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Article

Design of Micro Wind Power Plant using Dual Savonius Turbines

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Abstract: Wind power plants are one of the renewable energy solutions that are environmentally friendly and sustainable. The success of such plants heavily depends on the location, which plays a crucial role in determining the availability of wind. In addition to highlands, coastal areas can serve as suitable locations. Balikpapan, with its expansive coastlines, holds significant potential for harnessing wind energy as a source of electricity. However, the utilization of this wind energy, particularly on a micro-scale, remains suboptimal. Research conducted over three days recorded wind speeds between 4 m/s and 5 m/s, generating voltages between 3 volts and 4 volts, which is only 1/3 of the total potential voltage. There is still an untapped potential of about 2/3 or 6 volts that could be harnessed if wind speeds reach 12 m/s to 15 m/s. The study concludes that the wind speed at Airport Beach is not yet sufficient to produce the maximum possible voltage. The current wind speeds are only capable of powering a 5-volt capacity light, with the generated energy stored in a battery for later use.

Keywords: Coastal Areas, Renewable Energy, Voltage, Wind Power Plant, Wind Speed

1. Introduction

In support of global efforts toward sustainable energy and the green energy transition, Wind Power Plants are increasingly recognized as one of the most environmentally friendly renewable energy solutions [1]. Wind power plants utilize the kinetic energy of wind to generate electricity, offering a viable alternative that does not produce greenhouse gas emissions during operation. The success of Wind power plant development is largely contingent upon the careful selection of suitable locations where wind speed and patterns are adequate to ensure optimal electricity generation efficiency [2]. While highland regions are often preferred for wind power plant installations due to stronger wind currents, coastal areas also present significant potential, particularly in tropical countries like Indonesia, where coastal winds are generally more stable and consistent. The combination of suitable wind patterns, sustainable energy policies, and advancements in wind turbine technology has the potential to accelerate the deployment of wind power plants in these regions, contributing significantly to national energy security and the global push for low-carbon energy systems [3].

Balikpapan, located on the eastern coast of Kalimantan Island, boasts expansive coastlines and stable wind conditions throughout the year, making it an ideal location for developing wind power plants. Despite its potential, the wind energy resources in this area have not been fully exploited, particularly at the micro-scale level, which would be well-suited to meet local energy needs. Micro-scale wind power plants offer a flexible and scalable approach to harnessing renewable energy, providing a decentralized energy solution that can reduce reliance on traditional fossil fuels and contribute to local sustainability efforts. In this context, research focused on the design and implementation of micro-scale wind power plants is becoming increasingly critical, particularly in light of the growing demand for green energy [4]. This aligns with the strategic plans for the new capital city, Ibu Kota Negara (IKN) Nusantara, also located in East Kalimantan. As a future-oriented city, IKN aims to prioritize the use of renewable energy as part of its smart and sustainable city vision [5]. The development of renewable energy infrastructure, such as micro-scale wind power plants, could play a pivotal role in realizing this vision, supporting both regional and national goals for energy transition and environmental sustainability [6].

This research focuses on the innovative design of a micro-scale wind power plant utilizing dual Savonius turbines optimized for the wind conditions along the coast of Balikpapan. The Savonius turbine was chosen due to its ability to operate efficiently at low wind speeds, which are commonly found in coastal areas. Although the Savonius turbine generally has lower efficiency compared to conventional lift-type wind turbines, its advantage lies in its ability to initiate operation at slow wind speeds, offering significant opportunities for further optimization through advanced design improvements [7]. One of the key strategies proposed in this study is the implementation of a dual turbine configuration to enhance wind capture capacity and improve energy conversion efficiency [8]. Positioning two Savonius turbines in tandem or side-by-side is expected to increase the effective surface area exposed to the wind, thereby improving power output. Additionally, the study explores the potential for optimizing the rotor shape, blade curvature, and turbine spacing to maximize performance under varying wind conditions, contributing to more reliable and sustainable energy generation for local coastal communities [9].

The development of this micro-scale wind power plant will be carried out in a phased approach over a five-year period. In the first year, the focus will be on the initial design and simulation of the dual Savonius turbine system [10]. This stage will involve creating a conceptual model and conducting simulations to predict the turbine's performance under specific wind conditions in coastal Balikpapan [11]. The second year will be dedicated to design optimization, where key parameters such as blade size, angle of attack, and overall turbine geometry will be refined based on the results of the initial simulations [12]. The goal will be to maximize efficiency and adapt the turbine to the low wind speeds typical of coastal environments. In the third year, a prototype will be built, and initial field testing will be conducted to assess real-world performance and collect operational data. This data will be used to identify any necessary adjustments and to validate the simulation models [13]. The fourth year will see the final design phase, where efforts will be focused on minimizing energy losses and enhancing power output through advanced engineering solutions. Finally, in the fifth year, the micro-scale wind power plant will be implemented at a selected coastal site in Balikpapan, followed by extensive field evaluations to monitor system performance under actual operational conditions. This step will provide valuable insights into the practical feasibility and sustainability of the system, guiding future deployments and improvements [14].

In relation to IKN, the outcomes of this research are expected not only to provide a renewable energy solution for the local community in Balikpapan but also to contribute to the vision of IKN as a self-sustaining green city. Given the geographic proximity between Balikpapan and the IKN Nusantara site, the successful implementation of an efficient micro-scale wind power plant along the coast of Balikpapan could serve as a model for further development in the IKN area. Harnessing wind energy as part of the renewable energy portfolio for the new capital city would align with its goals of reducing reliance on fossil fuels and achieving long-term sustainability [15]. The deployment of such technology could complement other renewable energy sources, such as solar and hydropower, providing a diversified and resilient energy infrastructure for IKN [16]. Furthermore, this research holds strategic importance beyond local implementation, as it supports national green energy initiatives, particularly in East Kalimantan, where transitioning to renewable energy sources is critical for the region's economic and environmental future. By integrating micro-scale wind power plants into the broader energy strategy of IKN, this project could become a pivotal element in advancing Indonesia's commitment to reducing greenhouse gas emissions and promoting sustainable urban development.

2. Materials and Methods

The approach used in this research involves a research and development process focused on the Savonius turbine. This means that the turbine design will be optimized based on previous research findings as well as new insights gained during the research and development process. The goal is to create a turbine design that can significantly improve the efficiency of electricity generation, thereby making the micro-scale wind power plant a viable and sustainable renewable energy solution. This iterative research and development process will incorporate advanced computational simulations, material selection, and aerodynamic analysis to refine the turbine's performance, particularly in low-wind-speed environments typical of coastal areas. By integrating the latest technological innovations and addressing challenges such as reducing drag and enhancing rotational efficiency, the project aims to develop a more robust and scalable turbine design. Ultimately, this research seeks to contribute to the global effort to increase the adoption of renewable energy technologies by providing a practical and efficient solution that can be implemented in similar coastal regions with comparable wind conditions.

The Savonius turbine, a type of drag-based wind turbine, has the advantage of being able to start operating at low wind speeds. However, its efficiency is relatively lower compared to lift-based wind turbines. Several studies have been conducted to improve the efficiency of the Savonius turbine, yet its application at the micro-scale, particularly in Indonesia, remains rare. This research aims to develop, design, and implement a micro-scale wind power plant featuring dual Savonius turbines optimized for the specific wind conditions found along the coast of Balikpapan. The dual-turbine configuration is expected to enhance wind capture and improve overall energy conversion efficiency by increasing the swept area and optimizing the arrangement of the turbines. The research will also explore innovative modifications to turbine geometry, such as blade shape and spacing, to maximize performance under low and variable wind speeds. The outcomes of this study have the potential to provide a renewable energy solution for the surrounding community, offering a sustainable and scalable model for coastal regions with similar wind profiles. This project not only contributes to the body of knowledge on micro-scale wind energy systems but also supports local and national goals for increasing the use of clean energy sources.

The research roadmap focuses on the design and development of a micro-scale wind power plant utilizing dual Savonius turbines along the coast of Balikpapan. In the first year, the project will concentrate on the initial design and simulation of the turbine system, using computational tools to model performance under the specific wind conditions of the area. The second year will focus on optimizing the turbine design and constructing a working prototype, with adjustments made to key parameters such as blade geometry, rotor configuration, and material selection. In the third year, the prototype will undergo field testing, and data will be collected to analyze its operational performance in real-world conditions. Based on the testing results, design refinements will be made in the fourth year, culminating in the construction of the final version of the micro-scale wind power plant. In the fifth and final year, the optimized wind power plant will be implemented at a selected coastal site, followed by comprehensive field evaluations to assess its long-term performance and viability as a renewable energy solution. This research is expected to provide a sustainable energy alternative for the local community, helping to reduce reliance on non-renewable energy sources and contributing to broader national goals for renewable energy adoption. Figure 1 presents the research roadmap in detail.

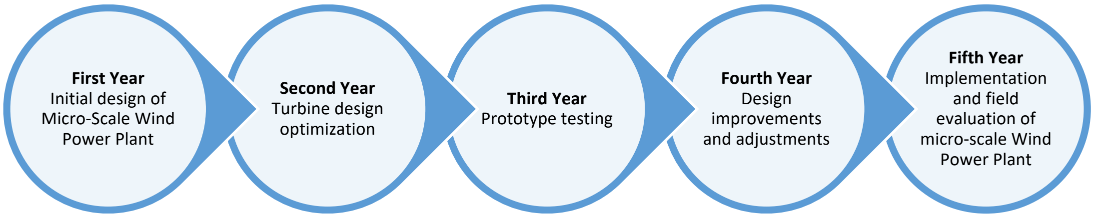

Figure 1. Research Roadmap

The research process begins with a comprehensive review of relevant literature, which is a critical foundation for the success of the study. This literature review includes an analysis of previous studies on Savonius turbines and wind power plants that have been developed and tested by other researchers. The review not only identifies gaps in the existing research but also highlights key findings that can inform the current project. By thoroughly understanding the performance characteristics, efficiency challenges, and design innovations from earlier work, the researchers can develop a solid framework for their own study. This foundational knowledge provides insights into various design strategies, material choices, and technological advancements that can be leveraged for the construction of a more efficient dual Savonius turbine system. The next step after completing the literature review is the detailed design of the dual Savonius turbine, tailored to the specific wind conditions at the coastal site in Balikpapan. Factors such as wind speed, turbulence, and directionality are taken into account to optimize the turbine's design. The goal is to maximize the efficiency of power generation, even at low wind speeds, by considering the ideal blade shape, turbine size, and overall system configuration. Once the design is finalized, the team proceeds with constructing the prototype of the micro-scale wind power plant.

The construction phase involves integrating various materials and components, including control equipment such as an Arduino Leonardo for real-time monitoring and control, a sturdy frame to support the dual Savonius turbines, and essential sensors to measure wind speed and voltage output. Additionally, an anemometer is used to measure and calibrate wind speed data, ensuring that the system is accurately adjusted to the local environmental conditions. The physical assembly of the turbines and the associated electrical system is a crucial stage, as it directly impacts the plant's performance. Once the wind power plant prototype is built, the system is tested at a selected coastal site in Balikpapan to assess its real-world performance. This testing phase aims to verify the operational efficiency of the turbines and evaluate their ability to generate usable electricity for the local coastal community. During testing, key data such as voltage, current, and overall power output are meticulously collected. The data is essential for a detailed analysis of the wind power plant's performance, helping to identify any areas for optimization or further development. After the field tests, the collected data is analyzed to assess the efficiency, reliability, and potential improvements for the system. Based on this analysis, the researchers draw conclusions regarding the viability of the design and its implications for renewable energy deployment in coastal areas and offer recommendations for future studies. These conclusions could include suggestions for refining the turbine design, improving system durability, and scaling up the technology for larger applications. Figure 2 illustrates the detailed flowchart of the entire research process.

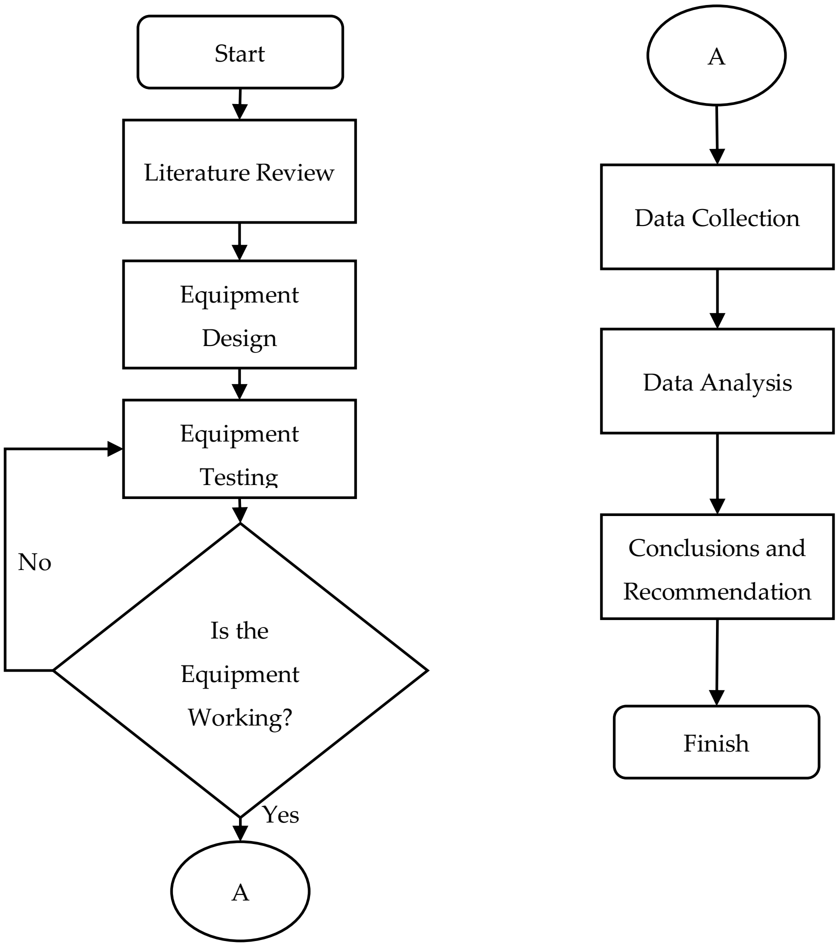

Figure 2. Flowchart Research

3. Results

The research was conducted over three days at Airport Beach, Gunung Bahagia, South Balikpapan, East Kalimantan. Data collection was carried out for one hour each day, specifically between 09:00 and 10:00 WITA (Central Indonesian Time). This time window was likely chosen to capture consistent wind patterns during morning hours when coastal winds are typically more stable. The experiment aimed to gather crucial data on wind speed and the electrical output of the wind turbine system that had been designed and constructed for this research. The equipment used for the data collection included a dual Savonius turbine, an anemometer to measure wind speed, a voltage sensor, and a data-logging system connected to a laptop for real-time monitoring and analysis. The setup was designed to assess the performance of the micro-scale wind power plant (PLTB) under the natural wind conditions found at the coastal location.

The analysis of the wind turbine system depicted in Figure 3 focuses on its potential to generate electrical energy through wind-driven mechanical motion. With a blade diameter of 100mm and a vertical-axis design, the turbine is optimized for omnidirectional wind capture. The motor, with a rated speed of 100 to 6000 rpm, can produce an output voltage ranging from 0.01V to 5.5V and a current of 0.01 to 100mA, depending on the wind speed and rotational velocity of the blades. At low wind speeds (<5 m/s), the output voltage is minimal due to insufficient torque; however, moderate to high wind speeds (>5 m/s) enable the system to reach higher voltages and current outputs, approaching the motor's rated maximums.

The dual vertical-axis wind turbine system, as depicted, consists of two turbines mounted symmetrically on a Y-shaped structure with a central pole height of 200 cm and a horizontal span of 150 cm, providing adequate spacing to minimize aerodynamic interference. The vertical-axis design allows the turbines to capture wind from any direction, making them suitable for variable wind conditions, while the separation between the turbines reduces wake effects and enhances efficiency. The structure's elevation ensures exposure to stronger wind currents, although it must be robust enough to withstand mechanical stresses from simultaneous wind forces on both turbines. Each turbine independently generates a voltage range of 0.01V to 5.5V (0.02V – 11.0V for both turbines), with the potential for combined output depending on the electrical configuration, doubling the energy capture without a significant increase in structural footprint.

Figure 4 provides a detailed view of a wind energy experiment being conducted at a beach, likely as part of a project to test the performance of micro-scale wind turbines. The first segment of the figure (left) shows a researcher holding an anemometer, a handheld device used to measure wind speed and temperature. The display indicates a wind speed of 3.7 meters per second and a temperature of 29.1°C, offering crucial data about the environmental conditions in which the experiment is taking place. In the background, a laptop is set up on a wooden table, likely being used to log data or monitor the turbine's performance. The beach setting, with the ocean in the distance, provides a natural environment for testing wind energy solutions, taking advantage of the steady coastal winds.

In Figure 4, in the second segment (middle), two individuals are seen assembling or adjusting the wind turbine system, which appears to feature a dual Savonius turbine design. The Savonius turbine is often chosen for low wind speed environments like coastal regions due to its ability to start operating in lower wind conditions. The individuals are working on a horizontal frame, attaching two turbines at either end of the structure. This suggests that they are refining the design to optimize the turbine's wind capture capabilities. The table is cluttered with tools and materials, indicating that they are still in the process of adjusting the equipment for field testing. The surrounding environment, including the tree and beach, indicates that the experiment is being conducted in an open outdoor setting where natural wind conditions can be measured and utilized.

In Figure 4, the third segment (right) shows the completed experimental setup, with the dual Savonius turbines now fully assembled and anchored into place on the beach. A laptop remains connected to the system, likely collecting data such as voltage output and wind speed to analyze the turbine's efficiency. The position of the equipment near the shoreline suggests that the experiment is designed to test the performance of the wind turbines under real-world coastal wind conditions, which tend to vary in speed and direction. This setup appears to be part of a broader research effort to develop a micro-scale wind power plant that can be implemented in coastal regions like Balikpapan. The purpose of this field test is likely to evaluate how well the turbine system generates electricity in low to moderate wind conditions, with the goal of improving renewable energy solutions for local communities.

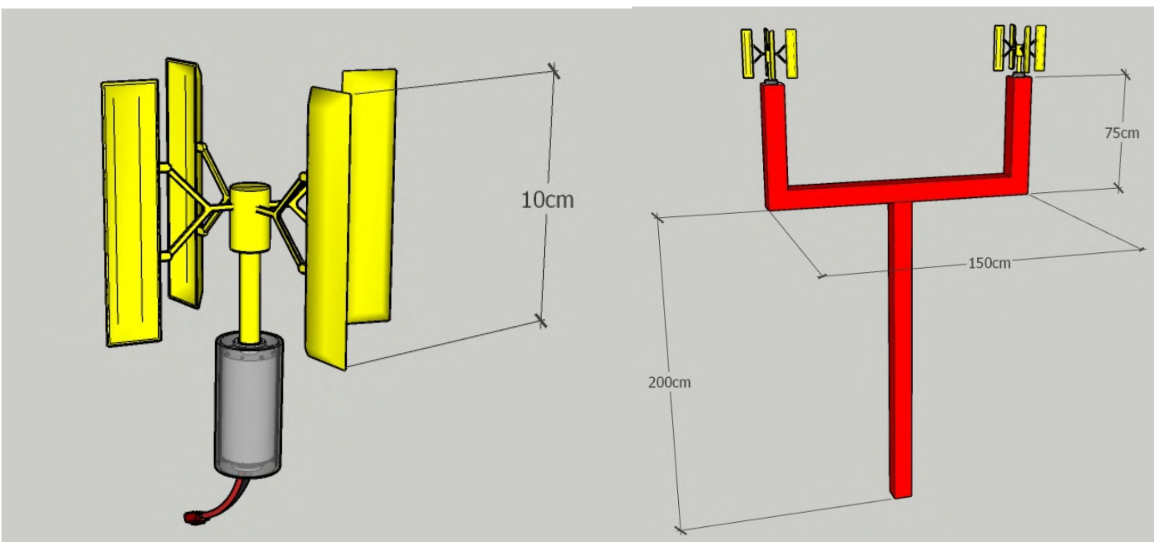

Figure 3. Wind Turbine Design

Figure 4. Field Experiment

Table 1. Spesification of Generator

Specifications	Value
Motor Type	DC (Generator)
Generator Voltage	DC 0.01V - 5.5 V
Generator Current	0.01 - 100mA
Sum of Propeller	4 Propeller
Speed of Propeller	10.5 – 628.3 m/s

Table 1 provides detailed information about the key parameters of the generator used in the research setup. The generator is of the DC (Direct Current) type, commonly employed in small-scale wind turbine systems due to its ability to convert mechanical energy (from the propeller) into electrical energy.

The generator voltage range is specified as 0.01V to 5.5V, indicating that the generator can operate within this voltage range depending on the wind speed and the rotational speed of the propeller. Similarly, the generator current is stated as 0.01mA to 100mA, signifying the range of current output the generator can produce, likely varying with wind conditions and turbine efficiency.

The generator is equipped with four propellers designed to capture the wind and convert kinetic energy into mechanical rotation. The speed of the propeller is specified as ranging from 10.5 m/s to 628.3 m/s, which reflects the range of rotational speeds the propellers can achieve under different wind conditions. The higher end of this range suggests that the system is capable of operating at relatively high wind speeds, contributing to the potential for higher power output.

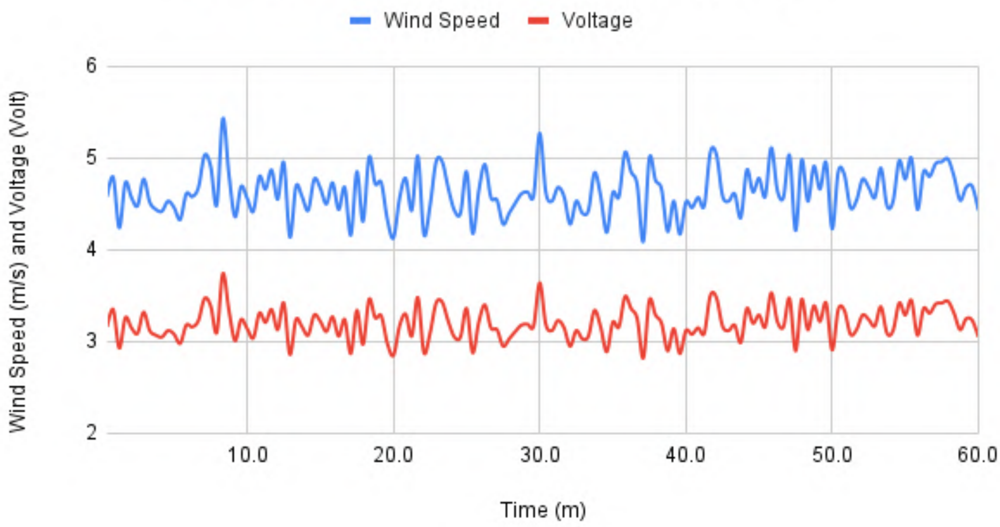

Figure 5. Wind Speed Vs Voltage for Day 1

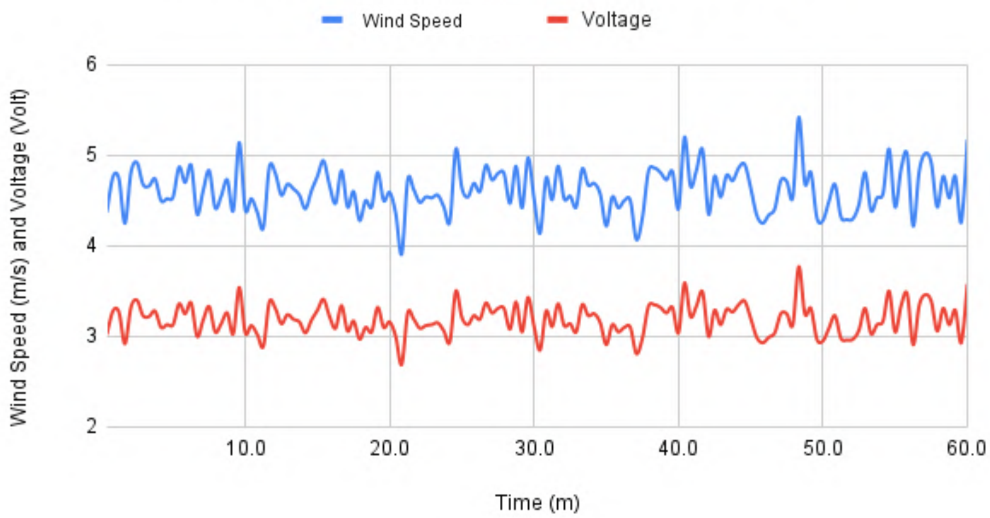

Figure 6. Wind Speed Vs Voltage for Day 2

Figure 5 illustrates the relationship between wind speed (m/s) and voltage (V) generated over a period of time on Day 1 of the experiment. The x-axis represents time in minutes, ranging from 0 to 60, while the y-axis shows both wind speed in meters per second (m/s) and voltage in volts (V). Two lines are plotted: a blue line representing wind speed and a red line representing the voltage output of the generator. The wind speed (blue line) fluctuates consistently throughout the duration of the experiment, generally ranging between 4 m/s and 5 m/s, with occasional spikes above 5 m/s. These variations in wind speed reflect the natural variability of coastal wind conditions, where brief increases and decreases in wind intensity occur frequently. Correspondingly, the voltage output (red line) follows a similar pattern but at a lower magnitude. The voltage fluctuates around 3 V to 3.5 V, with small peaks aligning with increases in wind speed. The voltage curve exhibits smaller variations compared to wind speed, indicating that while wind speed directly impacts voltage generation, the generator maintains a relatively steady output.

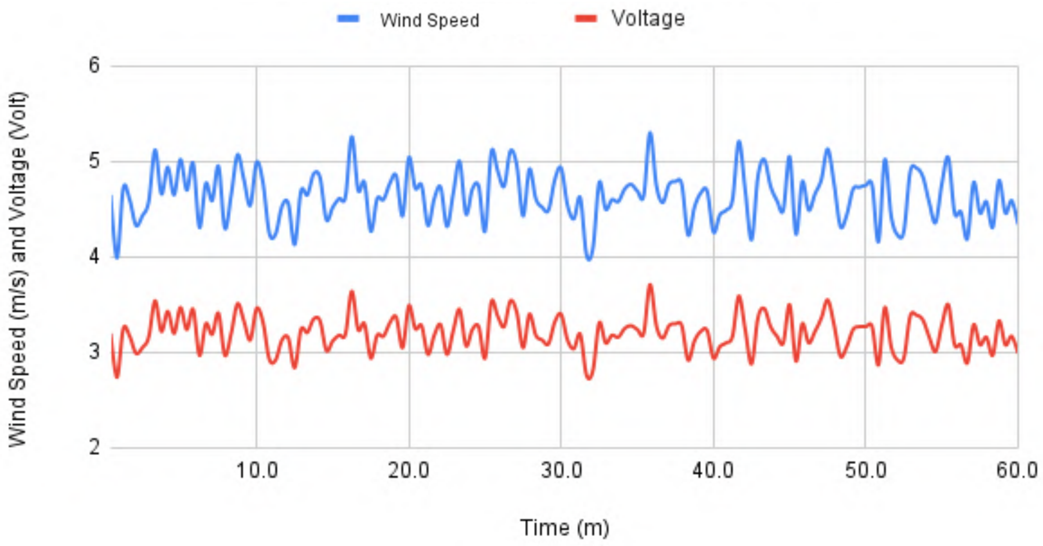

Figure 7. Wind Speed Vs Voltage for Day 3

Figure 6 presents the relationship between wind speed and voltage generated on Day 2 of the experiment, measured over a 60-minute period. The x-axis represents time in minutes, ranging from 0 to 60, while the y-axis shows both wind speed in meters per second (m/s) and voltage in volts (V). The blue line represents wind speed, while the red line represents the voltage produced by the generator. On Day 2, the wind speed fluctuates consistently, primarily within the range of 4 m/s to 5 m/s, with occasional peaks slightly above 5 m/s, similar to Day 1's data. The fluctuations in wind speed are relatively stable, though there are minor spikes, especially towards the later minutes of the experiment. The voltage output, represented by the red line, varies within a narrow range, mostly between 3 V and 3.5 V. Like the previous day, the voltage follows the wind speed fluctuations but maintains a lower, more stable trend. The voltage curve shows smaller variations compared to wind speed, indicating that while wind speed impacts the voltage generation, the system provides consistent electrical output despite the variability in the wind.

Figure 7 illustrates the relationship between wind speed and voltage on Day 3 of the experiment. The x-axis represents time in minutes over a 60-minute period, while the y-axis displays wind speed in meters per second (m/s) and voltage in volts (V). The blue line represents wind speed, and the red line represents the voltage output. On Day 3, the wind speed fluctuates within a range of 4 m/s to 5 m/s, showing a similar pattern to Days 1 and 2. The wind speed demonstrates consistent oscillations with some moderate peaks, especially around the 10, 30, and 50-minute marks. These fluctuations in wind speed are natural, reflecting typical coastal wind variability. The voltage output, on the other hand, remains relatively steady, fluctuating between 3 V and 3.5 V, mirroring the wind speed pattern but with less pronounced peaks. The voltage output appears stable with small variations, indicating that the wind turbine system is converting wind energy into electrical energy consistently despite the variability in wind speed.

4. Discussion

The detailed analysis of the wind speed and voltage output data from Day 1, Day 2, and Day 3 provides insights into the performance and limitations of the micro-scale wind power system. Over the three days, wind speeds fluctuated between 4 m/s and 5 m/s, with some occasional spikes exceeding 5 m/s. These speeds, while steady and consistent for a coastal environment, are moderate and do not reach the higher velocities needed for maximizing the voltage output. The wind turbine system, equipped with dual Savonius turbines, responded predictably to these variations, producing voltage outputs that remained relatively stable within the range of 3 V to 3.5 V. The data shows that the system functions reliably in low to moderate wind speeds, but there are limitations in the amount of power that can be generated under these conditions.

Throughout the three days, the voltage output closely followed the wind speed fluctuations. Higher wind speeds resulted in slight increases in voltage, but the system's overall output remained within a moderate range. This stable performance is indicative of the Savonius turbine's strength in maintaining a consistent output in low-wind-speed environments, where more conventional turbines might struggle to generate power. However, the voltage generated over the three days was not sufficient to power complex systems or higher-capacity devices. The turbine system produced enough voltage to power devices requiring low energy consumption, such as small lights or other low-power electronics.

The results of the study indicate that the wind speeds at Bandara Beach are not sufficient to generate the maximum possible voltage. The current wind speeds are only capable of producing enough power to operate a 5-volt capacity light, with the excess energy stored in a battery for later use. This highlights the need for additional wind turbines or more efficient turbine designs to increase the voltage output. By incorporating additional turbines or optimizing the current system, it may be possible to achieve higher voltage levels, which could then be used for more complex energy needs, such as powering larger devices or contributing to local energy grids. The findings suggest that while the current system is effective for small-scale energy needs, further enhancements are necessary to fully realize its potential in more demanding applications.

5. Conclusions

The data collected over the course of three days showed that wind speeds at Bandara Beach consistently ranged between 4 m/s and 5 m/s, resulting in a voltage output of 3 V to 4 V. This output represents only about one-third of the total potential voltage that could be generated. There remains untapped potential for an additional two-thirds of the voltage, or approximately 6 volts, which could be harnessed if wind speeds were higher, around 12 m/s to 15 m/s. The findings indicate that the wind speeds at Bandara Beach were insufficient to generate the maximum possible voltage, limiting the turbine system's ability to produce energy beyond powering a 5-volt capacity light, with the excess energy stored in a battery for later use. These results underscore the fact that the system is not fully optimized for more complex energy demands under the current wind conditions. To increase voltage output and meet more substantial energy needs, it is necessary to incorporate additional wind turbines or further refine the existing turbine design. This would allow the system to reach higher voltage levels and be applied in more complex settings, such as powering larger devices or contributing to local energy grids. Additionally, future research should explore the feasibility of testing the turbine system in locations with higher wind speeds, such as mountainous regions or other coastal areas, to evaluate the system's full potential under varying environmental conditions. By expanding the research to other locations, it may be possible to achieve higher wind speeds and, consequently, greater energy generation efficiency.

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