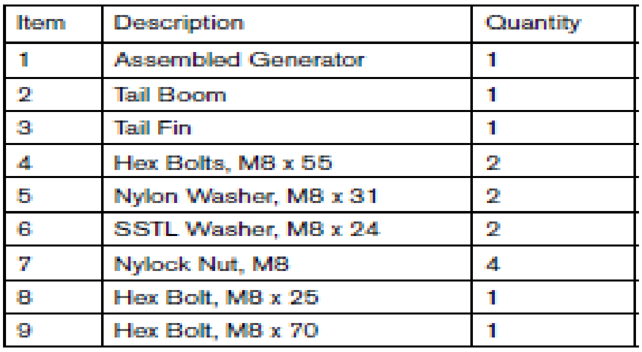
Table 4.2: Wire Size from Generator to Controller



Size	12 V	24 V	48 V
mm²	Distance*	Distance*	Distance*
4 mm² (12 AWG)	–	–	66 m (216 ft)
6 mm² (10 AWG)	–	–	106 m (346 ft)
10 mm² (8 AWG)	–	42 m (138 ft)	168 m (552 ft)
16 mm² (6 AWG)	–	66 m (218 ft)	266 m (872 ft)
25 mm² (4 AWG)	26 m (84 ft)	103 m (339 ft)	414 m (1356 ft)
27 mm² (3 AWG)	42 m (136 ft)	165 m (542 ft)	660 m (2168 ft)
34 mm² (2 AWG)	52 m (170 ft)	208 m (682 ft)	832 m (2728 ft)
42 mm² (1 AWG)	66 m (216 ft)	262 m (860 ft)	1048 m (3440 ft)
54 mm² (0 AWG)	82 m (274 ft)	335 m (1098 ft)	1338 m (4390 ft)
67 mm² (2/0 AWG)	104 m (342 ft)	416 m (1364 ft)	1662 m (5454 ft)
85 mm² (3/0 AWG)	132 m (434 ft)	528 m (1730 ft)	2110 m (6924 ft)
107 mm² (4/0 AWG)	166 m (546 ft)	664 m (2177 ft)	2654 m (8710 ft)

*If using aluminum wire, multiply the distances in the table by 0.65.
Distances are one way from the turbine connection to Whisper Controller terminals.

Table 4.3: Tail Specification



Item	Description	Quantity
1	Assembled Generator	1
2	Tail Boom	1
3	Tail Fin	1
4	Hex Bolts, M8 x 55	2
5	Nylon Washer, M8 x 31	2
6	SSTL Washer, M8 x 24	2
7	Nylock Nut, M8	4
8	Hex Bolt, M8 x 25	1
9	Hex Bolt, M8 x 70	1

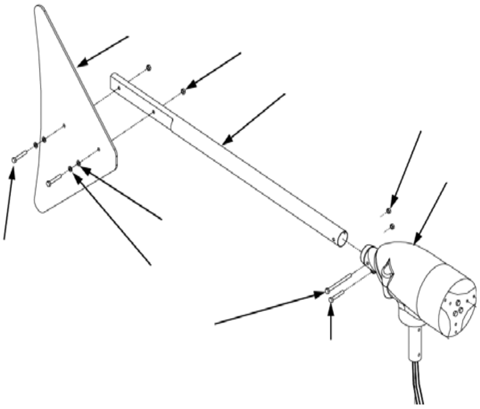
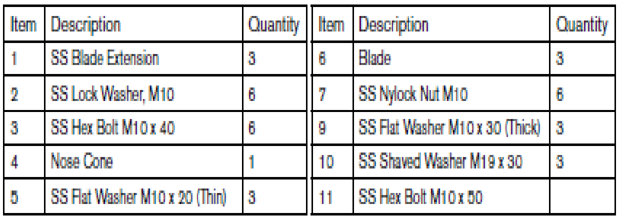


Fig.4.3 Tail and its parts

Table 4.4: Blade Specification



Item	Description	Quantity	Item	Description	Quantity
1	SS Blade Extension	3	6	Blade	3
2	SS Lock Washer, M10	6	7	SS Nylock Nut M10	6
3	SS Hex Bolt M10 x 40	6	9	SS Flat Washer M10 x 30 (Thick)	3
4	Nose Cone	1	10	SS Shaved Washer M19 x 30	3
5	SS Flat Washer M10 x 20 (Thin)	3	11	SS Hex Bolt M10 x 50	

Fig.4.4 Final Assembly of blades

4.2 Design Analysis

Power generated due to wind speed is given by following equation.

$P_w = 1/2 \times \rho \times A \times v^3 \times 0.59259$

Where,

P_w= Power of wind (watt)

ρ = Air density (Kg/m^3) (1.225 Kg/m^3)

A= Area of segment of the wind being considered

v = Undistributed wind speed (m/s)

The wind velocity is taken as 8 m/s

We can find the value of C_L and C_D from Design Foil for different angle of attack.

For AOA 10 degree,

C_L=1.279, CD=0.0144

Lift and Drag forces find out by following equation

$F_L = 1/2 \times \rho \times u^2 \times C \times lb. \times C_L$

$F_D = 1/2 \times \rho \times u^2 \times C \times lb. \times C_D$

Where,

C= chord length-1.1 m

lb.= length of blade element-2 m

C_L = lift coefficient

C_D = drag coefficient

4.3 Static Dynamic Structural Analysis

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. You will configure your static structural analysis in the Mechanical application, which uses the ANSYS depending on which system you selected, to compute the solution.

Table 4.5 Parameters used for structural Analysis

Parameters	**Values**
Number of Blades	3
Tip Speed Ratio	7
Wind Speed (m/s)	3.5-15
Power (Watts)	1000-5000
Number of Blade Selection	20
Air Density (kg/m^2)	1.224
Swept area of Rotor (m^2)	589
Power coeff.	0.5
Radius of rotor (m)	13.5

4.4 FEA Modeling Through ANSYS

1. Add a static structural analysis template by dragging the template from the Toolbox into the Project Schematic or by double-clicking the template in the Toolbox.

2. Load the geometry by right-clicking on the Geometry cell and choosing Import Geometry. Import the geometry in IGES format.

3. View the geometry by right-clicking on the Model cell and choosing Edit or double-clicking the Model cell. Alternatively, you can right click the Setup cell and select Edit. This step will launch the Mechanical application.

4. In the Mechanical application window, click on geometry and select the material.

5. Now click on Mesh and select generate mesh.

6. Click on Analysis setting and then select fixed support. Fixed the end part of the blade.

7. Click on loads and select pressure and then apply on the faces of geometry.

8. Now click on solution and select Total deformation, Equivalent stress, and Equivalent strain and click on solve all results.

9. Now save all the images and solution information in word document.

5. RESULTS AND DISCUSSIONS

Boundary Layer Conditions

Inlet Conditions (Velocity Inlet) for any system has to be precisely selected and added. In this case velocity of wind is inlet condition for virtual wind tunnel. Direction of wind striking the tunnel is perpendicular to its surface. Turbulence is main factor that affects the efficiency of the system. Inlet turbulence intensity is set to 0.5% and viscosity of 1.78e-05 for air flowing through the blade of wind turbine.

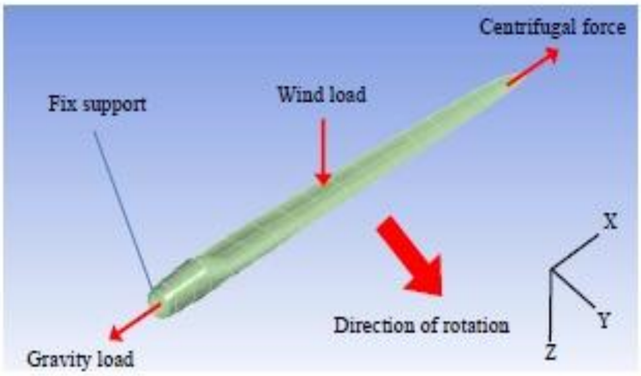


Fig.5.1 Load on wind turbine blade

Outlet Conditions (Pressure Outlet) is equally important to inlet conditions. This is because, behavior of air within the system depends on outlet condition. Outlet condition is set as pressure based. Pressure of air leaving is considered as atmospheric pressure.

No Slip Wall No slip condition is important condition in setting practical behavior of system. This accounts the friction between the wall and air molecules. Setting this condition ON, assumes velocity of air near on the blade near to zero.

Our project will focus mainly on the forces generated during normal and heavy wind conditions, however gravity will also be included with regards to a static loading of the blade. Aerodynamic forces working on the blades are very important aspects of loading conditions to inspect WT blade design and proper working at the operating speed largely dependent on the forces acting on the blades.

We have taken three blades rotor system for analyzing the stresses via loading conditions. In our project we have discussed many loading scenarios of a WT to investigate the performance of the system under stressed condition.
The inertial forces are the major concern when the rotor radius is 10 meters or greater than this our rotor radius is 13.5m.

For the sake of simplicity all the forces are not included in the FEA model. Eccentric loading is omitted. These loads will be the most significant loads applied in the FEA modeling portion of this project which will then be used to gauge the magnitude and location of stresses and strains caused in the blade structure.

The driving force generated while the turbine is in operation are by far the largest aerodynamic load, shown in Figure 5.2, with the highest driving force taking place at the external surface of blade sections. Tangential force is appreciably fewer than the driving force and are constant along the length of the rotor blade and decreases to zero towards the tip of the blade due to tip loss effects.

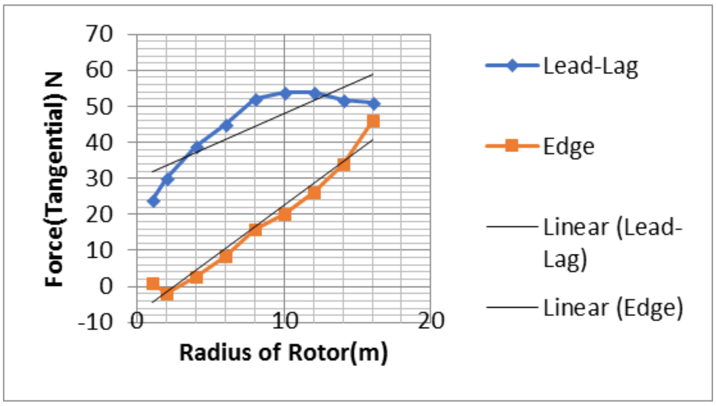


Fig.5.2 Forces acting on the rotor during normal blade speed about 12m/sec

Blade of a rotor in our case a three blades rotor system acts as a cantilever beam which is twisted under the application of large amount of driving as well as tangential force. It is experienced that the large axial force is observed towards the exterior surface of the blade, which is most efficient aerodynamically and generate the leading lift forces, which produces a huge amount of bending moment at the core of the blade. It is graphed in the fig.5.3.

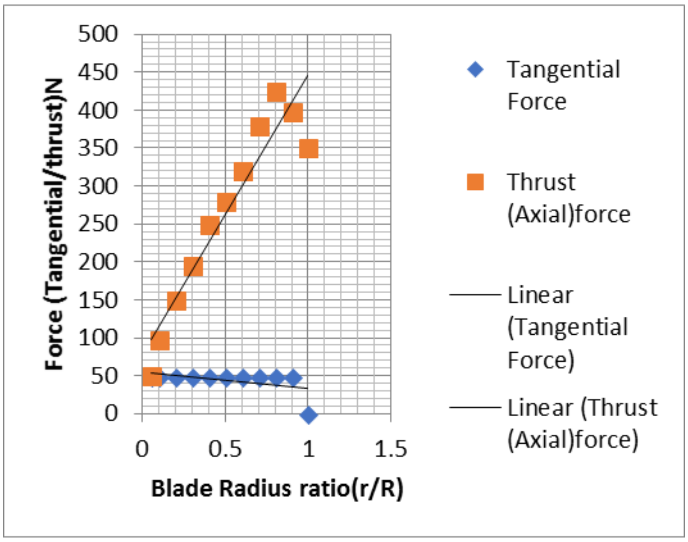


Fig.5.3 Tangential Forces acting on the blade rotor during normal operation

The effect of the alteration of forces between the blade root and the local blade reference systems may be seen in Figure 5.4 below.

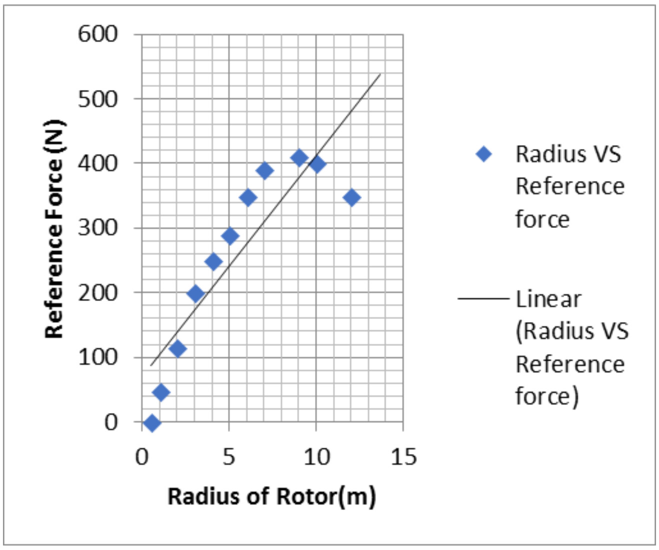


Fig.5.4 Radius of rotor Vs reference force

It can be seen that there is slight difference between the flap wise and flat wise forces near the blade root where the blade section twist angle is highest but these differences are shown to be insignificant when the flap wise and flat wise moments are compared as shown above in Figure 5.5.

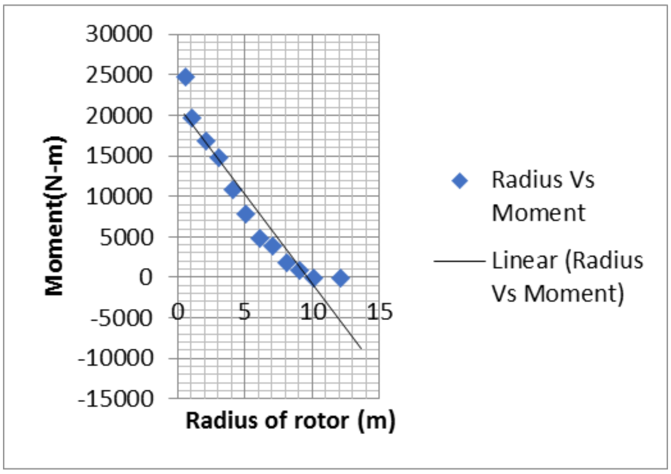


Fig.5.5 radius of rotor Vs Moment

For comparison, the lead-lag and edge-wise forces and the tangential moments which are generated along the length of the blade are diagramed in Figure 5.6 below.

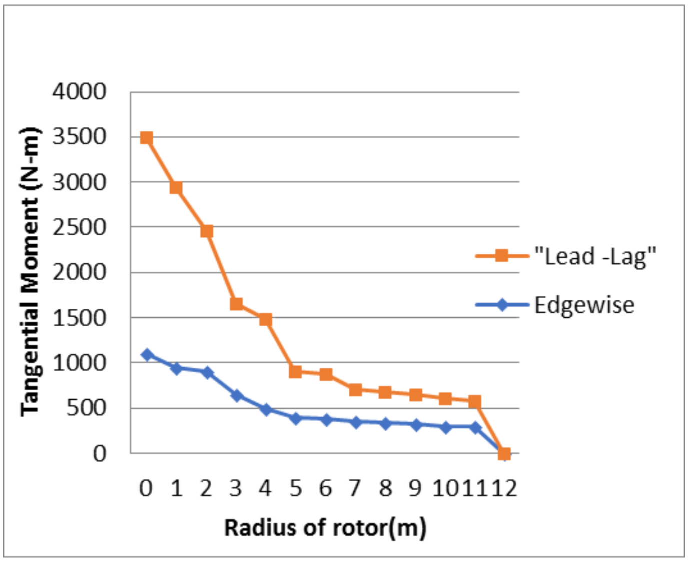


Fig.5.6 Radius of rotor Vs Tangential Moment

The ANSYS software has been used to analyze the deformation of the blades and the distribution of stress of the horizontal axis wind turbine blade. Blades are divided into the various number of elements and FEA mesh is prepared which is shown in the fig.5.8 below. FEA Mesh convergence was carried out for the element number from 5000 to 50000 and the optimal model was obtained when the blade model reaches more than 23000 elements, as shown in Figure 5.9, and the maximum von Mises stress approaches a convergent value.

In this study and analysis, the clockwise rotation speed of the wind blade was assumed at 12 m/sec, which is approximately nearer to the maximum designed wind speed of 18 m/s. The loading conditions are analyzed and discussed for the wind turbine blades.

The wind blades are subjected to the gravity force, the wind thrust, and tangential force. Figure 5.11,5.12 and 5.13 are showing various load and boundary conditions for the wind blade at the horizontal and vertical position and the gravity force is acting through the wind blade from its tip exterior position to the root (interior) end. The root end of the wind blade is fixed on the wind turbine hub, so the petiole degrees of freedom are all fixed.

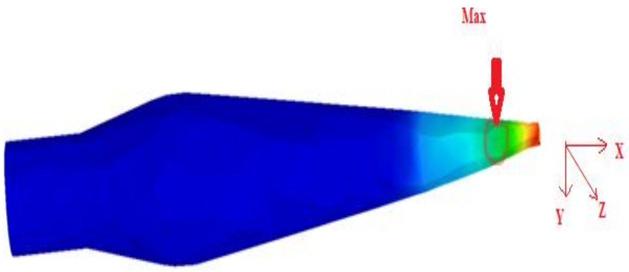


Fig.5.7 Stress Distribution

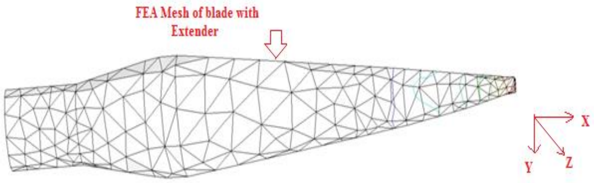


Fig.5.8 FEA Mesh model

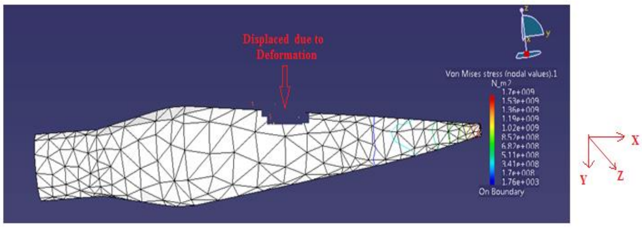


Fig.5.9 Von Mises Stress Distribution Mesh

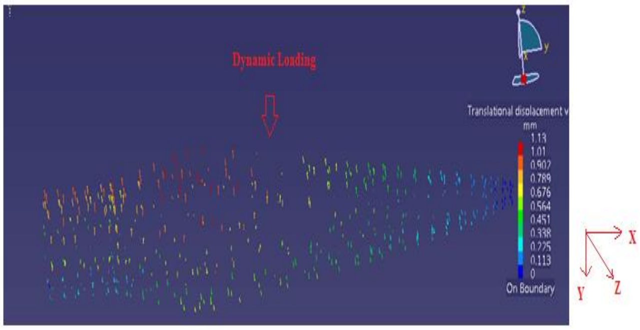


Fig.5.10 Translational Displacement dynamic loading condition

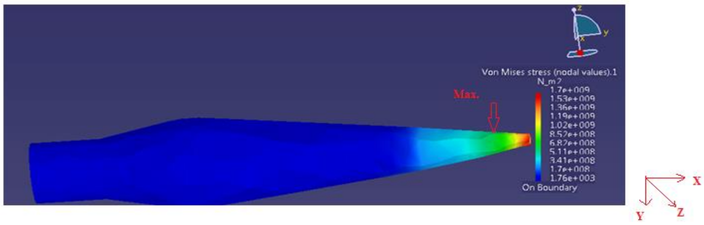


Fig 5.11. Von mises Stress distribution using Boundary condition 1

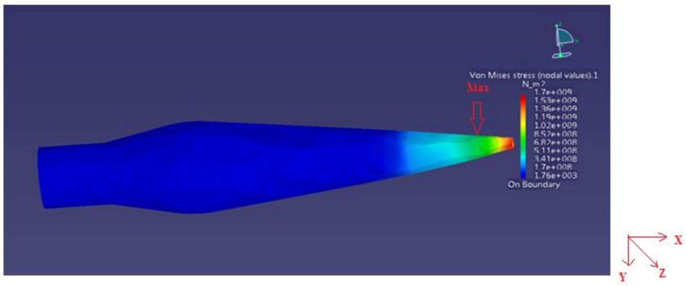


Fig 5.12. Von mises Stress distribution using Boundary condition 2

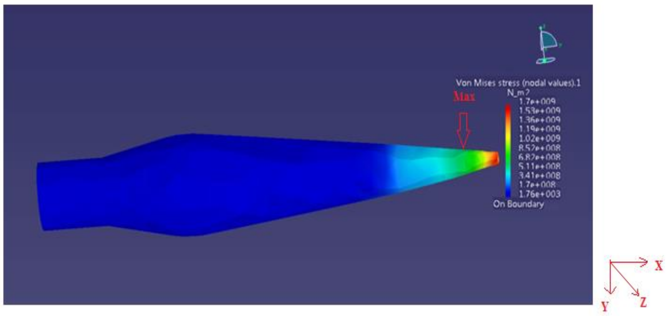


Fig 5.13. Von mises Stress distribution using Boundary condition 3

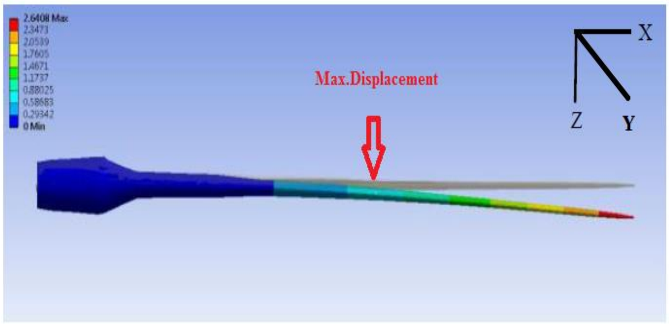


Fig.5.14 Deflection of blades

The wind turbine blade under wind load at different blade angular positions is inspected. With the fixed pitch angle horizontal position which is the reference position which is parallel to the ground, the wind blade is subjected to a maximum wind pressure load to bend the blade structure. The maximum stress occurs at the junction of root and wind blade extender and near the stiffener edge, where the blade shape changes a lot.

When the wind blade is located at perpendicular to the ground, the maximum von Mises stress value is 87.11 MPa.

When the blade is at 120° counterclockwise angular position from its highest vertex, the combination of the wind load, the gravity and the tangential force resulted in a maximum von Mises stress of 74.97 MPa at the combination of the extender and blade near the stiffener edge.

When the wind blade is at 120° clockwise angular position from its highest vertex, the load on the blade is added by the wind load, the gravity and the tangential force and resulted in a maximum value of von Mises stress 109.79 MPa at the combination of the extender and blade near the stiffener edge near the stiffener edge.

Figure 5 shows the stress distribution and the deformation of the wind blade at 120° clockwise angular position. The maximum tip displacements at three positions are 2.56 m, 2.37 m and 2.64 m, respectively. The deflection of wind blade is similar to that of a cantilever beam as shown in Figure 5.14 in the flap wise direction of wind blade. The maximum von Mises stresses and maximum tip displacements of 1000watts horizontal axis wind turbine blade at different angular position are shown in Table5.1.

Table 5.1 results of wind turbine blade at different angular position

S.No.	Value ($\sigma_{von\ mises}$) MPa	Tip displacement(m)	Blade angular position
1.	87.11	2.56	0 °
2.	74.97	2.37	-120 °
3.	109.79	2.64	120 °

The Tsai-Hill failure criterion has been used to determine the failure of wind turbine blades. And one blade of a three-rotor turbine has been taken into consideration and it's taken as a reference blade and maximum time three most achieving position are considered. Among which blades angles 0 °, -120 °, 120 ° are taken into consideration.

The maximum von Mises stresses, at 120° clockwise angular position in Table 5. 1, are summarized It can be seen from Table 5. 1, for the wind blade with fixed pitch angle, the wind blade with fixed pitch angle and if for certain case the pitch angle is increased so it is an alternative way to prevent the wind blade from failure.

6. CONCLUSION

- A simple HAWT blade material selection procedure was developed which combines weighted contributions of the material indices pertaining to the blade performance and longevity.
- The performance of a wind turbine blade is highly dependent on the structure and is critical to the wind turbine system service life. The results revealed that, from the performance point of view.
- The total deformation, equivalent strain and equivalent stress values of WHISPER 200 are 5.7065e-005m, 3.2052e-006, 2.2456e+005Pa. Thus, Carbon reinforced fiberglass is the best choice for the material.
- A preliminary parameter variation study was conducted which revealed that further improvements in the HAWT blade performance are possible with targeted changing the series of WHISPER 200.
- Stress analysis is a major topic in the wind turbine blades which is performed by software program. The stress and strain at different directions are considered in order to control the safety factor of the blade against applied loads.
- The most important parameter in the stress analysis of the blades is the maximum stresses and critical values. For a blade, Carbon reinforced fiberglass the normal and shear stresses are calculated initially and then the stresses are analyzed based on the Tsai-Wu failure criterion.
- Moreover, stress contour must be studied in the critical layer because the possibility of failure is highest in the whole structure.

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