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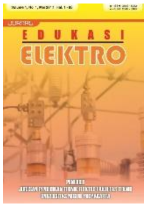

Design and Development of a Multi-Blade Horizontal Axis Wind Turbine as an Alternative Energy Source in Talang Solok Regency

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Abstract—Indonesian rural and highland areas have considerable potential for developing small-scale renewable energy, especially utilizing wind resources with low to moderate wind speeds. This research outlines the creation, design, and assessment of a six-blade horizontal axis wind turbine (HAWT) aimed at facilitating off-grid and decentralized electricity production in Talang, Solok Regency. To enhance the design methodology, a comparative design evaluation was performed by analyzing three-blade, four-blade, and six-blade rotor setups concerning starting torque traits, suitability for low wind speeds, and operational stability documented in earlier research. The six-blade design was chosen for its improved self-starting ability and dependable performance at wind speeds under 7 m/s. The created prototype features a rotor diameter of 1.5 m, a blade length of 0.75 m, a 1:5 gear ratio, and a 200 W DC generator. Performance testing took place over two months (August–September 2025) in natural wind conditions varying between 4.8 and 7.1 m/s. The turbine produced an open-circuit voltage of 2.5–4.4 V, and when under load, the peak electrical power output was 1.52 W. The determined power coefficient (Cp) varied from 0.12 to 0.18, demonstrating efficient energy conversion in low-speed wind conditions. The findings indicate that the suggested multi-blade HAWT design provides a technically viable, context-suitable, and scalable option for rural electrification, community-level renewable energy systems, and educational uses in areas with comparable wind conditions.

Keywords: wind potential, wind power plants, solok regency, electricity

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1 Introduction

The increasing demand for electrical energy has encouraged the development of alternative energy sources that are renewable and environmentally friendly. Renewable energy is anticipated to significantly contribute to addressing future global energy demands while reducing climate change and environmental contamination. As global energy demand rises at an average yearly rate, much of that demand is satisfied by fossil fuels, which have widely recognized harmful effects on the environment and climate. Wind energy is one of the most potential resources, particularly in areas with moderate wind conditions. Talang, Solok Regency, has an average wind speed that supports small-scale wind power generation. Wind turbines convert the kinetic energy of wind into mechanical energy, which is further converted into electricity. The effectiveness of this conversion depends on several design factors, including blade shape, number of blades, turbine diameter, and generator type [1] [2] [3]. To attain sustainability and lessen the impacts of global warming, nations around the globe are starting to adopt green energy as an alternative to conventional fossil fuel energy. Wind energy is an essential form of renewable energy, as it is sustainable and limitless with significant commercial and technical potential. Many researchers have sought to enhance wind turbine design to boost the efficiency of this conversion process. [4] [5] [6]. Considering the existing wind patterns in Indonesia, the primary wind direction usually originates from the southeast, especially in the east monsoon season (June–August). In this timeframe, the Australian monsoon system intensifies, producing steady easterly winds that move over the Indonesian archipelago. These winds, while most intense over areas like Java, Bali, and Nusa Tenggara, also reach into the western portion of Sumatra, covering West Sumatra Province. These geographical and climatic factors present considerable opportunities for harnessing wind energy in the coastal and mountainous regions of West Sumatra. The area has consistent and moderate wind speeds, particularly in the dry season, making it ideal for establishing small-scale horizontal axis wind turbine systems as a renewable and eco-friendly energy option [7].

In recent years, studies have primarily concentrated on wind turbines that function based on the lift force principle. In this kind of turbine, the force that propels the rotor is generated by the pressure disparity between the suction and pressure faces of the blades. In the course of optimization, the effects of the quantity and form of the rotor blades are examined. Research has shown that adding more blades enhances the turbine's self-starting capability and boosts its efficiency in lower wind speeds [8]. A potential solution trend for affordable renewable energy generation is the advancement and deployment of compact, small-scale wind turbines. However, due to factors such as intense turbulence, low wind speeds, reduced adaptability to changes in wind direction, and concerns over potentially high aerodynamic noise levels from the turbines, the implementation of small wind turbines in densely populated suburban regions remains relatively restricted [9]. Turbines can primarily be categorized into two main types: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). These are characterized by the rotor configuration and spinning axis, each possessing unique advantageous qualities. Nonetheless, VAWT designs cannot generate power on a megawatt scale and require further development to compete with HAWT, while the increased rotor control via pitch and yaw adjustments explains HAWT's popularity. Horizontal-axis wind turbines (HAWTs) are commonly employed to harness wind energy and transform it into electrical power [10] [11]. Blades for wind turbines were produced from a single type of material. These blades often encountered problems related to poor durability and elevated failure rates. To tackle these issues, composite materials, especially those utilizing polymer matrices, were introduced as alternatives. These composites exhibited exceptional performance, greatly improving the durability and dependability of turbine blades. Ongoing studies and experiments are dedicated to enhancing the aerodynamic efficiency and ecological characteristics of polymer composites in order to further refine the effectiveness of wind turbine blades. For large wind turbines, this approach poses difficulties because of irregular wind distribution throughout the extensive rotor area, resulting in unequal loads and mechanical imbalance. The significant rotational inertia restricts the turbine’s capacity to swiftly adjust to wind changes, necessitating quick control measures that could cause vibrations and structural strain. Thus, controlling the pitch is crucial for managing rotational speed and power output, reacting quickly to turbulence, and minimizing vibration and strain on the blades and tower [12].

The use of fiber-reinforced polymer composites is becoming more common in the wind energy industry because of their superior strength-to-weight ratio. Fiber-reinforced polymers made from glass have been extensively utilized for robust and effective turbine blades, whereas carbon fiber composites are receiving more focus for improved performance and lighter weight. Basalt fiber reinforced epoxy composites have also been employed in small-scale wind turbines, presenting a promising substitute for conventional materials [13]. Multi-blade horizontal turbines are generally more responsive at lower wind speeds, making them suitable for rural and medium-wind areas. Therefore, this study focuses on designing and developing a horizontal multi-blade wind turbine and evaluating its performance under varying wind speeds. Although many research efforts have examined small horizontal axis wind turbines, the majority concentrate mainly on performance evaluation of standard three-blade designs. Few studies directly focus on design choices for low-wind settings, especially in rural Indonesian areas where typical wind speeds seldom surpass 7 m/s. The uniqueness of this research stems from its context-focused design methodology, integrating a comparative evaluation of blade configurations with experimental confirmation in actual environmental settings. In contrast to earlier studies focused on general turbine optimization, this research incorporates local wind conditions, real-world construction limitations, and rural application requirements into the design and development stages. Consequently, this research assesses turbine efficiency while offering a systematic design approach for multi-blade HAWT systems appropriate for areas with low to moderate wind.

2 Method

This study utilizes a prototype development research framework. The methodological process is organized into multiple systematic phases: an initial review of literature, the identification and acquisition of necessary tools and materials, the structural and aerodynamic design of the wind turbine system, prototype construction and mechanical assembly, performance assessment and adjustments, and the ultimate evaluation of system performance. This research adopts an experimental prototype development approach consisting of six main stages: literature study, collection of tools and materials, tool design and construction, testing and evaluation, data collection and analysis, and conclusion. The overall research process is illustrated in Figure 1.

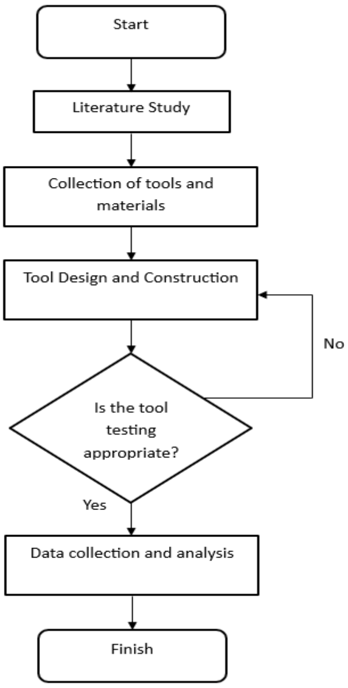

Figure 1. Flowchart of research

The literature review was performed to gather theoretical and empirical insights regarding wind energy conversion systems, aerodynamic performance of blades, characteristics of generators, and pertinent previous research. After this phase, the required elements including the turbine blades, DC generator, tower framework, gearbox, and measuring devices were gathered. The design and building stage included identifying blade shape, rotor size, number of blades, hub design, and support structures. The turbine prototype was subsequently constructed and mechanically connected to the generator and transmission system. Following assembly, a set of regulated performance evaluations were conducted to guarantee correct system operation. This testing phase also involved repeated modifications to enhance operational stability and power production as needed. After successfully confirming the operational capability of the turbine, the research moved on to the data gathering and analysis stage. The data analysis mainly concentrated on assessing the performance traits of the wind turbine at different wind speeds. The performance indicators assessed during this stage comprised turbine rotational speed (rpm), electrical voltage (V), current (A), and the produced power output (W). This analytical evaluation aimed to measure the energy conversion efficiency of the turbine and evaluate its potential as an alternative renewable energy source in Talang, Solok Regency

2.1 Collection of Tools and Materials

In this stage, the necessary materials and instruments were identified and prepared according to the design specifications. The main components include: Six-blade horizontal-axis turbine, DC generator, Gearbox, Tower structure, Tail vane, Measurement instruments (anemometer, multimeter, tachometer). All components were selected based on efficiency, durability, and compatibility with locally available materials to ensure practical implementation in rural areas.

2.2 Tool Design and Construction

The design phase focused on developing a horizontal-axis wind turbine equipped with six blades for enhanced energy capture efficiency. The prototype integrates a gearbox system that increases the generator's rotational speed, thereby optimizing voltage generation under varying wind conditions. Tool manufacturing planning can be defined as creating a design pattern, which is the initial stage before use. The Mechanical design of windmill blade parts and Generator gearbox frame design can be seen in the figure 2 and 3.

Figure 2. Mechanical design of windmill blade parts

Figure 2 illustrates the mechanical configuration of the windmill blade employed in the horizontal-axis wind turbine system. The blade features a total length of 0.75 m, with a maximum width of 0.075 m at the root area, narrowing to 0.04 m at the tip. The blade's geometry is designed to enhance aerodynamic efficiency by effectively capturing wind energy and facilitating smooth airflow across its surface. The blade design features an airfoil-shaped cross-section that balances lift and drag forces, guaranteeing effective rotation even in moderate wind conditions. The tapered and slim design aids in minimizing mechanical stress on the hub and shaft when operating at high speeds. This blade design was chosen to find a balance among structural integrity, low weight, and aerodynamic effectiveness, which are crucial for enhancing the overall functionality of small-scale wind turbines [14] [15].

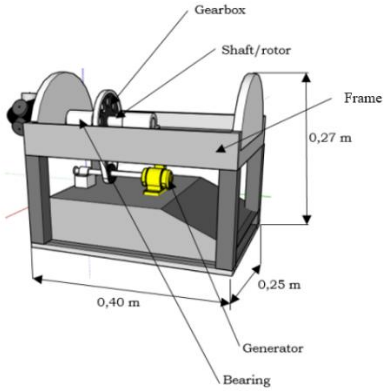

Figure 3. Generator gearbox frame design

Figure 3 depicts the configuration of the generator gearbox frame utilized in the wind power plant prototype. The system includes multiple key components, such as the gearbox, rotor/shaft, frame, generator, and bearing. The gearbox is linked to the rotor shaft, which conveys the mechanical energy produced by the wind turbine to the generator via the transmission system. The generator subsequently transforms the mechanical rotation into electrical power. The frame is built with measurements of 0.40 m in length, 0.25 m in width, and 0.27 m in height, delivering adequate stability and structural support for the parts during use. Bearings are fitted to decrease friction on the spinning shaft, promoting smooth rotation and reducing mechanical losses. This sturdy and compact design enables the system to function effectively while ensuring easy maintenance and portability, making it ideal for small-scale wind energy projects or prototype experiments in lab settings [16].

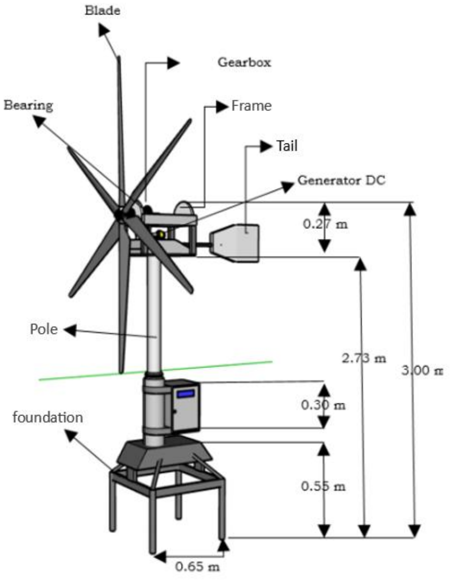

Figure 4. Overall Design of Wind Power Plant

The complete structural design and component layout are illustrated in Figure 4. Several components are used in the prototype system, and the following is an explanation of each parts in the design:

1. Blade: The blade length used on the tool is 75 cm.
2. The gearbox size used on the tool is 1:5.

3. Generator: The generator type used on the tool is a DC generator with a maximum power of 200 watts.
4. The tower or pole length used is 300 cm.

Figure 4 shows the comprehensive layout of the wind power plant model. The system comprises several key elements, such as the blade, gearbox, frame, DC generator, tail, pole, bearing, and foundation. The overall height of the structure is around 3.00 m, with the wind turbine positioned at 2.73 m above the base to guarantee sufficient wind flow exposure. The support pole measures 0.30 m in diameter and is securely fixed to a foundation that is 0.65 m wide to ensure structural stability while in use. The blade serves as the primary part for transforming wind energy into rotational movement, which is subsequently relayed through the gearbox to the DC generator. The generator transforms mechanical energy into electrical energy. The tail assists in keeping the turbine aligned with the wind direction, guaranteeing stable performance. Bearings are placed in the rotor and shaft areas to reduce friction losses and improve mechanical efficiency [17]. This complete arrangement shows a compact and reliable design appropriate for small-scale renewable energy uses. The system aims to be modular, simple to assemble, and able to function efficiently in the moderate wind conditions common at the test location in Solok

2.3 Tool Testing and Evaluation

After the turbine prototype was completely assembled, preliminary testing was carried out to assess its mechanical stability, rotational balance, and generator performance. The system experienced wind speeds between 4 and 8 m/s, reflecting typical wind conditions in the Talang region. If performance fell short of the required operational standards, modifications were performed on the blade pitch angle, gearbox alignment, or electrical connections prior to re-testing. This repetitive procedure guaranteed the dependability and precision of the experimental outcomes. The panel box is an essential element of a wind energy facility. It appears as a cabinet or box housing crucial electrical and electronic parts to regulate, safeguard, and handle the electricity produced by the wind turbine. In the panel box, power is changed from AC to DC for battery storage and then converted back to AC for usage or distribution to the power grid. Figure 5. below shows the wind power generator panel box in the research.

Figure 5. The wind power generator panel box

2.4 Data Collection and Analysis

After achieving optimal prototype performance, systematic data collection was carried out over a two-month period, with measurements taken every two hours. Recorded parameters included: Wind speed (m/s), Turbine rotational speed (rpm), Generated voltage (V), Current (A), Power output (W). Two experimental conditions were tested:

1. No-load testing, to determine the turbine's open-circuit voltage characteristics; and

2. Loaded testing, to analyze electrical performance under operational load conditions.

All data were compiled in Tables 5, 6, and 7 and analyzed to evaluate the correlation between wind speed, turbine speed, and electrical power output. An anemometer was utilized to assess wind speed and/or direction in this research. This device operates by assessing the impact of wind on a mechanical object or sensor, like a rotating cup anemometer or ultrasonic waves, and subsequently transforms this motion into a speed expressed in m/s [18].

2.5 Wind Power Calculation and Validation

The final stage involved interpreting the data to assess the turbine's overall performance, efficiency, and feasibility as a local renewable energy solution. Wind power is calculated using [19]:

$$Pin = \frac{1}{2}\rho A v^3 \tag{1}$$

explanation:
P_{in} = wind power (W),
ρ = air density (1.225 kg/m³),
A = swept area (m²),
v = wind speed (m/s).
Swept area:

$$P = \frac{1}{2}\pi d L \tag{2}$$

explanation:
d = Turbine diameter (m),
L = Turbine height (m)

2.6 Design Selection and Comparative Assessment

Before prototype construction, a comparative design analysis was performed to assess typical rotor blade configurations utilized in small-scale HAWTs, specifically three-blade, four-blade, and six-blade designs. The evaluation criteria comprised starting torque ability, aerodynamic resistance, cut-in wind speed, mechanical intricacy, and appropriateness for rural application as indicated by existing studies.

Three-blade turbines generally show improved aerodynamic efficiency in stronger winds but need higher cut-in speeds. Conversely, multi-blade turbines offer enhanced starting torque and greater rotational stability in low wind conditions. Considering that the typical wind speed in Talang varies between 4.8 and 7.1 m/s, the six-blade setup was chosen as the optimal design for guaranteeing dependable performance and energy collection in local circumstances.

2.7 Measurement Accuracy and Load Specification

Wind speed data were collected using a calibrated cup anemometer that has a measurement resolution of ±0.1 m/s. Voltage and current were assessed with a digital multimeter that has an accuracy of ±1.5%. The rotational speed of the turbine was measured with a handheld tachometer that has an accuracy of ±1 rpm. Load testing was performed with a resistive DC load simulating conditions similar to small-scale battery charging. This load choice reflects practical working scenarios for rural off-grid uses, including LED lighting and low-energy electronic gadgets.

3 Discussion

This section discusses the experimental data obtained from wind turbine performance testing conducted in Solok during August–September 2025. The focus is on analyzing how changes in wind speed influence the turbine's voltage and power output. In this study, the performance of a small-scale horizontal-axis wind turbine was tested to determine how variations in wind speed affect the electrical output. The experimental results for wind speed, turbine speed, voltage, and power generation are summarized and discussed in this section. The figure 6. below depicts the process for measuring wind speed with anemometer

Figure 6. Measuring wind speed using an anemometer

From the measurements in Figure 6. above, the results obtained are wind speed (m/s) for 8 weeks from the period August - September 2025 in the table below.

Table 1. Wind speed data

Week	Period	Wind Speed (m/s)
1	1–7 August 2025	4.8
2	8–14 August 2025	5.6
3	15–21 August 2025	6.2
4	22–31 August 2025	6.7
5	1–7 September 2025	5.4
6	8–14 September 2025	6.0
7	15–21 September 2025	6.5
8	22–30 September 2025	7.1

Table 1. displays the average weekly wind speed data collected in Talang, Solok Regency during August and September 2025. The documented wind speeds vary from 4.8 m/s to 7.1 m/s, suggesting moderate and fairly consistent wind conditions over the two-month duration. The pattern shows a steady rise in wind speed from the start to the end of the observation period, indicating seasonal wind intensification as late September approaches.

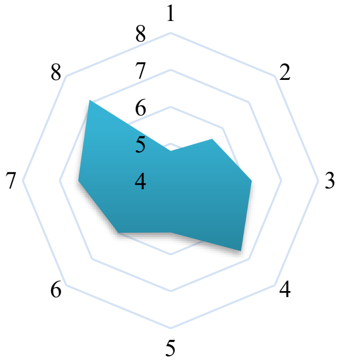

Figure 7. Wind speed (m/s) data per week (August – September 2025)

Figure 7. illustrates the wind speed distribution in a radar chart, clearly showing fluctuations between weeks. The visual representation highlights that the highest wind speed was observed in week 8 (7.1 m/s), while the lowest occurred in week 1 (4.8 m/s). These variations indicate the natural variability of local wind resources influenced by regional monsoon transitions.

3.1 Experimental Results and Performance Evaluation

This subsection showcases the experimental findings acquired from field trials of the created multi-blade horizontal axis wind turbine in genuine wind conditions in Talang, Solok Regency. The assessment of performance emphasizes the connection between wind speed, turbine rotation speed, and electrical output metrics, such as voltage, current, and power production. Measurements took place during a two-month observation period (August–September 2025) to record changes in local wind characteristics and their effect on turbine performance. The gathered data were analyzed to evaluate both no-load and load operating conditions, offering a detailed depiction of the turbine's electrical performance in real-world operating situations. The results are summarized in the tables below to aid in the quantitative analysis of turbine performance based on wind speed.

Table 2. No-load wind power plant testing

Week	Average Wind Speed (m/s)	Turbine Speed (rpm)	Voltage (V)	Current (A)
1	4.8	210	2.5	0.00
2	5.6	260	3.0	0.00
3	6.2	310	3.6	0.00
4	6.7	350	4.0	0.00
5	5.4	250	2.8	0.00
6	6.0	300	3.4	0.00
7	6.5	340	3.9	0.00
8	7.1	380	4.4	0.00
Note: Current = 0 because no load.				

Table 2. summarizes the no-load testing results of the horizontal-axis wind turbine prototype. In this condition, the generator produced voltage output ranging from 2.5 V to 4.0 V, depending on the wind speed, while the current remained 0 A due to the absence of load. The results show a positive correlation between wind speed and generated voltage — as wind velocity increases, the turbine's rotor speed (rpm) and voltage output also rise. This verifies that the designed multi-blade rotor effectively captures wind energy even at moderate wind speeds.

Table 3. Wind power plant testing with load

Week	Average Wind Speed (m/s)	Turbine Speed (rpm)	Voltage (With Load) (V)	Current (A)	Power (W)
1	4.8	210	2.1	0.21	0.44
2	5.6	260	2.6	0.26	0.68
3	6.2	310	3.2	0.32	1.02
4	6.7	350	3.6	0.36	1.30
5	5.4	250	2.4	0.24	0.58
6	6.0	300	3.0	0.30	0.90
7	6.5	340	3.5	0.35	1.23
8	7.1	380	3.9	0.39	1.52

Table 3. presents the results of load testing, where the turbine system was connected to an electrical load. The recorded voltage values ranged between 2.1 V and 3.9 V, with corresponding current outputs from 0.21 A to 0.39 A. The highest power output (1.52 W) was achieved at a wind speed of 7.1 m/s, while the lowest (0.44 W) occurred at 4.8 m/s. This demonstrates that the system's electrical performance improves proportionally with higher wind speeds and rotational speeds.

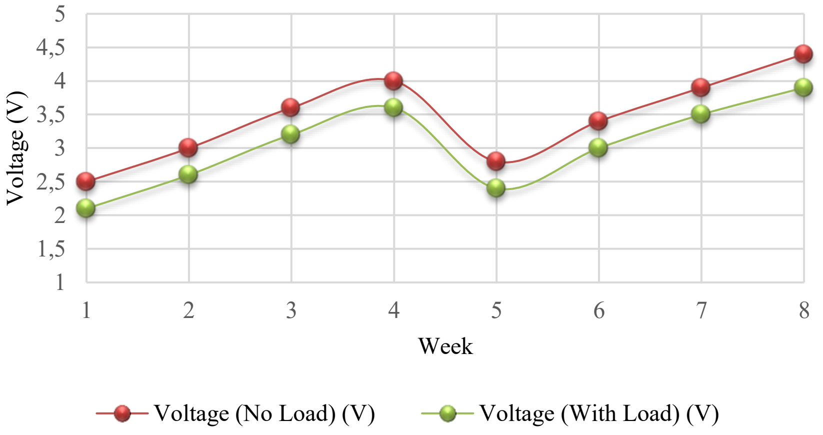

Figure 8. Average voltage output data per week (August – September 2025)

Figure 8. illustrates the weekly average voltage output under no-load versus load conditions. The orange line denotes the no-load voltage, which remains above the loaded voltage (gray line) because there are no resistive losses present. The shapes of both curves exhibit a comparable trend, indicating that voltage production is mainly affected by wind speed instead of changes in load. The comparison between no-load and load conditions, as illustrated in the graph, shows that voltage output under load was consistently lower than that of the no-load condition. This is due to the electrical resistance of the load that causes a voltage drop when current flows. However, the increasing pattern of voltage output with higher wind speeds remains consistent in both conditions.

Based on the results obtained from the performance testing of the multi-blade horizontal axis wind turbine, it can be observed that variations in wind speed have a significant influence on the rotational speed of the turbine and the electrical output generated. These observations confirm that the turbine's output power is directly proportional to the magnitude of the wind speed. It seems that energy rises with the increase in wind speed. The wind's velocity prior to reaching the turbine produces energy as it flows through the turbine; considering the turbine's area, it interacts with the blades, causing the turbine to rotate and harness wind energy, resulting in a reduction of power after the turbine due to the presence of movement and torque. The power factor of the turbine varies with the tip speed ratio and is influenced by the wind turbine's diameter. The turbine efficiency value is a power factor that indicates the ratio of output to input for a specified wind turbine area. In this instance, time does not play a role, yet wind speed and energy do influence the outcome. The design of the parabolic blade is selected to maximize airflow while minimizing wind speed [20].

Overall, the six-blade turbine design demonstrated good responsiveness to low-to-medium wind conditions. The increased number of blades contributes to higher starting torque, making it suitable for regions with moderate wind profiles such as Talang, Solok Regency. However, this blade configuration may introduce aerodynamic drag that can limit maximum efficiency at high wind speeds. Nevertheless, the turbine remains operationally stable and capable of producing usable electrical power within the observed wind range. Based on the test results, it can be concluded that wind speed has a direct and significant influence on the voltage and power output of the wind turbine. Higher wind speeds increase the turbine's rotational speed, which in turn enhances the electrical energy generated. These findings demonstrate the potential of small-scale horizontal-axis wind turbines for renewable energy generation in areas with moderate wind speeds like Solok.

3.2 Power Coefficient and System Efficiency Analysis

The wind turbine's aerodynamic efficiency was assessed through the power coefficient (Cp), which indicates the proportion of electrical power generated to the power present in the wind. The power coefficient was determined using the subsequent relationship:

$$Cp = \frac{Pout}{Pwind} \tag{3}$$

where the accessible wind energy is specified as:

$$Pwind = \frac{1}{2}\rho A v^3 \tag{4}$$

In these equations, P_{out} is the measured electrical power output (W), ρ is the air density (assumed as 1.225 kg/m³), A is the rotor swept area (m²), and v is the measured wind speed (m/s). The Cp values were calculated based on experimental data obtained during load testing. According to the observed wind speeds, swept area, and electrical output, the computed Cp values varied from 0.12 to 0.18 throughout the measured wind speed range. While these Cp values are not as high as those of large-scale commercial wind turbines, they align with earlier findings for small-scale multi-blade turbines functioning in low wind speed scenarios. The comparatively lower Cp is primarily due to heightened aerodynamic drag linked to greater blade numbers; nevertheless, this compromise is warranted by enhanced starting torque and operational dependability, which are essential for low-wind and rural uses.

Table 4. Power Coefficient (Cp) Based on Experimental Results

Week	Wind Speed (m/s)	Electrical Power Output (W)	Power Coefficient (Cp)
1	4.8	0.44	0.12
2	5.6	0.68	0.14
3	6.2	1.02	0.15
4	6.7	1.3	0.17
5	5.4	0.58	0.13
6	6	0.9	0.15
7	6.5	1.23	0.16
8	7.1	1.52	0.18

Note: *The power coefficient (Cp) values were calculated based on measured electrical power output and available wind power under consistent rotor swept area and air density assumptions*

3.3 Comparison with Previous Studies

The results of this research were additionally analyzed alongside earlier studies that explored small-scale horizontal axis wind turbines using various design and operational methods. Mujahid et al. (2021) carried out a design optimization analysis with Q-Blade software and noted that traditional three-blade turbines often reach superior peak aerodynamic efficiency; nonetheless, these setups necessitate higher cut-in wind speeds, restricting their performance in low-wind rural areas [10]. In contrast, this study employs a six-blade design that emphasizes starting torque and operational stability, allowing for dependable turbine functionality within the recorded wind speed range of 4.8–7.1 m/s. This design decision demonstrates a careful compromise between optimal efficiency and adaptability to low winds, making it better suited for the local environment in Talang, Solok Regency.

Furthermore, Bakkal and Mahmoud (2024) conducted field tests on a small horizontal wind turbine, reporting electrical power outputs under 5 W for wind speeds less than 8 m/s, highlighting practical implementation over aerodynamic efficiency. The highest power output achieved in this study (1.52 W) is within the stated range, suggesting that the experimental findings are valid and align with comparable field research. In contrast to simulation-based studies, the current research and the study by Bakkal and Mahmoud (2024) utilize actual environmental conditions, increasing the practical significance of the results for decentralized and off-grid energy uses [20].

In general, the comparison with these studies suggests that the suggested turbine focuses on operational reliability and suitability for low-wind conditions instead of maximum aerodynamic efficiency. Despite this design focus, the turbine demonstrates performance traits similar to those of current small-scale wind turbines, while offering improved suitability for rural and low-wind scenarios. This illustrates that the primary contribution of the current study resides in its contextoriented design approach and field-based experimental verification, providing practical insights that extend beyond mere theoretical optimization

4 Conclusion

From the design, construction, and performance evaluation of the multi-blade horizontal axis wind turbine, it can be concluded that the system is capable of generating electrical energy under natural wind conditions ranging from 4.8 to 7.1 m/s. From the experimental outcomes of the wind power plant tests carried out in Solok between August and September 2025, it can be inferred that wind speed is vital in influencing the efficiency of the wind turbine. The findings indicated that a rise in wind speed results in an equivalent increase in turbine rotation speed, output voltage, current, and power. With no load applied, the voltage output varied from 2.5 V to 4.4 V, influenced by changes in wind speed between 4.8 m/s and 7.1 m/s. When under load, the voltage output diminished slightly because of resistance, yielding values from 2.1 V to 3.9 V, while power output varied between 0.44 W and 1.52 W. The optimal performance occurred in the eighth week with a wind speed of 7.1 m/s, a turbine speed of 380 rpm, and a power output of 1.52 W. These results suggest that the multi-blade horizontal-axis wind turbine can effectively convert wind energy into electrical energy, even in moderate wind scenarios. Additionally, the system showcases the capability for small-scale renewable energy production ideal for rural or off-grid uses. It is suggested that future studies focus on improving blade design, generator efficiency, and load management to increase power output and stability in diverse wind conditions Further improvements may include optimizing blade shape for better aerodynamic efficiency, increasing tower height to access stronger wind layers, and integrating an automatic charging and power regulation system to improve energy utilization.

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