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International Journal of Renewable Energy and Its Commercialization (IJREC)

Vol: 11 , Issue: 01 , Year: 2025, ISSN: 2582-4120

Design and Fabrication of A Vertical Axis Darrieus Wind Turbine for Household Electricity Generation

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RESEARCH ARTICLE

Received Date: 11 December, 2024

Accepted Date : 09 February, 2025

Published Date : February 23, 2025

Abstract

The Vertical Axis Darrieus Wind Turbine (VAWT) market is growing at 15% annually, valued at $2.1 billion, with rising demand for 10-30 kW models for residential use. This Paper focuses on designing and fabricating a compact, efficient, and low-maintenance VAWT optimized for urban applications and low wind speeds. Addressing gaps in blade design, adaptability, and cost, the turbine features helical blades modeled in SolidWorks for optimal geometry and performance.Polylactic acid (PLA) was selected for blade construction, balancing durability and lightweight properties. A gear system efficiently transferred mechanical energy to a 12V DC generator, supported by a robust frame ensuring structural stability. Field tests confirmed reliable performance under real-world conditions. At a wind speed of 8 m/s, theoretical power output was 1785.36 W, with a practical output of 530 W, achieving 30% efficiency—on par with Horizontal Axis Wind Turbines (HAWTs).The turbine's twisted blade design enabled operation at minimal wind speeds, achieving a maximum coefficient of performance (C.O.P.) of 0.5926 and torque ranging from 0–0.2 N-m. Measurements of wind velocity, rotational speed, and power output demonstrated its suitability for residential applications, particularly in urban and low-height environments.

Keywords: Vertical Axis Wind Turbine (VAWT), Darrieus wind turbine, helical blades and renewable energy.

INTRODUCTION

Wind energy has emerged as a sustainable alternative to traditional power sources, offering solutions to global challenges such as climate change, pollution, and energy security. As a clean, abundant, and cost-effective resource, wind energy eliminates harmful emissions, reducing dependence on fossil fuels and their associated price fluctuations. Vertical Axis Wind Turbines (VAWTs) have garnered attention due to their adaptability in urban and residential settings, where unpredictable wind patterns prevail. Unlike Horizontal Axis Wind Turbines (HAWTs), VAWTs can capture wind from any direction, making them ideal for turbulent and low-wind conditions.[1]

Recent advancements, such as the incorporation of helical blades, have enhanced the performance and self-starting capabilities of VAWTs. Lightweight designs using polylactic acid (PLA) 3D-printed blades with reduced fill density have further optimized their efficiency by lowering weight and material usage. These innovations, coupled with the compact and easily maintainable nature of VAWTs, support decentralized energy generation for homes, parks, and offices. They also play a vital role in powering remote locations, reducing energy costs for businesses, and supporting sustainable urbanization.

Despite these advantages, challenges remain in addressing wake vortices, optimizing self-starting mechanisms, and integrating hybrid systems to enhance performance. With continued advancements in materials and design, VAWTs are poised to overcome these gaps, further driving their role in reducing reliance on fossil fuels and contributing to a sustainable energy future.[2]

Research on Vertical Axis Wind Turbines (VAWTs) has focused on advancing their design and performance to adapt to urban and turbulent wind conditions. Akanksha Mishra explored helical-shaped VAWTs optimized for urban settings, while Arifin Sanusi et al. and Ken-Yeen Lee et al. emphasized optimizing blade angles, lift, torque, and self-starting capabilities, alongside improving blade-to-wake interactions. Studies by Smith and Johnson, V Abimani et al., and Atharva N. investigated the feasibility of harnessing wind energy along highways, leveraging vehicle-induced airflow using semi-circular blade VAWTs. Shibo Liu et al. highlighted the challenges of low wind speeds and high turbulence in urban areas, whereas Oscar Garcia et al. evaluated drag-based turbines, like Savonius, for specific applications. Lei Xu et al. compared onshore and offshore wind turbines, providing insights into performance metrics across environments. Recent innovations include A.A. Safe et al.'s design of self-starting VAWTs for vehicles and the use of lightweight, 3D-printed PLA blades with reduced fill density for enhanced efficiency. [3]

While these studies demonstrate significant progress, critical gaps persist. These include optimizing self-starting mechanisms, mitigating efficiency losses due to wake vortices, and integrating hybrid systems to improve overall performance. The need for lightweight and adaptable materials, such as polylactic 3D-printed blades, further emphasizes the importance of material innovation in achieving low-weight and high-efficiency designs. Addressing these gaps is essential for enhancing VAWT performance in urban, highway, and rural settings, thus contributing to a more sustainable energy future.This paper aims to design a compact VAWT with helical blades for efficient, continuous energy capture in variable, low-speed winds. Optimized for urban settings, it features enhanced aerodynamics, low start-up wind speed, and aesthetic appeal, making it ideal for rooftops and small spaces. [4]

DESIGN AND FABRICATION

Modelling

The preliminary design of a (VAWT) focuses on maximizing energy capture from multi-directional winds. The Darrieus design, with its helical-shaped blades, is chosen for its efficiency and adaptability to low and variable wind speeds. Key components include the rotor, shaft, and generator, with blades optimized for aerodynamics using suitable materials and angles. Compact and stable, the turbine suits urban and remote applications, providing sustainable energy. Some components were fabricated using 3D printing, a layer-by-layer manufacturing process enabling precise, rapid production of complex designs using materials like plastics and resins, as illustrated in related Fig.1.

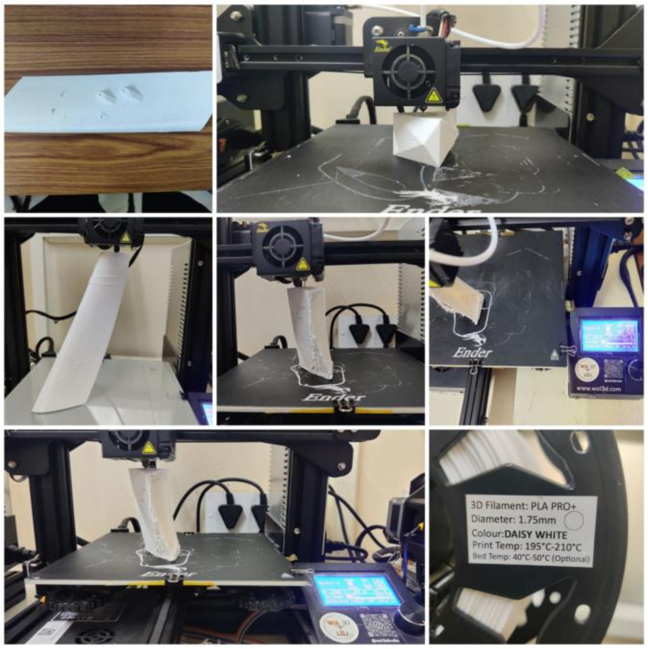


Fig.1: 3D Printed Materials (Blades, arms, Hubs and gears) for VAWT.

Ultimaker Cura, a free and user-friendly 3D printing software, converts 3D models into G-code for efficient printing. Supporting materials like PLA, ABS, and TPU, it offers features such as adaptive layer height, multi-material printing, and 3D previews for optimal results. We used Cura to fabricate the blade, arm, and hub, shown in Fig.2.leveraging its customization tools for precise settings, ensuring high-quality, optimized designs suitable for our Vertical Axis Wind Turbine Paper. [5]

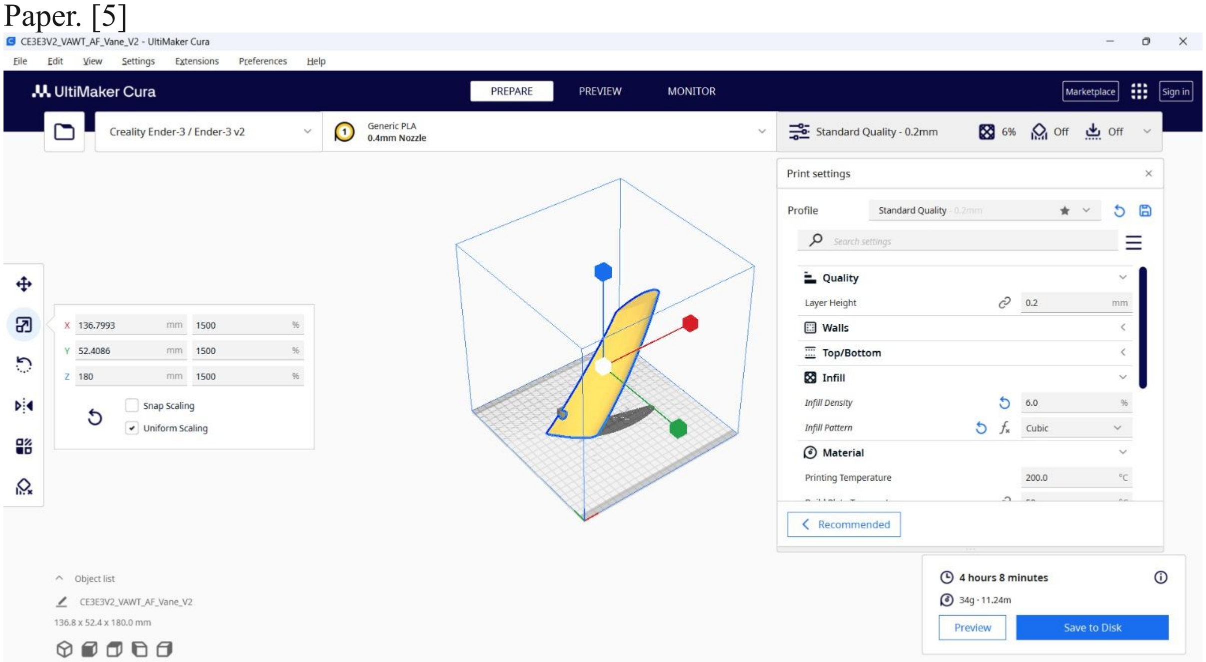


Fig.2:VAWT blade Modelling in Ultimaker cura software

The 3D-printed airfoil replicates turbine blade aerodynamics, reducing drag and maximizing lift.Blade Specifications are shown in below Table 1 Precise fabrication ensures accuracy, while optimized rib placement enhances structural stability for testing and prototype evaluation before scaling. [6]

Table 1: Verticle axis wind Turbine Blade Specifications

Rotor type -Helical
Rated wind speed -8 m/s
Rated power output - 530W
Power coefficient- 0.4
swept area- 1.57 m2
Rotor radius- 0.55 m
Rotor Height- 1.08 m
Chord length -0.25 m
Airfoil- NACA0012
Number of blades- 3

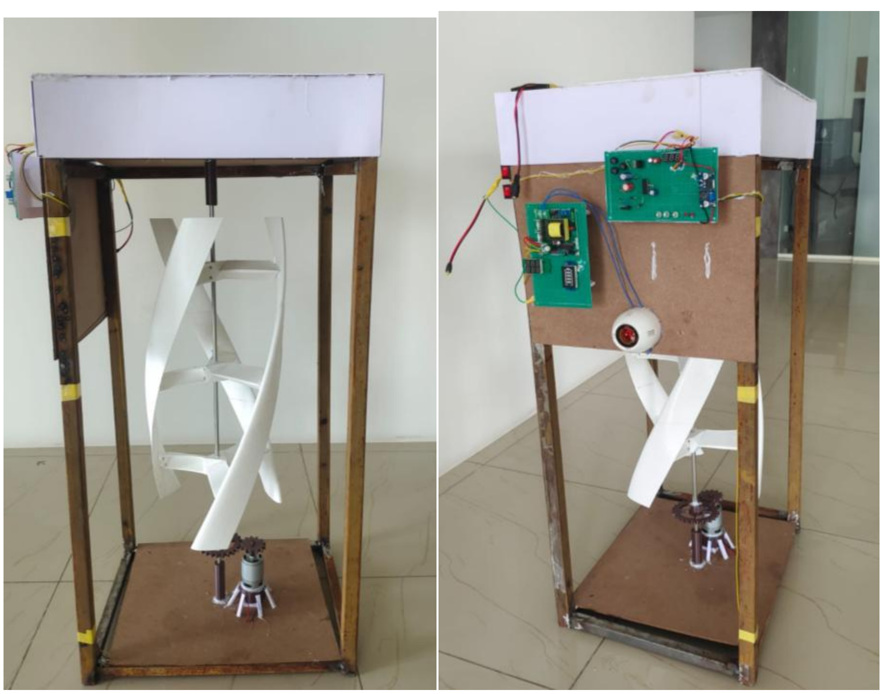
The 3D-printed arm connects the blade to the hub, featuring a lightweight, inclined design that reduces hub length, minimizes vibrations, lowers production costs, and enhances system stability and durability.
The 3D-printed hub securely transfers power from blades to the shaft using set screws. Featuring two flanges and a central cylinder, it ensures structural integrity and precise shaft alignment.
The vertical axis wind turbine features a durable steel frame, expertly welded for stability and support. It withstands rotational forces, minimizes vibration, and ensures reliable, long-lasting operation under variable wind conditions.12V batteries are vital for powering vehicles, backup systems, and portable electronics. They store energy for engine starts, support auxiliary systems, and provide reliable power in remote or off-grid solar applications.A 12V DC generator converts mechanical energy into 12V direct current, powering low-voltage devices or charging batteries in off-grid or portable systems. Commonly used in small-scale renewable energy setups, automotive applications, and emergency backup, it provides a reliable power source where conventional power might be unavailable. [7]
The anemometer measures wind speed using rotating cups or blades, providing data to evaluate turbine performance, optimize placement, and ensure efficient operation in varying wind conditions.
Polylactic Acid commonly used in 3D printing for various applications, including the printing of blades for prototypes and non-functional parts. However, when used for printing blades especially in contexts like wind turbine blades, fan blades, or other performance-critical applications there are some important considerations to keep in mind.A ball bearing reduces friction by using balls

to separate bearing races, enabling smooth rotation and supporting high loads. It enhances efficiency and durability, improving performance in machinery, automotive applications. [8]

Final Product :

The Vertical Axis Wind Turbine (VAWT) was designed for efficient, compact household electricity generation. Using SolidWorks, turbine blades with optimized twisted profiles were created, and Polylactic Acid (PLA) was chosen for its durability and light weight. A welded steel frame provided stability, while the alternator converted mechanical energy into electricity, with battery storage included. Field tests showed in Fig.3 (a) and (b) practical efficiency of 30%, proving its effectiveness in low wind speed residential settings. [9]

Fig.3:Completed VAWT System



(a) Blade view *(b) PCB view*

Experimental Result of Vertical Axis Wind Turbine.

VAWTs convert wind's kinetic energy into mechanical energy via rotating blades, which then drive a generator to produce electricity. Performance depends on factors like wind speed, blade design, shaft speed, and energy transfer efficiency. Wind energy increases with velocity, making wind speed crucial. The tip speed ratio (TSR), comparing the turbine's rotational speed to wind speed, affects efficiency. Field tests showed a practical efficiency of about 30% in moderate winds, making the VAWT suitable for areas with variable wind conditions. [10]

Wind Speed

Wind speeds above 7 m/s are essential for electricity generation using the Vertical Axis Wind Turbine.Higher speeds, such as 8.57 m/s and 9.58 m/s, boost power output, with 11.51 m/s providing optimal performance shown in Fig.4. Moderate speeds like 7.65 m/s also support consistent energy production for reliable residential use.

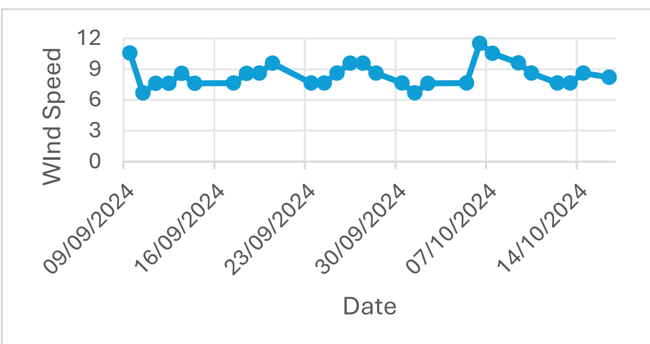


Fig.4: Wind speed v/s Date

Wind energy Available

Wind energy availability fluctuates due to changing wind speeds and environmental conditions, affecting the efficiency of Vertical Axis Wind Turbines . During testing, peak energy values reached 10.22 W, while lower values were 2.18 W, showing significant variability shown Fig.5. This highlights the need for optimized turbine designs that can efficiently capture energy in both high and moderate wind conditions for consistent power generation.

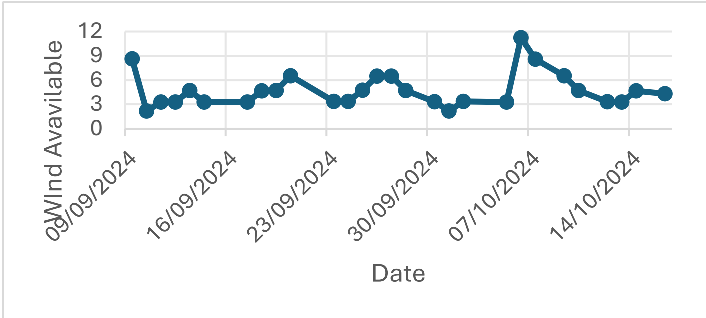


Fig.5: Wind Available vs Date

Power from Shaft

The turbine's shaft power data reveals fluctuations due to changing wind conditions. Higher power outputs, like 3.88 W on 06-10-2024, indicate favorable wind speeds, while lower values, such as 0.76 W on 10-09-2024, highlight challenges from reduced winds as shown in Fig.6. These variations emphasize the need for a robust shaft and gear design to ensure consistent power transfer and efficiency.

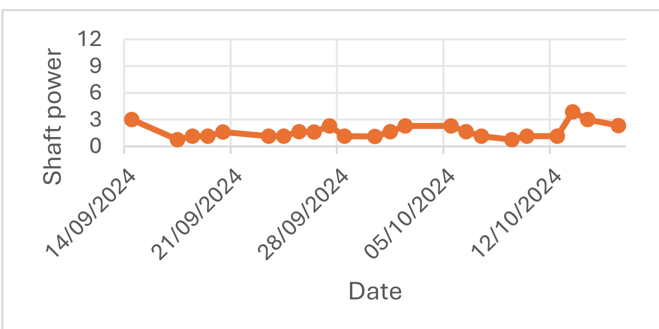


Fig.6:Shaft power v/s Date

Electricity Produce

Field tests of the Vertical Axis Wind Turbine (VAWT) revealed varying shaft power outputs based on wind conditions. On favorable days, power peaked at 3.52 W, while lower winds produced minimal outputs around 0.61 W.shown in Below Fig.7. Consistent power of 1.01 W under moderate winds demonstrates the turbine's reliability for household energy generation.

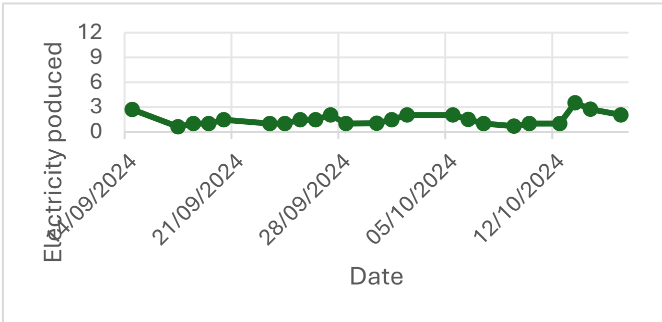


Fig.7: Electricity Produced v/s Date

Conclusion

The fabricated Vertical Axis Wind Turbine (VAWT) demonstrated an efficiency of approximately 30%, which is comparable to the efficiency of horizontal axis wind turbines (HAWTs), and significantly higher than the 17% efficiency observed in commercial VAWTs. While the efficiency is relatively low, it remains notable for its ability to generate usable power from wind, particularly in low wind conditions. One factor contributing to the lower efficiency is the substantial dead weight of the turbine. However, VAWTs offer advantages over HAWTs, particularly in their ability to operate effectively at lower heights, making them suitable for residential applications where they can be installed on individual houses. The power generated can be stored or used to charge a storage device for continuous power supply.

Despite the relatively low efficiency, the turbine is designed to achieve rotation at minimal wind speeds, utilizing drag force and a twisted blade configuration to maximize performance in low-wind environments. In experiments, the turbine generated 11.77 watts at 112 RPM and 8 m/s wind speed. Wind power, derived from kinetic energy flux, is quantified using fluid mechanics principles, and the turbine extracts energy by slowing the wind and transferring it to the spinning shaft, which drives a generator. The domestic helix design ensures safety, ease of installation, and surprisingly good performance, with a coefficient of performance (C.O.P.) of 0.5926 and a maximum torque of 0.2 N·m.

Scope for Future Work

1. Innovations in materials, blade designs, and AI-powered control systems enhance VAWT efficiency, durability, and adaptability to fluctuating wind conditions.
2. Compact and omnidirectional, VAWTs are ideal for urban and distributed energy setups, seamlessly integrating into rooftops and building facades for decentralized power.
3. Combining VAWTs with solar panels and advanced battery systems ensures consistent energy generation, addressing wind variability and off-grid demands.
4. VAWTs offer sustainable power for remote and developing regions, providing accessible, off-grid energy solutions with minimal maintenance.

5. As nations push for carbon neutrality and renewable energy adoption, VAWTs' suitability for space-limited areas and low-wind regions boosts their role in clean energy transitions.

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