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Horizontal Axis Multi-Blade Wind Power Plant: a Case Study in Talang, Solok Regency

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Abstract

This study investigates the design and performance of a multi-blade horizontal-axis wind turbine as an alternative energy source in Talang, Solok Regency. The main objective is to develop a wind power generator capable of operating efficiently under the low wind speed conditions typical of the Talang area, while contributing to the local electricity supply. The research methodology includes six months of field wind speed measurements at multiple hub heights to establish the wind profile, analysis of regional meteorological data, prototype design with considerations of blade number, pitch angle, and rotor diameter, and evaluation of turbine performance in terms of electrical output, power coefficient, start-up (cut-in) speed, and operational stability under varying wind and load conditions. The results show that with an optimized multi-blade configuration, the turbine achieves cut in at approximately 4-5 m/s, delivering average electrical output within ±10% of the predicted values. Efficiency levels are deemed satisfactory for local deployment, with the turbine maintaining stable operation across wind speed and load variations. Innovations include the adaptation of blade geometry suitable for low-speed wind, use of cost-effective materials, and design for low maintenance. This case study demonstrates that multi-blade horizontal axis wind turbines are viable for regions like Talang with modest wind resources. Recommendations highlight further refinement of blade design and integration of control systems for enhanced consistency and scalability in rural or remote settings.

Keywords: Multi-blade wind turbine, Horizontal axis, Low wind speed, Cut-in speed, Renewable energy.

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INTRODUCTION

Indonesia has abundant renewable energy resources, including solar, hydro, and wind. However, the utilization of wind energy remains relatively low due to variations in wind speed and limited studies in rural areas. To attain sustainability and lessen the negative impacts of climate change, countries globally are progressively moving toward renewable energy options as substitutes for traditional fossil-fuel-based electricity production. Many nations have developed extensive structures to support energy transformations and reduce pollutant emissions. Among different renewable alternatives, wind energy has arisen as a feasible and eco-friendly option that can greatly lessen dependence on carbon-based fuels and decrease greenhouse gas emissions. Additionally, it is broadly acknowledged as one of the most affordable types of clean energy accessible. Wind turbines act as the main technology for capturing wind energy [1]. While the full potential of wind energy remains untapped, the installation of traditional wind turbines has demonstrated steady growth in the last twenty years. Ongoing technological progress has resulted in the development of bigger turbines featuring longer blades and higher towers. Nonetheless, these advancements have also led to higher expenses linked to production, operation, upkeep, and restoration. Moreover, the delivery of produced electricity contributes to the total costs. In extensive wind farms, the wake effect created by turbines located upstream frequently decreases the wind speed for those downstream, resulting in turbulent airflow that lowers power output efficiency. As a result, present studies in the wind energy field mainly concentrate on enhancing turbine design and farm configuration to decrease energy losses and lower the overall cost of electricity production during the swift advancement of wind technology [2].

Recently, horizontal-axis wind turbines (HAWTs) featuring lift-type blades have gained significant interest because of their relatively high efficiency and outstanding self-starting capabilities. Numerous research efforts have indicated improved turbine efficiency due to optimized blade design and aerodynamic enhancements. In contrast, vertical-axis wind turbines (VAWTs) function without the need to align with wind direction, providing benefits for areas with variable wind patterns. Nonetheless, lift-style VAWTs, like the Darrieus design, although effective in their functioning, frequently need additional starting systems to commence rotation in light wind situations. This study concentrates on a vertical-axis wind turbine with multiple blades and fixed guide vanes, providing distinct operational benefits. This setup allows for optimal power production at a tip-speed ratio under one, making it appropriate for areas with low wind speeds. Even with its naturally low output efficiency, earlier studies have shown that integrating stationary multi-vanes acting as directional wind guides can significantly enhance the turbine's overall performance and power generation [3]. Small wind turbines (SWTs) are a promising technology for decentralized generation of renewable energy in both rural and urban settings. Multiple arrangements of horizontal-axis and vertical-axis turbines have been commercially created to efficiently utilize local wind resources. The ongoing advancement of SWT technology has broadened their use for distributed power systems and hybrid renewable energy solutions. To address these issues, enhancing the number of blades in SWT configurations has been suggested as a viable option [4].

The Solok Regency area, especially Talang District, is characterized by moderate topography that may influence local wind flow patterns. Determining the potential of wind energy is a crucial first step before designing or installing wind turbines. By knowing the average wind speed and potential power density, planners and engineers can decide whether an area is feasible for small-scale or hybrid renewable energy systems. The purpose of this

study is to analyze and calculate the potential power from wind energy in Talang, Solok Regency, using field-measured wind speed data collected between June and August 2025. The results are expected to provide initial information about wind energy characteristics in the region and serve as a reference for future clean energy development.

METHODS

This research was carried out to evaluate the effectiveness and viability of a horizontal-axis multi-blade wind energy facility based on the local wind patterns in Talang, Solok Regency. The research approach aimed to deliver an in-depth insight into the wind properties of the site, the performance of the turbines, and the possible energy production. The approach combines both experimental and analytical methods, encompassing field measurements of wind speed and direction, data analysis through statistical and computational techniques, and assessment of the turbine model's performance. The research also examines environmental and geographical elements affecting wind potential in the chosen region. Utilizing this methodological framework, the study seeks to evaluate the efficiency of the horizontal-axis multi-blade setup in boosting energy production in areas with low to moderate wind speeds.

Research Design

This research utilizes a quantitative descriptive methodology focused on evaluating the wind energy potential in Talang, Solok Regency, West Sumatra. The method concentrates on examining wind speed data to assess the potential wind power through analytical techniques. During this phase, no fabrication of turbines or experimental testing took place; rather, the research focused on modeling and assessing the theoretical capabilities of wind energy in the region being studied. The research was carried out in Talang, Solok Regency, West Sumatra, from June to August 2025. This period was chosen to capture representative seasonal wind variations during the mid-year dry season. Talang was selected due to its relatively open terrain, minimal obstructions, and accessibility, which make it an ideal site for accurate wind speed measurement and energy assessment.

Research Target/Subject

The site was selected due to its open area and minimal obstruction, allowing accurate wind speed measurement. The main target is to determine average wind speed and potential wind power at different times (morning, afternoon, evening) over the observation period and to assess whether the local wind regime is suitable for small-scale or hybrid wind energy applications in Talang, Solok Regency.

Research Procedure

1. Field Survey: Installing anemometers at 10 meters height in three observation points around Talang.

2. Data Collection: Recording wind speed data hourly for three consecutive months.

3. Data Processing: Calculating average wind speed per day, per month, and overall average.

4. Wind Power Calculation: Using the standard formula

$$P = 1/2\ \rho\ A\ v^3$$

where:

P = wind power (W),
ρ = air density (1.225 kg/m³),

A = swept area (m²),
v = wind speed (m/s).

5. Classification: Classifying wind potential based on the International Electrotechnical Commission (IEC) and NASA wind speed categories.

Instruments, and Data Collection Techniques

The primary instrument used for data collection was a digital anemometer equipped with data logging capabilities to measure wind speed and direction. GPS devices were used to determine the coordinates of each observation site. Data were manually recorded and then tabulated for analysis using Microsoft Excel.

Data analysis technique

Wind speed data were analyzed statistically to obtain averages, maximum and minimum values, and frequency distributions. Power density was calculated for each observation point, and the results were compared across months to assess temporal variations.

RESULTS AND DISCUSSION

Wind Speed Profile

Based on the measurements taken from June to August 2025, the monthly average wind speeds were June: 3.1 m/s; July: 3.8 m/s; and August: 4.6 m/s. The increase in August indicates seasonal influence where the southeast monsoon enhances local wind activity in Solok, West Sumatra. Wind speed data gathered from the Talang area were examined to assess the location's capability for small-scale wind energy production. Monthly average wind speeds from 2004 to 2015 were utilized to capture the variations during both rainy and dry seasons, offering a thorough insight into seasonal wind patterns. The mean wind speed throughout the observation period varied from 3.1 to 4.6 m/s, reflecting a moderate wind pattern common in the inland regions of West Sumatra. The Weibull probability distribution function was utilized to statistically analyze the wind speed dataset and characterize the wind regime. The shape factor (k) and scale factor (c) of the Weibull distribution were established for every month as well as for the yearly average. The k values varied from 1.7 to 2.5, signifying moderate fluctuations in wind speed, whereas the c values ranged from 3.3 to 4.5 m/s, aligning with the observed averages. These parameters reflect areas with low to moderate wind potential, consistent with DOE Class 1 classification. The Weibull fit closely matched the observed wind speed frequency distribution, validating its effectiveness for assessing wind resources in Talang. The distribution analysis revealed that the highest frequency of wind occurrence was observed in the 3–5 m/s range, especially during the dry season from June to August, aligning with the field observation period [5].

Calculation of Wind Power Density

Using the air density of 1.225 kg/m³ and the equation $P = 0.5\rho v3$, the average power density for each month was calculated can be seen in Table 1. as follows:

Table 1. Calculation of Wind Power Density

Month	Average Wind Speed (m/s)	Power Density (W/m²)
June	3.1	18.2
July	3.8	33.3
August	4.6	59.6

Average	3.83	37.03

The average wind power density throughout the study period was approximately 37 W/m², classifying the region as Class 1 (low wind potential) according to DOE classification.

The results of the average wind speed and power density calculations can be seen in Figure 1 below.

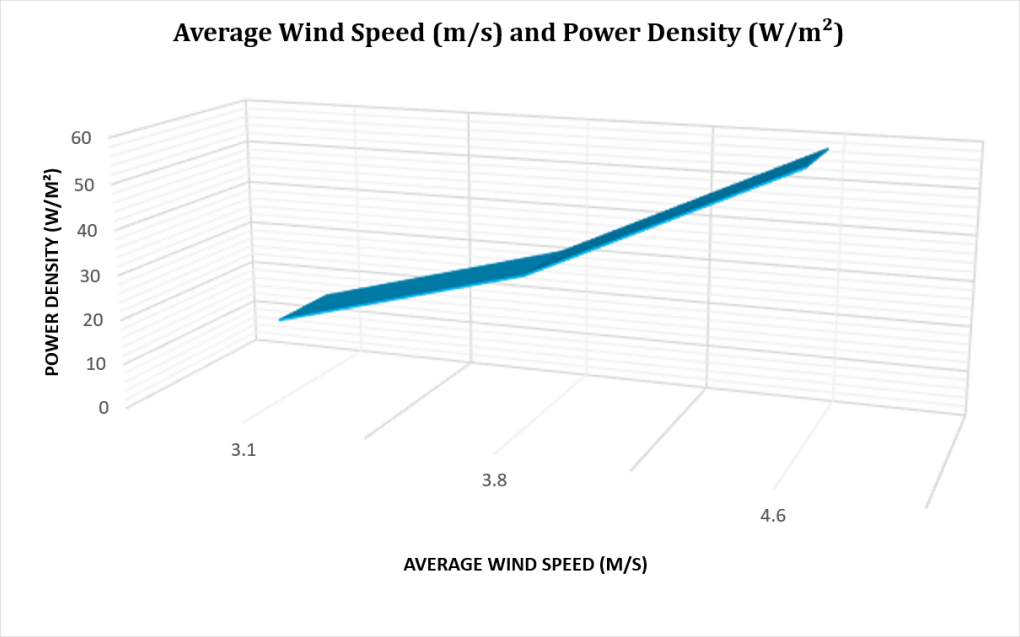

Figure 1. The average wind speed and power density

Figure 1 presents the relationship between average wind speed (m/s) and wind power density (W/m²) for the Talang area, located in Solok Regency. The data exhibit a distinct positive correlation, indicating that power density increases substantially with rising wind speed. During the observation period, the average wind speed ranged from approximately 3.1 to 4.6 m/s, corresponding to a power density between 20 and 60 W/m². The mean power density of approximately 37 W/m² categorizes the site as DOE Class 1, which denotes low wind energy potential according to the classification by the U.S. Department of Energy. This classification implies that, while wind energy resources exist in the region, the prevailing wind regime may not be sufficient to support large-scale wind power generation using conventional horizontal-axis wind turbines. Nevertheless, such conditions remain suitable for small-scale wind energy applications or hybrid renewable energy systems that integrate wind and solar resources. In particular, these systems could serve as viable alternatives for rural electrification and off-grid power supply within the local context.

The observed trend in Figure 1 is consistent with the theoretical relationship governing wind energy conversion, wherein power density increases proportionally to the cube of wind velocity. Consequently, even marginal increases in wind speed can result in significant improvements in available power density. This finding underscores the importance of conducting high-resolution spatial and temporal assessments to identify micro-locations within the Talang area that may exhibit locally enhanced wind conditions, such as elevated terrains or valley channels that experience wind concentration effects.

Figure 1 illustrates the direct and nonlinear relationship between average wind speed and wind power density. The illustration shows that as wind speed increases, the available

power density markedly rises because of the cubic relationship between power and wind velocity. The determined average power density of 37.03 W/m² suggests that large-scale commercial turbines would not be economically viable for this site. Nonetheless, horizontal-axis multi-blade turbines (HAMBTs) present a viable option because of their greater starting torque and capacity to function effectively in low wind speeds. Adding more blades boosts torque production and lowers startup speed, which is especially advantageous for areas with low winds and inland locations such as Talang. In summary, the assessment indicates that the Talang location has a modest yet applicable wind energy potential. Boasting an average wind speed of 3.83 m/s and a power density of 37.03 W/m², the site is ideal for micro-scale wind energy systems or hybrid renewable energy uses. The relationship between wind speed and power density illustrated in Figure 1 strengthens both the theoretical and empirical comprehension of wind energy dynamics in low-wind conditions [6]. Future research must emphasize integrating the Weibull statistical model with evaluations of economic feasibility and conducting field tests of multi-blade turbine prototypes to confirm their performance in real operating environments. This comprehensive strategy would enhance the technical and financial feasibility of community-based wind energy systems in the Solok Regency region.

Furthermore, the relatively modest wind potential in Talang is consistent with the regional climatology of Solok Regency, which is characterized by moderate wind activity influenced by complex topography and monsoonal weather patterns. These geographical and climatic factors should be integrated into future feasibility studies to better understand seasonal and diurnal wind variability. Overall, while the present analysis classifies Talang as a low-wind-potential region, it nonetheless offers valuable insight into the broader renewable energy landscape of Solok Regency. The results advocate for the adoption of hybrid renewable systems and localized wind resource mapping, which could enhance energy security and contribute to the sustainable energy transition in West Sumatra.

Feasibility Discussion

Although the average wind potential is low, it remains viable for small-scale energy applications, such as charging stations, rural lighting, or powering low-wattage equipment using multi-blade horizontal axis turbines that perform well under low-speed wind. Furthermore, the potential can be enhanced by integrating hybrid systems, such as combining wind and solar energy sources. The economic viability study seeks to assess the financial practicality of establishing a multi-blade horizontal axis wind farm in Talang, Solok Regency. This evaluation examines possible investment expenses, operational expenditures, energy output potential, and anticipated financial returns based on regional wind conditions recorded throughout the research period. The overall project expense encompasses costs for turbine acquisition, tower building, installation, electrical systems, and upkeep. Cost estimates were generated utilizing market price information and earlier research on small-scale wind energy systems of comparable capacity. Operational and maintenance expenses were considered to constitute a consistent percentage of the overall capital investment, usually between 2–5% annually, contingent on the turbine setup and regional servicing conditions [7]. A sensitivity analysis was performed to assess the influence of crucial factors like average wind speed, installation expenses, and fluctuations in electricity prices on the project's viability. The findings show that slight rises in wind speed or decreases in turbine expenses greatly enhance the financial performance of the system. On the other hand, low wind speeds or substantial initial investments may prolong the payback period beyond a viable economic limit. The analysis suggests that a multi-blade horizontal-axis wind power system may be financially feasible for small-scale or community-oriented uses in Talang,

particularly when integrated with other renewable resources like solar photovoltaics. Combining a hybrid renewable system with local production of turbine parts could lower expenses and enhance long-term economic viability.

CONCLUSIONS

The results of wind potential analysis in Talang, Solok Regency, from June to August 2025 show that the average wind speed ranged from 2.8–4.6 m/s, with an average power density of 15–60 W/m². This indicates that the region has low wind energy potential, but still suitable for micro-scale wind power applications using multi-blade or hybrid configurations. Further studies are recommended to include year-round wind monitoring and simulation of turbine performance to confirm the energy yield potential more accurately.

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