Design and static analysis of polymer composite wind turbine blade

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Abstract. Wind power is one of the world’s fastest-growing energy sector and relatively mature technologies. Wind power is changing the wind energy into electricity, in which the blade plays a very important role. At present large-scale wind turbine blades are almost made of composite materials. Composite materials are a kind of new materials. Because of its high strength, stiffness, weight-lightness, resistance to fatigue, vibration, high temperature, easy-to-design, etc, the composite laminates plates have been widely used in the wind energy field. Therefore, blade vibration analysis, structural design technology and composite materials technology are closely linked. This is a paper on static analysis of polymer composite material for wind turbine blade. By an analysis using CATIA a better wind turbine profile is to be obtained with increased efficiency of energy generation and reduced damage due to vibration.

Keywords: wind, composite, blade, static, turbine, analysis

1. Introduction

The wind turbines are mostly of two different configurations based on their mode of axis of rotation as horizontal and vertical axis wind turbine generators. Large areas installed with wind turbines, that is, wind farms are increasingly emerging today in most parts of the world as its emerging to be one of the leading renewable energy conversion. A wind turbine generator converts the kinetic energy of the wind to useful mechanical energy. This energy could be used in mechanical form or turn generator turbines and provide electricity. Just like in the hydropower systems, wind energy is harnessed through conversion of the wind kinetic energy to mechanical energy. The kinetic energy in wind is converted to electricity by wind turbine generators. They use the ancient concept used in windmills though with inherent technology, such as sensors, to detect wind direction, wind speed, etc., Almost all wind turbines have braking system to halt in case of strong winds to protect the rotor and blades from damage. There are gears connected to the rotor shaft to accelerate the rotor speed to a speed suitable for the generator. Inside the generator, electromagnetic induction (the basic method of conversion from mechanical energy to electricity) occurs. The shaft rotates a cylindrical magnet against an electric wire coil. All electricity from the turbines in a wind power station is assimilated to a grid system and converted to a high voltage. This is actually the conventional technique of transmitting electricity in the grid system. Large surface-tipped blades are needed although this should be determined by the noise that results from wide blades. A wind farm may have up to 100 generators, which will result in more noise. The blade element theory assumes that the flow at a given part of a wind turbine blade does not affect the
adjacent parts. This subdivision on the blade is called annulus. The momentum is calculated for each annulus. All the resultant values are then summed up to represent the blade and hence the entire propeller. The calculation of the breeze stream around pivoting sharp edges is an unpredictable issue. A thorough study on three dimensional Navier-Stokes on the turbine blade surfaces will provide a exact information on the breeze stream and the power expected. However the computational expense to acquire such exact arrangement disallows their utilization in the structure and examination situations [1].

The varied wind speed at different locations across the globe has lead to different kind of wind turbine designs specifically for applications to the concerned places. Wind speed data measured by Bangladesh meteorological data over a period of 10 years from 1998 to 2007 upon statistical analysis has resulted in installation of wind turbines for irrigation purposes in the delta region during the dry season rather than electric power conversion [2]. The data has been fitted for Weibull's distribution and determined two important parameters like Weibull's shape factor and Weibull's scale factor by three methods and compared to each other [2].

The average wind speed of 8 m/sec is mostly preferred for installation of wind turbines and thus sites are mostly selected based on the data measurement conducted over a period of at least an year. The department of energy conducts this survey by installation of wind measurement towers in potential places. The wind turbine blades are the most significant part of a wind turbine generator. The evoulution of wind turbine blades since the last few decades have lead to lot of design choices and can be chosen from standards. The blade profile is so significant that air foil cross section plays an important part in the range of power that is developed cutting across winds. The wind blade design is determined using blade element momentum. The blade design plays a significant factor, as it is a part of the energy absorption system. Horizontal axis wind turbine (HAWT) blade designs use airfoils to transform the kinetic energy in the wind into useful energy and it has to be designed carefully to enable to absorb energy with its highest efficiency. Among varying factors for selection of a blade profile, the chord length and twist angle are the one that depend on various values throughout the blade [3].

Analyses of blade designs are being done by Comsol Multiphysics software that is integrated with NACA series. Three dimensional models of blade done by Design Foil and Solidworks software followed by numerical simulation for analysing strength by investigating the Von Mises stress distribution will help in achieving a perfect design [4]. NACA 4412 blade profile provides maximum lift to drag ratio and it is one among the most preferred. Wind at a typical site provides a reynolds number of 46406 based on the viscosity, density and wind velocity [5].

Optimum design of composite wind turbine blades is done usually in two steps. The results of the first step are the aerodynamically optimal cord lengths and twist angles of airfoils for the blade cross-sections along the blade spanwise direction. The second step yields optimal material distribution for the composite blade. A typical 3 MW wind turbine with blades having cross-sections of NREL S818, S825 and S826 airfoil types loaded by maximum forces and moments extracted from simulated time series after a parameterized finite element model of the aerodynamically optimized blade created using the ANSYS software [6] will be an optimum design method.

At locations with moderately high wind speeds sufficient amount of energy can be harnessed by making use of multiple wind turbine units. The blades of such turbines are so designed that they generate lift from wind and thus rotate. Blades are usually manufactured using materials like structural steel, epoxy carbon, s-glass, e-glass and aluminium alloy [7]. Applying space coordinate transformation theory blade elements can be calculated by creating mathematical model using MATLAB tool based on Wilson method [8]. It is evident that wind offers environment friendly energy as no fossil fuel combustion is carried out during conversion of wind energy. This does not mean that there is absence of environmental impact. The effects arise while manufacturing the components of wind turbine, energy usage while transporting and commissioning at sites. The future projections for expansion of this industry strengthen the need for optimization in all facets, considering their total life cycle as the main tool. Composite materials are commonly used in wind turbines due to their excellent mechanical properties, matched by low weight. The recycling technology of such materials is limited primarily because of the lack of markets. Novel concepts must be generated [9].

The objective of this paper is to design and analyse polymer composite as a wind blade material for efficient conversion of wind to mechanical energy with low chances of blade
3. Breakage. Conventionally materials ranging from metals to composites are in use and still more combination of composites are in the research stage. Blades are vital part of the wind turbine and researchers are recommending the usage of the composite materials because of its light weight and stiffness. Polymer composite is chosen and applied to the material design as per the blade standard and an analysis is carried out using a finite element package. Hence, investigation is carried out on the structural characteristics by static analysis using finite element analysis method in CATIA to check the behavior of the turbine blades and their modes of behavior due to the high velocity wind flow and we are going to model the profile for better strength and shock absorbing properties.

2. Methodology

The Wind turbine blade used for the generation of electricity are of huge size which is very difficult to manufacture and to be tested which involves manual effort and expensive. The design of a wind turbine blade of polymer composite material for a 1 MW power generation capacity with the combination of N series and D series airfoils with different profile radius is carried out. A static analysis of the blades stiffness to withstand the force applied on the blade during heavy wind is performed. As part of it the bending stress and frequency analysis to check the resonant frequency is achieved. Comparison of average values of four criteria between selected NACA and NREL airfoils is mentioned below for proper selection of airfoils for small wind turbine for extraction of maximum wind energy. Average of maximum Grash of (Gr) number at Re of $1.0 \times 10^5$ for NACA airfoil is 46.5 whereas it is 41 for NREL airfoils.

Now there are many aerofoil series suited for individualistic applications and performances. In the 1990’s supercritical aerofoil profiles were meeting the high speed flying conditions and thus the evolution of high speed aerofoil designs took place [10].

The faster the wind blows, the more lift that is produced on the blade, hence faster the rotation. The advantages of a curved rotor blade compared to a flat blade is that lift forces allow the blade tips of a wind turbine to move faster than the wind is moving generating more power and higher efficiencies.

The early NACA airfoil series, the 4-digit, 5-digit, and modified 4-/5-digit, were generated using analytical equations that describe the camber (curvature) of the mean-line (geometric centerline) of the airfoil section as well as the section’s thickness distribution along the length of the airfoil. Later families, including the 6-Series, are more complicated shapes derived using theoretical rather than geometrical methods. Before National Advisory Committee for Aeronautics (NACA) developed these series, airfoil design was rather arbitrary with nothing to guide the designer except past experience with known shapes and experimentation with modifications to those shapes.

The aerodynamic coefficients are dependent on their body shape (airfoil section chosen), and also on the altitude (angle of attack), Reynolds number, Mach number, surface roughness, and air turbulence [11]. Figure 1, 2 & 3 shows the NACA airfoil with four, five and six digits has check the effects of airfoil thickness and maximum lift coefficient.

![Figure 1](Image) Four -Digit NACA Airfoil [12]  [Figure 2](Image) Five - Digit NACA Airfoil [12]  [Figure 3](Image) Six -Digit NACA Airfoil [12]
3. Result and Discussions
Wind turbine blade model 1 made of the epoxy polymer composite material to produce the 1 MW power is shown in fig.5. The critical part of the blade is designed based on its parameters like the chord length, radius of the blade and the distance between the sections. The cross-section of the blade is made chosen from N-series and D-series airfoil from the standard air foil tools. In the first model the cross-section is considered apart from the velocity of the wind and fluctuation of the rotor speed the blade are analyzed for its structural stiffness and the bending moment that can predict the stability.

A model 2 wind turbine is also designed of the same epoxy polymer composite material with the same cross-section foil with different radius and the chord length. The distances and thickness are maintained same.

Both the models are designed in the CATIA V5 and a static structural analysis was performed with longer edge being the boundary condition and 1000N force is applied on the system. The computation is made with pre-assigned material properties and the deformation, displacement and the principal stress tensor and von-misses stress are compared.

Table-1 Model-1 wind turbine blade parameters

| Section | Type of Cross section | Thickness | Chord length (mm) | Radius (mm) | Distance between sections (mm) |
|---------|-----------------------|-----------|-------------------|-------------|-------------------------------|
| 1       | N-Series NACA 64(1)-012 airfoil | 100%      | 100               | 0           | 0                             |
| 2       | N-Series NACA 64(1)-012 airfoil | 110       | 0                 | 0           | 150                           |
| 3       | N-Series NACA 64(1)-012 airfoil | 120       | 0                 | 0           | 250                           |
| 4       | N-Series NACA 64(1)-012 airfoil | 130       | 0                 | 0           | 350                           |
| 5       | D-Series DU84-132V3 AIRFOIL | 140       | 0                 | 0           | 450                           |
| 6       | D-Series DU84-132V3 AIRFOIL | 150       | 0                 | 0           | 550                           |
| 7       | D-Series DU84-132V3 AIRFOIL | 160       | 0                 | 0           | 650                           |
| 8       | D-Series DU84-132V3 AIRFOIL | 170       | 0                 | 0           | 750                           |
| 9       | D-Series DU84-132V3 AIRFOIL | 180       | 0                 | 0           | 850                           |
| 10      | D-Series DU84-132V3 AIRFOIL | 190       | 0                 | 0           | 950                           |

Fig.4 Epoxy Composite Blade-model 1
Fig.5 Meshed part of the model.1
Fig.6 Displacement diagram of model 1
Fig.7 Vonmises stress for model-1
Table 1 shows the description of the blade airfoil shape along with the chord length, thickness, radius and the distance between the subsequent profiles. 3D models of the blade for the given value are shown in Fig 4. The blade with meshes (tetrahedron mesh) and after the boundary condition with the necessary boundary condition and forces are shown in Fig 5. The displacement and the von-mises stress are shown in Fig 6 and Fig 7 respectively. In the same procedure the table 2 shows the sections and its parameters valued for model-2.

**Table 2** Parameters of wind turbine blade for model-2

| Section | Type of Cross section | Thickness | Chord length (mm) | Radius (mm) | Distance between sections (mm) |
|---------|-----------------------|-----------|-------------------|-------------|-------------------------------|
| 1       | N-Series              | 100%      | 100               | 0           | 0                             |
| 2       | NACA 64(1)-012 airfoil| 100%      | 110               | 500         | 150                           |
| 3       |                       | 100%      | 120               | 500         | 250                           |
| 4       | D-Series              | 100%      | 130               | 450         | 350                           |
| 5       | DU84-132V3 AIRFOIL    | 100%      | 140               | 450         | 450                           |
| 6       |                       |           | 150               | 400         | 550                           |
| 7       |                       |           | 160               | 400         | 650                           |
| 8       |                       |           | 170               | 350         | 750                           |
| 9       |                       |           | 180               | 350         | 850                           |
| 10      |                       |           | 190               | 350         | 950                           |

Fig. 8 Epoxy composite blade mode  
Fig. 9 Deformation of the model-2  
Fig. 10 Displacement of model-2  
Fig. 11 Principal tensor stress of model-2  
Fig. 12 Von mises stress value for model-2
The Fig.8 and Fig.9 shows the 3D model of the blade with the radius and deformation structure. Fig.10 and 11 shows the displacement and principal tensors along with that the fig.12 depicting the von-mises stresses.

And in the Table 3, the values obtained from the displacement and vonmises stress of the model 1 and 2 are tabulated for comparison. It is been observed from the graph obtained in Fig.13 that the model 2 values has the minimum deformation and displacement and less stress in comparison to model 1 of the epoxy polymer wind turbine blade.

Table 3- Comparison of the Displacement and Von-mises stress values

| Model 1 | Model 2 |
|---------|---------|
| Displacement(mm) | Displacement(mm) | Von-mises Stress(N/mm²) | Von-mises Stress(N/mm²) |
| 3.37 | 3.24E+06 | 2.09 | 2.25E+06 |
| 3.04 | 2.92E+06 | 1.88 | 2.02E+06 |
| 2.7 | 2.59E+06 | 1.67 | 1.80E+06 |
| 2.36 | 2.57E+06 | 1.46 | 1.58E+06 |
| 2.02 | 1.95E+06 | 1.25 | 1.35E+06 |
| 1.69 | 1.53E+06 | 1.05 | 1.13E+06 |
| 1.35 | 1.31E+06 | 0.88 | 9.06E+05 |
| 1.00 | 9.83E+05 | 0.62 | 6.83E+05 |
| 0.66 | 6.61E+05 | 0.48 | 4.60E+05 |
| 0.03 | 3.88E+05 | 0.22 | 2.36E+05 |
| 0 | 1.58E+05 | 0 | 1.30E+05 |

Fig.13 The comparison graph showing the blade models analysis

4. Conclusion
The two models of the wind turbine blade has been created using the Catia V5. The model 1 is created applying the combination of the N-series blade profile and D-Series blade profile by changing the length of the chord without changing the radius and thickness. The length of the blade is the combination of multi-section created by using the two series blade profiles. The model 2 is created using the same N and D series profiles but here the radius of the profile has been considered along with the chord length.

The comparison table and the chart show that the rigidity and stability of the model 2 are better in comparison to the model 1. Thus, the model 2 has better force withstanding structure. And in the near future the entire length of the profile angle may be optimized for better life of the blade.
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