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Design, Fabrication and Performance Evaluation of a Magnetically Levitated Vertical Axis Wind Turbine

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Abstract

This paper presents the design and experimental comparison of a magnetically levitated vertical axis wind turbine (VAWT). The proposed system utilizes permanent magnets to reduce friction between rotating components. A prototype model was constructed and tested under controlled airflow conditions. Comparative analysis was performed with and without magnetic levitation to evaluate differences in electrical output and rotational performance. Experimental results indicate that the magnetically levitated configuration generates approximately 2.8 V, while the conventional configuration produces around 1 V under similar conditions. The study demonstrates that magnetic levitation can significantly improve the performance of small-scale wind energy systems by reducing frictional losses.

Keywords

Magnetic Levitation, Vertical Axis Wind Turbine, Renewable Energy, Wind Power Generation

1. Introduction

Renewable energy sources have gained significant attention in recent years due to the increasing demand for clean and sustainable energy. Among the various renewable energy options available, wind energy has emerged as one of the most reliable and widely utilized sources for electricity generation. Wind turbines are used to convert the kinetic energy of wind into electrical energy, making them an important component in modern energy systems.

Vertical axis wind turbines (VAWTs) are particularly suitable for small-scale and urban applications due to their ability to operate independent of wind direction and their relatively simple mechanical design. Unlike horizontal axis wind turbines, VAWTs can capture wind from multiple directions without requiring complex yaw mechanisms, making them more adaptable in varying wind conditions.

However, one of the major challenges associated with small-scale wind turbines is the presence of mechanical friction in bearings and rotating components. This friction increases the required starting torque and results in higher cut-in speed, thereby reducing the efficiency of the system. To overcome this limitation, magnetic levitation has been explored as a potential solution to minimize contact between moving parts and reduce frictional losses.

Magnetic levitation systems utilize repulsive forces between permanent magnets to support rotating components, thereby reducing mechanical contact and improving rotational efficiency. The application of magnetic levitation in wind turbines has shown promising results in improving starting behavior and overall performance.

The present study focuses on the design, fabrication, and performance evaluation of a magnetically levitated vertical axis wind turbine. A comparative analysis is carried out between conventional and magnetically levitated configurations to evaluate parameters such as cut-in speed, voltage output, and rotational stability.

2. Literature Review

Research on improving the performance of vertical axis wind turbines has been widely carried out over the past few decades. Various methods have been proposed to enhance the efficiency and reduce the mechanical losses associated with wind energy systems. One of the key areas of focus has been the reduction of friction in rotating components, which directly affects the starting performance and energy output of the turbine.

Michael Kumbernuss [1] investigated the application of magnetic bearings in vertical axis wind turbines and demonstrated that the use of magnetic levitation significantly reduces mechanical friction. The study showed that the turbine exhibited smoother rotation and improved efficiency, especially under low wind speed conditions.

A. M. Dehghani [2] analyzed the performance of magnetically levitated wind turbine systems and concluded that the incorporation of permanent magnets improves the starting characteristics of the turbine. The results indicated a reduction in cut-in speed and an increase in overall energy output.

H. A. M. Badr [3] studied the performance of vertical axis wind turbines and highlighted the importance of rotor design in improving efficiency. The research emphasized that optimized blade design plays a crucial role in enhancing the aerodynamic performance of the turbine.

G. J. W. van Bussel [4] explored the application of small wind turbines in urban environments and concluded that VAWTs are more suitable for such conditions due to their ability to operate under low and variable wind speeds.

J. F. Manwell [5] provided a comprehensive analysis of wind energy systems and discussed the factors affecting turbine performance, including mechanical losses, generator efficiency, and environmental conditions.

T. Burton [6] presented detailed insights into wind turbine design and operation, emphasizing the role of aerodynamic efficiency and tip speed ratio in determining turbine performance.

S. Eriksson [7] evaluated different generator types used in wind energy systems and highlighted the importance of generator selection in improving the electrical output of small-scale turbines.

A. Paraschivoiu [8] focused on the design aspects of vertical axis wind turbines and discussed various configurations and their performance characteristics under different wind conditions.

In addition to these studies, several researchers have emphasized the importance of reducing mechanical losses and improving energy conversion efficiency in small-scale wind turbines. The integration of magnetic levitation systems has been identified as a promising approach to minimize friction and enhance performance.

Although significant progress has been made in theoretical and simulation-based studies, there is still a need for practical implementation and experimental validation of magnetically levitated wind turbine systems. The present work aims to address this gap by designing, fabricating, and experimentally evaluating a small-scale magnetically levitated vertical axis wind turbine.

3. System Design

The proposed system is a vertical axis wind turbine (VAWT) integrated with a magnetic levitation mechanism to improve its performance by reducing mechanical friction. The primary objective of the design is to convert wind energy into electrical energy efficiently while minimizing losses due to contact between moving parts.

The system consists of a rotor assembly mounted on a vertical shaft, which is connected to a DC generator. The rotor blades are designed to capture airflow from all directions, making the system suitable for low and varying wind conditions. Unlike horizontal axis wind turbines, the vertical configuration eliminates the need for complex alignment mechanisms, thereby simplifying the overall design.

A key feature of the system is the implementation of magnetic levitation at the base of the shaft. Permanent magnets are arranged in such a way that like poles face each other, creating a repulsive force. This magnetic force partially supports the weight of the rotor, reducing the load on the mechanical support and minimizing friction during rotation.

When airflow is directed towards the turbine blades, the aerodynamic force causes the rotor to rotate about the vertical axis. This rotational motion is transmitted through the shaft to the DC generator, which converts mechanical energy into electrical energy. The reduction in friction due to magnetic levitation allows the turbine to start rotating at lower wind speeds and improves the overall efficiency of the system.

3.1 Components of the System

The major components of the system are as follows:

- Rotor Blades: Capture wind energy and convert it into rotational motion.
- Shaft: Transfers rotational motion from the blades to the generator.
- DC Generator: Converts mechanical energy into electrical energy.
- Magnetic Levitation Unit: Reduces friction by supporting the rotor using magnetic repulsion.
- Base Frame: Provides structural support and stability to the entire setup.

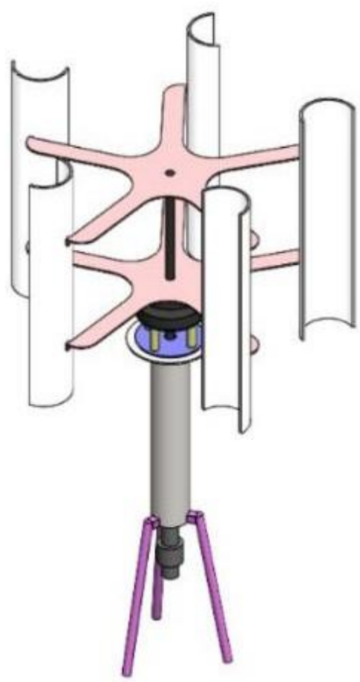


Figure 1: **Schematic Diagram of Magnetically Levitated Vertical Axis Wind Turbine**

Figure 2: Fabricated magnetically levitated vertical axis wind turbine prototype

3.2 Working Principle

The working principle of the system is based on the conversion of wind energy into electrical energy through rotational motion. When wind flows across the turbine blades, a force is exerted on them, causing the rotor to rotate. The rotating shaft drives the generator, producing electrical output.

The presence of magnetic levitation reduces the mechanical contact between the rotating and stationary parts, thereby decreasing frictional losses. This results in smoother rotation, lower cut-in speed, and improved performance of the turbine.

4. Magnetic Design and Calculations

The magnetic levitation system was incorporated into the wind turbine design to reduce mechanical friction between the rotating shaft and the supporting structure. This was achieved by using permanent ferrite magnets arranged in a repulsive configuration, where like poles face each other. The repulsive magnetic force helps in partially supporting the rotating assembly, thereby reducing the load on mechanical contact points and improving overall efficiency.

The magnets were placed at the base of the rotating shaft and aligned with corresponding magnets fixed on the support structure. A small gap was maintained between the magnets to ensure stable levitation. Proper alignment of the magnets is essential to avoid lateral movement and ensure smooth rotational behavior of the turbine.

4.1 Magnetic Force Consideration

The magnetic force between two magnets depends on their strength and the distance between them. Although the exact force calculation is complex, it can be generally understood that the force decreases with an increase in distance between the magnets.

$$F \propto \frac{1}{d^2}$$

where:

- F= Magnetic force
- d= Distance between magnets

Based on this relation, the spacing between magnets was adjusted carefully to achieve sufficient repulsive force while maintaining system stability.

4.2 Design Considerations

The following design factors were considered while implementing the magnetic levitation system:

- **Magnet Configuration:** Like poles were arranged facing each other to generate repulsive force.
- **Spacing Adjustment:** The gap between magnets was optimized experimentally.
- **Load Distribution:** Only the rotating assembly was considered for levitation.
- **Stability:** Proper alignment was ensured to avoid wobbling or imbalance.
- **Material Selection:** Ferrite magnets were chosen due to their availability and adequate magnetic strength.

4.3 Load Calculation for Levitation

In this design, only the rotating upper assembly of the turbine is levitated using magnets. The stationary components are not included in the calculation.

The components considered for levitation include:

- Aluminium windmill blades
- Mild steel blade holder plate
- Delrin shaft (attached to blade holder)

The total mass of the rotating assembly is calculated as:

$$m_{total} = 0.515 + 0.71 + 0.033$$

$$\mathbf{m_{total} = 1.26 kg}$$

4.4 Force Required for Levitation

The force required to support the rotating assembly is calculated using:

$$F = m \times g$$
$$F = 1.26 \times 9.81$$
$$\mathbf{F = 12.36 N}$$

4.5 Design Force with Safety Factor

To ensure reliable operation and to account for misalignment, vibrations, and external disturbances, a safety factor of 2 was considered.

$$F_{design} = 2 \times 12.36$$
$$\mathbf{F_{design} = 24.7 N}$$

4.6 Final Magnetic Design Requirement

Based on the above calculations, the required magnetic force for effective levitation is approximately:

$$F_{required} \approx 25–26 N$$

Permanent ferrite magnets of size **80 mm × 15 mm** were used to achieve the required levitation force. The magnets were arranged in a repulsive configuration, and the spacing between them was adjusted experimentally to obtain stable levitation and smooth rotation.

The implementation of magnetic levitation reduced friction between moving parts and contributed to improved performance of the wind turbine, as observed in the experimental results.

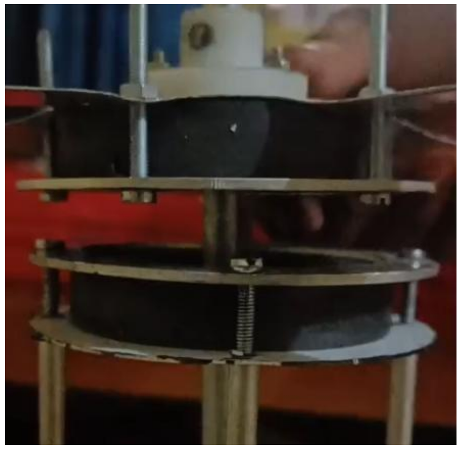


Figure 3: Magnetic Levitation Arrangement

5. Experimental Setup

To evaluate the performance of the proposed wind turbine model, an experimental setup was developed to analyze the rotational characteristics and electrical output of the system. The fabricated prototype of the magnetically levitated vertical axis wind turbine was tested under controlled indoor conditions.

A hair dryer was used as the wind source to generate airflow towards the turbine blades. The hair dryer was positioned at a fixed distance from the turbine in order to provide consistent airflow during the testing process. When the airflow from the hair dryer was directed towards the turbine blades, the aerodynamic force caused the rotor to start rotating.

The rotational motion of the turbine shaft was transferred to a DC motor that was used as a generator. As the shaft rotated, the generator produced electrical energy which was measured using a digital multimeter connected to the generator terminals.

Two different configurations of the turbine were tested in order to conduct a comparative analysis. In the first configuration, the turbine was operated without magnetic levitation, where the rotor was supported only by the mechanical structure. In the second configuration, permanent magnets were introduced to create a magnetic repulsion force that partially supported the rotor and reduced friction between the moving components.

During the experiment, observations were made regarding the cut-in speed, rotational behavior, and voltage output of the turbine. Multiple trials were conducted to ensure consistency in the measured values. The voltage outputs obtained from both configurations were then compared in order to evaluate the influence of magnetic levitation on the performance of the wind turbine prototype.

Figure 4: Experimental setup of the magnetically levitated VAWT.

5.1 Measurement Instruments

The following instruments and components were used during the experiment:

1. Hair dryer (used as wind source)
2. Digital multimeter (for voltage measurement)
3. DC motor used as generator
4. Permanent magnets (for magnetic levitation mechanism)

6. Results and Comparative Analysis

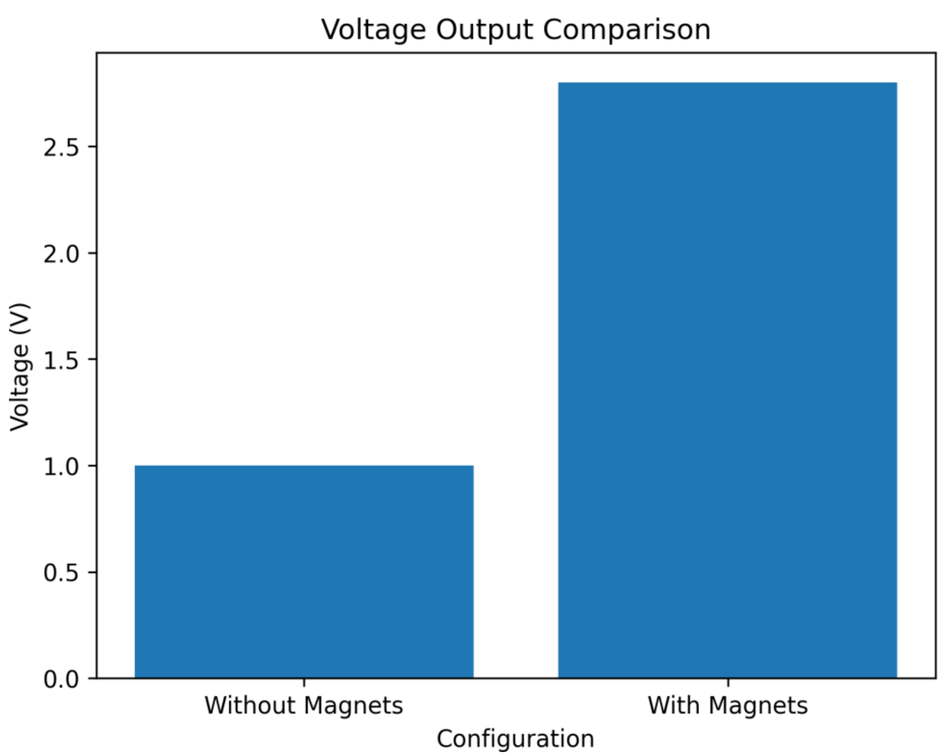
The experimental results obtained from the testing of the wind turbine show a clear difference in performance between the two configurations. It was observed that the turbine without magnetic levitation faced more resistance during rotation, which affected its ability to start and maintain smooth motion. On the other hand, the use of magnetic levitation reduced the mechanical resistance, allowing the turbine to rotate more freely.

One of the key observations was related to the starting behavior of the turbine. The configuration without magnets required comparatively higher airflow to initiate rotation, whereas the magnetically levitated system started rotating more easily even under lower airflow conditions. This indicates an improvement in cut-in performance due to the reduction in friction.

In addition to this, a significant improvement was also noticed in the electrical output. The magnetically levitated turbine produced a higher and more consistent voltage compared to the conventional setup. The difference in performance between the two configurations is further illustrated using graphs and tables in the following sections.

6.1 Voltage Output Comparison:

The voltage output of the wind turbine was measured for both configurations under similar operating conditions. It was observed that the turbine with magnetic levitation produced significantly higher voltage compared to the conventional setup. While the configuration without magnets generated relatively low voltage in the range of around 0.8 V to 1.2 V, the magnetically levitated system consistently produced higher output, reaching approximately 2.6 V to 2.9 V. This difference clearly indicates that the reduction in friction due to magnetic levitation allows the turbine to rotate more efficiently, resulting in improved electrical output. The results demonstrate that incorporating magnetic levitation enhances the overall performance of the wind turbine.



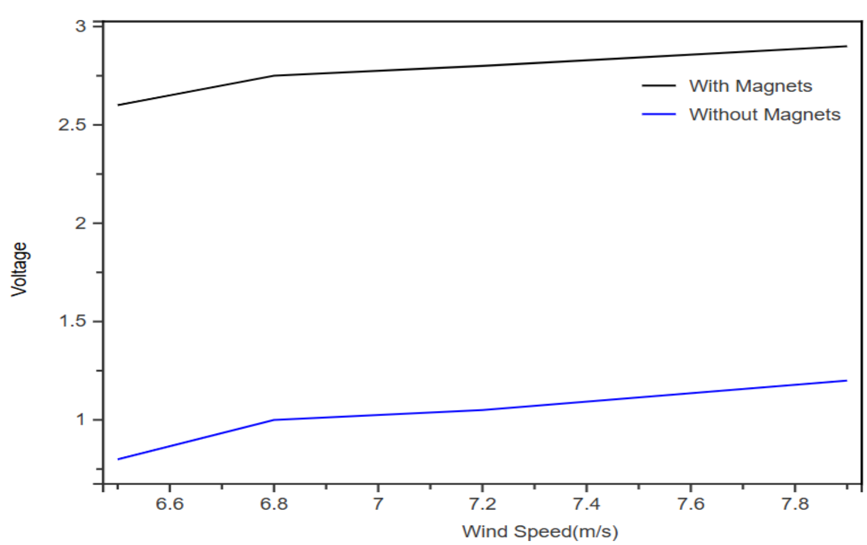
6.2 Trial Performance (Wind Speed vs Voltage):

The relationship between wind speed and voltage output was analyzed through multiple trials for both configurations of the turbine. It was observed that as the wind speed increased, the voltage output also showed a gradual increase. However, the rate of increase was more significant in the initial range and later became relatively stable at higher wind speeds. In the case of the magnetically levitated configuration, the voltage output remained consistently higher across all tested wind speeds, indicating improved efficiency. On the other hand, the turbine without magnetic levitation produced lower voltage and showed slight variations with changes in wind speed. These observations highlight the effectiveness of magnetic levitation in enhancing the overall performance and stability of the winturbine.

Table 1: Wind Speed vs Voltage Output

Wind Speed (m/s)	Voltage (With Magnets)	Voltage (Without Magnets)
6.5	2.6	0.8
6.8	2.8	1.0
7.2	2.8	1.1
7.9	2.9	1.2

Figure 5: Wind Speed vs Voltage Output for Different Configurations



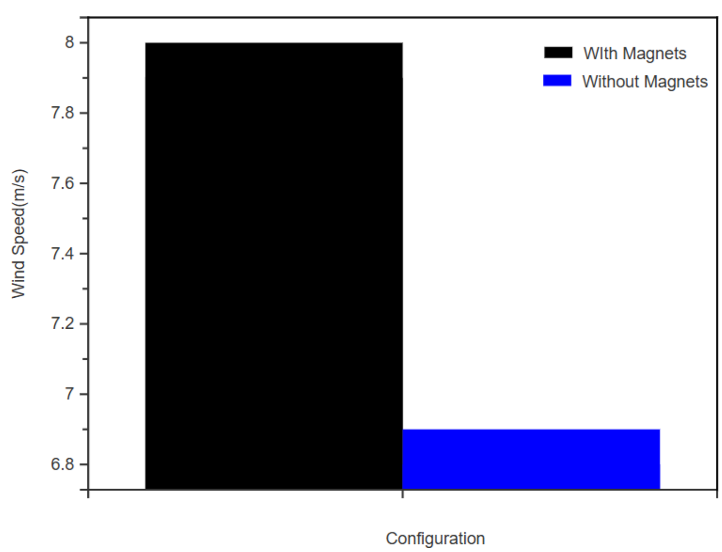
6.3 Cut-in Speed Comparison

The cut-in speed of the wind turbine was determined experimentally using an anemometer for both configurations. It was observed that the turbine without magnetic levitation required higher wind speed to initiate rotation, whereas the magnetically levitated configuration started rotating at comparatively lower wind speeds. This indicates that the presence of magnetic levitation reduces the starting resistance of the turbine.

Table 2: Cut-in Speed Measurement

Configuration	Trial 1 (m/s)	Trial 2 (m/s)	Average (m/s)
Without Magnets	7.9	8.0	8.0
With Magnets	6.8	6.9	6.9

Figure 6: Cut-in Speed Comparison



6.4 Overall Performance Comparison

Table 3: Performance Comparison of Turbine Configurations

Parameter	Without Magnets	With Magnets
Cut-in Speed (m/s)	~8.0	~6.9
Voltage Output (V)	~1.0	~2.8
Rotation Stability	Moderate	Smooth
Starting Behavior	Requires higher airflow	Starts easily
Friction Loss	Higher	Reduced

The comparison table summarizes the overall performance of the wind turbine under both configurations. It can be observed that the magnetically levitated system performs better in terms of lower cut-in speed, higher voltage output, and smoother rotational behavior. These improvements are mainly due to the reduction in friction achieved through magnetic levitation.

7. Conclusion

In this study, a prototype of a magnetically levitated vertical axis wind turbine was designed, fabricated, and experimentally evaluated to analyze its performance under controlled conditions. The primary objective of the study was to investigate the effect of magnetic levitation on the rotational behavior and electrical output of a small-scale wind turbine system.
Experimental testing was carried out using a hair dryer as the wind source to generate airflow across the turbine blades. Two different configurations were analyzed: one without magnetic levitation and another with the incorporation of permanent magnets to reduce friction between the rotating components. The electrical output of the turbine was measured using a digital multimeter connected to the generator.

The results obtained from the experiments indicated that the use of magnetic levitation significantly improved the performance of the turbine. The magnetically levitated configuration demonstrated smoother rotational motion and produced a higher voltage output compared to the conventional configuration. The system generated approximately

2.8 V with magnetic levitation, whereas the output without magnetic support was observed to be around 1 V under similar conditions.

The improvement in performance can be attributed to the reduction of mechanical friction between the moving components of the turbine. By partially supporting the rotor using magnetic repulsion, the turbine was able to rotate more freely and convert wind energy into electrical energy more effectively.

Overall, the experimental study demonstrates that magnetic levitation can be a promising approach for improving the efficiency and performance of small-scale vertical axis wind turbines. The findings of this work highlight the potential of magnetically assisted turbine systems for future renewable energy applications.

8. Future Scope

Although the developed prototype demonstrated the feasibility of a magnetically levitated vertical axis wind turbine, there are several areas where further improvements and research can be carried out to enhance the overall performance and practical applicability of the system.

One potential improvement is the optimization of blade design to increase aerodynamic efficiency and improve energy capture from airflow. By modifying the blade shape, size, and curvature, the turbine may achieve higher rotational speeds and improved power output.

Another possible development involves the use of higher efficiency generators specifically designed for low-speed wind turbines. This could significantly increase the electrical output of the system, especially in low wind conditions.

Future work can also focus on testing the turbine under real outdoor wind conditions instead of using artificial wind sources such as a hair dryer. Real environmental testing would provide more accurate insights into the performance and durability of the turbine.

Additionally, the system can be further improved by integrating energy storage components such as rechargeable batteries to store the generated electrical energy for practical use.

Finally, further research can explore the scaling of the design for larger wind turbine systems, which could potentially contribute to small-scale renewable energy generation in residential or remote locations

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