

Comparative Study of Wind Turbine Blade

Chandra Shekhar Mahto¹, N. V. Saxena²
Department of Mechanical Engineering, MIT, Bhopal, India

Abstract: In the wake of extraordinary consumption of customary vitality sources, there is popularity for the non-regular choices. Wind turbines give an elective method for producing vitality from the intensity of wind. Wind vitality is made when the air is warmed unevenly by the Sun; a few patches of air end up hotter than others. These warm fixes of air raise other air surges in to supplant them – therefore, wind blows. A wind turbine extricates vitality from moving air by backing the wind off, and moving this vitality into a turning shaft, which as a rule turns a generator to create power. The power in the wind that is accessible for reap relies upon both the wind speed and the region that is cleared by the turbine edges. With the improvement of wind control age innovation, the wind turbine sharp edge is ending up increasingly imperative. Demonstrating and stress examination of the wind turbine cutting edge are exceptionally basic for the further outline and the utilization of wind turbine edge

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I. INTRODUCTION

Wind power devices are now used to produce electricity, and commonly termed wind turbines. Wind control is developing at the rate of 30 % every year and, thus with this advancement, the outline of a wind turbine and its suggestions should be surely knew. Yearly vitality creation (AEP) and cost are the two significant drivers administering the general outline of a wind turbine. The plan ought to be sufficiently dependable to keep any undesirable upkeep or downtime and fundamentally stable enough to manage every one of the heaps following up on it through its normal lifetime of around 20 years.

Wind Turbines are one of the most useful non-conventional energy sources in present energy crisis scenario. But the initial cost of the Wind Turbine plant is very high. The manufacturing cost of the Wind Turbine blade is about 15-20% of the Wind Turbine plant cost. So it is likely to reduce the investment cost

of the Wind Turbine blade by maximizing the service life of the Wind Turbine blades. Different types of loads acting on the Wind Turbine blade and consequential stresses developed in blade. Blade is one of the most important components in wind turbine, its exterior shape is needed to ensure that wind power machine has sufficient elevating force and pneumatic force moment, and its structure is required to ensure that wind power machine can have sufficient stiffness, strength and stability. Therefore, the analysis of loading and strength of wind turbine blade is especially important when it is in normal operation. In this work a full scale single layer horizontal axis wind turbine blade is three- dimensionally modeled and Finite Element Analysis (FEA) is performed. The important aerodynamic parameters which decide the efficiency of the wind turbine blade are analyzed for the NACA 4420 airfoil.

Wind power gained remarkable attention in the past decade since worldwide policies are fighting climate

change through the support and investment into renewable energy sources. Recent investments into renewable energy-based power plants increased to a level of 3–1 compared with fossil fuel and nuclear power plants. Therefore one of the main global engineering challenges for wind energy sector is to develop efficient wind turbine blades with high fatigue life.

II. WIND TURBINE

Wind Turbine “rotary engine in which the kinetic energy of a moving fluid is converted into mechanical energy by causing a bladed rotor to rotate”. Wind turbine blades spin opposite of a fan from the wind and make energy, instead of using energy to make wind.

Wind rotates the turbine blades, spins a shaft connected to a generator and the spinning of the shaft in the generator makes electricity. Wind turbines, like windmills, are mounted on a tower to capture the most wind energy, wind speed varies by height, wind current 100m above the ground dropped in speed by 10% when its height declined to 50m. This property is known as wind shear in which wind speed increases in speed with height, due to friction at the Earth’s surface.

Wind turbine is one of the renewable energy sources whose importance is increasing. Therefore, the analysis, design and production of wind turbines is very important for the world's power generation industry. The most critical components of a wind turbine are turbine blades. The turbine blade, the first link in the energy conversion chain, is an important issue in wind turbine design. The kinetic energy in the wind should be transferred to the turbine blades without any loss. This significantly affects the yield to be achieved. For this reason, the turbine blades must be designed in such a way that they can capture the maximum energy from the wind. In the production of wind turbine rotors, the strength of the turbine blades at high wind speeds is an important consideration.

If this issue is not taken into account sufficiently, the results can be very harmful. If no action is taken, resistance problems may arise in the turbine tower and especially the blades at high wind speeds. As a result, the turbine elements may be deformed or even broken. The load that forces the tower is due to the wind force acting on the tower and especially the turbine blades.

Turbine blades have to withstand wind, gravity and centrifugal loads, because they produce electricity by rotation. The blades are affected by the tangential and normal components of the inertia forces resulting from both the wind force and the rotation of the blades. These forces cause bending stresses and normal stresses in towers and blades. If these stresses exceed the safe stress limit specific to the material used, they cause damage to the turbine tower and blades. Thus the structure of a turbine blade requires it to be made of strong materials

Turbines catch the wind's energy with their propeller-like blades. Usually, two or three blades are mounted on a shaft to form a rotor. The wind turbine blade acts an airplane wing. When the wind blows a pocket of low-pressure air forms on the downwind side of the blade. Air pressure is equal to the force exerted on an object by the weight of particles in air.

Generally, a wind turbine blade is classified “successful” if certain objectives are met, some of which are in conflict. Therefore, the designers confront a multidisciplinary optimization problem. We can summarize the key objectives and constraints of wind turbine systems as follows:

- Maximize the annual energy for a given wind speed distribution.
- Optimal power control, i.e. limit maximum power output.
- Fatigue and extreme load resistance.
- Minimize weight and cost.
- Avoid resonances and blade/tower collisions.

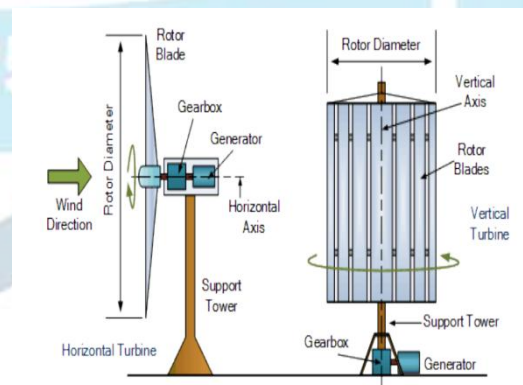


Figure 1: Model of Horizontal and vertical axis wind turbine

III. WIND TURBINE BLADE

The wind is a free vitality asset, until the point that administrations put a duty on it, however the wind is additionally an exceptionally capricious and a questionable wellspring of vitality as it continually altering in both quality and course. To create valuable measures of intensity, wind turbines for the most part should be substantial and tall, yet to work productively they additionally should be very much outlined and designed which makes them costly as well.

Most wind turbines intended for the creation of power have comprised of an a few bladed propeller pivoting around an even hub. It's conspicuous to state that these propeller like wind turbine cutting edge plans convert the vitality of the wind into usable shaft control called torque. This is accomplished by extricating the vitality from the wind by backing it off or decelerating the wind as it ignores the cutting edges. The powers which decelerate the wind are equivalent and inverse to the push compose lifting powers which pivots the sharp edges.

Much the same as a plane wing, wind turbine edges work by producing lift because of their bended shape. The agree with the most bend creates low gaseous tension while high weight air underneath pushes on the opposite side of the edge formed aerofoil. The net outcome is a lifting power opposite to the course of stream of the air over the turbines sharp edge. The trap here is to outline the rotor edge so as to make the appropriate measure of rotor sharp edge lift and push creating ideal deceleration of the air and along these lines better edge proficiency.

IV. Design of HAWT and VAWT

When designing a Wind turbine, many considerations must be kept in mind, both general and very specific. The design process involves a large number of mechanical and electrical components that are used to convert wind power into electrical power. This process is influenced by a number of constrains but the most fundamental ones involve the potential economic viability of the design. The turbine should be able to produce electricity at a lower cost than its competitors, competitors being fuel, gas and coals, and other renewables. There are many factors that influence the cost of the energy. The primary being cost of the turbine itself and the annual energy productivity. Other costs are installation, operation and maintenance. Those factors influence the design of the turbine and must be kept in mind in the design

process. The productivity is controlled by both the wind resource and the design. The resource cannot be controlled, but the designer must consider how it is best utilized. The turbine must be strong enough to survive extreme events, be reliable with minimum repairs and the weight of the components must be as low as possible to minimize costs. Those components experience high and variable stresses. The fundamental consideration of the designer should be to balance the cost of the wind turbine and the lifetime of the turbine when it comes to fatigue.

Design Procedure Some approaches can be made when designing a wind turbine and many issues have to be considered. This section outlines the steps in one approach. The key design steps are as follows :

A. Determine application The first step when designing a wind turbine is to determine the application. Wind turbines that are being used for largescale power production have a different design than those used in more remote areas. Major factor in choosing the size of the turbine is the application or the usage. The type of generator, method of control, and how it is to be installed and operated are also major factors.

B. Review previous experience Step two is reviewing previous experience, mainly when it comes to building a turbine for similar applications. Older turbines give useful information in how they were built and tested. Helping the designer narrow the options. General previous experiences have shown that the, maintenance, and service to the turbine must be safe and straightforward.

C. Select a layout There are many layouts that can be chosen in the design of a wind turbine and most of them relate to the rotor. This chapter provides an overview of factors that must be considered. The most important considerations are listed below:

- Rotor axis orientation: horizontal or vertical
- Power control: stall, variable pitch, controllable aerodynamic surfaces and yaw control
- Rotor position: upwind, downwind, Darrieus, Savanius, H-Darrieus etc.
- Yaw control: driven yaw, free yaw or fixed yaw
- Rotor speed: constant or variable
- Design TSR and solidity

- Type of hub: rigid, teetering or hinged blades
- Number of blades
- Tower structure

D. Preliminary loads estimate It is vital to estimate the loads the turbine must be able to withstand, which is done early in the design process. Those estimated loads influence individual components in the turbine. At this stage it is important to keep in mind all the loads that the turbine will be able to withstand in operation.

E. Develop tentative design A preliminary design can be developed after the layouts have been chosen and loads have been estimated. The design consists of number of subsystems which are:

- Rotor (blades, hub, aerodynamic control surfaces)
- Drive train (shafts, couplings, gearbox, mechanical brakes, generator)
- Nacelle and main frame
- Yaw system
- Tower, foundation and erection

V. LITERATURE REVIEW

Jack P. Salameh et. al.[2025] worked on Gearbox condition monitoring in wind turbines: A review.a review on different methods and techniques for gearbox condition monitoring in wind turbines. Furthermore, various methods and techniques in the literature will be presented in order to get an insight onto the most used methods in wind turbine gearbox condition monitoring.

Teng et al. (2023) Composite material selection for wind turbine blades has historically focused on balancing stiffness, weight, cost, and fatigue life. conducted a comprehensive assessment of carbon fiber composites for large-scale turbine blades, concluding that while CFRP offers superior stiffness-to-weight performance, its cost limits full-scale adoption.

Aluko-Olokun (2024) compared carbon fiber single-blade designs with traditional GFRP three-blade configurations using FEA and CFD simulations, revealing that carbon fiber designs offer notable stiffness and vibration advantages, albeit with greater manufacturing carbon footprint. Hybrid layup strategies have also been extensively studied.

Jixie Qiangdu Journal (2024) reported that mixed layups, varying proportions of carbon and glass fibers, can achieve structural performance comparable to full carbon fiber blades when carefully placed, especially near blade tips. used ANSYS FEA to identify optimal hybrid replacement of glass fiber with carbon fiber, finding that 75% carbon replacement in spar caps significantly enhances structural performance. Thermoplastic composites have been explored for enhanced impact resistance and repairability. demonstrated that thermoplastic resin-based blades showed promising flexural and impact strengths using ANSYS ACP, supporting their viability as sustainable alternatives to traditional thermosets.Lifecycle and environmental concerns are also guiding material selection.

Gursel et al (2025) underlined the growing need for recyclable strategies given the challenge of decommissioning GFRP blades. evaluated CFRP, GFRP, and hybrid composites with FEA and experimental data, emphasizing the implications of tensile strength, fatigue life, environmental sensitivity, and cost. These studies collectively reflect the state-of-the-art in composite blade research, from material selection and hybrid layup strategies to environmental lifecycle, fatigue behaviour, passive aerodynamics, and predictive maintenance techniques.

Xiaosong Huang (2024) CFRP continues to be favored for high-stiffness and low-weight structures, whereas GFRP remains cost-effective in suitable applications. Hybrid designs and thermoplastic alternatives are gaining traction, particularly for balancing performance with sustainability. Furthermore, modeling of fatigue, defects, and structural health is becoming crucial to extending blade lifespan and optimizing maintenance

Chen-Hsu Wang et. al. [2020] worked on Stress analysis of composite wind turbine blade by finite element method. The finite element analysis software ANSYS was used to analyze the composite wind turbine blade. The wind turbine blade model used is adopted from the 5 MW model of US National Renewable Energy Laboratory (NREL).

Chong-weiZheng,et. al. [2022} worked on Rezoning global offshore wind energy resources. In this study, a new wind energy classification scheme that incorporates a comprehensive consideration of wind

energy factors, environmental risk factors and cost factors is proposed to rezone the potential offshore wind energy resources worldwide.

Cristina L. Archer [2019] worked on Wind farms with counter-rotating wind turbines. The objective of this study is to assess the effects of using counter-rotating wind turbines on the performance of a wind farm. Large eddy simulations, coupled with the actuator line model, were conducted to investigate flow through a test wind farm with 48 large-scale wind turbines with the same layout as Lillgrund in Sweden.

Sami et al. [2020] extracted fundamental flap wise and edgewise modal frequency of a 5KW GFRP wind turbine blade by using 3d shell elements. It is to understand better the dynamic behaviour that he conducted experiments using electrodynamic shaker system to predict the resonant frequencies. He observed that flap wise frequencies are found to be in agreement to each other while % of error is more in case of edgewise frequency.

Yangfeng Wang [2017] considered two cases of turbine blades having 1m and 5m in length and conducted damage detection technique by comparing the dynamic response analysis and mode shape curvature methods using composite multi-layer materials. The dynamic analysis method is used to understand the damage severity of wind turbine blades.

X Y Wang [2015] worked on Comparison of the pressure distribution of a wind turbine blade based on field experiment and CFD. The distribution of pressure is gathered by disposed 191 taped pressure sensors span-wise on seven particular sections of a blade. And the parameters of experimental condition of inflow and operation condition of the wind turbine are obtained at the same time.

Summary of Literature Review

Most of the literature dealt with investigation of various air foils design, aerodynamic evaluation by simulation tools, and the analysis of complex composite web section blades using various techniques including FE modelling, analytical approaches as well as experimental works. The main objective of project is to protect the turbine blade from various hazards like deformation and directional deformation.

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