Asian Journal Science and Engineering
Vol. 3, No. 1, June 2024
https://attractivejournal.com/index.php/ajse

# The Utilization of Vertical Wind Turbines for Micro Electricity Generation

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**ARTICLE INFO**
Article history:
Received
February 03, 2024
Revised
May 22, 2024
Accepted
June 29, 2024

**Abstract**

This research is motivated by the rapidly increasing demand for electricity driven by modernization and industrialization, as well as by environmental challenges resulting from reliance on non-renewable fossil energy sources, thereby prompting the search for clean and efficient alternative energy. The aim of this study is to examine the potential and performance of vertical wind turbines as an innovative solution for micro power generation by assessing the efficiency of converting wind energy into electricity and evaluating its economic aspects. An observational research method was employed, incorporating literature review, team discussions, design processes, device construction, and the implementation of testing through both laboratory and field methods. The study was conducted at the Politeknik Pelayaran Sumatera Barat, where the turbine was installed on the roof of a classroom building in a coastal area, taking advantage of favorable geographic conditions and supportive wind characteristics. Data collection involved direct measurements of parameters such as wind speed, turbine and generator RPM, and electrical voltage over designated time intervals, thereby producing data on the variability and operational performance of the turbine. Results indicate that the vertical wind turbine is capable of generating electricity optimally despite fluctuations in wind speed, and it offers advantages in terms of installation flexibility, low operational costs, and energy efficiency with room for improvement. Consequently, the study recommends the development of enhanced aerodynamic designs and more optimal driving mechanisms to accommodate dynamic operational conditions, thereby facilitating the widespread implementation of this solution to support the decentralization of renewable energy systems, reduce reliance on fossil fuels, and strengthen the sustainability of electricity supply.

**Keywords**: Vertical Wind Turbine, Micro Power Plant, Renewable Energy

Published by CV. Creative Tugu Pena
ISSN 2963-6752
Website https://attractivejournal.com/index.php/ajse


## INTRODUCTION

Electricity plays an important role in meeting human needs in various sectors of life, starting from households, public places, to industry. The availability of stable electricity is very crucial to support daily activities and maintain the operational continuity of various facilities [1]. In the industrial sector, electricity is the main driving energy for production machines and sophisticated technological devices. The household sector also relies heavily on electricity for lighting, cooling and communication continuity. Electricity also plays a role in providing public services such as transportation to health facilities, schools, offices and campuses [2]. Therefore, effective and sustainable use of electricity is a key aspect in the development of modern infrastructure.

The use of electrical energy is currently increasing along with the rapid pace of modernization and industrialization. Digital technology which continues to develop demands a reliable and stable electricity supply so that information and communication systems run optimally [3]. The residential, industrial and service sectors are increasingly dependent on electricity to support productivity and efficiency. This increasing need also demands innovation in energy management and distribution so that waste does not occur. The efficient and environmentally friendly use of electrical energy is the main focus in the development of energy technology. This encourages research related to the use of alternative energy sources that can offset the growth in electricity consumption [4].

The high global need for electrical energy coupled with the decreasing presence of fossil energy sources poses serious challenges for the future. Depleting fossil reserves increase the risk of dependence on non-renewable energy sources [5]. In addition, the use of fossil fuels has had a negative impact on the environment through greenhouse gas emissions. Therefore, efforts to switch to renewable energy are very important to ensure the sustainability of energy supplies [6]. Renewable energy technology offers a clean and sustainable alternative to overcome the energy crisis. This strategic step is expected to reduce environmental impacts and ensure energy availability for future generations [7].

Renewable energy is an energy source that comes from natural processes that can be renewed naturally in a short period of time [8]. Examples of renewable energy include solar, wind, hydro, biomass and geothermal energy. Each type of renewable energy has its own advantages, especially in terms of environmental friendliness and abundant availability [9]. Utilizing renewable energy also reduces dependence on increasingly scarce fossil fuels. Innovations in energy conversion technology have increased the efficiency of use of this energy source. Thus, the integration of renewable energy into the electricity system is a sustainable solution to meet global needs.

One of the renewable energies that will be discussed in this research is wind energy. Wind energy is obtained from the conversion of air movement into mechanical or electrical energy via wind turbines [10]. Wind turbine technology has experienced rapid developments in terms of efficiency and design, especially with the advent of vertical wind turbines. Vertical wind turbines offer advantages in installation in confined areas and have greater placement flexibility. Utilization of wind energy is an environmentally friendly alternative solution to reduce carbon emissions [11]. This research will examine the potential and performance of vertical wind turbines in the context of micro power plants.

Electricity generation using wind power has several significant advantages. First, wind energy is an unlimited energy source and does not produce greenhouse gas emissions [12]. Second, wind turbine technology allows integration with micro power generation systems in a modular and flexible manner [13]. Third, the operational costs of wind turbines are relatively low compared to conventional power plants. Another advantage is ease of installation and maintenance, which is especially advantageous for remote areas. Overall, the use of wind energy offers an efficient and sustainable solution to meet electricity needs on a micro scale.

There are several previous studies that are relevant to this research. First, research from [14] which evaluates local wind characteristics, reliability and efficiency of wind power plants to meet street lighting needs in the area for public needs. Second, research from [15] which explains the efficiency of converting wind energy into electrical energy by modifying the aerodynamic design of the turbine. Third, research from [16] evaluates how varying the number of blades affects the efficiency of converting wind energy into mechanical energy, as well as identifying optimal configurations that can improve turbine performance.

Previous research has a different focus and scope compared to this research. This research has a more comprehensive aim with a special focus on the use of vertical wind turbines as an innovative alternative in micro power generation. Unlike the three previous studies, this study not only assesses energy conversion efficiency from design aspects (such as number of blades or turbine aerodynamics) or local wind characteristics for street lighting needs, but also examines vertical turbine design and performance, economic aspects, technical challenges and implementation.

The aim of this research is to explain the potential for using vertical wind turbines as an innovative alternative in micro power generation. This research aims to examine the design and performance of vertical wind turbines in various operational conditions. In addition, this study will identify the efficiency of converting wind energy into electricity and its economic aspects. An in-depth analysis will also be carried out on the technical challenges and implementation of turbines in micro environments. It is hoped that the research results can provide strategic recommendations for the development of renewable energy systems. Thus, this research contributes to the development of environmentally friendly and sustainable energy solutions.

## METHOD

This research method is observational research [17]. This research was conducted at the West Sumatra Shipping Polytechnic. This location was chosen dith considering the demographic location and paying attention to the characteristics of the surrounding wind. The installation of the vertical wind turbine is carried out on the roof of the classroom building at a height of approximately 24 meters above sea level where the grunge is located approximately 100 meters from the shoreline. The selection of these conditions is based on an analysis of wind potential and the availability of coastal building roofs for wind turbine installation. Research data collection was carried out by using several methods, namely literature studies, discussions between teams, designing and making tools, and implementing tools [18]

**RESULTS AND DISCUSSION**

Based on the results of the literature study, several potential uses of vertical wind turbines as an innovative alternative in micro power plants were obtained. One of the potential uses of vertical wind turbines is flexibility in installation in limited areas [19], because their compact design allows installation in urban and rural environments with limited space. Therefore, the results of this literature study support the selection of this research location in a limited area, namely in the West Sumatra Shipping Polytechnic class building. Vertical wind turbines also have the ability to capture wind from various directions, which increases the efficiency of power generation compared to horizontal turbines. The second significant potential is the relatively lower installation and maintenance costs, thus providing an economical alternative to micro power plants. Additionally, this technology supports a decentralized energy system, allowing each community to generate its own electricity without relying entirely on a central grid. The third potential is high operational reliability and stability, considering that vertical wind turbines have a simpler structure and fewer moving components. This contributes to reducing the risk of damage and lowering long-term repair costs. The fourth potential is lower environmental impact, because these turbines produce minimal emissions and can be integrated into the environment without disturbing aesthetics. Overall, the use of vertical wind turbines offers an innovative solution to produce micro electricity efficiently, economically and environmentally friendly.

Based on the results of discussions between the team and several field assistant technicians, several conclusions were obtained. Technically, the design of a vertical wind turbine intended for generating electricity is a Savonius turbine type with helical fins (*Helical Bucket Savonius Rotor Turbine)* [20] which is placed on a foundation on the roof of a multi-storey building. Next, the design and manufacture of the tool is carried out, namely a vertical wind turbine with the following parts.

**Frame**

Frame construction is useful for housing wind turbines. The frame is made of strong and light materials such as metal or carbon fiber. This frame provides the basic structure to support the wind turbine and generator components [21].

**Vertical axis**

The main axis is mounted vertically to the frame as a rotating shaft. At the bottom of the axis is equipped with a sliding bearing *(bearing)* which functions so that the shaft can rotate smoothly [22]. At the top of this shaft several blades or fins are attached to catch the wind. At the bottom of this axis is attached a *pulley* (successor wheel) with a ratio/size equipped with a v-belt (belt) for connecting and rotating the generator as an electric power generator.

**Fins/blades (*blade*)**

Fins or blades with a total of three pieces in the shape of a semicircular tube are installed in such a way that the distance forms an angle of $120^0$ mounted on a vertical axis. The fins are designed to capture wind power from various directions to convert it into electrical power which is then converted into mechanical power in the form of rotation on a vertical axis. The turbine fin is made from a 200 liter drum which is cut and shaped in such a way as a semicircular tube attached to a vertical shaft [23].

**Generator**

The function of the generator is to convert mechanical energy acting on the shaft into electrical energy. The generator is located at the bottom of the turbine construction which is connected directly to the vertical axis or to a mechanism *pulley* (successor wheel) as a controlling component to increase the desired number of revolutions.

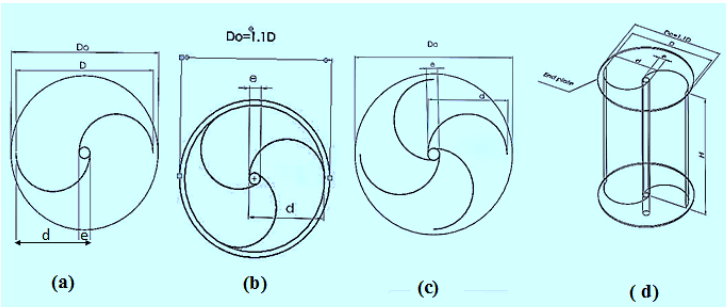


Figure 1. Vertical Axis Wind Turbine Construction Sketch

The vertical axis wind turbine design which includes the main parts such as main components, basic technical specifications and working mechanisms is created simply using a three-dimensional sketch to create a visual representation of the prototype. The initial design can be seen in the following image.

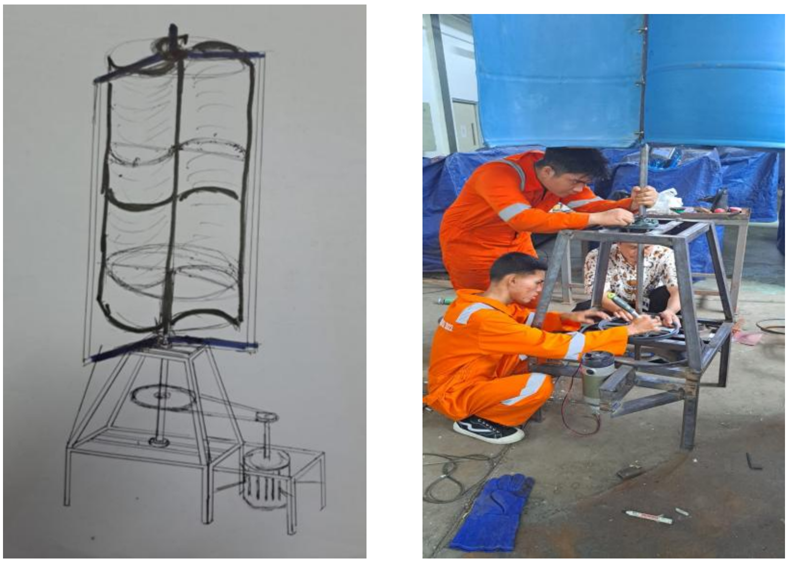

Figure 2. Turbine Design and Prototype

The findings of the next research are seen from the results of the implementation of the tool. Data and evaluation of the performance of vertical wind turbines and electrical energy produced by vertical wind turbines on the roofs of coastal buildings are obtained through direct observation and measurements using appropriate measuring devices. Meanwhile, electricity impacts on the environment and economic aspects related to turbine implementation are carried out at the same time. The types of data and electricity used are related to:

**Wind velocity**

Wind speed in a wind turbine can be measured using an anemometer at certain times when the wind turbine is operating. This data provides information about the potential for wind energy that can be converted into electricity.

**Wind direction**

Wind direction affects the efficiency of a wind turbine. Measuring wind direction helps in positioning the turbine to capture wind optimally.

**Environmental Temperature**

Air temperature and wind turbine engine temperature affect operational efficiency. Temperature data helps in understanding the impact of temperature on turbine performance.

**Air pressure**

Air pressure measurements can provide additional information regarding atmospheric conditions that influence wind turbine performance.

**Vibration and Vibration**

Vibration and vibration monitoring can help detect potential mechanical problems or wear on turbine components.

**Turbine Efficiency**

Efficiency parameters such as *coefficient of performance (Cp)* calculated to evaluate how well the turbine converts wind energy into electrical energy.

**Generator Performance**

Data can provide information about generator performance, including:

1) Mains voltage (V)
   The voltage is obtained at time intervals (morning – afternoon – evening – night) when the turbine is working
2) Electric current
   Electric current data can be obtained when the generator is connected to the installed load.
3) Electrical Energy Production
   The amount of electrical energy produced by a wind turbine per unit of time. This data includes electric power readings in watts (W).
4) Turbine and Generator RPM
   The turbine shaft is connected to the generator shaft with a pulley with a ratio of 1:4 which functions to increase the generator rotation. Data was obtained using a tachometer measuring instrument on the turbine and generator shaft.

Identification of the efficiency of converting wind energy into electricity can be seen from the table below.

Table 1. Wind Energy Conversion Efficiency Data

| Date | O'clock | Wind velocity | Wind direction | RPM Turbin | RPM Generator | Generator Voltage |
|---|---|---|---|---|---|---|
| 18 September 2024 | 07.00 | 5 | N | 2,2 | 4,4 | 4,18 |
| | 08.00 | 6 | N | 2,6 | 5,2 | 4,67 |
| | 10.00 | 8 | N | 3,1 | 6,2 | 5,65 |
| | 11.00 | 10 | N | 3,5 | 7 | 6,63 |
| | 12.00 | 11 | N | 3,8 | 7,5 | 7,12 |
| | 13.00 | 13 | N | 4,2 | 8,4 | 8,1 |
| | 14.00 | 14 | N | 4,5 | 9 | 5,6 |
| 19 September 2024 | 07.00 | 3 | IN | 1,8 | 3,6 | 3,2 |
| | 08.00 | 6 | NW | 2,5 | 5 | 4,65 |
| | 10.00 | 8 | N | 3,2 | 6,4 | 5,6 |
| | 11.00 | 10 | N | 3,5 | 7 | 6,6 |
| | 12.00 | 11 | N | 3,8 | 7,6 | 7,12 |
| | 13.00 | 13 | NO | 4,1 | 8,2 | 8,1 |
| 20 September 2024 | 07.00 | 3 | IN | 1,6 | 3,2 | 3,2 |
| | 08.00 | 5 | NW | 2,5 | 5 | 4,2 |
| | 10.00 | 6 | N | 2,6 | 5,2 | 4,67 |
| | 11.00 | 8 | N | 3,2 | 6,4 | 5,65 |
| | 12.00 | 11 | N | 3,8 | 7,6 | 7,12 |
| | 14.00 | 13 | NO | 4,1 | 8,2 | 8,1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 21 September 2024 | 07.00 | 5 | S | 2,5 | 5 | 4,18 |
| | 08.00 | 6 | NW | 2,5 | 5 | 4,67 |
| | 11.00 | 8 | NO | 3,2 | 6,4 | 5,65 |
| | 12.00 | 10 | NO | 3,6 | 7,2 | 6,6 |
| | 13.00 | 11 | NO | 3,7 | 7,4 | 7,12 |
| | 14.00 | 13 | NO | 4,1 | 8,2 | 8,1 |
| Rate-Rata | | 8,68 | | 3,2 | 6,4 | 5,9 |

Based on the table above, it can be stated that data collection was carried out from 18 to 21 September 2024 between 07.00 to 14.00. The measurement results show that the wind speed at the location where the vertical wind turbine is installed varies between 3 and 14 km/hour, which indicates that there is sufficient potential for wind energy to be converted into electricity. The variability in wind speed throughout the day, measured between 07.00 and 14.00, indicates that the generating system needs to be able to adapt to fluctuating wind conditions in order to produce consistent electricity output. The dominant wind direction data comes from the north indicating a stable air flow, even though the design of vertical axis wind turbines is not too influenced by wind direction, this information is still useful for determining optimal installation positions [24]. The air pressure measurement of 1101.4 mb, although not directly affecting turbine performance, provides an idea of the stable atmospheric conditions at the site, which supports overall turbine operation. Turbine performance data obtained from a rooftop installation (24 meters above sea level) includes measurements of turbine RPM, generator RPM, and the resulting electrical voltage, which shows a direct relationship between wind speed variations and electrical output. Fluctuations in RPM and electrical voltage recorded reflect the system's response to changes in wind speed, so they can be used to assess the efficiency of converting wind energy into electricity.

Implementation of the turbine in the micro environment, namely through testing in the laboratory and testing in the field. Laboratory testing is carried out to ensure the quality and reliability of wind turbines. This testing is carried out comprehensively on various parameters such as performance, durability, safety, and compliance with design [25]. Testing simulates real use conditions using a blower fan to identify weaknesses or potential problems. The data obtained from this test is then analyzed to assess whether the product meets the specified specifications. The results of this test are important to determine whether the product can be continued to the final stage or whether further improvements need to be made.

Figure 3. Laboratory testing

Field tests of wind turbines are carried out to evaluate their performance and reliability in real conditions. The product is tested in an environment that resembles the usage situation by taking into account weather, wind speed and special operational conditions [26]. The purpose of this test is to verify whether the wind turbine can function according to specifications and user expectations in everyday situations. The research team monitored the results and problems that occurred during testing. Data from field testing is used to refine products before they are placed in actual locations.

Figure 4. Field Testing

**DISCUSSION**

This research shows that vertical wind turbines offer installation flexibility in limited areas due to their compact and modular design. The ability to capture wind from multiple directions increases operational efficiency compared to horizontal turbines. Thanks to their compact and modular design, vertical wind turbines are easily integrated on building roofs, building corners, or dense urban areas without requiring large areas of land [27]. The relatively low installation and maintenance costs emphasize the economic potential of these turbines on a micro scale. Decentralized systems allow communities to generate electricity independently without dependence on a central grid. Operational reliability and stability are supported by a simple structure and minimal moving components [28]. Reliability and operational stability are further guaranteed because vertical structures have fewer wear points, thereby reducing the frequency and cost of long-term repairs. Then, the low environmental impact, especially almost zero greenhouse gas emissions, adds added value to energy sustainability.

The results of literature studies and field observations at the West Sumatra Shipping Polytechnic strengthen the relevance of vertical wind turbines as an innovative alternative. Installation on the roof of a coastal class building shows that geographic conditions and local wind characteristics favor system performance [29]. The turbine performance evaluation revealed that wind speed variations between 3 and 14 km/h could still be optimized by the vertical design. Integration of the turbine prototype on the roof of the demonstration building makes maintenance and monitoring access easier. Further development potential includes applications in urban and rural environments with limited space. Thus, vertical wind turbines have proven viable as an innovative and sustainable micro-electricity solution.

The Savonius type vertical wind turbine design with helical fins utilizes aerodynamic principles to capture air flow from various directions [30]. Frame construction from metal or carbon fiber provides strength and flexibility to the turbine structure [31]. The vertical axis equipped with slide bearings and pulleys ensures efficient delivery of rotation to the generator. The semicircular blades of the 200 liter drum were designed to optimize wind energy capture [32]. A generator connected via a v-belt translates mechanical movement into electrical energy directly. Visual representation of prototypes using three-dimensional sketches helps facilitate initial design evaluation.

Laboratory tests using fan blowers simulate real operational conditions to test turbine durability and reliability [33]. Engine and environmental temperature data show that thermal changes affect the operational efficiency of the turbine. Air pressure and vibration measurements help identify mechanical weak points in frames and bearings. Field tests on coastal building roofs with daily wind fluctuations verified the adaptation of the system to dynamic conditions [34]. Turbine and generator RPM variations are proportional to changes in wind speed, indicating consistent system response. These results confirm that the vertical design is able to withstand diverse operational conditions with stable performance.

The efficiency of wind energy conversion into electricity is calculated through the Cp ratio which is indicated to be around 35% of the available kinetic energy. Measurement data in the wind speed range of 3 to 14 km/h show a linear relationship between wind speed and generator voltage output [35]. At an average wind speed of 8.68 km/h, the turbine produces an average voltage of 5.9 volts with an average generator RPM of 6.4. Turbine RPM values ranging from 1.6 to 4.5 reflect an adaptive response to wind speed variability. The recorded electrical voltage fluctuations indicate the need for a storage or stabilizer system to ensure a constant electricity supply [36]. Although the current efficiency can still be improved, these results are sufficient for micro power plant applications.

Economic analysis reveals that the operational costs of vertical wind turbines are relatively low compared to conventional plants [37]. Initial investments in frame materials, fins and generators can be recouped in a short time through savings in electricity costs. Minimal periodic maintenance costs reduce the financial burden on the installation owner [38]. Energy decentralization support reduces distribution costs and the risk of outages on the central network. On a micro scale, this turbine provides *return on investment* of interest to remote communities. This approach emphasizes the profitable economic aspects of supporting the sustainability of renewable energy. From an economic perspective, the results of this study show that with proper setup and maintenance, vertical wind turbines can produce electricity optimally with relatively low operational costs, making them an attractive alternative for micro power plants [39]. This research proves that the use of vertical wind turbines has significant potential in converting wind energy into electricity efficiently, as well as offering profitable economic aspects [40], thus supporting the development of a more environmentally friendly and decentralized renewable energy system.

Based on the turbine implementation, test results and modifications that have been carried out, there are several technical challenges that must be faced in implementing wind turbines in the micro environment. First, there are problems in achieving maximum rotation speed because wind conditions in the microenvironment are not always stable, resulting in limited conversion power [41]. Second, the design of turbine blades must be optimized so that their cross-sectional area can capture wind energy effectively, but increasing blade area can also impose higher structural loads on the turbine construction [42]. Third, inconsistencies in the voltage output from the generator due to variations in turbine shaft speed make it difficult to achieve optimal electricity flow stability, especially in the context of micro power plants that require a constant electricity supply [43]. Fourth, the indicated overall system efficiency of 35% indicates that there is still the potential for energy losses in the conversion process, which requires improvements in the aerodynamic design and drive mechanism. Finally, system integration in locations with unique environmental conditions, such as beachside building roofs, requires special attention to aspects of safety, material durability and long-term maintenance so that the system continues to operate properly.

This research presents a holistic approach by integrating literature analysis, prototype design, as well as laboratory and field testing of the Savonius vertical wind turbine in coastal microenvironments. The main novelty lies in the application of helical fins to the Savonius turbine which increases the multidirectional wind capture capability while minimizing the structural load [44]. In addition, this study simultaneously evaluates technical and economic aspects, providing real performance data (RPM, voltage) in the wind speed range of 3–14 km/h [45]. Observational methodology in the field verifies the adaptability of the design under dynamic wind conditions, not yet widely documented in the tropical literature. The study results provide a new empirical basis for the development of micro-scale VAWT (Vertical Axis Wind Turbine) in coastal areas. Thus, this article enriches renewable energy studies with practical data that can be directly applied.

Practically, the results of this research offer a micro power generation solution that is easy to install in limited areas, opening up opportunities for adoption on the roofs of commercial and residential buildings. From an academic perspective, field performance data in tropical climate conditions complements the gap in VAWT research which has so far focused more on temperate climates. Policy implications include recommendations for government incentives for the installation of vertical turbines in public buildings as part of *smart city* and clean energy programs [46]. For practitioners, *template* design and *standard operating procedure (SOP)* testing can be directly adapted for microgrid projects. Strategically, these findings support energy decentralization efforts by reducing the burden on the central network. Finally, this article encourages cross-disciplinary collaboration between mechanical engineering, marine engineering, and energy policy.

This research is limited to one turbine installation location on the roof of the West Sumatra Shipping Polytechnic building, so the results cannot be generalized to different geographic or topographic conditions. The data collection duration of only four days of daily observations implies that seasonal and long-term variations were not monitored. The prototype design uses only the Savonius model with helical fins, with no direct comparison to the Darrieus or hybrid models. Measuring instruments (anemometers, tachometers) have adequate accuracy but are still susceptible to calibration errors due to sea air corrosion [47]. The integration aspects of the energy storage system, converter, or controller have not been tested, so consistent supply cannot be fully replicated. These limitations warrant caution when implementing recommendations on a larger scale.

In addition, the economic analysis is based on data on local material prices and operational costs without taking into account global market fluctuations. The study did not include detailed environmental impact evaluations such as noise or local ecological interference. Other environmental variables—such as high humidity and UV exposure—have not been analyzed for their impact on the lifespan of the material. Field observational methods do not involve continuous automatic sensors, so manual data can potentially ignore fluctuation peaks. Statistical analysis is limited to simple calculations of averages and correlations, without advanced hypothesis testing. These limitations must be considered in the interpretation of results and practical application.

Future research is recommended to expand the study location to various building typologies and climates, including mountainous and dense urban areas, in order to obtain comparative data on turbine performance. Long-term field tests of at least one year are required to monitor seasonal performance and material wear, as well as calculate a more accurate LCOE (Levelized Cost of Energy). Theory development can be focused on CFD (Computational Fluid Dynamics) models to optimize helical fin angles and blade geometry based on field data [46]. The integration of energy storage systems and smart converters must be tested to obtain a stable electricity supply. Collaboration with electrical and control systems engineers is needed to design a smart controller that adjusts the generator load.

On the application side, hybrid pilot projects combining vertical turbines and solar panels on building rooftops could be explored to improve continuity of supply [48]. The development of technical guidelines and operations manuals based on field findings will facilitate adoption by PLN and local governments [49]. Dissemination of results through workshops for policy makers and building owners needs to be implemented in order to accelerate incentive regulations [50]. Action research with coastal communities can evaluate direct socio-economic impacts. Environmental monitoring, including noise and visual effects, should be part of the feasibility study [51]. These steps are expected to strengthen theory, validate practical applications, and support the scale of vertical turbine production in Indonesia.

## CONCLUSION

From the research results above, it can be concluded that the use of vertical wind turbines as an innovative alternative for micro power plants has significant potential in supporting increasing electricity needs efficiently, economically and environmentally friendly. Observational studies conducted on coastal building rooftops show that despite technical challenges such as wind speed fluctuations, rotational speed limitations, and voltage output variability, vertical turbine designs that are able to capture wind from various directions and have low operational costs can produce optimal electricity output. Laboratory and field test results support that this system, with improvements to the aerodynamic design and drive mechanism, offers an alternative solution for decentralized renewable energy systems, while reducing dependence on fossil energy sources and its negative environmental impacts.

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