

Development of Advanced Composite Materials for Wind Turbine Blades

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Abstract

Small-scale, standalone wind turbine systems are the focus of current research. The use of wind turbines to produce electricity has significantly increased. Many of these tiny wind turbines were first installed to supply electricity to remote farms. The ability of small wind turbines to generate electricity at a comparatively low cost is one of their many advantages. Additionally, they can be put in less populous areas, such as rural or mountainous areas, which helps save money on expensive power transmission line construction. Small wind turbine systems can be a wise choice in places where natural catastrophes have damaged power cables because they are simple to install. Focusing on the development of tiny wind turbine systems for energy generation is essential for all of these reasons. The primary objective is to develop compact wind turbine systems that are economical, dependable, and efficient. This study focuses on developing blade profiles utilizing a specific design methodology developed for small horizontal axis wind turbine systems.

Keywords: Wind, Turbine, Blades.

Introduction

In today's world, electricity is in high demand and plays a crucial role in our lives. Unfortunately, our planet has suffered significant pollution due to the various methods we use to generate power. It's essential that we explore alternative sources, like green energy, to meet our energy needs. While technology can help us fulfil human requirements, it's important that it doesn't disrupt the natural balance (Raponi, 2021). Wind energy has emerged as a key player in providing clean energy, serving as a vital alternative source for power generation. Temperature variations over the Earth's surface cause wind to move; warmer air rises and cooler air rushes in to fill the void. Wind patterns around the world are influenced by a number of things. Because wind is renewable, environmentally benign, and abundant in nature, it is regarded as a major energy source. Lower pressure results from the warming of the Earth's surface in the equatorial zone, which also causes the air above it to warm and rise. At higher elevations, this causes a phenomenon called geostrophic wind, which pulls cooler air from the poles toward the equator. The Earth's atmospheric circulation is driven by pressure and density differences created by the unequal heating of the planet's surface, which is mostly caused by solar radiation (Reddy et al., 2021). The Coriolis Effect, ocean currents, and land formations are some of the elements that affect the direction and intensity of wind travel from particular places.

Wind Turbine Technical Basics

The turbine blades in VAWT revolve on a vertical axis. The turbine blades in HAWT revolve on a horizontal axis. Horizontal axis wind turbine systems make up the majority of wind turbines used to generate electricity today. Interestingly enough, nevertheless, vertical axis wind turbine systems were the first to convert wind energy. The fact that Darrieus rotors require a starter engine to start is a disadvantage, but (Finnegan et al., 2021). Savonius rotors, on the other hand, work on drag and look like a cup anemometer. Three straight blades positioned vertically on the rotation axis make up the H-Rotor design. Simplified versions of these VAWT concepts are shown in Fig. 1. One of the great things about VAWTs is their straightforward structure and assembly, which allows for making maintenance a breeze. Plus, there's no need to orient VAWT rotors into the wind, which is particularly beneficial in locations where wind direction changes frequently.

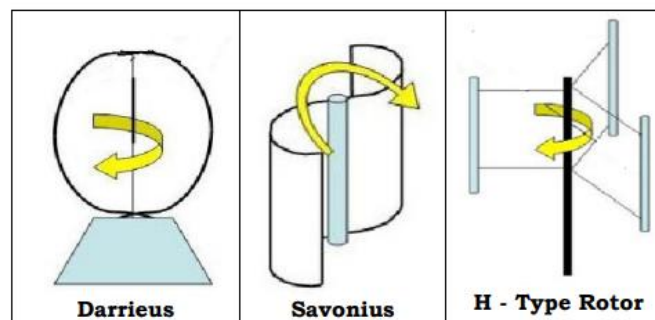


Fig. 1: Various Designs of VAWT

The text we are examining is as follows: Efficiency and minimizing material costs are the primary issues while manufacturing Horizontal Axis Wind Turbine systems. The basic parts of a HAWT include rotor blades, a hub, an electrical generator, a nacelle, a tower, and a yaw mechanism. For smaller turbines, you will additionally need a pitch mechanism, a yaw drive, and a gearbox (Karthikeyan et al., 2019). You can see a typical small HAWT in the schematic representation shown in Fig. 2.

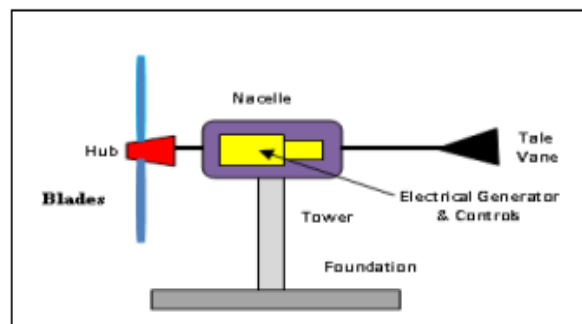


Fig. 2: Simplified Schematic of a HAWT

Larger wind turbines typically have pitch control, stall control (passive or active), and a brake system to protect the rotor system. When it comes to small wind turbines, they often use a furling mechanism or blade flutter to manage their operation. For horizontal axis wind turbines (HAWTs), there are several over-speed protection devices that kick in when the wind speeds exceed the nominal levels, ensuring safe and efficient power production from the generator.

Wind Turbine Blade Aerodynamics

The main goal behind creating wind turbine blades is to generate the most power while keeping costs as low as possible. When designing these blades, aerodynamic needs take center stage, but we also have to consider the economics, which means the blade shape often ends up being a compromise to keep construction costs down (Kumar et al., 2016). In reality, the blades are usually thicker than what would be ideal for aerodynamics, especially near the base where bending stresses are highest.

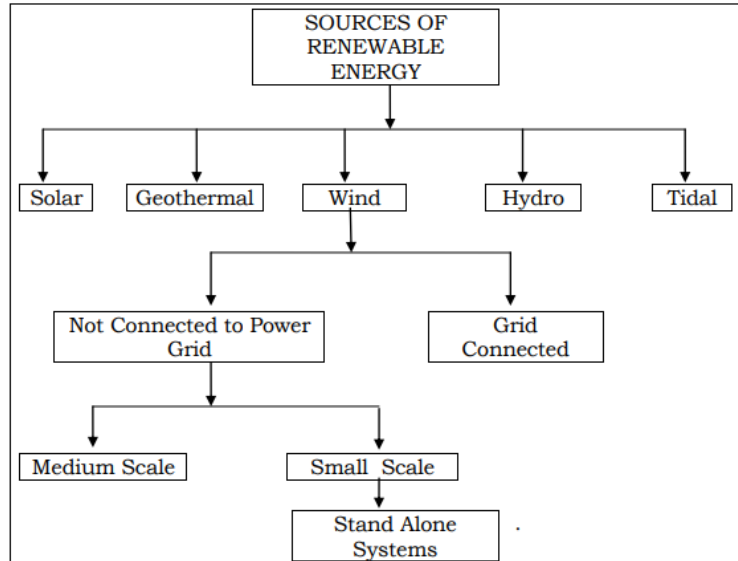


Fig. 3: Classification of Renewable Energy Sources and Wind Energy System Subclassification

Selecting the appropriate materials and production processes is essential to producing a blade with improved aerodynamic performance. For instance, compared to injected fiberglass, prepreg carbon fiber delivers more stiffness in addition to strength. the increase in loads that are incorporated into the structural plan. Issues found at this point could be useful in changing the shape if needed (Pradeep et al., 2019). Off-grid applications such as supplying electricity for sailboats or small cottages, cathodic protection for subterranean pipelines, replacing diesel power supplies, and remote monitoring devices are the primary uses for small-scale and micro wind turbines. In contrast to smaller wind turbine systems, the majority of wind turbines are located in isolated locations where installation, maintenance, and inspection expenses can mount up significantly. Figure 3, which also breaks down wind energy by size and power production, shows the many types of renewable energy sources. Current research focuses on freestanding, small-scale wind turbine systems. The use of wind turbines to produce electricity has grown dramatically. Initially, many small wind turbines were set up to provide distant farms with electricity (Ebissa & Alemu, 2024). One of the many fantastic qualities of small wind turbines is their capacity to provide electricity at a relatively low cost. Plus, they can be installed in less populated places, like mountains or rural communities, which helps avoid hefty investments in building power transmission lines.

Results

Finite element analysis is performed on all types of blades to understand how they behave under load. We use ANSYS to conduct a static analysis, where we calculate the Von Mises stresses and the resulting deformations of the blades. Next, we dive into the vibration characteristics by carrying out a modal analysis.

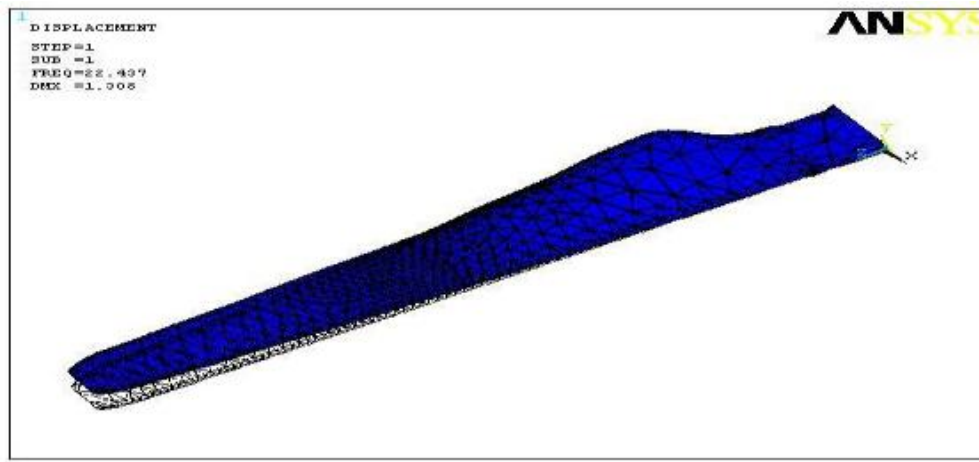


Fig. 4: ANSYS Result

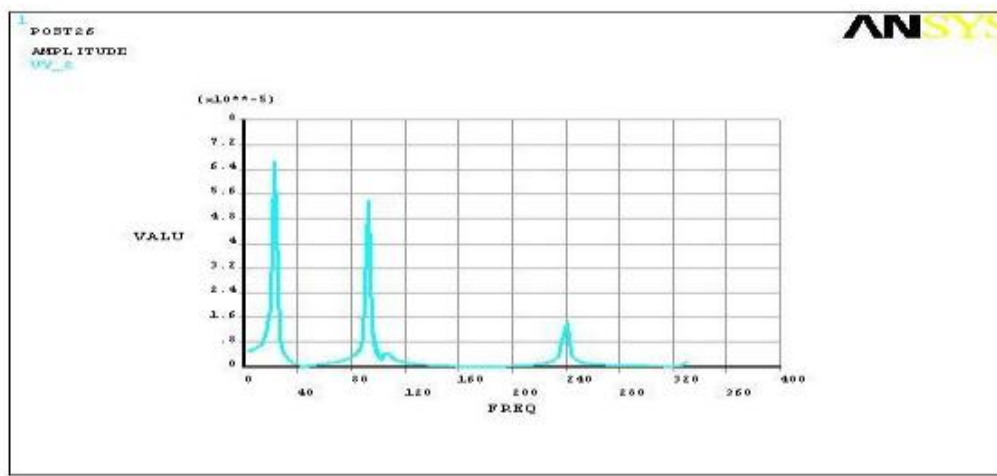


Fig. 5: Harmonic Analysis

A wind turbine rotor system has a number of unique features despite its blades. We further investigate the vibration characteristics of a wind turbine rotor having two-dimensional air foil blades. Using harmonic analysis and the Finite Element Method (FEM), it is possible to assess the excitation forces acting on the blades due to unpredictable wind loads. This allows us to calculate the steady response of the blades using ANSYS (Thomas & Ramachandra, 2018). Additionally, the solid models for the R21 and R22 blade variations are created using Pro-Engineer software.

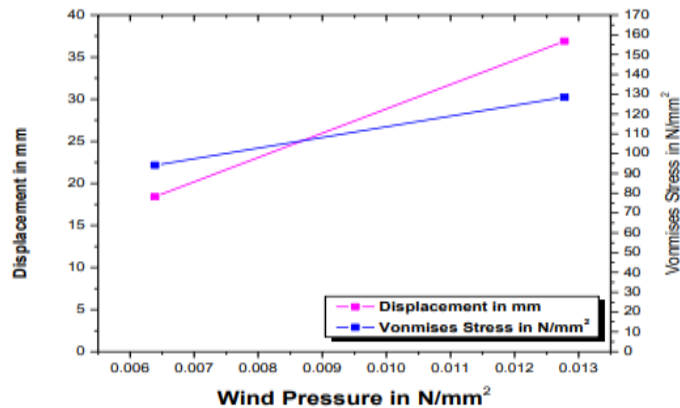


Fig. 6: Wind Pressure Vs Displacement

The solid models for the R21 and R22 profile blades, which we have manufactured in three different material variations, were built using Pro/Engineer. These models are then imported into ANSYS using IGES, where we evaluate and determine the best-performing blade model by performing modal, harmonic, and static structural analysis.

Conclusion

In this study, a particular design process designed for tiny horizontal axis wind turbine systems is used to create blade profiles. After doing a structural analysis to comprehend the behaviour of the recently created blade models in static settings, we use modal analysis to investigate their mode forms. We conduct a harmonic analysis to determine the maximum deflection and stresses for each type of blade. After creating power curves for each of the six blade types, we were able to determine which model was the best. With modal analysis, we can figure out the fundamental frequency values and their corresponding mode shapes. However, to find the amplitude values along with the frequency, we need to conduct harmonic analysis. That's why we also carry out harmonic analysis on all the blade models. By combining modal and harmonic analysis, we can pinpoint the critical points where the maximum frequency of vibrations occurs, identified by their node numbers.

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