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A Review of Vertical Axis Wind Turbine Blades

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Abstract: This abstract presents a comprehensive review of aerodynamic noise sources and recent advances in noise mitigation techniques. Numerous studies have linked wind turbine noise with annoyance and sleep disturbance, emphasizing the need to reduce these noise emissions by targeting specific sources. Trail edge noise, tip noise, and leading-edge inflow noise are identified as the primary aerodynamic noise sources in wind turbines. Trailing edge noise occurs due to the interaction of the wind with the turbine blades' trailing edges, resulting in turbulent flow and noise generation. Tip noise is produced by the vortices shed from the blade tips as they rotate through the air. Leading-edge inflow noise arises from the interaction between the incoming wind and the blade's leading edge.

1. INTRODUCTION

Because of the rising global energy demand recent years have seen a significant shift in the emphasis on renewable energy resources as a response of rising environmental pollution and increased energy demand. Biomass, solar, geothermal, hydroelectric, and wind are examples of renewable energy sources. Since wind has abundantly available so it is to be one of these resources that is less expensive than other alternative energy sources, significant study has been done to advance the technology of producing electricity from the wind. Wind energy has enormous potential for use in power generation around the world (Aslam Bhutta et al.2012). In places with suitable sites, wind energy has already surpassed traditional fossil fuels as the main method of generating electricity. Large onshore and offshore projects with MW capacities that are far from wind turbines were expected to make the most progress. These projects provide an efficient approach to capture the wind's energy (Dai et al., 2015). More wind farms are being built in order to meet the world's rising demand for energy, and it is getting harder to keep them far from populated areas. Numerous problems, including noise, structural vibration, and visual effect, have been noted by the surrounding community as a result of the placement of these turbines close to human habitats. One of the main obstacles to the growth of the wind power industry is wind turbine noise (Dai et al., 2015).

Horizontal-axis wind turbines (often abbreviated as HAWTs) and vertical-axis wind turbines (sometimes abbreviated as VAWTs) are the two basic categories of wind turbines (VAWTs). VAWTs have a number of advantages over HAWTs, including the fact that they can function autonomously regardless of the direction in which the wind is blowing, the fact that they do not need an additional yawing mechanism, and the fact that they require a lower wind speed to start functioning. In addition, the operating condition that results in the greatest amount of productivity is one in which the tip speed ratio is low (TSR). In circumstances that call for wind turbines that are both compact and self-sufficient, VAWTs are the best option. Freestanding wind turbines are often positioned in close proximity to the residential areas that will benefit most from the electricity they provide. Lift (also known as Darrieus) and drag are the two categories of VAWTs (Savonius). When compared to Darrieus turbines, Savonius turbines require a lower wind speed before they can begin to function.

The vertically axis wind turbine, or VAWT, is a type of turbine that rotates along a vertical axis. A relatively low cut-in wind speed is required for VAWTs to begin producing power from the wind in any direction. These turbines are far less audible than traditional HAWTs, in addition to being lightweight and simple to instal in a variety of settings. These turbines, with the exception of those of the Darrieus type, are governed by the aerodynamic drag forces. These turbines are the topic of research that is being conducted with the goal of improvinsg the aerodynamic efficiency by reducing the effect of drag and increasing the lift forces (Sun et al., 2016, p. xx). It was hypothesised that they might prove to be a useful alternative in metropolitan regions characterised by varying wind speeds. Savonious and Darrieus are the two main categories that can be used to classify VAWT's designs.

Aerofoil is designed in such a way that it generates the lift which rotate the blade

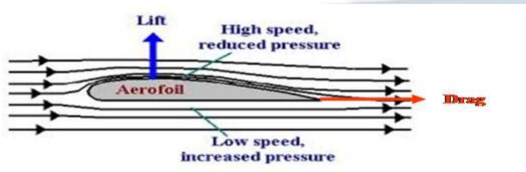

Figure 1: Basic Design of Aerofoil(Aerofoil, nd)

Basic Working of VAWT

The blade is an aero foil and when air flows over it. it creates a lift force perpendicular to the wind direction, a component of this force is in the right direction to create a torque that will rotate the shaft. In VAWT - Blades rotate around the shaft axis so the local airflow is affected by the rotational speed as well as the wind speed. So, at different points in its path the blade is oriented differently relative to the wind. Consider a case where the blade is on the downside of the rotor and perpendicular to the wind, in this condition we add the wind and the blade velocity vectors and use trigonometry to find the resultant wind speed and angle of attack, and then we can resolve that to find force acting in the tangential direction which turns the rotor.

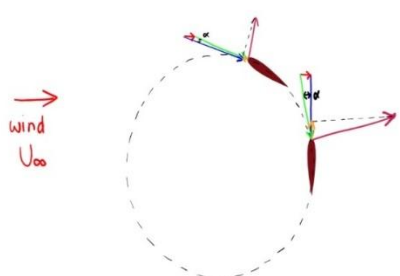

Figure 2: Aerodynamic Forces on VAWT Blades (Meanwell et.al.2010)

As the blade turns further around the angle of attack gets smaller, meaning the lift force and torque gets smaller too as shown in Figure 1.

It can be clearly understood from **Error! Reference source not found.** that at 90-degree angle when the blades are parallel to wind there is no angle of attack and assuming we have symmetrical air foil, then there is no lift only a small drag force which acts opposite to the direction of the rotation, so we have small negative torque.

II. LITERATURE WORK

Dynamic Stall Phenomenon:

Studies have highlighted the detrimental effects of dynamic stall on VAWT performance (Gomes et al., 2017; Kim et al., 2018). Dynamic stall occurs when the angle of attack at the blade's leading edge exceeds the critical value, causing flow separation. This separation generates unsteady vortices, leading to torque and power fluctuations.

Flow Control Strategies:

To mitigate the adverse effects of dynamic stall, researchers have explored various flow control strategies. One promising approach involves implementing leading-edge wavy serrations and helical blade structures. These strategies aim to modify the flow characteristics and reduce flow separation (Shirazi et al., 2019; Chen et al., 2021).

Computational Fluid Dynamics (CFD) Simulations:

CFD simulations have emerged as a powerful tool for analyzing the flow behavior in VAWTs and assessing the performance of different design configurations. Through CFD simulations, researchers can obtain detailed flow characteristics and evaluate the impact of flow control strategies (Ghasem et al., 2016; Chougule et al., 2020). CFD enables the visualization and quantification of flow separation, torque fluctuations, and power output.

Taguchi Method for Optimization:

The Taguchi method, a robust statistical approach, has been widely used for optimization in various engineering fields. In the context of VAWTs, the Taguchi method can be applied to determine the optimal combination of design parameters, such as serration amplitude, wavelength, and blade twist angle (Wu et al., 2018; Ghosh et al., 2022). By considering the interaction effects among these factors, researchers can efficiently identify the optimal design configuration.

Performance Evaluation and Comparison:

Researchers have conducted comprehensive simulation studies to evaluate the performance of optimized VAWT models. Comparative analyses between the optimized designs and baseline configurations, typically employing straight blades, provide insights into the effectiveness of flow control strategies (Xu et al., 2017; Lee et al., 2020). Parameters such as power output, torque fluctuations, and force reductions are assessed to quantify the improvements achieved through optimized designs.

The reviewed literature demonstrates that the combination of CFD simulations and the Taguchi method offers a promising approach to optimize the aerodynamic performance of VAWTs at low TSRs. The implementation of leading-edge wavy serrations and helical blade structures effectively suppresses flow separations, reduces torque fluctuations, and enhances power output. The optimized VAWT models exhibit notable performance improvements compared to baseline designs. Furthermore, the reduction in force fluctuations achieved through the helical blade design contributes to improved turbine lifespan.

The findings of this literature review emphasize the potential of these optimized VAWT designs for both rural and built environments with limited wind energy resources. The incorporation of flow control strategies, guided by CFD simulations and the Taguchi method, holds promise for enhancing VAWT efficiency in low TSR conditions.

It is important to note that while the reviewed studies provide valuable insights into VAWT aerodynamics, further research is needed to explore additional design parameters and validate the results through experimental testing. Continued investigation into optimizing VAWTs will contribute to the development of sustainable wind energy solutions and their widespread adoption.

Overall, this literature review highlights the significance of addressing dynamic stall in VAWTs and presents a novel design approach that shows promising results in improving their aerodynamic performance. The reviewed studies collectively contribute to the understanding of flow control strategies and optimization techniques, further advancing the field of VAWT technology.

III. CONCLUSIONS

It is believed that the aerodynamic noise that i produced by the blades is the result of a number of distinct mechanisms that are connected to the manner in which the flow over the aero foil interacts with the air that is in the surrounding area.

Wind Turbine Acoustic

Both mechanical and aerodynamic noise are the two basic types of noise that are produced by wind turbines. Tonality is present in the mechanical noise that is produced by the many parts of the wind turbine that make up its equipment. The contact of airflow above the blades with the surface of the blades results in a variety of aerodynamic noise sources. This interaction gives rise to the phenomenon known as aerodynamic noise. The section that comes after this one provides a more in-depth explanation of these mechanisms.

Mechanical Noise Sources

The nacelle of a wind turbine has a number of moving parts, such as the gearbox, the generator, and the cooling fans, all of which contribute to the generation of mechanical noise. The majority of mechanical noise is tonal, which indicates that it has peaks at particular frequencies; this type of noise is more annoying to the human ear than wideband noise. Despite this, it is possible to drastically reduce the amount of mechanical noise by properly isolating the nacelle with sound-absorbing materials and vibration suppression (Wagner et al., 2012). Because of this reduction, aerodynamic noise has taken over as the primary source of noise in wind turbines, which is the topic of the research being conducted.

This research intends to lessen the noise caused by vertical axis wind turbine blades so that they can be deployed in densely populated regions. "Noise" has been one of the major obstacles that scientists have encountered while attempting to generate electricity from vertical axis wind turbines. In addition, numerous research on the impact of wind turbine noise on human health have connected wind turbine noise to discomfort and sleep disturbance. Thus, it is necessary to limit these noise emissions, which can be accomplished by focusing on the individual sources of noise. Using the Solid works flow simulation program, mitigation techniques for trailing edge noise and leading-edge inflow noise were examined. Thus, the purpose of this project is to lower the noise generated by the VAWT's blades by modifying their design, and to generate more electricity from wind, a renewable energy source.

Aerodynamic Noise Sources

The term "aerodynamic noise" refers to the flow-induced noise that occurs as a result of the interaction between flow structures and the blade wall. Aerodynamic noise from wind turbines can be broken down into two distinct categories: inflow turbulence noise and airfoil self-noise. These noise sources and the strategies they use are going to be looked at in greater detail in the next sub-sections.

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