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Effect of Wind-Induced Vibration on Leading Edge Protuberance Vertical Axis Wind Turbine

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SUMMARY:
The effect of the turbulent flow field on the functionality of a non-linear engineering system is of utmost importance in the recent era of research. Because of global warming and whirlwind carbon emissions, the timely variation of this natural phenomenon occurring within the atmospheric boundary layer has posed significant risks to engineering structures. Vertical axis wind turbines (VAWT) could potentially benefit from the earlier phenomenon; however, they are influenced by the aerodynamic phenomenon of dynamic stall, which leads to structural instability because of the wind-induced vibration. The leading edge protuberance blades with various solidities were tested at various tip speed ratios and various pitch angles. The triaxial accelerometer and a versatile data acquisition system were used to measure the acceleration data from the shaft of the VAWT, and the results were compared with the corresponding straight-blade VAWT for the improvement in efficiency and the suppression of wind-induced vibration. The VAWT with LEP has shown a reduction in fluctuation, which is quantitatively evident from the spectral analysis of the acceleration data obtained. The effect of LEP on the increase in pitch angle has shown consistent rotational speed for various wind conditions, whereas, for the base model, there was a drastic decrease in tip speed, proving evidence for the occurrence of the dynamic stall phenomenon.

Keywords: Wind-induced vibration, dynamic stall, Leading Edge Protuberance.

1. INTRODUCTION

The wind energy sector seems to be one of the glaring renewable energy harvesting sectors, with almost 12% of annual growth and a positive upward trend. The fight to reduce carbon emissions caused by global warming has proposed a 1.4 times increase in the rate of wind turbine installation over the current rate (Lee and Zhao, 2022). Although horizontal-axis wind turbines appear to have high individual efficiency, they require careful design consideration for turbine placement to achieve maximum efficiency. Instead, the Vertical Axis Wind Turbines (VAWT) has been found to perform better in groups by harnessing the maximum possible wind energy close to the Earth's surface by utilizing the maximum turbulence wind energy due to the Earth's surface boundary layer (KC et al., 2019; Kumar et al., 2018). Although the fluctuating wind is the potential source for the harvesting power compared with its horizontal counterpart, there is wind-induced vibration on the lift-type vertical axis wind turbine that is caused because of vortex-induced vibration (VIV), galloping, buffeting, etc(Lokesh et al., 2021; Horcas et al., 2022; Le

Fouest and Mulleners, 2022; Li and Feng, 2022; Kishore et al., 2018). At larger angles of attack, the airfoil induces vortex-induced vibration, which causes limited cycle oscillations (Hu et al., 2021). The vibration can damage the turbine, reducing its efficiency, and causing it to vibrate or shake, thereby leading to a failure (KC et al., 2020; Orlando et al., 2021). The dynamic stall due to the instantaneous aerodynamic load was delayed, suppressing the fluctuations occurring in the base airfoil (Zhang et al., 2020). The LEP results in the formation of a secondary vortex that weakens the leading edge vortex, thereby increasing the coefficient of lift in both static and dynamic conditions (Hrynuk and Bohl, 2020; Wang et al., 2021). The effects of free stream instantaneous wind loads on the VAWT with straight and LEP blades for different pitch angles, solidity ratios, and tip speed ratios are investigated and analyzed in this study for the reduction of fluctuations caused by aerodynamic loads.

2. EXPERIMENTAL METHODOLOGY

For the investigation, the NREL S1046 airfoil is used, which is considered a high-performance airfoil developed for use in wind turbine blades with a high lift-to-drag ratio, low stall speed, and improved power output(Feng et al., 2018).

Table 1. The model description used for the investigation

Blade Description	Model	No of Blades (N)	Solidity Ratio (σ)
Straight blade (Chord C =14 cm)	Model 1	4	0.68
LEP blade (A = 14% C , W= 36% C)	Model 2	3	0.47
	Model 3	4	0.68

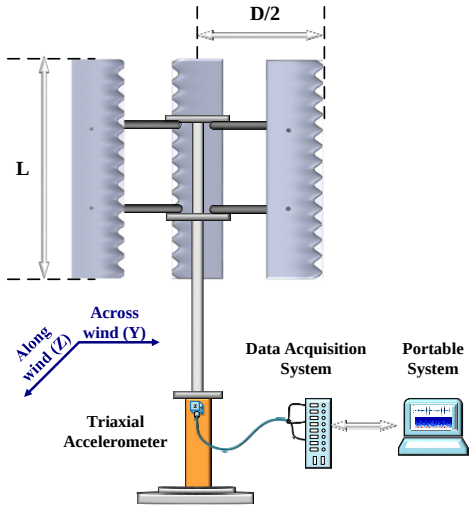

Figure 1. The conceptual diagram of the experiment with LEP blades mounted with blade Model 2

3. RESULTS AND DISCUSSION

The tip speed was higher for the setup with a 0° pitch angle, but with the increase in the pitch angles from 0° to 5°, there is a drastic decrease in the tip speed, which further decreases with the increase in the pitch angle. The configuration with LEP blades has suppressed the sudden decrease in the tip speeds with the increase in the pitch angles, thereby providing evidence of the negligible effects caused by the dynamic stall phenomenon. This helps us understand the enhanced aerodynamic stall behaviour which maintained a constant tip speed and suppressed the vibrational effects which were earlier caused due to the straight blades.

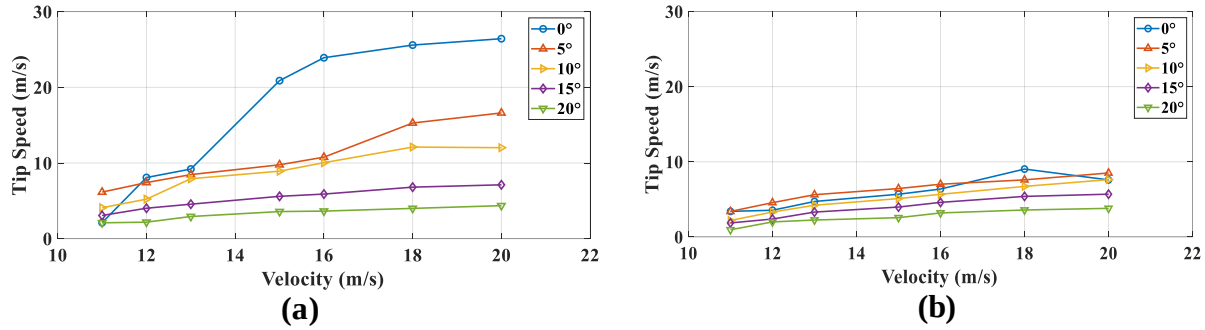

Figure 2. Variation of tip speed for different inflow conditions corresponding to different pitch angles (a) Model 1 (b) Model 2

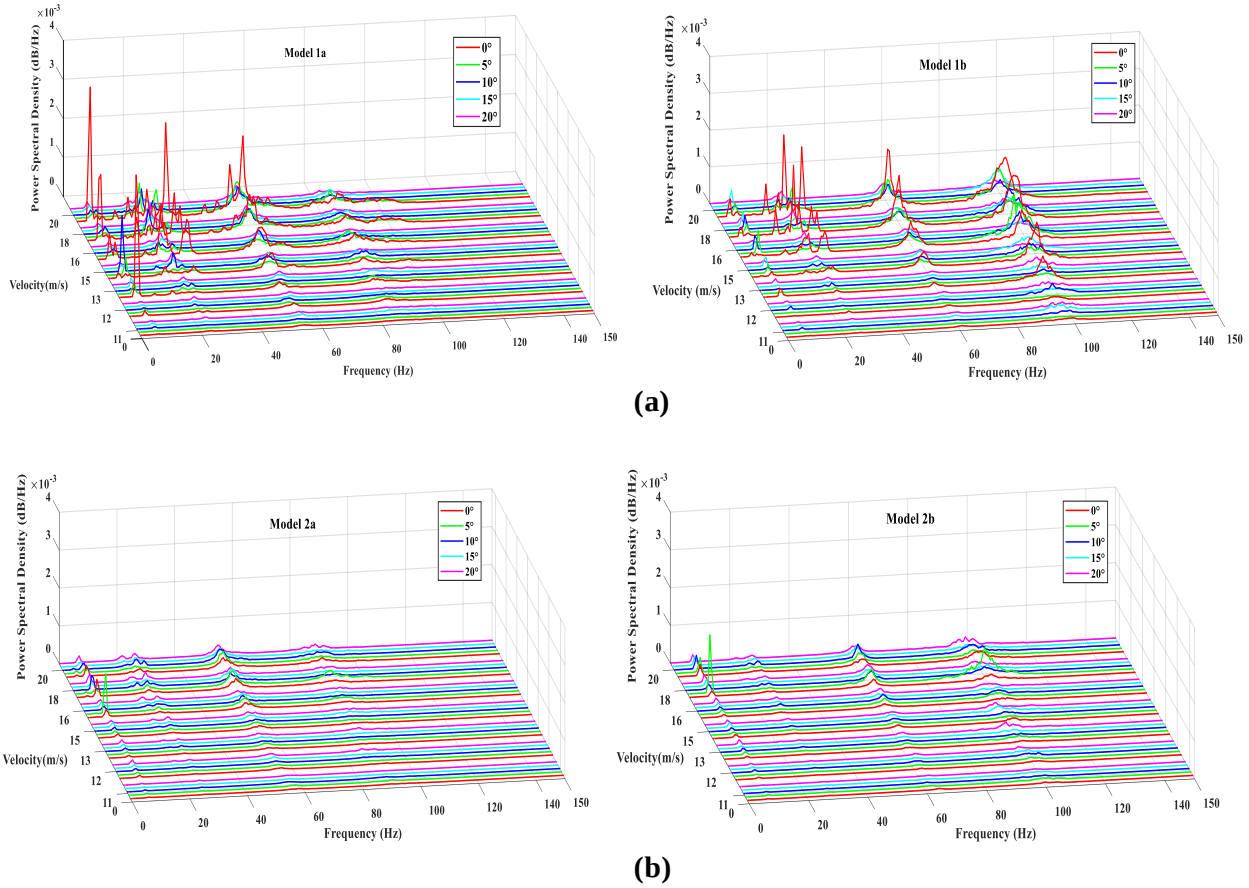

Figure 3. Variation of Power Spectral density of acceleration data along and across direction for different inflow conditions for various pitch angles (a) Model 1a: across the wind, Model 1b: along wind (b) Model 2a: across the wind, Model 2b: along the wind

4. CONCLUSIONS:

The series of experimental investigations performed on the VAWT configuration with LEP blades has put forward the following conclusion.

1. The LEP on the wind turbine blades has resulted in consistent tip speed for various pitch

angles for both pre-stall and post-stall when compared with the straight-blade wind turbine.
2. Spectral analysis demonstrates the suppression of excited modes of peak frequency on the structure caused due to the variation in the aerodynamic flow phenomenon throughout the blade due to LEP.
3. The effects of the dynamic stall phenomenon on the structural vibration are observed clearly from the reduction in tip speed for the VAWT with straight blades and the corresponding evidence of suppression of the structural vibration was seen in the case of VAWT with LEP blades.

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