

## DEVELOPMENT OF A HELICAL-TYPE VERTICAL AXIS WIND TURBINE PROTOTYPE UNDER URBAN WAKE CONDITIONS

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**Abstract.** Urban environments are characterized by complex wake flows generated by buildings and moving vehicles, which significantly affect wind energy harvesting performance. This study presents the development of a helical-type Vertical Axis Wind Turbine (VAWT) prototype designed to operate under urban wake conditions. The prototype was designed, fabricated, and evaluated to analyze its aerodynamic behavior and performance when subjected to disturbed and unsteady airflow. Computational Fluid Dynamics (CFD) simulations were employed to investigate the velocity and pressure distribution around the helical blades under wake flow conditions representative of urban environments. The results indicate that the helical blade configuration improves flow continuity and reduces torque fluctuations compared to conventional straight-bladed VAWTs. Furthermore, the turbine demonstrates improved self-starting capability and stable performance under low and fluctuating wind speeds. This research highlights the potential of helical-type VAWTs as a viable solution for small-scale wind energy harvesting in urban areas.

**Keywords:** Computational Fluid Dynamics; Helical Blade; Renewable Energy; Urban Wake Flow; Vertical Axis Wind Turbine.

### 1. INTRODUCTION

The utilization of wind energy as a renewable energy source in urban areas faces major challenges in the form of relatively low wind speeds, unstable flow directions, and high turbulence levels caused by interactions with buildings and infrastructure (P. Pamungkas et al., 2025). These conditions limit the performance of horizontal axis wind turbines, which generally require stable airflow with higher wind speeds. Therefore, alternative technologies that are more adaptive to urban wind characteristics are required.

Vertical Axis Wind Turbines (VAWT) have significant potential for urban applications because they are capable of capturing wind from various directions without requiring a yaw mechanism, have a more compact configuration, and produce relatively low noise levels (Nurul Haq & Riono, 2025). One widely studied development of VAWTs is the helical-type vertical axis wind turbine, which is designed with a twist angle on its blades to enhance rotational stability. This helical design allows a more even distribution of aerodynamic forces along the axial direction of the blade, thereby reducing torque fluctuations and improving turbine performance under turbulent flow conditions and low wind speeds (Divakaran et al., 2020).

This study focuses on the design, fabrication, and experimental testing of a helical-type vertical axis wind turbine prototype intended for application in urban environments. The design process considers key geometric parameters such as turbine diameter and height, number of blades, and helical twist angle to obtain a configuration suitable for urban wind characteristics. In addition, the energy conversion system is designed using a 12-volt generator.

The resulting prototype was tested at low wind speeds to evaluate performance characteristics, including shaft rotational speed and electrical power output. Performance analysis was conducted to assess the effectiveness of the helical design in improving operational stability and energy conversion efficiency. The results of this study are expected to provide scientific and practical contributions to the development of helical-type vertical axis wind turbines as efficient, environmentally friendly, and feasible small-scale renewable energy solutions for urban areas.

## **2. LITERATURE REVIEW**

### *2.1 Theoretical Background*

A prototype is an initial representation of a system developed to verify concepts, evaluate performance, and assess design feasibility before being realized as a final product. In the context of wind turbine applications, a prototype serves as a physical model used to analyze aerodynamic response, mechanical stability, and the system's capability to convert mechanical energy into electrical energy (Hasbiyati, Qanitah, & Nuruddin, 2024).

The existence of a prototype is crucial in the development process because it enables concept validation, early identification of technical problems, and comprehensive functional testing. Based on the level of similarity to the final product, prototypes are classified into high-fidelity prototypes, which closely resemble the final product and can be fully operated, and low-fidelity prototypes, which have simpler forms for rapid and low-cost testing of basic concepts.

#### *a. Wind Energy*

Wind is the flow of air mass generated by atmospheric pressure gradients on the Earth's surface, where air moves from high-pressure regions to low-pressure regions. These pressure gradients are formed due to uneven distribution of solar radiation, resulting in differences in air temperature and density, both temporally (day–night) and spatially, such as between land and sea or between lowlands and highlands (Nur Ilahi et al., 2023).

This air movement process occurs continuously. In urban areas, wind flow profiles are generally divided into two layers: the Urban Canopy Layer (UCL), which extends from ground level up to building height, and the Urban Boundary Layer (UBL), which is located above building height (Utami et al., 2023). In urban environments, interactions between wind flow and buildings or surrounding objects increase turbulence and vortex formation. Therefore, the installation of wind turbines in urban areas is recommended at higher elevations, such as rooftops, to obtain more stable wind flow conditions (Khanafi & Sudarti, 2022).

#### *b. Wind Turbines*

A wind turbine is a device that functions to convert wind energy into electrical energy. Wind turbines are generally classified into two types:

1. Vertical Axis Wind Turbine (VAWT) is a wind turbine with vertically oriented blades. This type of turbine has a low rotational speed (below 100 rpm) but produces relatively high torque (Norsk Geografisk Tidsskrift – Norwegian Journal of Breer og Morener I Jotunheimen, 2008).
2. Horizontal Axis Wind Turbine (HAWT) is a type of wind turbine with a rotational axis parallel to the direction of wind flow. This turbine is the most commonly used wind energy conversion technology and is widely applied in small- to large-scale power generation systems (Verma & Baloni, 2022).

#### *c. Conversion of Wind Energy into Mechanical Energy*

The conversion of wind energy into mechanical energy occurs through the transformation of the wind's kinetic energy into rotational torque on the turbine rotor. Airflow generates

aerodynamic forces that drive the turbine shaft, allowing the resulting mechanical power to be utilized for various applications. The efficiency of energy conversion is influenced by blade design, wind characteristics, and the system employed (Khusnawati, Wibowo, & Kabib, 2022).

The average wind speed characteristics in Indonesia indicate sufficient potential to be utilized as a source of electrical power generation through wind energy conversion systems, both on small and large scales (Mukhrijal, Teuku Zulfadli, & Andi Mulkan, 2021).

#### d. Generator

A generator is an essential component in an electrical power system that functions to convert mechanical energy resulting from turbine rotation into electrical energy. The working mechanism of a generator in a wind turbine system is as follows:

1. The turbine rotor rotates due to the kinetic energy of the wind.
2. This rotation is transmitted to the generator rotor.
3. The generator rotor drives permanent magnets or electromagnets, generating a rotating magnetic field.
4. Changes in magnetic flux induce voltage in the stator windings.
5. The generated voltage is then converted into AC or DC electrical output through a power conversion circuit.

### 2.2 Previous Research

Research on helical-type vertical axis wind turbines in urban areas has been widely conducted to support the development of renewable energy systems that are efficient and adaptive to various geographical conditions and application requirements. For urban applications, research conducted by M. Z. Shiraz, A. Dilimulati, and M. Paraschivoiu investigated building-integrated wind turbines, which represent a relatively new technology for urban wind energy utilization. Their study focused on wind turbines installed on building rooftops. Computational Fluid Dynamics (CFD) methods were employed to analyze turbine performance and the interaction between airflow, the turbine, and surrounding buildings. The results indicated that airflow conditions around buildings have a significant impact on turbine performance, particularly when the turbine is located in the wake region downstream of the building relative to the wind direction (Shiraz et al., 2019).

Jackson et al. (2019) suggested that vertical axis wind turbines are a suitable option for isolated urban and semi-urban areas due to their good performance under low and unstable wind conditions, minimal noise issues, and favorable aesthetic characteristics that allow effective integration into urban environments.

Bereziartua-Gonzalez, Retegi, and Ukar (2025) stated that the environmental impact of rooftop wind turbines plays an important role in supporting urban decarbonization efforts, as such systems are capable of significantly reducing carbon emissions. Consequently, this technology is increasingly considered feasible for implementation in urban areas.

Furthermore, Torn et al. (2023) reported that wind speed is the primary determining factor influencing wind turbine efficiency. Their study emphasized that variations in wind speed have a direct and substantial effect on turbine performance.

## 3. RESEARCH METHODS



Figure 1. Flowchart

This study employs an engineering method that focuses on the design and fabrication process of a helical-type vertical axis wind turbine (VAWT) prototype. This method is combined with an experimental approach to evaluate the performance of the developed prototype. The engineering method is applied to produce a turbine design and prototype that meet technical feasibility requirements, while the experimental method is used to measure turbine performance based on operational parameters, including rotational speed (RPM), torque, electrical power output, and power coefficient.

#### *A. Research Location*

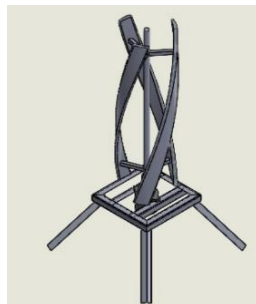
This research was conducted in laboratory facilities and open areas at the campus of Universitas Muhammadiyah Sumatera Barat. The selection of this location was based on the availability of facilities that support the prototype fabrication process, wind turbine performance testing, and controlled as well as continuous data collection.

#### *B. Research Time and Duration*

The study was carried out over a period of four months, from November 2025 to February 2026. This time frame was determined by considering the readiness of laboratory facilities, the availability of research components, and environmental conditions suitable for testing. The duration was deemed sufficient to complete all stages of the research, including design, prototype fabrication, testing, and data analysis.

#### *C. Research Object*

The object of this study is a helical-type vertical axis wind turbine prototype designed to operate under urban wind flow conditions. The prototype was developed by considering several key parameters, including turbine dimensions, number of blades, blade twist angle, shaft system, and generator type. The selection of a helical-type vertical axis wind turbine is based on its advantages in operating under low wind speeds and turbulent flow conditions, which are commonly found in urban environments.



**Figure 2.** Helical Turbine Design

#### *D. Research Instruments and Materials*

The instruments used in this study include wind speed measurement software, namely Windy.app, a tachometer to measure shaft rotational speed, a multimeter to measure electrical voltage and current, as well as supporting tools such as a drilling machine, grinder, and welding machine. The research materials consist of helical turbine blades, a shaft, a supporting frame, and a 12-volt generator with a current rating of 55 amperes. The selection of these instruments and materials was adjusted to meet the requirements for measurement and prototype fabrication.

#### *E. Research Procedure*

The research procedure begins with a literature review related to helical-type vertical axis wind turbines. The next stage involves designing the prototype based on predetermined parameters. The prototype is then fabricated and assembled according to the planned design. Subsequently, turbine performance testing is conducted by varying wind speed conditions. The test data are recorded and collected for further analysis.

#### *F. Data Collection Methods and Instruments*

Data collection is carried out using direct measurement methods. The instruments used include an anemometer to measure wind speed, a tachometer to measure shaft rotational speed, and a multimeter to measure the voltage and current generated by the generator. This method was chosen because it produces accurate and objective data. Compared to visual observation methods, direct measurement offers advantages in terms of precision and ease of quantitative analysis.

#### *G. Data Analysis Technique*

The collected data are analyzed quantitatively. The analysis stages include grouping the test data, calculating turbine performance parameters such as power output and efficiency, presenting data in the form of tables and graphs, and drawing conclusions based on the analysis results. The analysis process is carried out systematically to ensure that the research results can be scientifically justified.

### **4. RESULTS AND DISCUSSION**

The helical-type vertical axis wind turbine prototype was successfully designed and fabricated in accordance with the specifications established during the design stage. The turbine consists of three helical blades with a tilt angle of 6°, a main shaft made of aluminum alloy 6061, a bearing system to minimize friction, and a generator with a nominal voltage of 12 V and a current capacity of 55 A as the electrical energy source.



**Figure 3.** Prototype of a helical type vertical axis wind turbine

Visually and structurally, the prototype demonstrated good mechanical stability during testing. The turbine frame and mounting system were able to support all components without experiencing deformation. The helical blade design allows the turbine to capture wind from various directions without the need for a yaw system, making it suitable for the variable and unpredictable wind conditions commonly found in urban environments.

#### *4.1 Wind Speed and Rotor Rotational Speed Test Results*

The testing was conducted in an urban environment characterized by low and turbulent wind conditions. The average wind speed recorded during the testing was 2 m/s.



**Figure 4.** Measuring wind speed against rotor rotation

The test results indicate that:

1. The turbine is capable of operating independently at low wind speeds.
2. The rotor rotational speeds obtained during the experiments were 193.2 RPM, 330.0 RPM, and 446.1 RPM.
3. The rotor rotation remained relatively stable because the helical blade design is able to reduce torque fluctuations.

This rotational stability indicates that the helical configuration provides a more uniform distribution of aerodynamic forces along the blades, making it well suited for use under variable wind conditions.

#### 4.2 Current, Voltage, and Electrical Power Test Results

The 12 V generator used in this study was able to produce electrical voltage at low rotational speeds. The output voltage and current increased with increasing rotor rotational speed, which was directly influenced by wind speed.



**Figure 5.** Current, Voltage and Electric Power (DC) Testing

The test results indicate that:

1. The output voltage increases proportionally with the increase in RPM.
2. The generated current remains relatively small, which is consistent with the characteristics of prototype-scale testing.
3. The electrical power produced indicates that the turbine operates as a small-scale power generator.

After conducting the tests, three output voltage values were obtained:

1. 0.61 V with a current of 50 mA (0.05 A), therefore the electrical power generated can be calculated using the following equation:

$$P = V \times I$$

$$P = 0,61 \times 0,05 = 0,030 \text{ W}$$

2. 03 V with a current of 50 mA (0.05 A), therefore the electrical power generated can be calculated using the following equation:  $P = V \times I$

$$P = 1,03 \times 0,05 = 0,052 \text{ W}$$

3. 1.4 V with a current of 50 mA (0.05 A), therefore the electrical power generated can be calculated using the following equation:  $P = V \times I$

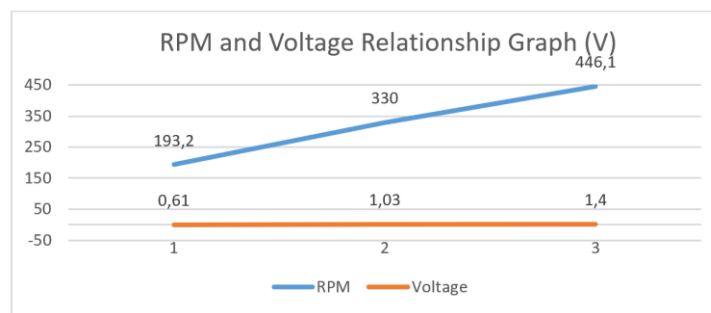
$$P = 1,4 \times 0,05 = 0,070 \text{ W}$$

The obtained power values indicate that the prototype is capable of converting wind energy into electrical energy, although the output remains at a relatively low scale.

**Table 1.** Relationship between RPM and Voltage and Electrical Power

RPM	voltage (V)	current (A)	Power(W)
193,2	0,61	0,05	0,030
330,0	1,03	0,05	0,052
446,1	1,40	0,05	0,070

Based on the table, an increase in RPM results in higher output voltage and electrical power, while the current remains relatively constant. This indicates that the system's output power is primarily influenced by the increase in voltage as the rotational speed increases.



**Figure 6.** Graph of the Relationship between RPM and Voltage (V)

#### 4.3 Analysis of Tip Speed Ratio (TSR) and Power Coefficient (Cp)

Based on the experimental test data, an analysis of the Tip Speed Ratio (TSR) was conducted to evaluate the aerodynamic performance of the turbine. The parameters used in this analysis are as follows:

- Rotor radius, R = 0.3 m
- Wind speed, V = 2 m/s
- Rotor rotational speed, n = 193,2 rpm, 330,0 rpm, 446,1 rpm

1. The angular velocity of the rotor is calculated using the following equation:

$$\omega = \frac{2\pi n}{60}$$

$$\omega = \frac{2\pi \times 193,2}{60} = 20,25 \text{ rad/s}$$

Thus, the TSR value is obtained as follows:

$$\lambda = \frac{\omega R}{V}$$

$$\lambda = \frac{20,25 \times 0,3}{2} = 3,0375$$

2. The angular velocity of the rotor is calculated using the following equation:

$$\omega = \frac{2\pi n}{60}$$

$$\omega = \frac{2\pi \times 330,0}{60} = 34,56 \text{ rad/s}$$

Thus, the TSR value is obtained as follows:

$$\lambda = \frac{\omega R}{V}$$

$$\lambda = \frac{34,56 \times 0,3}{2} = 5,184$$

3. The angular velocity of the rotor is calculated using the following equation:

$$\omega = \frac{2\pi n}{60}$$

$$\omega = \frac{2\pi \times 446,1}{60} = 46,71 \text{ rad/s}$$

Thus, the TSR value is obtained as follows:

$$\lambda = \frac{\omega R}{V}$$

$$\lambda = \frac{46,72 \times 0,3}{2} = 7,008$$

A TSR value of 7.008 indicates that the blade tip speed is relatively high and falls within the operational range of lift-based helical-type vertical axis wind turbines. The power coefficient ( $C_p$ ) is calculated by comparing the turbine power to the available wind power. The wind power is calculated using the following equation:

1) RPM = 193,2 rpm

- $\omega = 20,25 \text{ rad/s}$
- $\lambda = 3,0375$
- Voltage = 0,61 V
- Current = 0,05 A

Turbine power:

$$P_{\text{turbine}} = V \times I = 0,61 \times 0,05 = 0,0305 \text{ W}$$

Power coefficient:

$$C_p = \frac{P_{\text{turbine}}}{P_{\text{wind}}}$$

$$C_p = \frac{0,0305}{0,346}$$

$$\boxed{C_p = 0,088}$$

2) RPM = 330,0 rpm

- $\omega = 34,56 \text{ rad/s}$
- $\lambda = 5,184$
- Voltage = 1,03 V
- Current = 0,05 A

Turbine power:

$$P_{\text{turbine}} = 1,03 \times 0,05 = 0,0515 \text{ W}$$

Power coefficient:

$$C_p = \frac{0,0515}{0,346}$$

$$C_p = 0,149$$

3) RPM = 446,1 rpm

- $\omega = 46,71 \text{ rad/s}$
- $\lambda = 7,008$
- Voltage = 1,40 V
- Current = 0,05 A

Turbine power:

$$P_{\text{turbine}} = 1,40 \times 0,05 = 0,0700 \text{ W}$$

Power coefficient:

$$C_p = \frac{0,0700}{0,346}$$

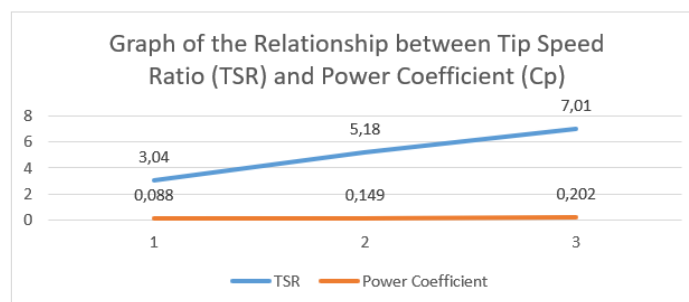
$$C_p = 0,202$$

The obtained **C<sub>p</sub>** value remains below the theoretical Betz limit (**0.593**), but it reflects a realistic performance for a small-scale wind turbine operating under low wind speed conditions in an urban environment.

**Tabel 2.** relationship between TSR and power coefficient (C<sub>p</sub>)

RPM (rpm)	$\omega$ (rad/s)	TSR ( $\lambda$ )	power (W)	C <sub>p</sub>
193,2	20,25	3,04	0,0305	0,088
330,0	34,56	5,18	0,0515	0,149
446,1	46,71	7,01	0,0700	0,202

Based on the table and graph, increases in RPM and angular velocity ( $\omega$ ) lead to a higher Tip Speed Ratio (TSR), which is followed by an increase in power output (W) and power coefficient (C<sub>p</sub>). The highest C<sub>p</sub> value of 0.202 was achieved at a TSR of 7.01, indicating that the turbine performance becomes more efficient at higher TSR values within the tested range.



**Figure 7.** Graph of the Relationship between Tip Speed Ratio (TSR) and Power Coefficient (C<sub>p</sub>)

#### *4.4 Discussion of Turbine Performance under Urban Wake Conditions*

Urban wake conditions, characterized by high turbulence and fluctuating wind directions, did not hinder the basic operation of the turbine. The test results indicate that the turbine was still able to rotate and generate electrical energy even though the incoming wind flow was non-uniform and variable. This demonstrates that the helical-type vertical axis wind turbine exhibits adaptive operational characteristics under unstable urban wind conditions.

The helical blade design provides several key advantages under these conditions. First, the turbine can capture wind from various directions without requiring a yaw mechanism, making it well suited for environments with frequently changing wind directions. Second, the helical shape produces smoother and more stable rotor rotation due to a more uniform distribution of aerodynamic forces along the blades. Third, the noise level generated is relatively low, making the turbine safer and more comfortable for application in residential areas or campus environments. Fourth, this turbine has strong potential for integration with urban buildings as a small-scale renewable energy source, particularly for low-power applications such as lighting or monitoring systems.

#### **CONCLUSION**

Based on the design, fabrication, and testing of the helical-type vertical axis wind turbine prototype, it can be concluded that the developed turbine successfully operated in accordance with the research objectives. The prototype consists of three helical blades with a tilt angle of 6°, a shaft made of aluminum alloy 6061, a bearing system, and a 12 V generator. During testing, the turbine demonstrated good mechanical stability and did not experience any structural deformation.

Testing conducted in an urban environment with an average wind speed of 2 m/s showed that the turbine was capable of operating independently under low and turbulent wind conditions. The rotor achieved a maximum rotational speed of 446.1 rpm, indicating that the helical blade design was able to generate sufficient torque to drive the generator while maintaining relatively stable rotation. This stability confirms that the helical configuration is effective in reducing torque fluctuations caused by variations in wind direction and speed.

From an electrical perspective, the 12 V generator produced an output voltage of approximately 1.4 V with a current of 50 mA, resulting in an electrical power output of about 0.07 W. This result indicates that the prototype is capable of converting wind energy into electrical energy, although the output remains relatively low and is not yet optimal for applications requiring higher power levels.

Aerodynamic analysis yielded a Tip Speed Ratio (TSR) value of 7.008, which falls within the operational range of lift-based helical-type vertical axis wind turbines. The power coefficient ( $C_p$ ) of 0.202, although still below the theoretical Betz limit (0.593), reflects a realistic performance for a small-scale wind turbine operating under low wind speed conditions and urban wake environments.

Overall, the results of this study indicate that the helical-type vertical axis wind turbine has potential for development as a small-scale power generation system in urban environments. The helical design offers advantages such as the ability to capture wind from multiple directions without the need for a yaw system, smoother and more stable rotation, and relatively low noise levels. Although the electrical power output is still limited, the prototype has successfully fulfilled its basic function as a wind energy-to-electricity converter and can serve as a foundation for further development aimed at improving efficiency and power output.

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