"Design, Modeling & Analysis of Small Horizontal Axis Wind Turbine Blade Operating at Low Wind Speed"

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ABSTRACT

Wind power is one of the most important sources of renewable energy. Wind-turbines extract kinetic energy from the wind. In this present scenario where the conventional energy resources (coal, petrol etc.) are being vanished away, non-conventional energy resources like wind energy has attracted a great deal of attention in recent years and as one of the possible alternative renewable energy resources. India has great potential for Non-conventional energy resources (solar energy, wind energy), but in India harvesting of wind energy is rare and it is carried out only in large scale mainly for power generation. Currently much research has concentrated on improving the aerodynamic performance of wind turbine blade through wind tunnel testing and theoretical studies. These efforts are much time consuming and need expensive laboratory resources. However, wind turbine simulation through ANSYS software offers inexpensive solutions to aerodynamic blade analysis problem. In this study, two-dimensional aerofoil (i.e. SG 6043) models are presented using ANSYS software. This micro wind turbine is a horizontal axis wind turbine (HAWT) consists of 3 blades. So this micro wind turbine can generate power which can be use for domestic purposes like water lifting, electricity etc.

Keywords: *Micro Wind Turbine, Blade, SG, FRP, HAWT, Airfoil*

1. INTRODUCTION

Renewable Energy Source (RES) are playing an increasing role in the modern electric power generation system due to their local availability. Due to technological improvements wind power makes up for the largest shear of RES electricity production today. The utilization of wind energy for electrical power generation purpose is become gaining a great shear in the electric power production market worldwide. The basic principle of wind turbine blade converting wind energy into electricity comes from the lift produced by the air flowing over the blade. Blade capture wind energy which is converting into mechanical and then this again converted into electrical energy by using generator. The actual flow of air is passing over the blade it can move by the wind velocity and then by movement of blade it wills generator the electric power. In this study the operational aerodynamic parameter has a direct effect on the power generation. scientists and researches globally to explore power generation from renewable source such as wind the domestic scale wind turbine have immense potential for wind power generation in built up areas It can describe a multi objective optimization method for the designing of a small HAWT blade design. The scope of the method to design a blade is to achieve the trade of performance between the two objectives: annual energy production per square meter of wind power (to be maximizing) and cost of energy (to be minimization). For designing blade BEM theory is used and the computer program is developed to complete the procedure of design

1.1. Problem Definition

To develop blades for a small scale wind turbine so as optimized the blade geometry and maximize power coefficient. Simulation based design procedure selection for best airfoil, blade geometry and also reduces aerodynamic losses by using best airfoil and also increases blade strength.

1.2 Need for Small Wind Turbine

Small wind turbines may be used for a variety of applications including on or off-grid residences, telecom towers, offshore platforms, rural schools and clinics, remote monitoring and other purposes that require energy where there is no electric grid, or where the grid is unstable.

2. METHODOLOGY AND DESIGN PROCEDURE

Blade design and engineering is one of the most complicated and important aspects of current wind turbine technology. Today engineers strive to design blades that extract as much energy from the wind as possible throughout a range of wind speeds and gust yet is durable, quiet and cheap.

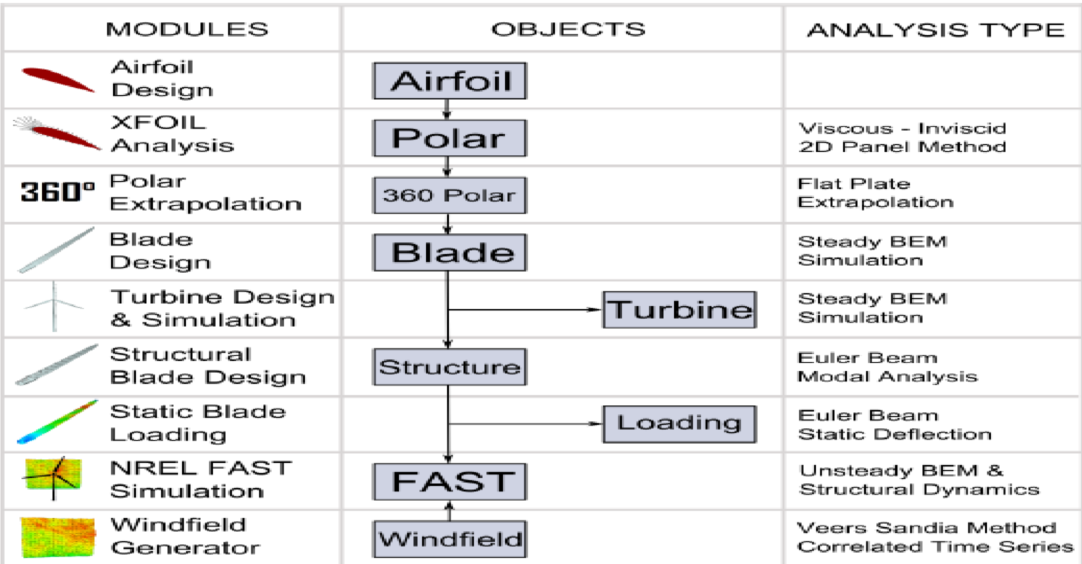

Figure 1: Flowchart

3. BLADE DESIGN THEORY

3.1 Theories Used For Wind Turbine Blade:

There are two theories used in design of wind blade, these are – i) Blade Element Momentum Theory. ii) Rotor disc theory The basic assumption in blade element momentum theory is that the force of the blade element is solely responsible for the change of momentum in the air which passes through the annulus swept by the blade element. Therefore it is assumed that there is no radial interaction between the flows.BEM theories equates two methods of examining how a wind turbine operates. The first method is to use a momentum balance on a rotating annular stream tube passing through a turbine. The second is to examine the forces generated b the aerofoil lift and drag coefficients at various sections along the blade. An annular ring is created when a blade element is swept in the axial direction of the blade while the blade rotates. If two dimensional airfoil characteristics along with an angle of attack calculation are utilized, then the forces present on this blade element can be calculated. In the case of the axial flow induction factor *a* and the tangential flow induction factor *a'*, values can be calculated with information about the aerofoil characteristic coefficient of drag *Cd* and coefficients of lift For the following equations, consider a wind turbine with *N* blades of tip radius *R* each with chord *c*. Let the blades be rotating at angular velocity Ω and let wind speed be *U*∞, angle φ is the angle between the drag vector and the lift vector and angle α is the angle of attack.

3.1.1 Rotor Disc Theory:

The manner in which the extracted energy is converted into usable energy depends upon the particular turbine design. Most wind energy converters employ a rotor with a number of blades rotating with an angular velocity about an axis normal to the rotor plane and parallel to the wind direction. The blades sweep out a disc and by virtue of their aerodynamic design develops a pressure difference across the disc, which, as discussed in the previous section, is responsible for the loss of axial momentum in the wake. Associated with the loss of axial momentum is a loss of energy which can be collected by, an electrical generator attached to the rotor shaft, as well as a thrust, the rotor experiences a torque in the direction of rotation. The generator exerts a torque equal and opposite to that of the airflow which keeps the rotational speed constant. The work done by the aerodynamic torque on the generator is converted into electrical energy.

3.1.2 Selection of Airfoil:

The airfoil shape of the blade helps to generate lift by taking advantage of the Bernoulli Effect. Wind turbine blade designers have experimented with many different airfoil shapes over the years in an effort to find the perfect shape that will perform well in a range of wind speeds. Even minor changes in this blade shape can dramatically affect the power output and noise produced by a wind turbine. To get some ideas of different airfoils used in airplane wings and wind turbine blades, research the United States National Advisory Committee for Aeronautics (NACA). This group was responsible for designing a wide range of airfoils in the

1940's. The airfoil profile (shape) of a turbine blade will actually change down the length of the blade, generally getting flatter and narrower toward the tips of the blades. This is to optimize the lift and minimize drag.

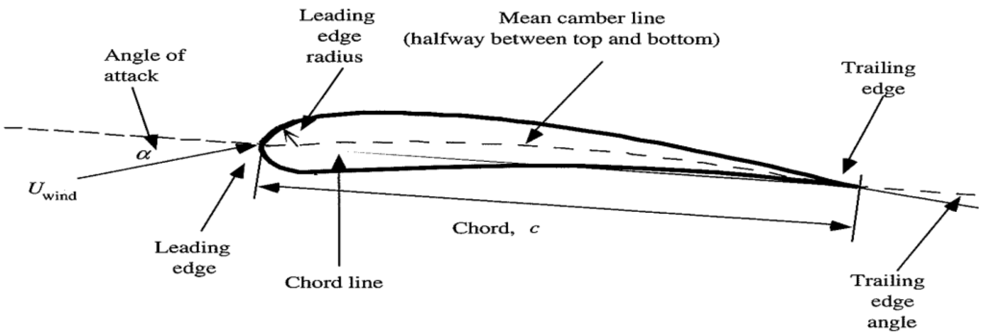

Figure 2: Airfoil Nomenclature

3.2 Specifications Of Wind Turbine:

Table 1: Specifications of Wind Turbine

Sr. No.	Parameter	Details
1	Blade Length	0.746 m
2	Rotor Diameter	1.492 m
3	Number of Blades	3
4	Blade Material	E-Glass Fiber
5	Tip speed ratio	9
6	Lift coefficient	1.2
7	Mean wind speed	11 m/s
8	Density of air	1.227 kg/m^3
9	Angle of attack	6°

3.3 Optimized Blade Geometry

Figure 3 indicates that axial induction factor decreases when local tip speed ratio increases hence local tip speed ratio direct impact on the blade design

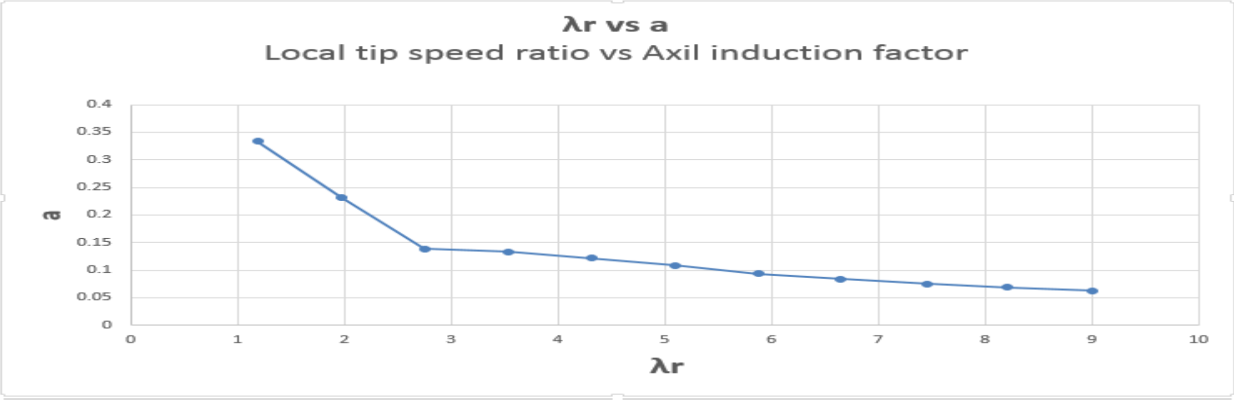

Figure 3: Local tip speed ratio(λr) versus axial induction factor (a)

Figure 4 indicates that rotational induction factor decreases when local tip speed ratio increases.

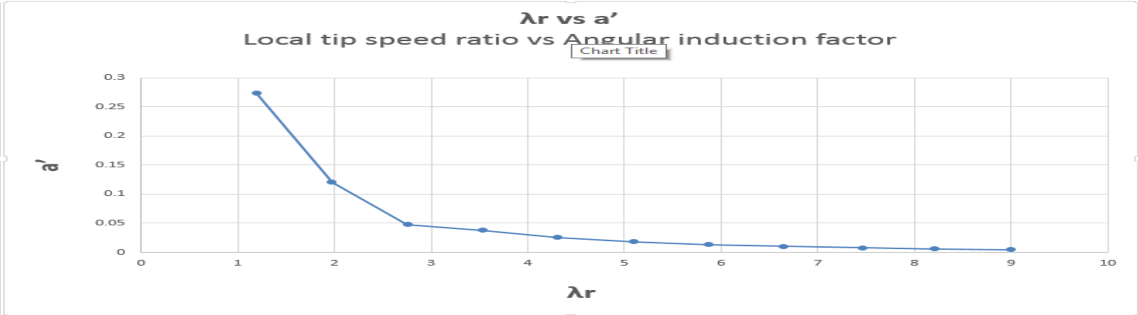

Figure 4: Local tip speed ratio(λr) versus rotational induction factor (a')

Figure 5 indicates that maximum twist occurs at the root while at the tip twist angle equal to be approximate zero degree**.**

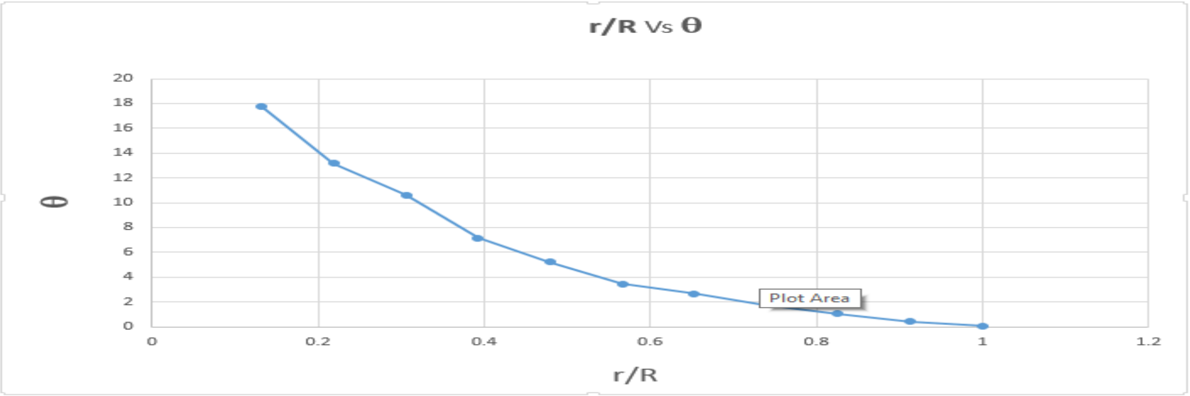

Figure 5: Section radius versus (r/R) versus Twist angle (θ)

Figure 6 indicates that when solidity increases then blade performance will be increases. Solidity increases by increasing the chord length as well blade number. Therefore blade number and chord length impact on the blade performance.

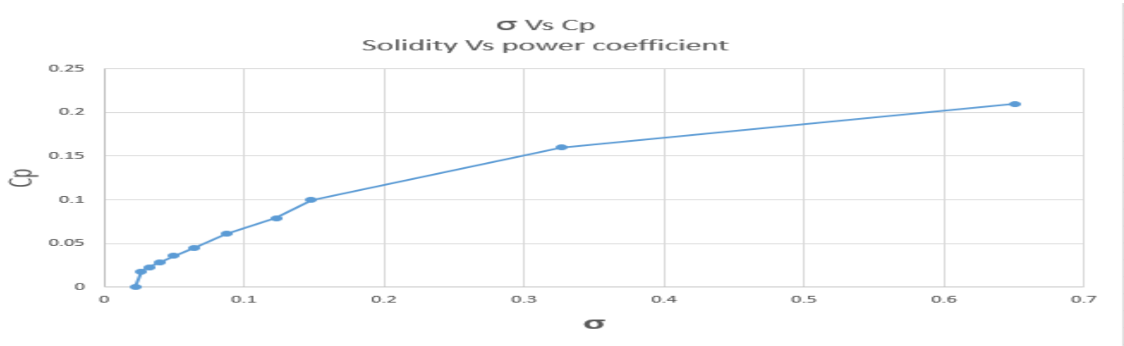

Figure 6: Solidity (σ) vs. Coefficient of power (Cp)

4 .LOADS ON WIND BLADE

Loads acting on wind blade during operation are as follows:

1. Aerodynamic loads 2. Gravitational loads 3. Centrifugal load. 4. Gyroscopic load. 5. Operational load.

The load magnitude will depend on the operational conditions. As turbines increase in size, the mass of the blade is said to increase proportionately at a cubic rate. The gravitational and centrifugal forces become critical due to blade mass and are also elaborated. Gyroscopic loads results from yawing during operation. They are system dependent and generally less intensive than gravitational loads. Operational loads are also system dependent, resulting from pitching, yawing, breaking and generator connection and can be intensive during emergency stop or grid loss scenarios. Gyroscopic and operational loads can be reduced by adjusting system parameters. Blades which can withstand aerodynamic, gravitational and centrifugal loads are generally capable of withstanding these reduced loads. Therefore, gyroscopic and operational loads are not considered within this work

5. CAD MODELING IN CATIA SOFTWARE

First to developed blade design model in CAD software then further simulation in ANSYS software

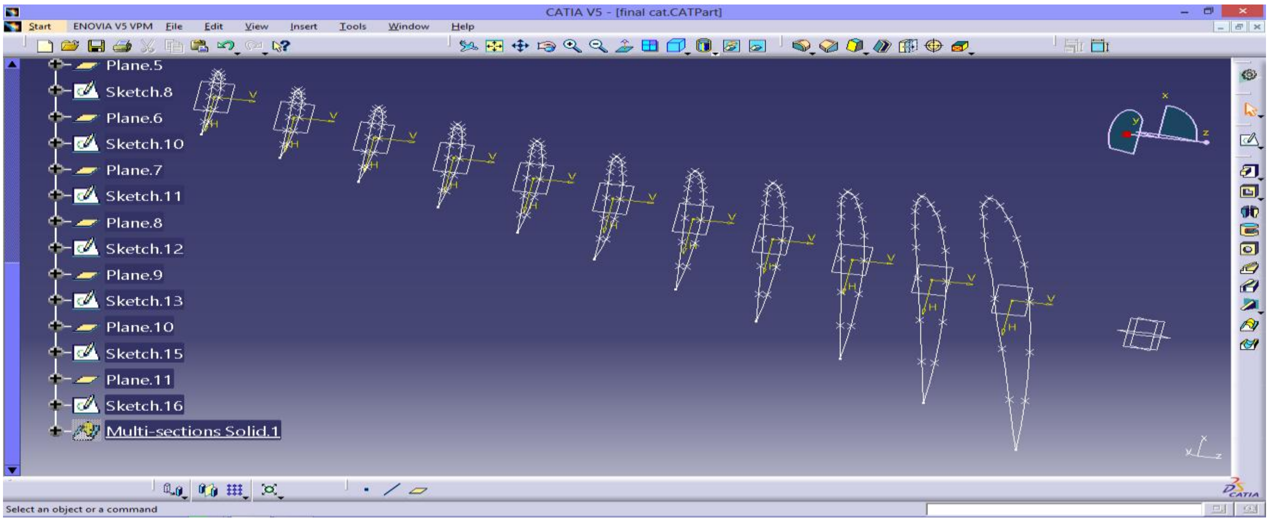

Figure 7: Creating sections of the blade

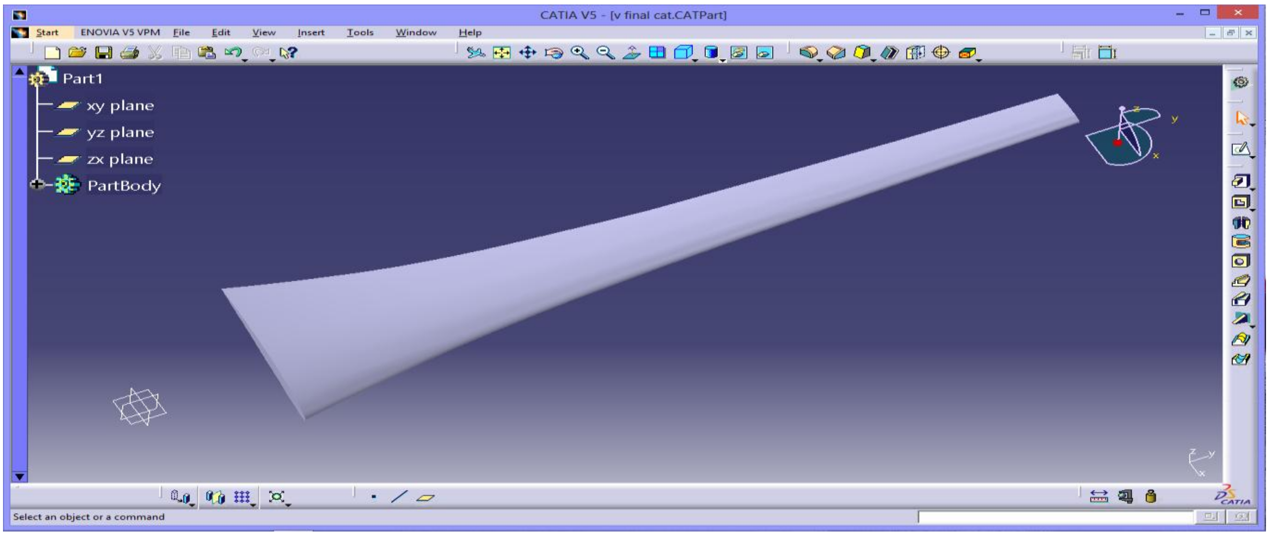

Figure 8: Cad modeling

5.1 Finite Element Analysis (FEA)

Finite Element Analysis of the Small Wind Turbine Blade was carried out using ANSYS software. Small wind Turbine Blade is considered for case study.

1) Description- Analysis is done on the small wind blade to understand the dynamic and to serve as milestone point, form where we can assess the performance of blade.

2) Geometric modeling- The major dimensions and the solid model of the Small Wind Turbine blade are as shown in Figure. The solid model of Blade can be imported in ANSYS from other CAD software.

5.2 Structural Analysis:

Meshing-Meshing was done using the Software: ANSYS Workbench 14.5

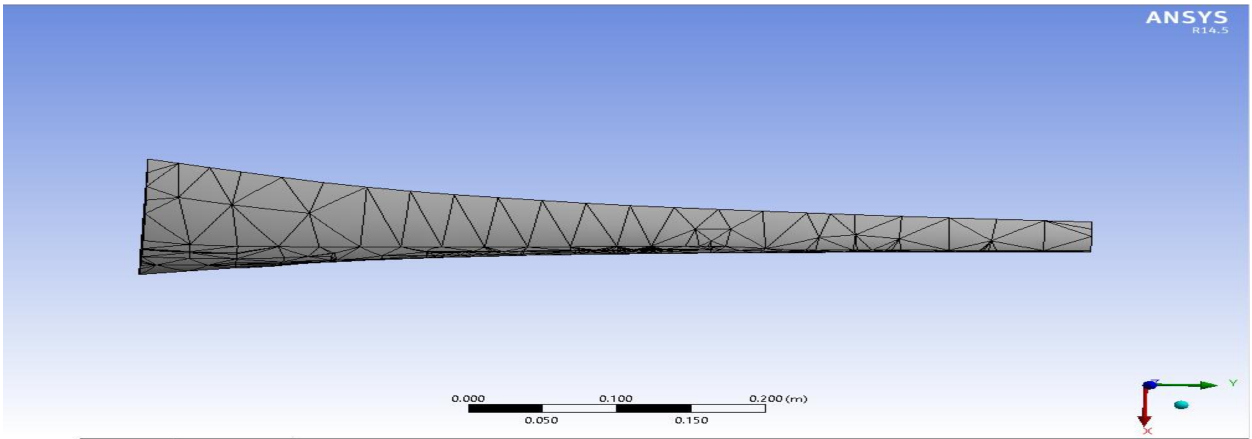

Figure 9: Meshing of Blade

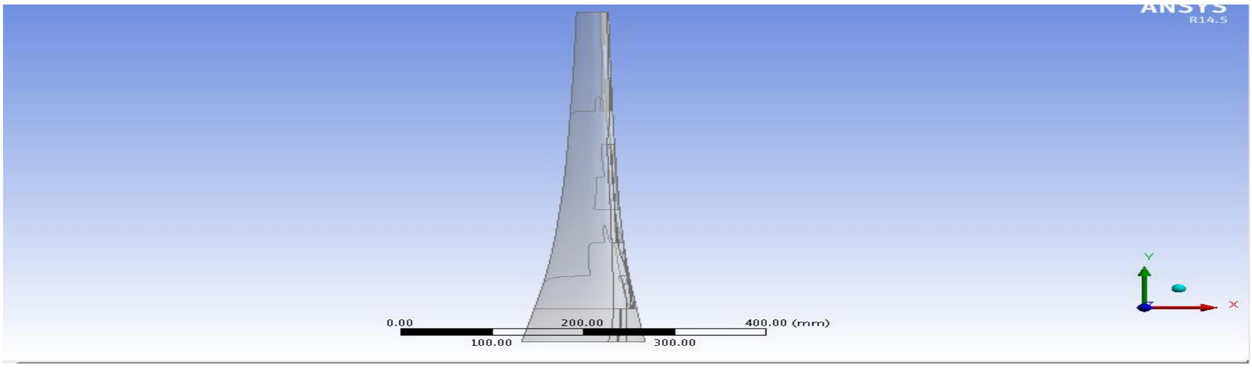

Figure 10: Model of wind turbine blade in Ansys

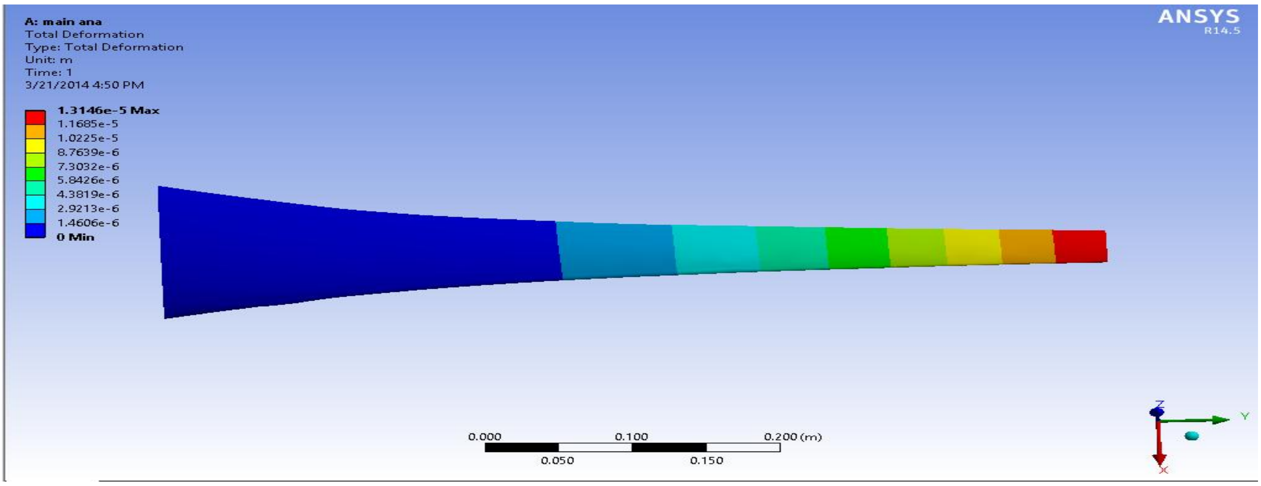

Figure 11: Total Deformation of wind blade

Figure 9, represents meshed in ANSYS Workbench 14.5 with consideration of 5180 nodes. in Figure number 10 and 11 indicates minimum deformation occurs at the tip, while at root minimum deformation is and total deformation is 0.013 mm,

VI RESULT

The resulting stress pattern after solving blade is shown in figure .The maximum Von misses stress is 3.10e7 Pa, which occurs in the area of a blade which is shown in red color. The deflection of the blade is shown in figure. The maximum deflection being 0.013mm occurring at the tip of the blade and is shown by red color.

Table 2: Deformation Result

Component Name	**Total Deformation (mm)**	**Equivalent Von- Misses Stress (Pa)**	**Yield Stress (Pa)**	**Factor of safety**	**Element Size**	**Nodes**	**Method**
Small wind Turbine blade	0.013	3.10e7	2.09e8	6.72	2.79e-4	5180	Hex Dominant

Table 3: Structural Analysis

Analysis	**Analytical**	**Structural**
Yield strength of material (pa)	2.09×10^{8}	$2.09\times^{8}$
Max. equivalent stresses (pa)	3.89×10^{7}	3.10×10^{7}
Max. total deformation (mm)	0.0021	0.013
Factor of safety	5.37	6.72

7. CONCLUSION

From the paper it concluded that wind has a lot of potential in it and if properly harnessed then it can help solve the energy crises in the world. The study of wind turbine and its characteristics showed that how it can be properly designed and used to get the maximum output. Also we conclude that the airfoil SG 6043 is best suited airfoil for our design. We are using the ANSYS software for analysis the design of blade and comparing the results with analytical results. Our factor of safety by analytical method is 5.37 and by structural method are 6.72. Hence design is safe.

NOMENCLATURE:

a = Axial Induction Factor.

a' = Tangential Induction Factor.

B = Number of blades.

C = Chord length (m).

R = Blade tip radius (m).

r = blade radius at section (m).

D = Drag (N).

L = Lift (N).

Cd = Drag coefficient.

Cl = Lift coefficient.

Cp = Power coefficient

ρ = *Air density (kg/m^3).*

σ = *Solidity.*

λ = *Tip speed ratio.*

λr = *Local tip speed ratio.*

α = *Angle of attack.*

ϕ = *Setting angle.*

θ = *Twist angle*

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