Fluttering Analysis in 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 thesis 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.
Acknowledgements

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Prabaharan Elangovan.
# Contents

1. NOTATIONS 4
2. INTRODUCTION 6
   2.1 Background 6
   2.2 Aim and Scope 8
3. WIND TURBINE TECHNOLOGY 9
   3.1 Types of Wind Turbines 10
   3.2 Rotor 14
   3.3 Aerodynamic Loads on blades 15
4. DESIGN METHODOLOGY 17
5. THEORY 23
   5.1 Introduction to ANSYS 23
   5.2 Introduction to FEM 23
   5.3 Introduction to Aeroelasticity 24
   5.4 Blade Element Momentum Theory 27
6. FEM ANALYSIS 29
   6.1 Static Structural Analysis 29
   6.2 Modal Analysis 32
7. OBSERVATIONS 39
8. CONCLUSION 39
9. FUTURE WORK 40
10. REFERENCES 41
# 1. NOTATIONS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Area</td>
</tr>
<tr>
<td>CFD</td>
<td>Computational Fluid Dynamics</td>
</tr>
<tr>
<td>c</td>
<td>Chord length</td>
</tr>
<tr>
<td>$C_L$</td>
<td>Coefficient of Lift force</td>
</tr>
<tr>
<td>$C_D$</td>
<td>Coefficient of Drag force</td>
</tr>
<tr>
<td>dr</td>
<td>Blade element</td>
</tr>
<tr>
<td>$dF_L$</td>
<td>Differential lift force</td>
</tr>
<tr>
<td>$dF_D$</td>
<td>Differential drag force</td>
</tr>
<tr>
<td>$dF_T$</td>
<td>Differential thrust force</td>
</tr>
<tr>
<td>$dF_{FM}$</td>
<td>Differential force of moment</td>
</tr>
<tr>
<td>E</td>
<td>Young’s modulus</td>
</tr>
<tr>
<td>F</td>
<td>Force</td>
</tr>
<tr>
<td>$F_L$</td>
<td>Lift force</td>
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<td>Thrust force</td>
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<td>$F_{FM}$</td>
<td>Force of moment</td>
</tr>
<tr>
<td>FEA</td>
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<tr>
<td>FEM</td>
<td>Finite element method</td>
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<tr>
<td>FSI</td>
<td>Fluid structure interaction</td>
</tr>
<tr>
<td>HAWT</td>
<td>Horizontal axis wind turbine</td>
</tr>
<tr>
<td>K</td>
<td>Kinetic energy</td>
</tr>
<tr>
<td>MW</td>
<td>Mega Watt</td>
</tr>
<tr>
<td>m</td>
<td>Mass</td>
</tr>
<tr>
<td>N</td>
<td>Newton</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>NACA</td>
<td>National Advisory Committee for Aeronautics</td>
</tr>
<tr>
<td>P</td>
<td>Power</td>
</tr>
<tr>
<td>VAWT</td>
<td>Vertical axis wind turbine</td>
</tr>
<tr>
<td>$v^2$</td>
<td>Airspeed</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Density</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Angle</td>
</tr>
</tbody>
</table>
2. 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 [9]. 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.

2.1 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 [9].

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.
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 [2]. 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 [3].

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 [3]:

1. The Flutter experiments where it has no experimental data for observation of flutter limits.
2. The unsteady aeroelastic effect due to wake effects on flutter limits and it is high at tip of the blade.
3. The yaw misalignment on wind turbine blades which is blade rotation with high relative speed.
4. The damping of trailing edge flaps leads to suppression.

### 2.2 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.
3. WIND TURBINE TECHNOLOGY

The process in which the wind from the earth’s surface is used to generate mechanical power or electrical power is termed as Wind energy or Wind power. This power can be used to grinding grain or pumping water and as a generator can convert this mechanical power to electricity.

The wind turbine works by blades which rotates by in taking the air and gives power to a generator connected by a shaft, this generator produces an electric current. The rotor blade turns a shaft, which in turn connects to generator for producing electricity. The entire set up of wind turbine is shown in the figure below.

*Figure 3.1 Components of Wind turbine*

*source: NREL*
The nacelle is placed on top of wind turbine tower contains major parts such as gear box, shafts and generator and it holds the turbine hub which in turn holds the blades. The wind turbine blades functions with principles of lift to transfer the wind energy into mechanical energy. The large wind turbine blades are twisted. Since, stall regulated blades limits lift and reduces damaging the machine [10].

The wind turbine blades have several aerodynamic and an aeroelastic behavior which affects the efficiency of turbine and so careful considerations has to be done before designing the blade. Necessary analysis such as fluttering analysis is needed to be done before manufacturing the blade. Modern wind turbine design has good stability and produces enormous amount of wind energy thus by increasing more amount of electrical energy which helps in utilizing for human needs.

### 3.1 Types of Wind Turbine:

Modern wind turbines have two basic groups depending on axis of rotation of rotor blades. They are

- Horizontal Axis Wind Turbine (HAWT)

Horizontal axis wind turbine is the common wind turbine which is been commercially using all over the world now. HAWT has axis of rotation horizontal to ground and parallel to wind flow. The power output from the HAWT comparatively higher than the VAWT due to better power co-efficient since the angle of attack automatically adjusted. By the usage of this, the turbine gets more amount of wind energy and it also has an ability to pitch the rotor which has not leads to damage of the blades during extreme weather conditions.

In Horizontal Axis Wind Turbine there are two types, upwind rotors and downwind rotors. Upwind rotors normally facing the wind has a merit of avoiding the wind shade effect from tower but it also needs a yaw mechanism to position the rotor axis with direction of the flow of wind. Downwind rotors normally on the lee side of the tower. Since it don’t need yaw mechanism because the design allows the wind to flow passive and main disadvantage is the fluctuations which leads to larger fatigue loads [2].
Vertical Axis Wind Turbine (VAWT)

Vertical axis wind turbines are used in past centuries to produce power from the wind. VAWT is also designed to act towards air, since its principle exactly works HAWT and by complex design, poor efficiency it has not been used widely [2]. The components of this wind turbine are placed on the bottom of the tower, it can be easily accessible for maintenance and it is the greater advantage in this design.

The vertical axis wind turbine perfectly suits for mounting it in an area where it has extreme weather conditions like mountains because it can produce enormous amount of electricity.
Apart from these, wind turbine technology development leads to offshore and onshore construction of wind turbine.

Offshore wind turbines are usually placed on sea bed where it has wind speed higher over the open water. Offshore wind turbines are almost as similar as onshore wind turbines but with some design consideration it leads to a greater extent such as well technical, corrosion resistant and in built cranes for maintenance. The main advantage of offshore wind turbines is having low acoustic noise, low wind turbulence at high speeds and enormous amount of wind energy compared to onshore wind turbines.

Figure 3.1.2 the three main kind of Darrieus VAWT (including giromill)  
Source: www.eolienne.comprendrechoisir.com
Figure 3.1.3 Middelgrunden wind farm outside of Copenhagen, Denmark.

Onshore wind turbines are often placed outside the water bed and it has also performing some design considerations which is similar to offshore turbines. Onshore wind turbines normally produce some acoustical noises but there are some advantages like low construction period, cheaper installation of electrical network and lower maintenance.

Figure 3.1.4 Wind farm in pellworm.
3.2 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.

\[ \frac{dm}{dt} = \rho \times A \times v \]

Then, the energy per unit time is given by

\[ \frac{dK}{dt} = \frac{1}{2} \times \frac{dm}{dt} \times v^2 \]

\[ \frac{dK}{dt} = \frac{1}{2} \times \rho \times A \times v \times v^2 \]
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.

3.3 Aerodynamic loads on blades:

![Aerodynamic loads on blades](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. [2]
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

\[ F_L = C_L \frac{1}{2} \rho AV^2 \]

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

\[ F_D = C_D \frac{1}{2} \rho AV^2 \]

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 to \( F_D \). [11] 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.
4. 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.

![Flowchart of fluttering analysis](image)

*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.

![Airfoil Parameters](https://www.forum.randi.org)

*Figure 4.2 Airfoil Parameters*

*Source: www.forum.randi.org*

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.
Figure 4.3 NACA blade profile - ANSYS model
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>
<thead>
<tr>
<th>Density Kg m^-3</th>
<th>Young's Modulus Pa</th>
<th>Poisson's Ratio</th>
<th>Bulk Modulus Pa</th>
<th>Shear Modulus Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>2700</td>
<td>6.8948e+010</td>
<td>0.33</td>
<td>6.7596e+010</td>
<td>2.592e+010</td>
</tr>
</tbody>
</table>

*Table 4.1 Material properties*

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 stress is plotted.
The dynamic property of the structure under free vibration is a study called modal analysis is used to obtain the structure mode shapes and natural frequencies on a free vibrating condition. The results obtained by using FEM are quite acceptable and so FEM method is often utilized to perform the modal analysis. The Eigen systems gives rises to mode shapes and frequencies in modal analysis and the most desired modes in which the structure vibrate has lowest possible frequency dominating all other higher modes.
The aeroelastic stability analysis is done after the Eigen value analysis which gives the aeroelastic frequencies and damping of modes. This analysis is done by using an aeroelastic stability tool. The instability in blade occurs when mode shapes shows negative damping. The modes are obtained at several different points and these points are received by the rotational speed, wind speed and the blade pitch. By using this analysis, it possible to obtain or achieve the aeroelastic instability and critical flutter limit, it is dependent on the wind speed of the blade. The result actually gives the aeroelastic frequency and damping. The aeroelastic frequency shows the vibration of blades due to rotational speed, wind speed and elasticity. The damping shows the amplitude of vibration which shows the fluttering conditions [3].

The Fluid structure interaction is the combination of fluid and solid structure. It is a multiphysics problem which has effects of fluid on solid structure leads to deformation of geometry. Failing of oscillatory interactions leads to damage in structure. The FSI is done by solving the computational fluid dynamics (CFD) and finite element analysis (FEA) solvers independently and by combining both the solvers [12].

These above stated analysis are needed to perform for fluttering analysis. The results obtained from these clearly indicate the aeroelastic instability and fluttering analysis in wind turbine blades.
5. THEORY:

5.1 Introduction to ANSYS:

ANSYS is a computer aided engineering simulation software found in 1970 by USA. It is a FEM package used for numerically solving many mechanical related problems such as static and dynamic structural analysis (Linear and Non-linear), heat transfer, fluid problems, acoustic problems, electromagnetic problems.

The ANSYS workbench is a product of Ansys software which has two interface areas such as Toolbox and Project schematic. The toolbox is able to build a project which in turn has system templates. The project schematic is able to manage a running project. ANSYS workbench manages the project workflow by combines the strength of our solvers with project management tools [8]. With the help of CAD connection, auto mesh, and some integrated tools helps to perform or deliver a very good simulation product. ANSYS design modeler helps in accept a geometry which helps in direct access and user friendly.

5.2 Introduction to FEM:

FEM is abbreviation of Finite Element Method. FEM is a numerical technique for determining solutions to partial differential equations. In finite element method, the model is divided into number of elements and the elements are connected to each other at a point termed as nodes. The finite element method is solved using several steps [6]. They are as follows

1. The strong form of the governing differential equation is established.
2. The differential equation is then transformed into the weak form.
3. Meshing the solution domain after choosing element type.
4. For each element particular set of algebraic equations are established by choosing weight functions.
5. The global systems of equations are obtained.
6. Apply boundary conditions to global system of equations.
7. The algebraic solutions are then solved.
8. The solutions are presented or used for further calculations.

The FEM calculations normally not only be done by considering the strength and stiffness of the structure but also it consists of several analysis in mechanical structures such as static analysis, Frequency analysis, Dynamic analysis, Buckling analysis and Thermal analysis needed to be perform in order to get better efficiency.

![Finite element model](image)

*Figure 5.2.1 Finite element model.*

**5.3 Introduction to Aeroelasticity:**

The term Aeroelasticity is defined as combination of aerodynamic forces together with the elastic forces and dynamic forces. There is an interaction between all these forces leads to complex problems in structures. Aeroelasticity can also be defined as influence of aerodynamic forces which affects elastic bodies. The constructions such as bridges, buildings, aircrafts and wind turbines are subjected to forces from wind, waves so Aeroelasticity is to be considered here.

Arthur Roderick Collar is a scientist and engineer from University of Bath in 1947 clearly explains the behavior of all these forces. In wind turbine, the control surfaces play an important role. Pitch and generator have major influence on the aeroelastic stability of the wind turbine.
The aerodynamic forces on the structure depend on velocities of the air passing through the assembly and if the structure is deformed, the deformation will affect the aerodynamic forces. The time derivatives of the deformation will also change in aerodynamic force behaviors. The inertia force also plays a major role in correlation between aerodynamic and elastic forces. Due to changing forces the structure oscillates and the structure leads to unstable condition. Since the structure is elastic, it responds when vibrates and produces geometric patterns and these patterns are called mode shapes. These mode shapes gives corresponding mode frequency and the vibration occurs at modal frequency. Since wind turbine is a flexible structure the above stated phenomenon are obtained and the aerodynamic damping forces also has an effect on mode shapes and frequencies and so careful considerations are taken while designing the large wind turbines [5]. These aeroelastic phenomenons are very dangerous.
to structures and hard to calculate. The world famous aeroelastic instability accident occurs in Washington, U.S.A in 1940 at Tacoma Narrows Bridge which is shown in figure 5.3.2. This failure occurs due to change in phase difference between the motions of aerodynamic forces and structure where the aerodynamics forces sends energy to structure leads to failure of the structure. The bridge failure happens due to wind speed is not tolerable by bridge and which is not calculated in bridge design. After the bridge failure, it is concluded that failure is due to stall flutter, it is an aeroelastic instability occurs on structure in stalled conditions [3].

From the beginning of wind turbine technology, one of the major problems in designing the safer wind turbine is fluttering phenomenon. In fluttering, the wind turbine blades will vibrate with increasing amplitude and it may lead to structural damage and loss of control of the blade. Therefore, it is necessary for engineers to prevent the flutter in wind turbine [5].

![Figure 5.3.2 Vibrations in Tacoma Narrows Bridge](image-url)
5.4 Blade Element Momentum Theory

The blade element momentum theory is a 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 obtaining maximum power output from the wind. The blade has several elements and 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 determine 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 [11]

*Figure 5.4.1 Blade element*
The differential lift force of the blade element is

\[ dF_L = C_L \left( \frac{1}{2} \rho AV^2 \right) c \cdot dr \]

The differential drag force blade element is

\[ dF_D = C_D \left( \frac{1}{2} \rho AV^2 \right) c \cdot dr \]

The differential thrust force of the blade element is

\[ dF_T = dF_L \cos \phi + dF_D \sin \phi \]

\[ dF_T = \frac{1}{2} \rho AV^2 \left( C_l \cos \phi + C_d \sin \phi \right) c \cdot dr \]

The differential force of moment of the blade element is

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

\[ dF_{FM} = \frac{1}{2} \rho AV^2 \left( C_l \sin \phi - C_d \cos \phi \right) c \cdot dr \]

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.
6. FEM ANALYSIS

The fluttering analysis in wind turbine blades has been performed by studying Finite element method through structural analysis, modal analysis, FSI of blades. Now, in this project the general structure of static structural analysis and modal analysis are performed. These structural performances are studied using several assumptions, boundary conditions and load behaviors.

6.1 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](image)

*Figure 6.1.1 Force and Support*
Total deformation

Figure 6.1.2 Total Deformation
Equivalent 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.

Figure 6.1.3 Equivalent (Von-Misses) Stress
6.2 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
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.

<table>
<thead>
<tr>
<th>Mode Number</th>
<th>Frequency (Refined Mesh 1) [Hz]</th>
<th>Frequency (Refined Mesh 2) [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>9.3753</td>
<td>9.3736</td>
</tr>
<tr>
<td>2.</td>
<td>17.8</td>
<td>17.79</td>
</tr>
<tr>
<td>3.</td>
<td>33.751</td>
<td>33.743</td>
</tr>
<tr>
<td>4.</td>
<td>78.307</td>
<td>78.278</td>
</tr>
<tr>
<td>5.</td>
<td>118.82</td>
<td>118.79</td>
</tr>
<tr>
<td>6.</td>
<td>121.07</td>
<td>121.01</td>
</tr>
</tbody>
</table>

*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.
7. 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.

8. 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.
9. 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.
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