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Design, Fabrication and Testing of V-shaped Vertical Axis Wind Turbine

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Abstract: This paper attempts to propose Design, Fabrication and Testing of V-shaped Vertical Axis Wind Turbine structure with V-shaped blade to improve the power outputs at moderate tip speed ratios through testing at 5.9m/s wind speed. Focusing on torque, power, and turbine behavior, the research examines the impact of tip speed ratio (TSR) on performance. CAD modelling and fabrication were used to create the turbine, which was tested in open atmospheric conditions.

Torque analysis reveals decreasing torque at higher tip speed ratios due to increased blade rotation. Torque coefficient also declines with higher wind speeds, with maximum values observed when blades are stationary. Power output peaks at an optimal TSR range, showing operational efficiency. The results indicated that the maximum enhancement in power coefficient obtained in the optimal V-shaped blade was at 2.2 TSR and in addition to the great improvement of the power efficiency, and self-starting characteristics. This research underscores the V-shaped VAWT's potential, emphasizing optimal TSR ranges for efficiency. Future research directions include design optimization. It was finally concluded that the current work could be practically applied to the design and optimization of the VAWT blades

Keywords: *V-shaped blade, Vertical axis wind turbine, Experimentation, performance Optimization*

1. Introduction

The escalating global demand for clean and sustainable energy sources has intensified research efforts towards wind power as a prominent renewable energy solution [1]. Wind energy's inherent environmental benefits, coupled with its potential to contribute significantly to the global energy mix, underscore the significance of innovative wind turbine designs [2]. Within this context, vertical axis wind turbines (VAWTs) have emerged as a promising alternative to traditional horizontal axis wind turbines (HAWTs) [3]. VAWTs offer distinct advantages such as simplified installation, reduced noise emissions, and the capacity to capture wind from varying directions, making them particularly suitable for urban and decentralized energy generation scenarios.[4]

Among VAWT configurations, the V-shaped vertical axis wind turbine design has garnered substantial attention due to its potential for enhanced performance across diverse wind conditions. This research endeavors to unravel the intricacies of the V-shaped VAWT through a comprehensive investigation of its performance characteristics [5]. By focusing on critical parameters such as torque, power output, and tip speed ratio (TSR), the study aims to provide deeper insights into the turbine's behavior under varying operational scenarios [6].

The initial phase involves the meticulous design and development of a V-shaped VAWT using cutting-edge computer-aided design (CAD) software. Subsequently, the physical turbine is meticulously fabricated based on the CAD model, facilitating the translation of theoretical concepts into tangible machinery. [7] Rigorous testing is then conducted under real-world open atmospheric conditions to validate the theoretical predictions and empirically assess the turbine's performance.[8]

The Novel V-shaped VAWT blade is planned to increase the performance of the conventional Darrius vertical axis wind turbine. In this work, a number of V-shaped blades were created in an effort to significantly improve VAWT performance. This incorporates a contemporary approach to wind turbine design that might be used to structural optimization. By examining the flow structure surrounding the blade, which was seldom ever done in the prior study, this analysis will improve comprehension of the stalling process. A full history of force-time provides a thorough overview of the evolution of aerodynamics. Also, comparing the flow system and the application of pressure at various points along the blade helps determine which element maximizes the blade's efficiency. Anticipated outcomes from this study hold the potential to illuminate critical aspects of the V-shaped VAWT's operational dynamics. The investigation is poised to elucidate the nuances of torque behavior, power generation trends, and the complex interplay between TSR and turbine efficiency. Moreover, juxtaposing the study's empirical findings with established data will serve as a means of validating the real-world viability of the turbine. [9]

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2. Methodology

This research employs a meticulously designed methodology to comprehensively investigate the performance characteristics of the V-shaped vertical axis wind turbine (VAWT). The methodology encompasses theoretical modelling, practical fabrication, all orchestrated to unveil crucial insights into torque, power output, and tip speed ratio behavior.

Power Coefficient

The performance of a wind turbine rotor is typically shown in a power coefficient vs tip speed ratio graph because the rotor's power production changes with rpm.

The power coefficient is defined as

$$C_p = \frac{T\omega}{0.5\rho A U^3}$$

Tip Speed Ratio (TSR)

The tip to wind speed ratio, or tip speed ratio or TSR is defined as.

$$\lambda = \frac{R\omega}{\mathrm{u}}$$

Torque Coefficient

The torque coefficient basically depends upon the torque produced due to the rotation of turbine. The torque coefficient is calculated through the equation.

$$C_T = \frac{T}{0.5\rho A U^2 R}$$

Number of blades

The number of blades directly influences how smoothly a rotor operates because they can balance out cyclic aerodynamic loads. The variation in rotor torque was greater for turbines with an even number of blades as two blades than for turbines with an odd number of blades as three blades. For three-bladed tiny VAWT systems, where the higher manufacturing and installation costs are less significant than for big rotors, such behavior might be quite advantageous.

Turbine aspect ratio

A high aspect ratio translates into higher rotational speed and torque and vice versa for the same power. The ratio between blade height and rotor radius plays a significant role in the VAWT design process. Aspect ratio influences the Reynolds number and as a consequence the power coefficient.

Turbine solidity

The solidity σ is defined as the ratio between the total blade area and the projected turbine area. It is an important non-dimensional parameter which affects self-starting capabilities and for straight bladed VAWTs is calculated with:

$$\sigma = B/cR$$

Where B is the number of blades, c is the blade chord; it is considered that each blade sweeps the area twice. This formula is not applicable for HAWT as they have different shape of swept area. Solidity determines when the assumptions of the momentum models are applicable, and only when using high $\sigma \geq 0.4$ a self-starting turbine is achieved

Airfoil type

Airfoil proper selection for your VAWT is important in many ways. The airfoil should be selected based on many factors:

1. Chambered or symmetrical 2. Lift/drag ratio 3. Aerodynamic performance to increase output power 4. Airfoil thickness

Pitch angle

It was clearly seen that proper airfoil selection make great contributions to the improvement of aerodynamic performance, but it was difficult to give consideration to self-staring capability, higher power coefficient and wider operational region. Fortunately, it was found out that pitch angle had significant impacts on overall performance of wind turbines.

n-offset blade pitch angle ethe effective region with high power coefficient in advance, while the out-offset blade pitch angle can delay to exist the effective region. From that we investigate the effect of different pitch angles to increase the coefficient of power.

Turbine Design Parameters

Airfoil		**Airfoil NACA0021**
No: of blades	N	3
Chord length	C	100 mm
Height	S	400 mm
Diameter	D	600 mm

3d Design Of V-Shaped Wind Turbine

The research initiates with the conceptual design and CAD modelling of the VAWT. Airfoil coordinates are sourced from the University of Illinois at Urbana-Champaign, serving as the foundation for the CAD model created using SolidWorks 2015. Design parameters encompass airfoil type, blade count, chord length, height, and diameter, meticulously translated into a detailed CAD representation.

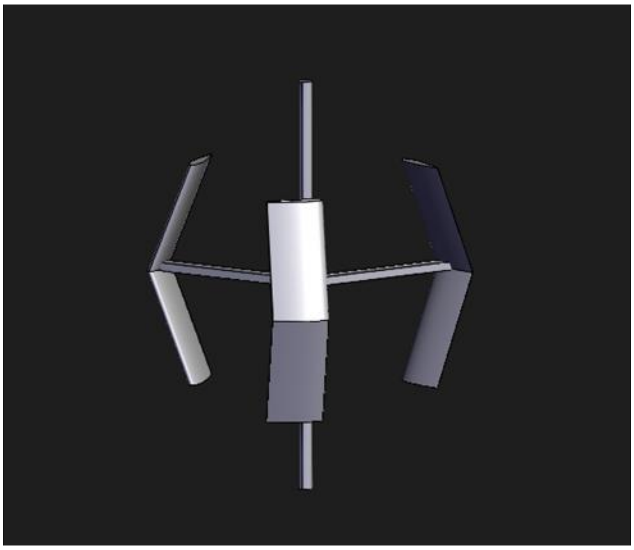

Fig. 1: Front view of V-shaped VAWT

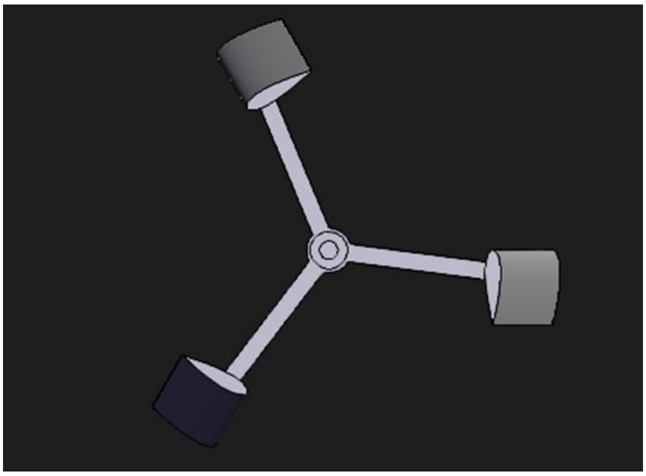

Fig. 2: Top view of V-shaped VAWT

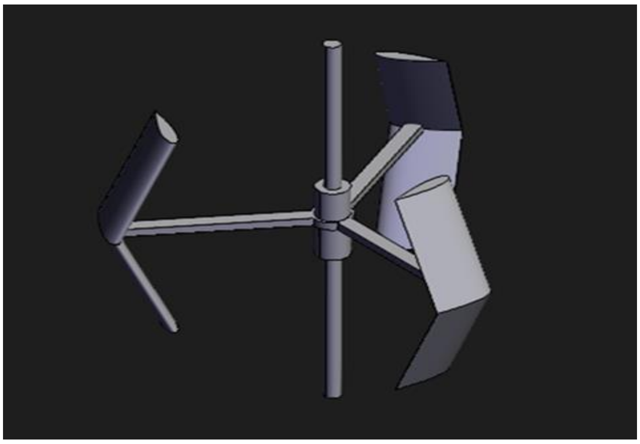

Fig. 3: Auxiliary view of V-Shaped VAWT

Fabrication Process

Subsequently, the meticulously designed CAD model culminates in the physical fabrication of the VAWT. Utilizing materials such as aluminium, cast iron, and mild steel, the components including blades, connecting arms, and central shaft are meticulously crafted. The assembly intricacies are scrupulously adhered to, ensuring accurate translation of the CAD model into a functional physical turbine.

Fabrication of Centre shaft

The center shaft is hollow shaft where another shaft should go through it to fasten it in any wind testing criteria either in tunnel or in atmospheric conditions. The center shaft is made up of mild steel at lathe machine by facing and turning of the shaft at desired length and diameter

Figure.4. Fabricated central shaft

Turbine assembly

For testing turbine, the metal frame is made. The frame is made up of rectangular metal pipes simply known as L angles which are welded together by arc welding. With the help of frame, the turbine can be tested anywhere at any place in open atmosphere. To place turbine in frame two bearings are connected to the turbine rotor shaft as the turbine rotates easily inside the frame where the bearing at the lower part supporting the weight of the turbine by acting as thrust bearing. The pulley is also installed at the top of turbine rotor shaft which rotates with the rotation of rotor shaft. The belt is rounded over the pulley whose one end is connected to nut and other end is attached to the spring balance to measure force applied by the turbine. The installed turbine assembly is shown below in figure.5.

Figure.5. Assembly of the turbine

3. Results and Discussion

The investigation into the performance characteristics of the V-shaped vertical axis wind turbine (VAWT) yields invaluable insights into its torque, power output, and tip speed ratio (TSR) behavior. This section presents a detailed examination of the obtained results, coupled with a comprehensive discussion that delves into the implications and significance of the findings.

Torque Analysis

In figure.6. the torque coefficient at higher resulting in maximum torque. When the wind speed increases, however, the torque gradually declines as the turbine achieves its ideal rpm. the torque coefficient is correspondingly high with low tip speed ratios, in range of from 2-2.2 TSR. When the tip speed ratio increases, the turbine's torque coefficient decreases. This is because the turbine blades move in a more disk-like pattern, limiting torque performance. Furthermore, at high wind speeds (5.9 m/s), torque performance is good at low tip speed ratios due to more wind being passed through the turbine. It should be noted that a low TSR range is essential for the turbine's optimal torque coefficient or torque performance.

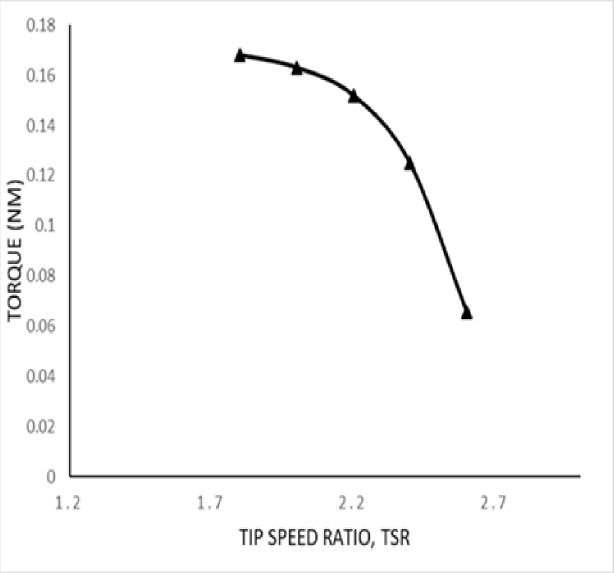

Figure.6. Torque vs tip speed ratio

Torque Performance Analysis

The figure.7 displays the turbine torque as a function of tip speed ratio at 5.9m/s wind speeds. The torque value is high at wind speeds and low at tip speed ratios. When TSR increases, the rpm of the blades increases, causing the torque of the blades to decrease.

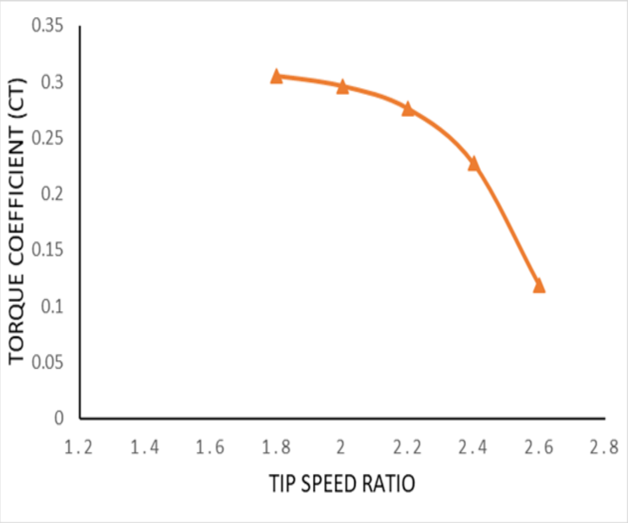

Figure.7. Torque coefficient vs tip speed ratio

Power Analysis

The figure.8. shows the turbine's power production at 5.9m/s wind speeds. Power production is initially modest at low wind speeds, but improves as the tip speed ratio increases. Nevertheless, beyond an ideal TSR (between 2-2.4), the power production begins to decline owing to lower turbine torque. The lower torque limits the turbine's power production when the turbine blades rotate in a more disk-like configuration.

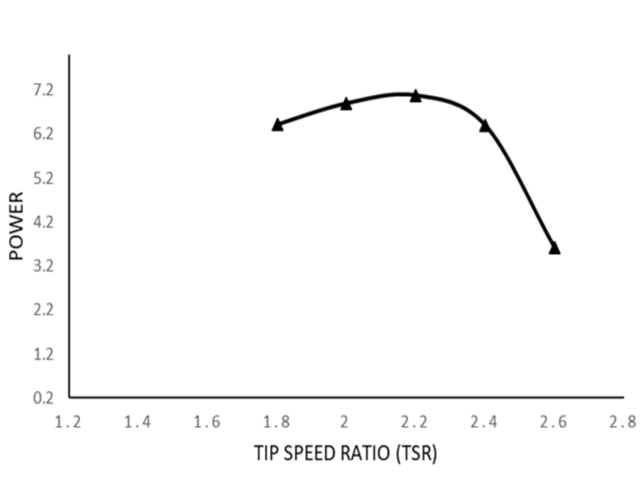

Figure.8. Power vs Tip Speed Ratio

Power Performance Analysis

The Figure.9. displays the power coefficient versus TSR. Because of the poor power generation at low TSR, the power coefficient is initially low, which is caused by low rpm. After a certain point, however, the power coefficient increases at low TSR and reaches an ideal value in the 2-2.2 TSR range. TSR has the same impact on the power coefficient with wind speed: as TSR increases, the power coefficient of the turbine drops. This is due to the fact that at low TSR, the turbine rotates slowly, enabling more wind to travel between the blades while delivering less power. When the TSR increases, the blades rotate quicker, resembling a solid disc and lowering the turbine's power coefficient. It is difficult to calculate the appropriate TSR value for the turbine's power production since it is directly impacted by the TSR. Nevertheless, for optimal power output of a small-scale vertical axis wind turbine, a low TSR in the range of 2-4 is preferred.

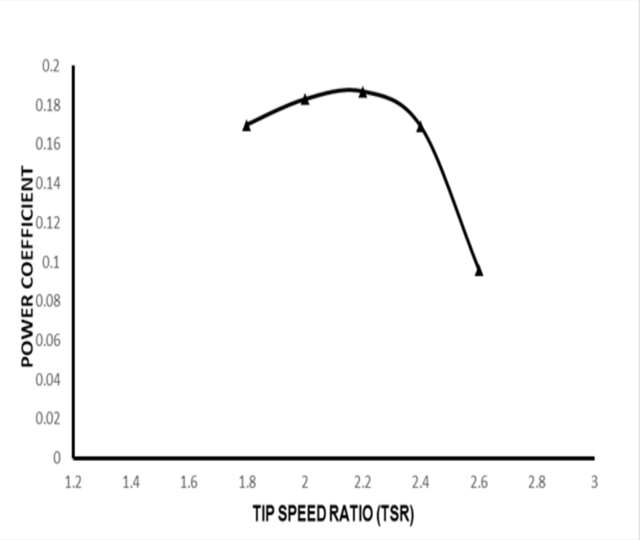

Figure.9. Power Coefficient Vs Tip Speed Ratio

4. Conclusion

In summary, this study explored the power performance enhancements achieved by implementing novel V-shaped blades in a vertical axis wind turbine (VAWT). Initially turbine was designed with CAD modelling and then fabricated to establish turbine assembly to place it at a certain height to understand turbine behavior. For testing turbine, the tachometer was also used to measure RPM of the rotating shaft. Furthermore, torque and power performance of the turbine was calculated numerically and plotted over the graph which pretends turbine behavior with the effect of tip speed ratio in the range of (1.4-2.6). So its behavior is pointed below:

The V-shaped blades exhibit superior VAWT performance compared to the straight blade. The V-shaped blade with a specific geometry parameter showcased optimal power output, yielding over a 20% increase in power coefficient. Optimal power generation predominantly occurs within defined angular regions, demonstrating the effectiveness of V-shaped blades in stabilizing performance and minimizing rotor vibrations. While V-shaped blades slightly influence power coefficients, they effectively mitigate average lateral loads on the wind turbine structure.

Torque and torque coefficient is inversely proportional to tip speed ratio, by increasing tip speed ratio torque and torque coefficient will reduce.

Similar effect was found for power performance after an optimum point with the increase of TSR the power coefficient of turbine decreases. It means turbine performance will be maximum at low tip speed ratio.

Implementation of V-shaped blades redistributes low-speed regions within the wake of the turbine, warranting consideration in wind farm layouts.

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