International Journal of Research Publication and Reviews, Vol 3, no 6, pp 4410-4418, June 2022

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Stability Analysis of Wind Turbine Blade

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ABSTRACT:

The wind turbine blades often subjected by a phenomenon fluttering which leads to a structural damage. Therefore, it is necessary for design engineers to predict the fluttering behavior while designing the blades. The main scope of the work is to analyze and study the fluttering behavior by conducting structural analysis, modal analysis, Aeroelastic stability analysis and FSI of standard wind turbine blade. The analysis is carried out in ANSYS work bench and the preliminary results shows that blade structure shows some variation which has to prone to flutter.

Keywords: Wind turbine blade, Aerodynamic loads, Finite Element Method, Mode shapes, Deformations and ANSYS.

INTRODUCTION :

In our planet earth, there is lot of natural energy source which makes very comfortable for human life to live and survive. Among all these energy sources the renewable power air from the earth's surface creates the valuable wind energy. The wind energy is the fastest growing booming energy source in the world. In order to use the greater extent of wind energy source, the engineers all around the world working with maximum efforts to rectify the challenges facing while trying to use the valuable –renewable energy source of the world.

Background

In the past decades, the growth in using the valuable energy sources especially wind energy has been increased significantly. For the sustainable protection, these wind energy is used nowadays to a greater extent to gain electricity. As of today, the commercial wind turbine expels the power output ranging from 0.3 MW to 7.5 MW as shown in figure 1.1 below. The wind energy in the world has began as early as 200 B.C in Persian and middle east where wind mills with Woven read sails were grinding grains. People in the world has been harnessing by the energy of the wind. The wind turbine sizing plays a major role in capturing larger wind energy. For this instance, most of the wind turbine manufactures produces a large wind turbines. Even though with greater advantages, the cost of labor, maintenance, and construction of tower and rotor for large wind turbines are extremely high so the manufacturers concentrates more on bringing down the prices of turbines. In order to get more power from turbine, it is essential to build a large rotor by considering size and shape of tower. Under variable wind condition, the rotor performs several aerodynamic behaviors so careful considerations such as material selection, vibration analysis, structural analysis etc are need to be taken before manufacturing a blade.

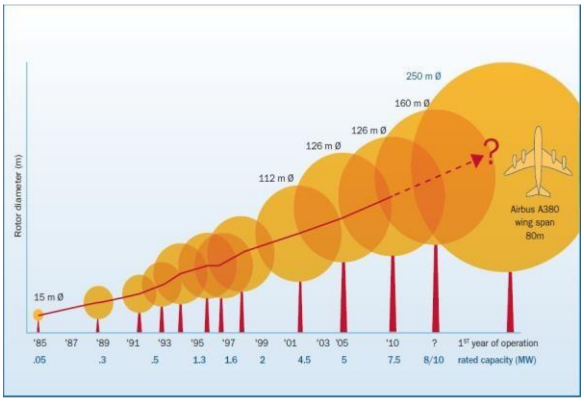

Figure 1.1 Development of Wind turbine

Flutter is an aeroelastic instability which leads to a large amplitude vibration ends up in structural failure. Normally it has two degrees of freedom, flap-wise and torsional. Flutter occurs by coupling of both flap-wise and torsional vibrations. Even though there are several critical conditions for flutter to occur on structures, there are two most important conditions The insufficient separation in frequencies of a flap-wise bending mode and first torsional mode. The centre of mass for blade cross section is positioned after the aerodynamic centre of the blade. So careful design considerations are taken into account while designing a new blade where it has high torsional stiffness and centre of mass for blade cross section is located exactly between the leading edge and chord point. The flutter does not exists on the smaller wind turbines due to blade stiffness whereas for large wind turbines critical flutter should be calculated to be minimum couple of times of the operating speed of the wind turbine The flutter occurs in wind turbine at the following conditions is achieved such as attached flow, low stiffness, high tip speeds, centre of mass aft of the aerodynamic centre, blade aspect ratio, air-blade mass ratio and material damping. For overcoming these problems, FEM analysis, aeroelastic analysis and FSI are needed. The state of the art issues in aeroelastic phenomenon's are as follows he Flutter experiments where it has no experimental data for observation of flutter limits. The unsteady aeroelastic effect due to wake effects on flutter limits and it is high at tip of the blade. The yaw misalignment on wind turbine blades which is blade rotation with high relative speed. The damping of trailing edge flaps leads to suppression.

Aim and Scope:

The thesis named ´Fluttering analysis in Wind Turbine Blade´ is worked mainly for the purpose of analyzing the fluttering behavior on blades of wind turbine by analyzing, structural analysis, modal analysis, Aeroelastic stability analysis, FSI and provides possible solutions to overcome the problem. The aim is achieved by conducting Finite Element Analysis test on standard NACA blade profile and the corresponding results are obtained.

LITELTURE REVIEW

Windmill Power Generation Using Mult-Generator and Single Rotorby S.Siva Sakthi Velan, G.

Muthukumaran S. Balasubramaniyan…..…..et al 2019

The aim of the paper was “to produce current using multi generator and single rotor”. This paper proposes multigenerator to address potential challenges: dimension, cost and reliability. The two electromagnetic induction generators are desired to share the single shaft through straight bevel gears. These poles of the two generators will be changed as alternate to parallel. This paper discussed about the design procedure of gears, gear life and wind turbine rotors. The output current is stored in series of battery to appliances through converter and step up transformer. In this paper The Construction, working, parts of wind-mill, materials are discussed in detail.

Design and Analysis of Ducted Wind Turbine for House Hold Purpose Priyanka.Chore, Dr.

L.G.Navale…………………………………..…….et al 2018

An Energy harnessing from non-conventional energy sources has become necessary due to drawbacks of conventional sources. All these sources are renewable or inexhaustible and do not cause environmental pollution. Tremendous work done on wind energy conversion and windmill. Convention windmill has some disadvantages like large size of blades, maintenance complications and harmfulness to ecosystem. Ducted Wind Turbine means increased velocity, is the system that uses the principles of flow of fluids through convergent section, so as to increase incoming air velocity at throat section. In Ducted Wind Turbine system, air captured from height with initial natural velocity and passes it through closed reduced area section to the ground. Air flow through convergent section of venturi, so we get higher air velocity at ground level. At throat section of venturi where the turbine is placed to get desired output. The main advantages of Ducted Wind Turbine over traditional windmill will be as, conversion of energy system will be placed at ground level, so to reduce damage and maintenance. Comparatively lower blade size required for same energy output due to high air velocity at blade plane, less effect on ecosystem due to enclosed energy conversion system. Mainly the manufacturing and installation cost will be reduced largely.

An analytical review on the evaluation of wind resource and wind turbine for urban application:

Prospect and challenges Zinat Tasneem, Abdullah Al Noman …………………………et al 2020

Wind energy is a promising scheme in the power generation sector due to pollution-free power production and wind resources' sufficiency worldwide. Installing wind turbines in all the possible extents can mitigate the rising energy demand. Built-up areas possess high potential for wind energy, including the rooftop of high-rise buildings, railway track, the region between or around multistoried buildings, and city roads. Harnessing wind energy from these areas is quite challenging since it has dramatic nature and turbulence for higher roughness on urban surfaces. This review paper endeavors to highlight the present status of urban wind farm technology and its commercial and environmental aspects. Observations and upcoming research trends have been presented based on up-to-the-minute information. It is concluded that further investigation of wind mapping and the suitable design of turbines is essential to make the urban wind farm a reliable and feasible option for decentralized power generation

Small Scale Wind Turbines Optimized for Low Wind Speeds T. Letcher, The Ohio State University, Columbus, OH.

A combination of common vertical axis wind turbines (VAWT) rotors was designed and tested for optimal performance in low wind speeds.

The Savonius rotor creates high torque and is self-starting even at low wind speeds, but is relatively low in efficiency rating. The Savonius rotor is used to start the straight bladed Darrieus rotor. The Darrieus rotor is not a self starting rotor, but has much higher efficiency than the Savonius rotor. The combination of rotors increases the total power of the turbine in lower wind speeds.

FORMULATION OF PROBLEM

Rotor:

The rotor is the main part of wind turbine which has nacelle and hub which in turn fixed with blades. The rotor plays a primary role in working of a wind turbine as it turns the turbine blades and converts the obtained kinetic energy from the wind and transforms into mechanical or electrical energy based on the need for purpose. The kinetic energy from the atmospheric wind can be written as [12]

$$K = \frac{1}{2} * m * v^2$$

Where ‘m’ is mass in kg and ‘v’ is speed of wind in m/s. Now the mass flow rate in rotor disc area ‘A’ is determined by differentiate mass with respect to time.

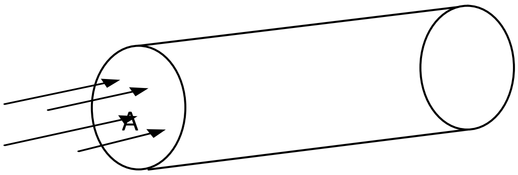

Figure 3.2.1 Flow of air through rotor with area

$$\frac{dm}{dt} = \rho * A * v$$

Then, the energy per unit time is given by

$$\frac{dK}{dt} = \frac{1}{2} * \frac{dm}{dt} * v^2$$

$$\frac{dK}{dt} = \frac{1}{2} * \rho * A * v * v^2$$

$$P = \frac{dK}{dt} = \frac{1}{2} * \rho * A * v^3$$

There are several other aerodynamic parameters are needed to design a rotor such as radius of rotor, angle of attack and number of blades. The rotor blade materials are normally chosen based on the blade geometry and structure stress conditions. The blade materials are structural steel for tower structure and basement of turbine, Alloy steels, Fiber reinforced fabrics are also used in designing the rotor of wind turbine.

AERODYNAMIC LOADS ON BLADES:

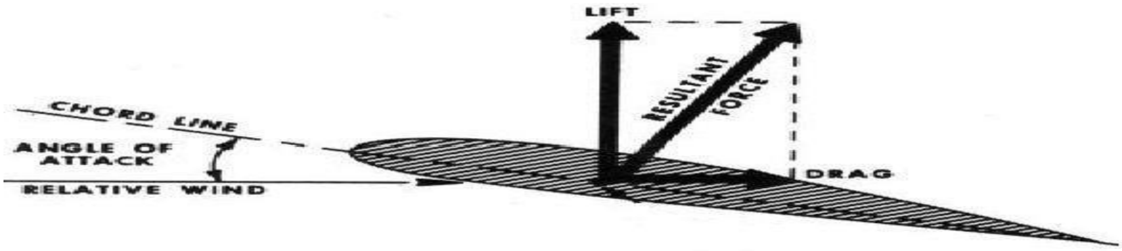

Figure 3.3.1 Loads on airfoil

Source: www.avstop.com

The airfoil has a pressure change when it subjected to airflow. There are different pressure changes on upper and lower side of the airfoil. Therefore, these difference will cause a force ´*F*´ in two main components in *x* and *y* direction. The aerodynamic loads on the blades are lift force and drag force.

Lift force acts vertical to the airflow. This force shows the variation in both the sides of airfoil surfaces. The lift force is given by

$$F_L = C_L * \frac{1}{2} * \rho A V^2$$

Drag force acts parallel to the airflow. This force shows the viscous friction surfaces at airfoil surfaces. The drag force is given by

$$F_D = C_D * \frac{1}{2} * \rho A V^2$$

From the resultant of both the lift and drag forces gives a new forces called the thrust force and the force of moment.
Thrust force acts parallel with axial axis. The thrust force is the combination of cosine to F_L and sine to F_D. The thrust force is given by

$$F_T = F_L \cos\phi + F_D \sin\phi$$

Force of moment or torques is the force rotates the turbine and it is tangent to rotor diameter. The torque is the combination of sine to $F_L$minus cosine toF_D. The force of moment is given by

$$F_{FM} = F_L \sin\phi - F_D \cos\phi$$

These are all the aerodynamic forces which act on the surfaces of the blade and lead to analyze several pressure changes behaviors on a surface. **DESIGN METHODOLOGY** The wind turbine often subjected by an aeroelastic phenomenon called fluttering is studied and analyzed here. The theory behind wind turbine technology is discussed earlier in the chapter 3. The process starts with selection of airfoils for wind turbine blades, static structural analysis, modal analysis, stability analysis and FSI of blade. The entire process is shown in figure 4.1.

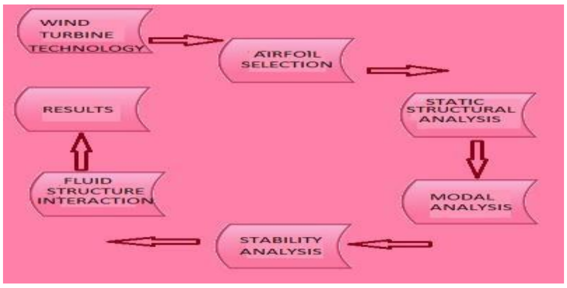

Figure 4.1 Flowchart of fluttering analysis

The NACA airfoils are the shapes of airfoil of aircrafts which are developed by 'National Advisory Committee for Aeronautics' and these airfoils are stated by series of numbers representing their blade profile. These digits are followed after the word NACA which represents the camber line and chord line of the airfoil and corresponding blade profile equations are generated to obtain the cross section of the airfoil.

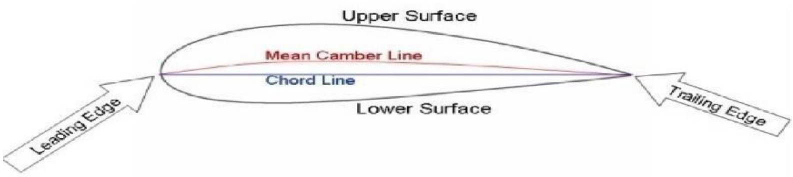

Figure 4.2 Airfoil Parameters Source:

The NACA series airfoil performs greater efficiency in wind turbine blade and so 4 digit series NACA airfoil is taken into consideration and fluttering analysis is performed. The standard wind turbine blade profile is obtained which is a pre-designed model [7]. The NACA 4 digit airfoil blade profile is shown in below figure 4.3. The cross section of the wind turbine blade has an airfoil; it is responsible for producing power by air flow around the airfoil.

NACA BLADE PROFILE BLADE MODEL IN ANSYS

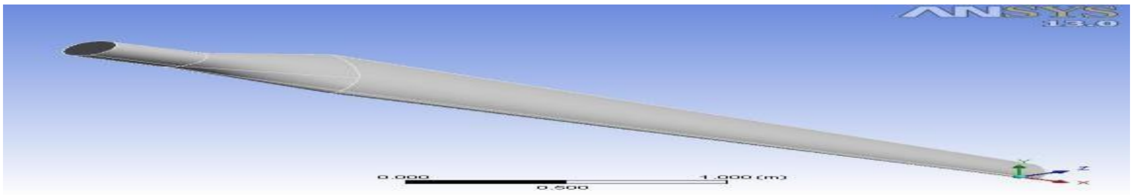

Fig 4.3

The airfoil is chosen carefully and then the static structural analysis begins with material selection and meshing of the model. The material Aluminum 6061-T6 is used in this analysis and the properties of the material are inserted in engineering data and the list of material properties used is shown in table 4.1.

Table 4.1 Material properties

Density Kg m^-3	Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
2700	6.8948e+010	0.33	6.7596e+010	2.592e+010

The static structural analysis is usually analyzed to determine the stress, strain load deflection, acceleration and stability of the structure by some load applies on it. A static structural analysis includes the inertial load and time varying loads which also used to predict the fluttering behavior in wind turbine blades. So this analysis is also performed at desired load conditions to view the behavior of the material.

The static analysis performs only in certain loads. They are as follows

- Force and pressure
- Steady state inertial force
- Temperatures

The shell model is meshed automatically in the Ansys workbench and it is obtained after refinement. The meshed blade profile is shown in figure 4.4. The meshing of the model determines the element numbers and element size and here default element size and number is chosen for meshing. The model is fixed at one end and free at another end. The force is applied on the tip of the blade and a force of 10N is applied on the blade tip. This force gives a deformation in the blade. The static structural analysis shows the total deformation of the blade and corresponding equivalent tress is plotted.

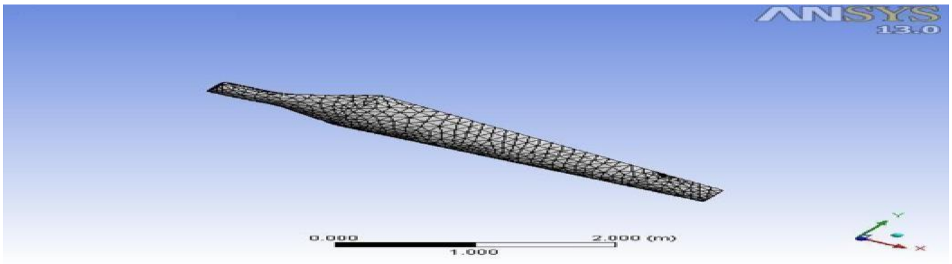

Figure 4.4 Meshed model

Blade Element Momentum Theory The blade element momentum theory is major design consideration in manufacturing the wind turbine blades. The blade element theory refers to force analysis in blade geometry of the wind turbine. This theory helps us to improve the blade design and rotor design to get the perfect aerodynamic design for the following necessary assumptions are to be made.

- In between the elements in blade, there is no aerodynamic interaction.
- There should be no radial flow.
- The lift and drag characteristics of airfoils determines the forces of the blades.
- The blade should not bend and should be very strong.
- The wind direction may change slowly but wind velocity should be steady flow.

The differential aerodynamic forces are now obtained with incremental radius '*dr*' of the blade element. The chord length '*c*' of the airfoil also considered in the equations and they are as follows.

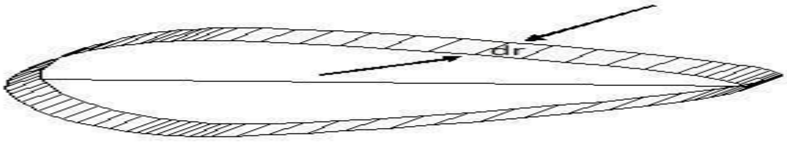

Figure 5.4.1 Blade element

FORCES ON BLADE ELEMENT

The differential lift force of the blade element is

$$dF_L = C_L * (\frac{1}{2} * \rho A V^2 * c * dr)$$

The differential drag force blade element is

$$dF_D = C_D * (\frac{1}{2} * \rho A V^2 * c * dr)$$

The differential thrust force of the blade element is

$$dF_T = dF_L \cos\phi + dF_D \sin\phi$$

$$dF_T = \frac{1}{2} * \rho A V^2 * (C_l \cos\phi + C_d \sin\phi) * c * dr$$

The differential force of moment of the blade element is

$$dF_{FM} = dF_L \sin\phi - dF_D \cos\phi$$

$$dF_{FM} = \frac{1}{2} * \rho A V^2 * (C_l \sin\phi - C_d \cos\phi) * c * dr$$

These parameters are to be considered before designing the blade and necessary calculations are to be done. The efficiency of the wind turbine normally depends on the design of the blade so careful assumptions, calculations and design are needed. obtaining maximum power output from the wind. The blade has several elements and

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RESULTS AND DISCUSSION

Static Structural Analysis

The static structural analysis is done by using ANSYS workbench. In this analysis, the structure is fixed at one point and point load is applied on the tip surface of the wind turbine blade and their corresponding deformation, Equivalent stress behaviors are obtained. They are as follows.

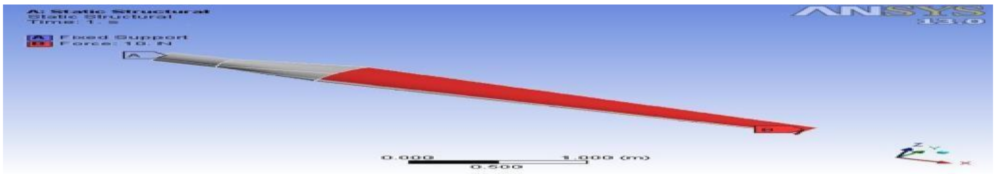

Figure 6.1.1 Force and Support

Total deformation

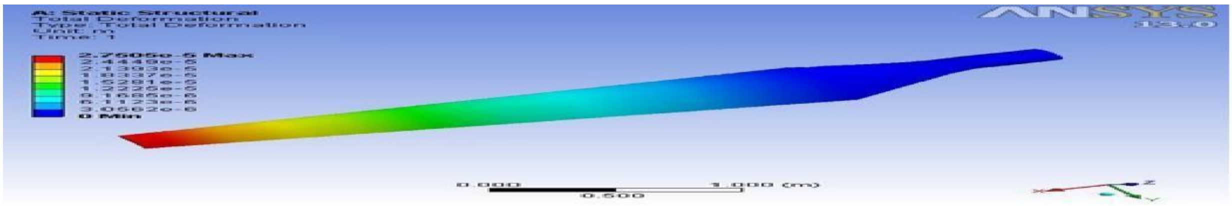

Figure 6.1.2 Total Deformation

THE result obtain shows the maximum deflection in blade element is 2.75 *10-6 meter under dynamic loading conditions Equivalent Stress

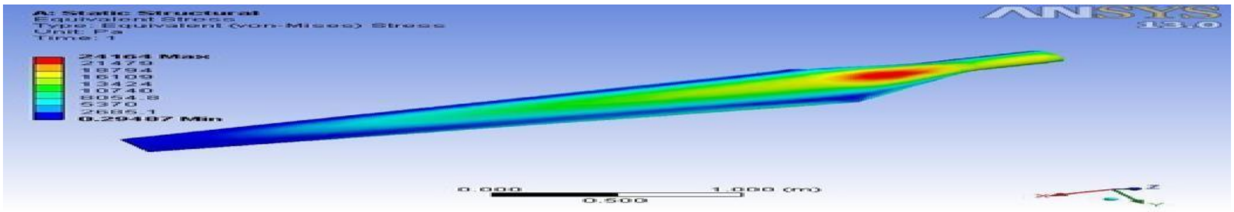

Figure 6.1.3 Equivalent (Von-Misses) Stress

The total deformation gives the maximum deformation at tip of the blade and minimum at fixed end whereas the stress formation shows that nearby fixed point gives more and minimum at tip of the blade. The von misses stress gives minimal stress around the neutral axis of the blade. From the above shown results, it is clear to analyze that at some specified location in the blade there is a high deformation, various stress and strain behaviors are viewed and so careful selection of material and finite element calculations are need to be done before conducting a structural behavior of the blade.

Modal Analysis

By performing this analysis, the first 5 mode shapes of the blade are obtained with their corresponding natural frequencies. The sixth mode called breathing mode where the lower and upper surfaces of the blade displaces upside and downside is also calculated for natural frequency. The refined model is refined further to get better results and the comparison of both meshes mode shapes and natural frequency is calculated and results are shown in figure below.

Mode shape 1:

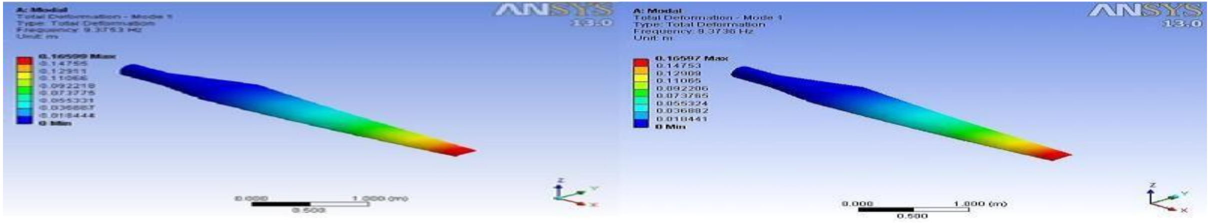

Figure 6.2.1 Comparison of Total Deformation- Mode 1

Mode shape 2

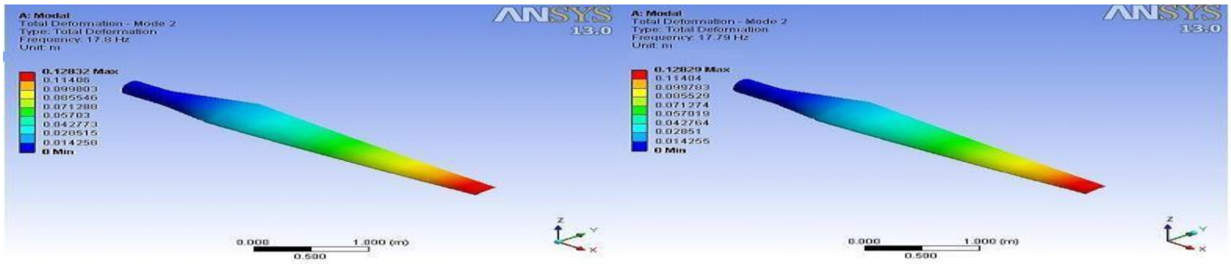

Figure 6.2.2 Comparison of Total Deformation- Mode 2

Mode shape 3

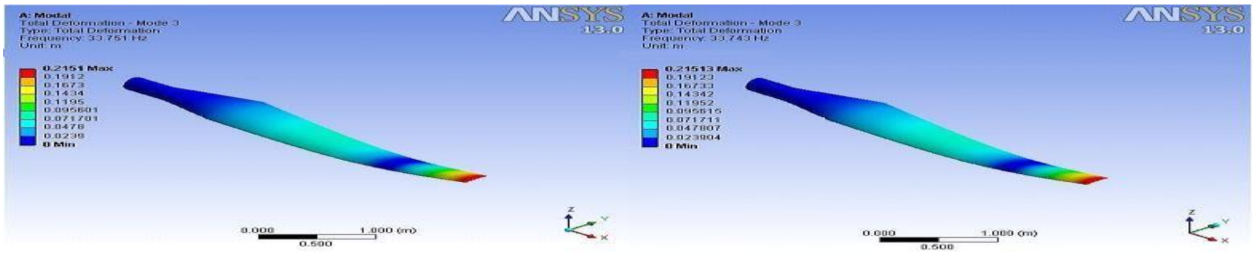

Figure 6.2.3 Comparison of Total Deformation- Mode 3

Mode shape 4

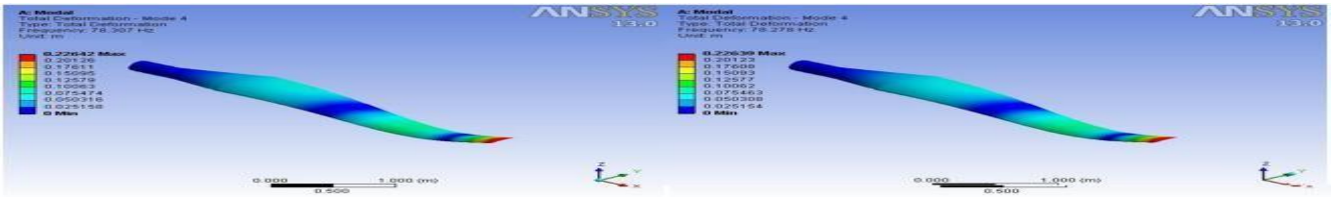

Figure 6.2.4 Comparison of Total Deformation- Mode 4

Mode shape 5

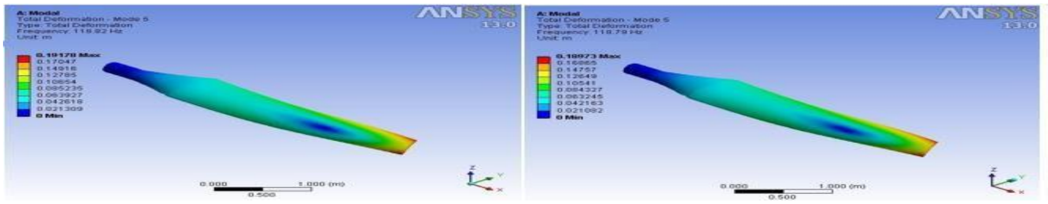

Figure 6.2.5 Comparison of Total Deformation- Mode 5

Mode shape 6- Breathing mode

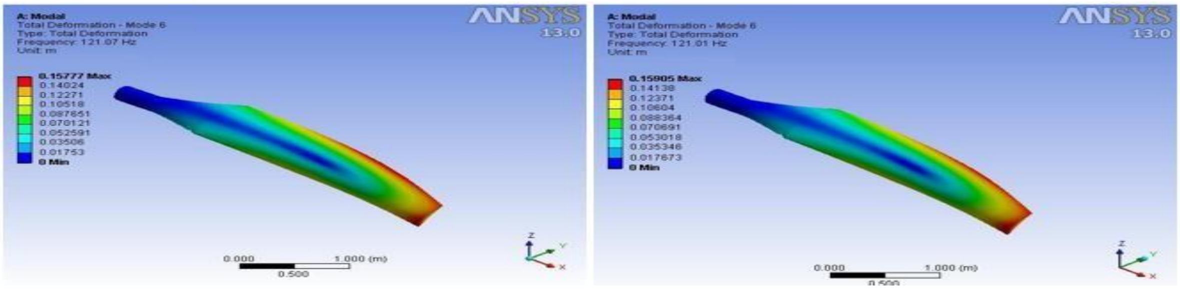

Figure 6.2.6 Comparison of Total Deformation- Mode 6

Thus the mode shapes and their respective frequencies are obtained by using FEM method. These mode shapes predicts the classical flutter behavior in this wind turbine blades and it has least frequency level at mode 1 and high frequency level at mode 6.

The table 6.2.1 below represents the mode shapes and their corresponding frequency levels.

Mode Number	Frequency (Refined Mesh 1) [Hz]	Frequency (Refined Mesh 2) [Hz]
1.	9.3753	9.3736
2.	17.8	17.79
3.	33.751	33.743
4.	78.307	78.278
5.	118.82	118.79
6.	121.07	121.01

Table 6.2.1 Comparison of Mode shapes and Frequencies

By comparing the frequencies in both the meshes, there is no much change in natural frequencies of the blade and so there is no need to refine the mesh further. The above stated mode shapes and natural frequencies are done with modal analysis of the blade and the vibrations produced at mode shapes are obtained. Then the next step in analysis is obtaining the aeroelastic stability analysis of the blade.

OBSERVATIONS

From the above performed analysis, it is shown that with general load conditions the deformation obtained in the blade is to analyzed properly. The structural deformation and stress behavior also observed carefully and several load conditions needed to perform for better performance of the blade. Since with further précised calculations and analysis it should be neglected or reduced to get the better efficiency of the blade performance. The modal analysis shows satisfied meshing conditions since there is no need for further refined meshing of the blade model. The FEM tool ANSYS workbench helps in conducting the static structural analysis and modal analysis. The aeroelastic instability may cause structural damage to wind turbine blades and so further aeroelastic stability analysis calculations are needed to get the entire fluttering behavior of the analyzed wind turbine blade model. These aeroelastic stability analyses are done by using a special software package.

CONCLUSION

In the performed analysis, it is shown that flutter occurs at their blade natural frequency; then further stability analysis is required to have better efficiency of the blade and so high torsional stiffness is required to get better efficiency and there leads to be a structural fatigue failure may occur by seen in the structural analysis. So with the obtained fluttering results in static structural analysis and modal analysis, it is very clear that fluttering behavior is major phenomenon taken into consideration while designing the blade of the wind turbine. With the further précised analysis, we can able to predict or manage this aeroelastic phenomenon without affecting the performance and efficiency of the blade. The aeroelastic stability analysis and fluid structure interaction of the blade is required to get better performing or efficient conditions of the blade. The mode shapes and their natural frequencies show the vibration of the blade at specified points in free vibrating conditions.

FUTURE WORK

From these report, we can say that with the further considerations of blade properties, damping conditions, finite element analysis, aeroelastic stability analysis and fluid structure interaction in the blade are needed for better performance of the blade. The aeroelastic stability analysis gives aeroelastic frequency and damping of an blade where the negative damping in mode shapes gives prone to ability of flutter, thereby neglecting negative damping it is possible to overcome the fluttering phenomenon of the blade. The Fluid structure interaction of the blade gives the interaction of fluid on solid geometry which is also needed for analyzing the fluttering conditions of the wind turbine blade. This above stated analysis is required to get the complete analysis of fluttering in wind turbine blade.