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DESIGNING VERTICAL AXIS WIND TURBINE FOR SMALL SCALE POWER GENERATION WITH 3D PRINTER

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ABSTRACT

In our modern world, where electricity usage continues to rise, the potential of wind power as a convenient and sustainable energy source cannot be overstated. The key lies in harnessing this abundant resource effectively. In conjunction with smart grid technology, small-scale wind turbines have emerged as a means to enhance the resilience and robustness of our power grids. What sets these small wind turbines apart from their conventional counterparts is their ability to capture energy from low-speed winds, making them versatile and adaptable. Unlike traditional horizontal axis wind turbines, these smaller models employ a vertical axis design, with variations such as the Savonius, which utilizes wind drag, and the Darrieus, which harnesses wind lift. Leveraging 3D printing as the primary manufacturing method for these turbines is an innovative approach. This article focuses on the quest to find an optimal Vertical Axis Wind Turbine (VAWT) design tailored for small-scale operations in low-speed wind conditions, often found in urban environments. To achieve this, a comprehensive literature study was conducted to determine the most suitable VAWT design, resulting in the selection of the Helical Savonius with three blades. The 3D model was meticulously crafted using Autodesk Fusion, followed by the setup of the 3D printer using Cura. In this article, the Ender 3v2 was chosen as the 3D printer of choice. While the printed design exhibited minor deviations of 2mm from the original, and some setup improvements are needed, the turbine holds promise for utilization in various projects, including power generation.

1. Introduction

In our modern world, electronic devices have seamlessly integrated into our daily lives, serving as essential tools across all segments of society. These devices rely on a consistent supply of electrical energy for tasks ranging from everyday chores like laundry and hair drying to leisure activities such as watching television. As our reliance on electronic devices grows, so does our hunger for electricity. Ensuring a reliable power supply emphasizes the importance of a resilient electrical grid. A smart grid offers the promise of a more efficient and robust network that can withstand disturbances and reduce the risk of blackouts.

While the development of a smart grid is a significant advancement, it alone cannot fully meet the increasing demand for electricity. To address this challenge, it's crucial to explore diverse avenues for electricity generation. The energy landscape provides a wealth of options, including both non-renewable and renewable sources. Non-renewable resources like coal and natural gas have been staples of our energy production but pose environmental concerns due to greenhouse gas emissions. This realization has led to a shift toward cleaner, more sustainable alternatives.

Among these alternatives, wind power has emerged as a prominent player in the realm of renewable energy. Wind turbines, capable of harnessing the kinetic energy of the wind, stand as the second-largest contributors to renewable electricity generation, following closely behind solar power [1]. Nevertheless, large wind turbines designed to capture high-speed winds at elevated altitudes have presented certain challenges. These include the generation of significant noise due to wind drag, which can disrupt local ecosystems [2]. Moreover, their substantial investment costs and site-specific requirements limit their widespread deployment.

In response to these challenges, a new generation of smaller wind turbines has emerged, offering innovative solutions to mitigate these issues. While smaller wind turbines may not reach the extraordinary wind speeds of their larger counterparts, innovative adjustments to their axis orientation have significantly improved their efficiency. This reduces their reliance on exceptionally high wind speeds for optimal performance. The transition towards smaller, more adaptable wind turbines not only enhances their environmental compatibility but also broadens their applicability across diverse landscapes.

Furthermore, the compact size of these turbines makes them amenable to manufacturing using 3D printer technology. The versatility of 3D printing allows for the creation of various and unique turbine designs, and with the decreasing cost of filament materials, manufacturing wind turbines through 3D printing has become a cost-effective approach.

Integrating these small wind turbines into smart grids further contributes to grid resilience, bolstering our capacity to meet the escalating demands for electricity. Given all these reasons, conducting research to optimize the design of small wind turbines represents a critical first step in addressing our growing demand for electricity. In doing so, these smaller, more efficient turbines will not only meet our energy needs but also harmonize more effectively with the surrounding environment.

2. Method and materials

In the pursuit of finding the optimal and versatile design for a Vertical Axis Wind Turbine (VAWT), we conduct a comprehensive literature review focusing on critical parameters like design shape, size, and experimental outcomes. Specifically, we compare the Savonius and Darrieus VAWT designs, where the former relies on drag forces and the latter on lift forces for rotation. We explore various iterations of these designs to determine the most efficient and adaptable one, balancing performance, simplicity, and versatility.

Following our literature review, we create the selected design using 3D modeling applications like Autodesk Fusion or SketchUp, which convert the design to .stl format. This is necessary for further conversion to .Gcode, accomplished using software like Cura, to configure the 3D printer. The Ender 3v2 3D printer is chosen for manufacturing, utilizing PLA filament.

This multi-faceted approach, encompassing a literature review, design creation, and physical realization, promises to provide profound insights into the potential of VAWTs and pave the way for more efficient and versatile wind energy solutions. To provide a clear overview of the article's structure, **Figure 1** will outline the article's trajectory and organization.

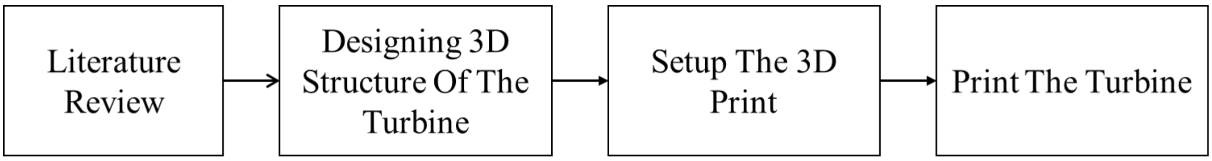


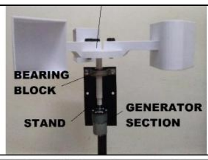
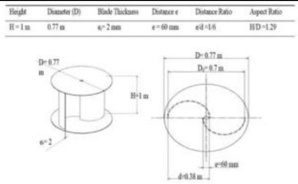
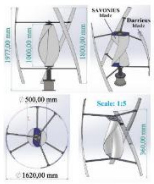
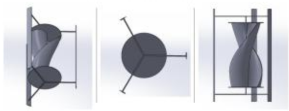
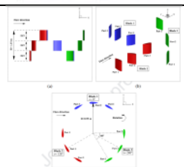
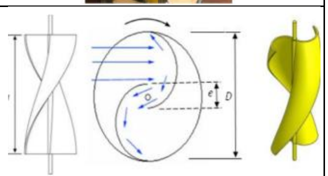
Figure 1. Block diagram

3. Result and discussion

3.1 Literature Review

This literature review is an assembly of ten articles that delve into a range of Vertical Axis Wind Turbine (VAWT) designs, each subject to thorough performance evaluations. Within this review, **Table 1** provides a comprehensive listing of these diverse designs, along with their respective sizes, as sourced from these scholarly references.

Table 1. List Of All Articels That Being Compared

Article	VAWT Design	VAWT Size	VAWT Picture
Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT) [3]	Darrieus	$20\ cm \times 20cm \times 20\ cm$	
Review Paper on Vertical Axis Wind Turbine [4]	Savonius	$77\ cm \times 77cm \times 100\ cm$	
Aspects Regarding the Use of 3D Printing Technology and Composite Materials for Testing and Manufacturing Vertical Axis Wind Turbines [5]	Savonius - Darrieus	$180\ cm \times 162cm \times 162\ cm$	
Numerical Investigation of Hybrid Savonius Darrieus Vertical Axis Wind Turbine at Low Wind Speeds [6]	Savonius - Darrieus	$103\ cm \times 103\ cm \times 145\ cm$	
Design, Fabrication, and Performance Test of a 100-W Helical-Blade Vertical-Axis Wind Turbine at Low Tip-Speed Ratio [7]	Helical Darrieus	$103\ cm \times 103\ cm \times 145\ cm$	
Performance investigation of a new Darrieus Vertical Axis Wind Turbine [8]	Helical Darrieus	$33\ cm \times 33\ cm \times 99\ cm$	
Design and Manufacturing of Horizontal and Vertical Wind Turbine With 3D Printing Technology [9]	Helical Savonius	$20\ cm \times 20cm \times 20\ cm$	
Experimental study of helical savonius rotor profiles with different number of blade [10]	Helical savonius	$46\ cm \times 46cm \times 80\ cm$	
Performance and wake of a Savonius vertical -axis wind turbine under different incoming conditions [11]	Helical savonius	$33\ cm \times 33\ cm \times 99\ cm$	
Data set on the experimental investigations of a helical Savonius style VAWT with and without end plates [12]	Helical Savonius	$66,66\ cm \times 66,66cm \times 100\ cm$	

Based on the insights derived from the comprehensive review of various articles mentioned earlier, several key conclusions emerge regarding Vertical Axis Wind Turbine (VAWT) designs. Firstly, the Darrieus design and its variants have proven practical for harnessing wind speeds of approximately 5 meters per second (m/s) [3], [7], [8]. This design boasts an impressive power coefficient (Cp) of 0.163, signifying that for every 1000 units of power entering the turbine, it can yield 163 units of power. However, it's worth noting that achieving this Cp necessitates an average wind speed of 5 m/s. Nonetheless, the Darrieus design does have its limitations, including the requirement for a specific wind angle of elevation to generate lift and rotor rotation. Additionally, robust structural support is essential to withstand the forces exerted by the blades.

In contrast, Savonius design and its variations have proven effective at lower wind speeds, around 4.5 m/s or even lower [4], [9]–[12]. Although the Cp for this design peaks at around 0.12, which is lower than that of the Darrieus design, Savonius variations excel in operating efficiently at lower wind speeds. Furthermore, the Savonius design boasts a relatively straightforward turbine structure, making it more accessible for manufacturing.

Lastly, the hybrid VAWT design, which combines elements of both Savonius and Darrieus, leverages both lift and drag forces from the wind [5], [6]. However, this hybrid approach introduces increased design complexity in pursuit of higher power output.

In summary, these conclusions underscore the suitability of Darrieus and Savonius designs for distinct wind speed ranges, with Darrieus excelling at moderate speeds and Savonius variations proving efficient at lower speeds. The hybrid design, while promising, entails greater design complexity to harness both lift and drag forces.

3.2 Designing 3D Structure of The Turbine

Taking into account the extensive literature review, a decision has been reached to adopt a helical Savonius design featuring three blades, with dimensions measuring approximately 20 cm × 20 cm × 20 cm. This choice is underpinned by several compelling reasons, primarily the suitability of helical Savonius designs for low-speed applications and their inherent simplicity in design. Additionally, these dimensions align seamlessly with the printing bed capacity of the Ender 3v2, which measures approximately 21 cm × 21 cm × 25 cm.

The design process for this turbine will be conducted using the Autodesk Fusion Desktop application. Throughout the design phase, several crucial aspects require dedicated attention. One notable consideration involves establishing a seamless means for the generator to attach to the turbine. This will be accomplished by incorporating a slot beneath the turbine, capable of accommodating various components such as gears or additional turbines. This design approach not only promotes modularity but also simplifies the printing process, allowing for the concurrent production of identical parts. During printing, two turbines of 10 cm in height will be used. Visual representations of these modular components can be found in **Figure 2** and **Figure 3**, while **Figure 4**and ***Figure 5*** provide comprehensive details regarding the turbine's dimensions.

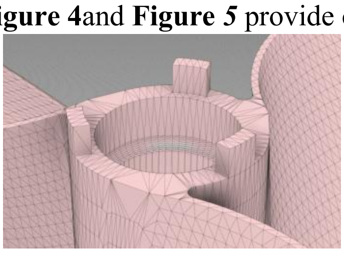


Figure 2. Top of Turbine

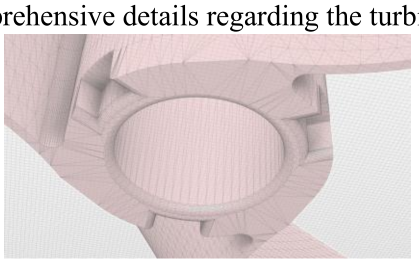


Figure 3. Bottom of Turbine

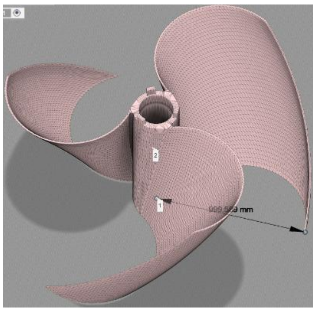


Figure 4. VAWT Design from above

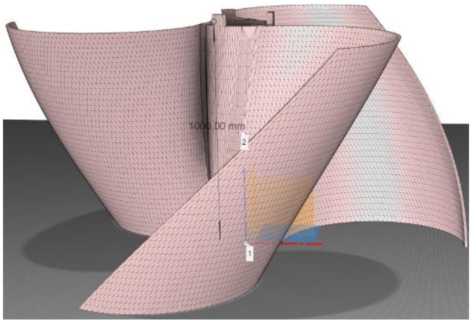


Figure 5. VAWT Design From The Front

3.3 Setup The 3D printer

In this article, the process of converting .stl files generated in Autodesk Fusion to .Gcode files will be facilitated through the use of Cura software. The selected printing settings for the production of the turbine involve using a 0.5 mm nozzle, implementing a 20% infill density, adhering to standard quality parameters, selecting the gyroid infill pattern, maintaining a print speed of 50 mm/s, setting the infill speed at 25 mm/s, establishing a printing temperature of 210 °C, keeping the built plate temperature at 60 °C, and operating the cooling fan at 100% speed. These settings have been meticulously chosen to ensure the attainment of optimal results throughout the 3D printing process for the turbine. A visual representation of the Cura interface can be found in Figure 6.

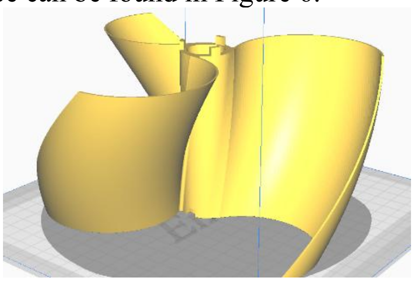


Figure 6. VAWT Turbine Preview on Cura

3.4 Print The Turbine

The .Gcode file generated by Cura is then transferred to a micro SD card, which is subsequently inserted into the Ender 3v2 for the 3D printing process of the turbine. This intricate printing operation spans approximately 9 hours and 53 minutes, during which it must remain undisturbed to ensure precision and consistency. Figure *7* and Figure *8* provides a visual representation of the final outcome of the print, showcasing the tangible result of this meticulous 3D printing endeavor.

Figure 7. Height of The Turbine

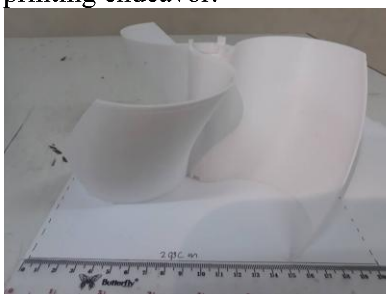


Figure 8. Diameter of The Turbine

4. Conclusion

This article yields several noteworthy conclusions:

- Darrieus Vertical Axis Wind Turbines (VAWTs) exhibit a higher Cp (power coefficient) when compared to Savonius VAWTs, particularly at higher wind speeds. This indicates that Darrieus designs are more efficient in harnessing wind energy under these conditions.
- Savonius VAWTs are optimized for operation at lower wind speeds, making them well-suited for environments with less wind intensity. They excel in scenarios where wind speeds are not consistently high.
- While 3D printing is a valuable manufacturing technique, it may not always yield perfect results in terms of dimensional accuracy. In this study, there were slight differences between the designed specifications and the actual printed turbine, with variations observed in a few millimeters.
- The turbine designed in this study demonstrates potential applications in power generation for low-speed conditions or in small-scale operations. Its suitability for such scenarios highlights its versatility and potential for addressing specific energy needs.

These conclusions provide valuable insights into the performance and applications of different VAWT designs and underscore the importance of considering specific operational conditions and manufacturing limitations in wind turbine design.

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