A FEA Analysis of Blade of HAWT: A Review

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

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

Abstract - *In this paper Exhaustive review of various research paper has been carried out to find the advancement for the future application of FEA analysis of HAWT blades. Our project is an attempt to study and analyze the wind turbine blades. FEA software ANSYS has been used to analyze the stresses and loading condition of wind turbine blades. The wind regime of the region for every month is found out with the help of wind charge controller integrated with the wind turbine. In this study, the finite element analysis of various blades geometry of different wind turbine installed at different location of the world has been carried out.*

Key Words: FEA Analysis, HAWT Blades, Wind Regime, Wind Speed, Blades Geometry

1.INTRODUCTION

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

A wind turbine consists of the following parts:

- blades

- rotor,

-generator,

-driven chain,

-and Yaw system

-control system and so on.

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

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

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

2. LITERATURE REVIEW

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

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

All structures act specifically under the action of aerodynamic forces, structures can change its properties like structure constants, stiffness coefficient and natural frequencies under the influence of aerodynamic forces. So, the structure becomes instable even the reliability of the design of the system is improved. Due to the instability of the system the system has been destructed by an amount of specific force this phenomenon of destruction due to the specific amount of forces which is created by the specific amount of relative velocity is called Flutter phenomenon. And the specific speed responsible for destruction is called the speed of fluttering [9]. For making the safety of the system once the flutter speed has been recognized then the safety of structure can be ensured. In structures like an aeroplane, flutter speed is considered as the limiting velocity. Limiting velocity is the velocity which must not be reached by an aircraft under any circumstances.
An aero elastic instability may be the cause of failure of an aerospace or air crafts so for ensuring the same the Joint Aviation Requirements (JAR) [10] standard is used for preventing the flutter phenomenon in the vicinity of fluid velocity, and the bending and torsion frequencies are isolated.

Shokrieh and Taheri [11] carried out a mathematical and experimental study of aeroelastic stability which is based on this standard of composite blades of aircrafts. Baxevanou et al. [12] discussed a new aeroelastic geometric model, which combines a Navier-Stokes equation with the solutions of CFD with a model of elasticity and the schemes of two coupling for studying the aero-elastic behavior of wind turbine blades undergoing flutter phenomenon. Fazel-Zadeh et al. [13] worked on the couple of bending-torsional moment which contribute a flutter phenomenon of a wing containing a randomly placed mass under a dynamic force which drives the process.

Effect of the location and magnitude of the mass and the driving force on the fluttering phenomenon and the frequency of the air crafts blades are shown in the study and it is important to notice that the results are considerable. Performance and characteristics of wind turbine blades are investigated by Lee et al. [14]. They proposed a Strip theory which is known as Modified Strip Theory which is based on the fluid –structure interaction.

Fatigue phenomenon of the blades has been considered by several researchers and found out the fact that failure started from the root and digital sampling strain gauge is used to find out the strain at a particular location. And by using Miner's rule [15] total load spectrum has been calculated, total load is obtained by the summation of all weighted load spectra.

And it is observed that some shortcoming of Miner's rule like its linear nature and simulation in the load sequence and history of load events for the consideration of fatigue failure in the metal or in the composites materials [16].

Many researchers and observers have been observed that for the fatigue simulation of the composite blades structure a deterministic approach is of importance so their main focus is the deterministic approach and finding the proper place to install the strain gauge for extracting the load spectrum and its magnitude [15].

M. Grujicic, G. Arakere, E. Subramanian, V. Sellappan, A. Vallejo, and M. Ozen [18], in this paper discussed about the problem of mechanical design, performance prediction, and material selection for a horizontal-axis wind turbine (HAWT) blade is investigated using various computeraided engineering tools. A fully parameterized computer program has been developed for automated generation of the geometrical and finite-element meshed models of the HAWT-blades. The program enables the specification of the basic blade geometrical and structural parameters.

N. Manikandan, B. Stalin [19] The ultimate objective of the work is to increase the reliability of wind turbine blades through the development of the airfoil structure and also to reduce the noise produced during the running period of the wind turbine blades. The wind turbine blade is modeled and several sections are created from root to tip with the variation from the standard design for improving the efficiency. The blade has to be designed carefully to enable to absorb energy with its greatest efficiency.

Admittedly many researches have considered the fatigue simulation of the composite blades, but the most of them have focused on the deterministic approach. Furthermore, there are other problems for fatigue in the blades by these methods such as recognizing a place to install the strain gauges in order to extract the load spectrum and also using a massive and high-cost material fatigue database.

The main reason to create fatigue in the wind turbine blades is cyclic loads. Variation of wind speed, annual gust, rotation of rotor, and variation of weight vector direction toward the local position of the blade [17] are the production sources of the cyclic loads. These sources have different effects on the cyclic load. The two first sources change the total amount of the load. Also, rotation of rotor produces fluctuating load with a frequency identical to the rotor rotation frequency. Last one is the effect of wind shear which arises from change of wind speed by changing in height.

Considering the effect of wind shear in the design process is not necessary, because its influence on the fatigue damage is negligible [18]. Moreover, gust phenomenon is studied annually based on the Germnaschier Lloyds standard [19]. During gust occurrence, vibration is created in the blade due to the gust impact effect, which arises the linear combination of its mode shapes. Eggleston and Stoddard [20] investigated engineering design of wind turbine. The results of their study showed that the first mode shape had the most significant role in displacements. Furthermore, the effect of wind direction on the turbine blades is not considerable, because the turbine always stays upwind and with changing the wind direction, the active yaw control system will adapt the turbine with new direction of wind vector as quickly as possible. Therefore, after defining cyclic loading sources, all corresponding applied stresses are derived from full range static analyses covering all events [17].

Designing, stress analysis, aeroelasticity, and fatigue of a composite blade wind turbine are investigated in this chapter. First, the geometry of blades is designed using the finite element method (FEM) for considered materials and layups. Then, using the static and dynamic analyses of the blades, the critical zone and flutter phenomenon are considered. Also, the damage is estimated utilizing accumulated fatigue damage modeling.

Designing of the blades to get the maximum energy from the wind flow is an essential topic which is according to a refined aerodynamic science. Stiffness and strength to weight ratios are two important parameters to design the blades. Blades of horizontal axis are now completely made of composite materials that not only have they lower weight and appropriate stiffness, but also providing good resistance to the static, dynamic, and fatigue loadings. To attain the highest possible power output from the wind turbine under specified atmospheric conditions, changing two parameters are necessary. The first is change of the dynamic and mechanical properties of the wind turbine blade which modify the composite material, which the blade is made of it, and the second is changing shape of the blade. Admittedly change of the shape of blade modifies the stiffness and stability, but it may influence aerodynamic efficiency of wind turbine. Therefore, specifying the optimal shape of blade and optimal composite material are an important and complex problem. Nevertheless, selection of airfoil and also calculating the loading are two significant topics to design the composite blade.

M. Grujicic, G. Arakere, E. Subramanian, V. Sellappan, A. Vallejo, and M. Ozen [18], in this paper discussed about the problem of mechanical design, performance prediction, and material selection for a horizontal-axis wind turbine (HAWT) blade is investigated using various computeraided engineering tools. A fully parameterized computer program has been developed for automated generation of the geometrical and finite-element meshed models of the HAWT-blades. The program enables the specification of the basic blade geometrical and structural parameters.

N.Manikandan, B.Stalin [19] The ultimate objective of the work is to increase the reliability of wind turbine blades through the development of the airfoil structure and also to reduce the noise produced during the running period of the wind turbine blades. The wind turbine blade is modeled and several sections are created from root to tip with the variation from the standard design for improving the efficiency. The blade has to be designed carefully to enable to absorb energy with its greatest efficiency. Generic model developed could take different shapes and sizes with the help associated parameters and could be used in the pre-design stage of winglets. T. Vishnuvardhan, Dr. B. Durga Prasad, [20] The electricity produced by wind power is cost effective when compared with remaining green energy sources. Small wind turbine systems can be easily installed near the site where the power is required thus the investment on power transmission lines can be reduced. Finite element analysis was conducted by varying the composition of materials used for blade fabrication. All the blades are capable to bear maximum loading value when applied at the root section and the blades will fail at lower magnitude of loading, when the load is applied at tip of the blade. It is observed that all the blades when subjected to loading irrespective of the location at which the load is applied, the

failure crack is observed near the root of the blade. Peter J. Schubel and Richard J. Crossley [21] A detailed review of the current state-of-art for wind turbine blade design is presented, including theoretical maximum efficiency, propulsion, practical efficiency, HAWT blade design, and blade loads. The aerodynamic design principles for a modern wind turbine blade are detailed, including blade plan shape/quantity, aerofoil selection and optimal attack angles. A comprehensive look at blade design has shown that an efficient blade shape is defined by aerodynamic calculations based on chosen parameters and the performance of the selected aerofoils. The optimum efficient shape is complex consisting of aerofoil sections of increasing width, thickness and twist angle towards the hub. This general shape is constrained by physical laws and is unlikely to change. However, aerofoil lift and drag performance will determine exact angles of twist and chord lengths for optimum aerodynamic performance. Arvind Singh Rathore, Siraj Ahmed [22] An aerodynamic analysis tool for analysis of horizontal axis wind turbine blades is developed by using both Blade Element Momentum (BEM) Theory and Computer Program. The method is used to optimize blade geometry to give the rotational speed, a number of blades and a blade radius. The airfoil profiles and their aerodynamic data are taken from an existing airfoil database for which experimental lift and drag coefficient data are available. In this paper a computer program is used for analysis of aerodynamics of different airfoil. We take the 11 airfoils data for 21m length of blade out of which NACA-2415 airfoil has generated maximum power at nominal wind velocity. This program can be used for any number of airfoils.

3. CONCLUSIONS

From the exhaustive literature review it is observed that a simple HAWT blade material selection procedure was developed which combines weighted contributions of the material indices pertaining to the blade performance and longevity.

The performance of a wind turbine blade is highly dependent on the structure and is critical to the wind turbine system service life. The results revealed that, from the performance point of view.
and advancement in the previous research can be carried out.

REFERENCES

[1] Jureczko M, Pawlak M, Mezyk A. Optimisation of wind turbine blades. Journal of Materials Processing Technology. 2005; 167, 463–471. doi: 10.1016/j.jmatprotec.2005.06.055

[2] Guo S. Aeroelastic optimization of an aerobatic aircraft wing structure. Aerospace Science and Technology. 2007; 11, 396–404. doi: 10.1016/j.ast.2007.01.003

[3] Veers PS, Ashwill TD, Sutherland HJ, Laird DL, Lobitz DW. Trends in the design, manufacture and evaluation of wind turbine blade. Advances in Wind Energy. 2003; 6, 254–259. doi:10.1002/we.90

[4] Baumgart, A. A mathematical model for wind turbine blades. Journal of Sound and Vibration. 2002; 251, 1–12. doi:10.1006/jsvi.2001.3806

[5] Larsen JW, Nielsen SR. Nonlinear parametric instability of wind turbine wings. Journal of Sound and Vibration. 2007; 299, 64–82. doi:10.1006/jsvi.2001.380

6] Petrini F, Li H, Bontempi F. Basis of design and numerical modeling of offshore wind turbines. Structural Engineering and Mechanics. 2010; 36, 599–624. doi:10.12989/sem. 2010.36.5.599

[7] Lee JW, Kim JK, Han JH, Shin HK. Active load control for wind turbine blades using trailing edge flap. Wind and Structures. 2013; 16, 263–278. doi:10.12989/was. 2013.16.3.263

[8] Tenguria N, Mittal ND, Ahmed S. Structural analysis of horizontal axis wind turbine blade. Wind and Structures. 2013; 16, 241–248. doi:10.12989/was.2013.16.3.241

[9] Fung YC. An introduction to the theory of aeroelasticity. Dover Publications, INC, Mineola, New York; 1969.

[10] Joint aviation requirements, (JAR-23), Normal, Utility, Aerobatic and Commuter Category Aeroplanes, Joint Aviation Authorities, Hoofddorp, The Netherlands. March 1994.

[11] Shokrieh MM, Taheri-Berooz F. Wing instability of a full composite aircraft. Composite Structures. 2001; 54, 335–340. doi:10.1016/S0263-8223(01)00107-6

[12] Baxevanou CA, Chaviaropoulos PK, Voutsinas SG, Vlachos NS. Evaluation study of a Navier–Stokes CFD aeroelastic model of wind turbine airfoils in classical flutter. Journal of Wind Engineering and Industrial Aerodynamics. 2008; 96, 1425–1443. doi: 10.1016/j.jweia.2008.03.009

[13] Fazel Zadeh SA, Mazidi A, Kalantari H. Bending-torsional flutter of wings with an attached mass subjected to a follower force. Journal of Sound and Vibration. 2009; 323, 148–162. doi: 10.1016/j.jsv.2009.01.002

[14] Lee JW, Lee JS, Han JH, Shin HK. Aeroelastic analysis of wind turbine blades based on modified strip theory. J. Wind Eng. Ind. Aerod. 2012; 110, 62–69. doi: 10.1016/j.jweia. 2012.07.007

[15] Sutherland HJ. On the fatigue analysis of wind turbines. Sandia National Laboratories, Albuquerque, New Mexico; 1999.

[16] Mandel JF, Samborsky DD, Cairns DS. Fatigue of composite materials and substruc-tures for wind turbine blades. Sandia National Laboratories, Albuquerque, New Mexico; 2002.

[17] Shokrieh MM, Rafiee R. Lifetime prediction of HAWT composite blade. In: 8th International Conference of Mechanical Engineering (ISME), Iran; 2004. p. 240.

[18] Noda M, Flay RGJ. A simulation model for wind turbine blade fatigue loads. Journal of Wind Engineering and Industrial Aerodynamics. 1999; 83, 527–40. doi:10.1016/S0167-6105(99)00099-9Composite Blades of Wind Turbine: Design, (PDF Download Available). Available from: https://www.researchgate.net/publication/305687344_Composite_Blades_of_Wind_Turbine_Design_Stress_Analysis_Aeroelasticity_and_Fatigue [accessed May 05 2018].

[19] Germanischer Lloyd Rules and Guidelines Industrial Services, Part IV, Guideline for the Certification of Wind Turbines, Chapter 4, Load Assumptions, Hamburg, Germany, Edition 2010.

[20] Eggleston DM, Stoddard FS. Wind turbine engineering design. Springer, Van Nostrand Reinhold Co. Inc., New York, USA; 1987.

[21] Ghasemi AR, Jahanshir A, Tarighat MH. Numerical and analytical study of aeroelastic characteristics of wind turbine composite blades. Wind and Structures. 2014; 18, 103– 116. doi:10.12989/was.2014.18.2.103

[22] Ghasemi AR, Tarighat MH. Aeroelastic analysis of composite wind turbines blades. Journal of Mechanical Engineering University of Tabriz. 2015; 44, 31–39.