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Mini VAWT Generator

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Abstract

This project designs, fabricates, and tests a prototype of a Mini Vertical Axis Wind Turbine (VAWT) Generator for small-scale energy generation. This mini VAWT's vertical blade design enables omnidirectional wind capture, enhancing reliability in variable wind conditions. Mechanical energy is converted into electricity via a shaft and spur gear system, stored in batteries, or used to power small appliances like light bulbs. The electrical system includes a battery management system, an AC-to-DC circuit, and a voltage regulator for stability. The prototype blades and shaft are 3D-printed using PLA material for cost-effectiveness and ease of fabrication. Testing shows the turbine generates 0.31 to 1.23 VDC at wind speeds of 1.4 to 7 m/s, successfully charging the integrated battery. This project demonstrates the potential of small-scale VAWTs as sustainable energy solutions for low-power applications, particularly in urban or remote areas. Future work will focus on material optimisation and efficiency improvements for broader implementation.

1. Introduction

Despite the growing demand for renewable energy solutions, small-scale wind turbines, particularly Vertical Axis Wind Turbines (VAWTs), remain underutilised in urban and residential settings. While large-scale wind farms and solar panels dominate the renewable energy landscape, they often fail to address localised energy needs, especially in areas with variable wind speeds or limited space [1]. This project aims to bridge this gap by developing a mini prototype of a VAWT system capable of generating low-voltage electricity for domestic usage in future. By leveraging advanced manufacturing techniques like 3D printing and optimising turbine components through parametric analysis, this project seeks to provide a sustainable, cost-effective, and adaptable energy solution for decentralised electricity generation.

Current research on wind energy has predominantly focused on large-scale horizontal-axis wind turbines (HAWTs) and offshore wind farms, which are unsuitable for urban environments due to their size, noise, and reliance on consistent wind direction [2]. Small-scale VAWTs, while promising, have received limited attention, particularly in optimising their efficiency and adaptability for low-wind-speed conditions. Studies have shown that existing VAWT designs often suffer from low energy conversion rates and high manufacturing costs, limiting their widespread adoption [3]. This lack of innovation in small-scale wind energy systems highlights a critical gap in renewable energy research.

Moreover, integrating advanced manufacturing technologies, such as 3D printing, into wind turbine design remains underexplored. While 3D printing has revolutionised prototyping and production in various industries, its application in renewable energy systems, particularly for VAWTs, is still in its infancy [4]. Additionally, there is a lack of research on using parametric analysis to optimise VAWT components for specific environmental conditions, such as the variable wind speeds typical in residential areas. These gaps underscore the need for innovative approaches to improve the performance and affordability of small-scale wind turbines.

Furthermore, the potential of VAWTs to operate efficiently in urban environments, where wind patterns are often turbulent and multidirectional, has not been fully realised. While HAWTs require consistent wind direction and high wind speeds, VAWTs can harness wind from any direction, making them ideal for urban settings. However, existing VAWT designs often fail to capitalise on this advantage due to inefficiencies in blade design and energy conversion mechanisms [5]. This project addresses these shortcomings by developing a VAWT system specifically tailored for urban and residential applications.

Addressing these research gaps is crucial today, with the demand for decentralised and sustainable energy solutions rapidly increasing. Urbanisation, coupled with the growing need for energy security and carbon emission reduction, necessitates innovative approaches to renewable energy generation [6, 7]. Small-scale VAWTs offer a viable solution by providing a reliable and environmentally friendly energy source for households and small businesses. By optimising VAWT designs and integrating advanced manufacturing techniques, this project contributes to the global transition toward sustainable energy systems.

This project focuses on designing, fabricating, and testing a mini Vertical Axis Wind Turbine (VAWT) prototype for small-scale electricity generation. The primary objective is to develop a prototype of a mini VAWT generator that generates low voltage under varying wind speeds, typically found in residential areas. The energy generated is stored in a lithium polymer (LiPo) battery, powering low-amperage appliances such as LED bulbs. Key innovations include using 3D printing for cost-effectiveness and ease in manufacturing turbine components and parametric analysis to optimise the shaft and gear systems for enhanced performance. The selected generator can generate a low voltage up to 12 direct current (VDC) range, ensuring versatility across different conditions. The experimental test demonstrated the system’s ability to generate electricity at wind speeds as low as 1.4 m/s, highlighting its potential as a practical and sustainable energy solution for decentralised applications.

2. Methodology

The flowchart in Fig. 1 outlines the systematic process of developing a mini Vertical Axis Wind Turbine (VAWT) generator. The project begins with Idea Generation, where the initial concept is formulated. This is followed by the design stage, which includes conceptual, preliminary, and detailed design to produce a comprehensive blueprint for the generator. Critical components such as the bearing type for the shaft, gear ratio, dynamo size, and blade sizes are carefully considered during this phase to ensure optimal performance. If the design meets the required criteria, the project proceeds to the fabrication stage, where the machine's components and system are developed. Each machine system and component undergo an initial test before integrating all systems. Any system or component not meeting the design requirement is revisited and refined.

Once fabrication is complete, the project moves to the testing and observation stage, where the turbine's performance is evaluated under various wind conditions. The effect of deflectors is incorporated to observe its effect on the machine's performance. The results from testing are then analysed in the result and discussion phase, leading to a Report Discussion summarising findings and insights. If the results are satisfactory, the project concludes.

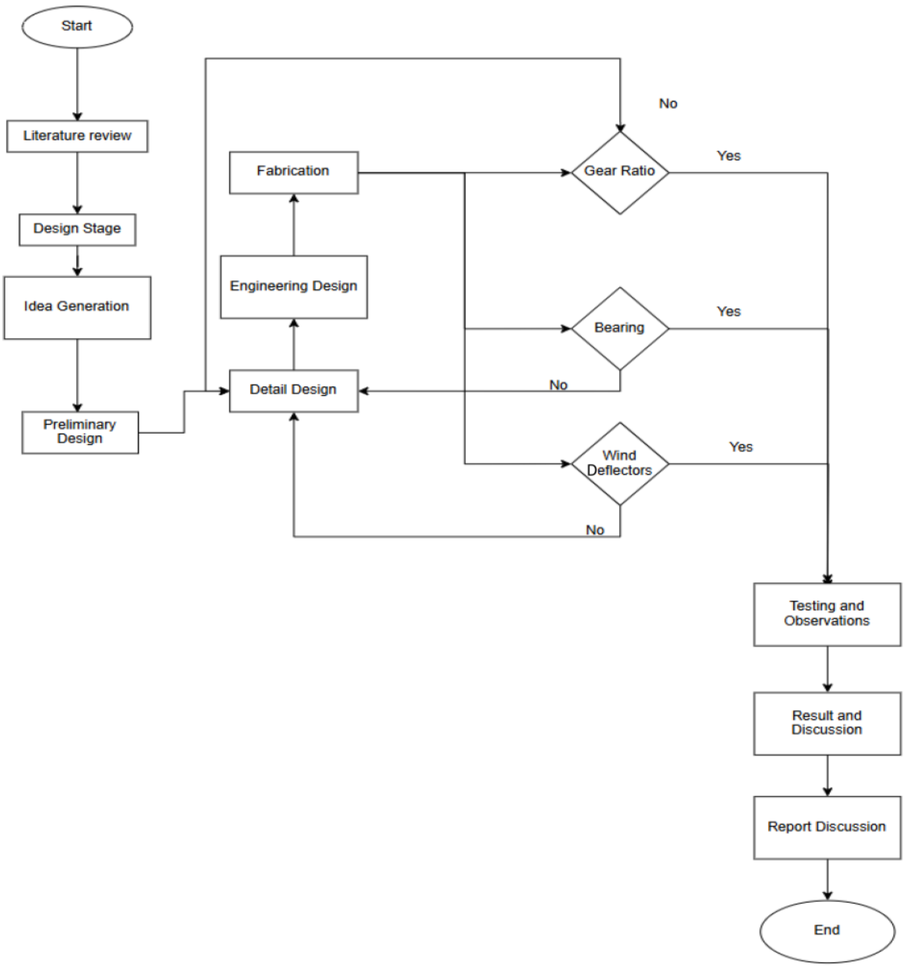

Fig. 1 *Project Flow*

2.1 Turbine blade

Fig. 2 illustrates the selected Vertical Axis Wind Turbine (VAWT) design for its superior efficiency and performance in harnessing wind energy [8]. The design features a height of 120 mm and a width of 35 mm, resulting in a calculated swept area of 0.0042 m^2. This compact design is particularly advantageous as it incorporates the concept of omnidirectional wind acceptance, allowing the turbine to efficiently capture wind from any direction, making it highly suitable for urban environments with variable wind patterns [9]. Integrating these parameters ensures optimal energy conversion and adaptability, aligning with the project's goal of developing a reliable and sustainable small-scale wind energy solution.

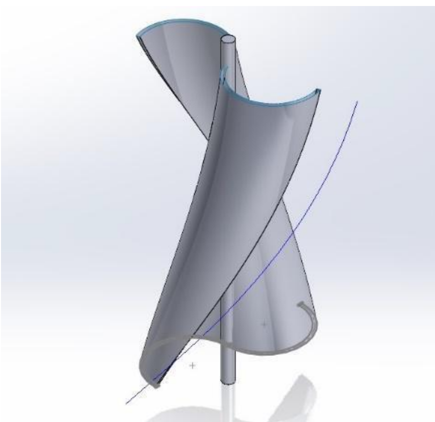

Fig. 2 *VAWT blade*

2.2 Power Output to Wind Speed Graph

The power curve, or the power output to wind speed curve, illustrates a turbine's expected electrical power output across varying wind speeds. This curve is derived from field measurements using anemometers, which accurately record wind speed data [10], as depicted in Fig. 3. Key parameters on the power curve include the cut-in speed, which is the minimum wind speed required for the turbine blades to start rotating and generating power, and the cut-out speed, which is the wind speed at which the turbine automatically shuts down to prevent damage [11]. Additionally, the curve highlights the rated output power and rated speed, representing the maximum power output and corresponding wind speed at which the turbine operates optimally. These parameters are critical for understanding the turbine's performance and efficiency under different wind conditions [12].

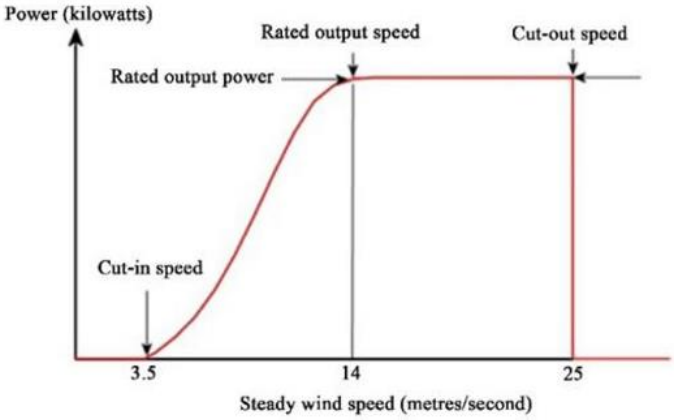

Fig. 3 *VAWT Power Output to Wind Speed Graph [10]*

2.3 Local Wind Data

Wind speed data was collected for the Pagoh area in Muar, Johor, utilising the AccuWeather program (version 15.12.2) to evaluate the turbine's efficiency and electricity generation capabilities. The data presented in Table 1 reflects a three-week average, serving as a critical reference for subsequent testing. This approach aligns with methodologies in wind turbine research, emphasising the importance of accurate wind speed measurements for performance assessment [13]. The minimum average wind speed in the local area is 1.95 m/s.

Table 1 *Local Wind Speed Data*

Week	Average wind speed/ week (m/s)
1	2.36
2	1.95
3	2.17
Average	2.16

2.4 Material Selection

The selection of the materials for the machine component is made during the detailed design stage. The choice of materials is based on several criteria, including price, availability, strength, and environmental effects [14]. However, the material selection up to this stage is for prototype testing and has not yet been finalised for mass production. The blade, gears connected to the dynamo, and the main body of the machine are 3D printed using PLA filament. Lithium-polymer (Li-Po) batteries are selected to store the energy generated by the system [14]. The 3D view of the machine is shown in Fig. 3. In the main body consists of a set of gears and electronic circuits.

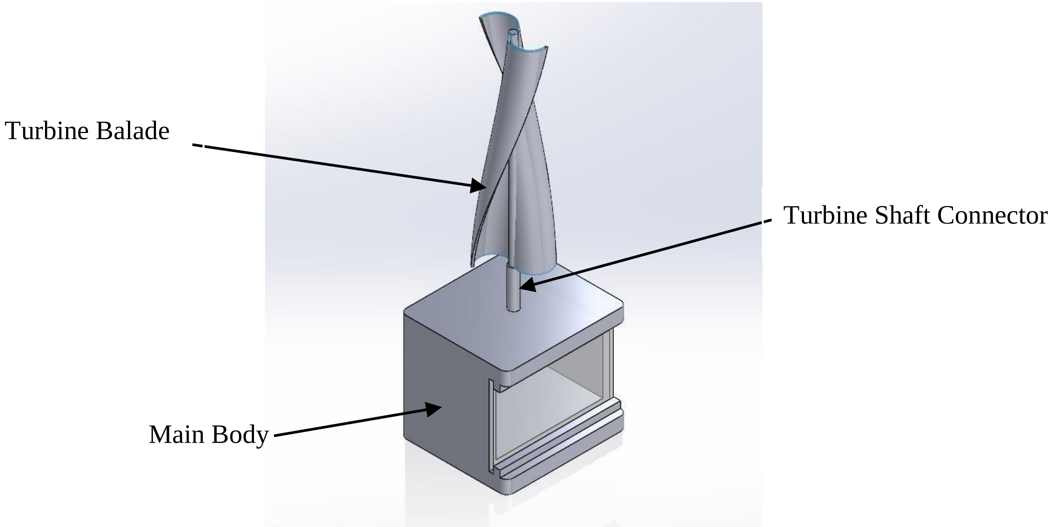

Fig. 3 *3D view of the Mini VAWT Generator*

3. Results and Discussion

This section presents the outcomes of the dynamo output and voltage generation tests. The tests aim to evaluate the system's ability to produce electrical power under different conditions, such as varying rotational speeds and wind inputs. The results provide useful insights into the performance and efficiency of the setup, supporting further design improvements.

3.1 Dynamo Output Test

This testing phase evaluates the rotational speed (rpm) required for the dynamo to generate a specific output power. The dynamo is manually rotated, and its rotational speed is measured using a tachometer, while the corresponding voltage output is recorded with a multimeter. The target voltage outputs for this test are set at 5VAC and 10VAC. Based on the results, the average rotational speeds needed to achieve these voltages are 884 rpm for 5VAC and 1638 rpm for 10VAC. These findings provide critical insights into the dynamo's performance and efficiency, helping to optimise the gear ratio selection to amplify the shaft rotation to rotate the dynamo.

3.2 Voltage Generation Test

The voltage generation test is implemented by imposing the turbine to an artificial wind to rotate the blade according to a certain wind speed. The test is implemented in a laboratory with a controlled environment to ensure constant wind speed can be obtained. The wind speed is measured using an anemometer (Testo 410i), and the turbine blade revolution is recorded using a tachometer. The wind speed is from a single fan source, and its distance to the turbine varies to adjust the wind speed. The wind speed varies from 1.4 m/s to 7 m/s; the test result is shown in Fig.4.

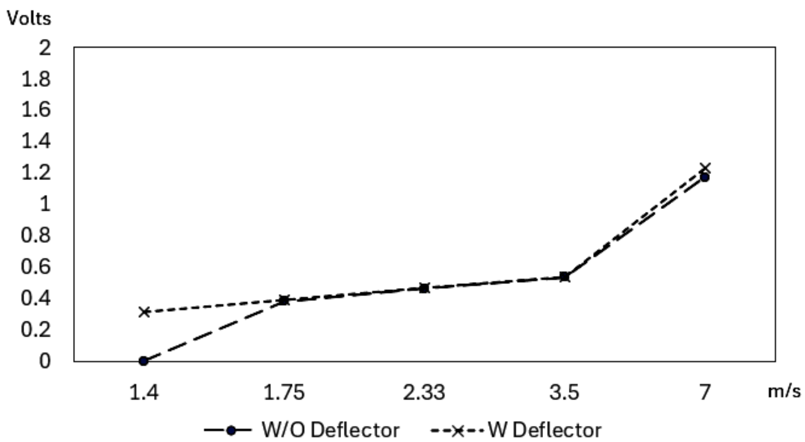

Fig. 4 *Voltage generation with deflector and without deflector*

From the data presented in Fig.4, the trend of voltage generation is increasing with the increase in wind speed. The voltage value is varied from 0.38 to 1.17 VDC without the wind deflector installed. By installing the wind deflector, the voltage generated ranges from 0.31 to 1.23 VDC, which shows an increment of up to 5% higher than without the deflector. This can be explained by observing the trend of the blade rpm shown in Fig.5. Without the deflector, the blade does not rotate at 1.4m/s wind speed, while with the installation of the deflector, the blade rotates at 19 rpm at the same wind speed. The increment of the blade rotation speed is up to 17% faster with the installation of the wind deflectors.

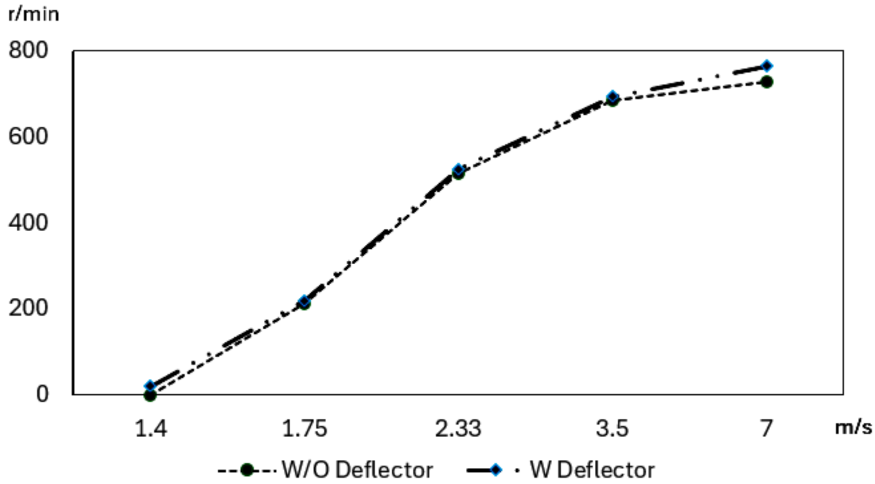

Fig. 5 *Blade rotation with deflector and without deflector*

However, the voltage value generated is lower than the initial test performed on the dynamo due to a few factors. One factor contributing to this result is the slip/losses within the gear teeth connecting the blade shaft to the dynamo gear. This slip has caused the dynamo to rotate slower than it should be, thus generating less voltage. Another factor is the rotational inertia of the turbine blade and shaft, which can cause a delay in reaching voltage at a certain wind speed [15]. Wind speed variability or minor turbulence is also one of the factors that can affect the rotational speed of the blades. A deflector can improve the performance, but its effectiveness may vary with the wind speed, leading to non-linear voltage generation [15].

4. Conclusion

This project successfully designed, fabricated, and tested a Mini Vertical Axis Wind Turbine (VAWT) Generator, demonstrating its potential as a sustainable and reliable solution for small-scale energy generation. The VAWT's innovative vertical blade design enables omnidirectional wind capture, making it adaptable to variable wind conditions, particularly in urban or remote areas. Testing results confirmed that the turbine generates 0.31 to 1.23 VDC at wind speeds ranging from 1.4 to 7 m/s, effectively charging the battery and validating its functionality. These findings underscore the viability of small-scale VAWTs as a practical renewable energy solution for low-power applications. However, opportunities for improvement remain, particularly in material optimisation and efficiency enhancements, to further increase energy output and durability. Future work will focus on refining the design, exploring advanced materials, and scaling the system for broader adoption. This project contributes to motivating more researchers to explore and optimise the configurations of the generator as well as its efficiency.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** Ahmad Faiz Mat Zin, Adam Haziq Hishamudin, Mohamad Aqmal Mohamad Ariff, Muhammad Syahmi Azami; ***data collection:*** Adam Haziq Hishamudin, Mohamad Aqmal Mohamad Ariff, Muhammad Syahmi Azami; ***analysis and interpretation of results:*** Ahmad Faiz Mat Zin, Adam Haziq Hishamudin, Mohamad Aqmal Mohamad Ariff, Muhammad Syahmi Azami; ***draft manuscript preparation:*** Ahmad Faiz Mat Zin, Adam Haziq Hishamudin, Mohamad Aqmal Mohamad Ariff, Muhammad Syahmi Azami, Muhammad Sufi Roslan, Ishkrizat Taib. *All authors reviewed the results and approved the final version of the manuscript.*

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