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The Effect of Pulley Variation on the Power Output of a Three-Bladed Savonius-Type Vertical Axis Wind Turbine

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Abstract: This study aims to analyze the effect of pulley diameter variation on the performance of a three-bladed Savonius-type vertical axis wind turbine. Three pulley diameter variations were used, namely 3 inch, 5 inch, and 8 inch, with testing conducted at wind speeds ranging from 3 to 4.5 m/s. The performance parameters measured included rotational speed (RPM), current, voltage, electrical power output, and torque. The results indicate that the 3-inch pulley configuration provides the best overall performance, producing an average power output of 31.01 W, a rotational speed of 145.53 RPM, and a torque of 12.60 Nm. The 5-inch pulley generated an average power output of 29.14 W with a torque of 10.25 Nm, while the 8-inch pulley produced the lowest average power output of 21.56 W and a torque of 9.4 Nm. The decline in performance observed with larger pulley diameters is attributed to increased rotational load and higher wind speed requirements. Therefore, smaller pulley diameters are more suitable for low wind speed conditions, as they enable more efficient power generation. This study provides a useful reference for the development of small-scale wind turbine designs for renewable energy applications.

Keywords: Vertical Axis Wind Turbine, Savonius Turbine, Pulley Variation, Power Output, Renewable Energy

INTRODUCTION

At present, electricity demand in Indonesia continues to increase. However, fossil fuels such as coal and petroleum remain the primary sources of energy. Emissions resulting from the combustion of these fossil fuels have adverse impacts on the environment and all forms of life (Listrik et al., 2021).

Access to electrical energy is a fundamental need for society. At the national level, electricity consumption rises in line with population growth, yet the energy industry has not been able to fully meet this demand. Coal, petroleum, and natural gas currently dominate the country's energy sector. The future supply of various energy sources, particularly petroleum, is expected to become increasingly limited due to continuous growth in demand. The declining availability of fossil fuels makes them an uncertain source for future energy needs. Since fossil fuels are non-renewable, it is necessary to urgently explore renewable energy sources.

In 2020, Agris and Turbin Agris developed wind-powered systems that convert wind energy into usable electrical power. Generators play an integral role in wind turbines by converting wind energy into electricity. As a component that transforms mechanical motion into electrical energy, the generator functions as a core element of wind turbine systems. Generators capable of producing maximum electrical energy at low rotational speeds are required to achieve optimal power output (Herlambang et al., 2021).

Power transmission through gears or belt systems is required to increase the rotational speed of the generator rotor. In this study, a belt connects the driving pulley and the generator pulley, forming a power transmission system. According to a recent study (Mustopa et al., 502), mechanical energy rotates the turbine, which is then converted into electrical energy through the generator. The influence of pulley ratio on the electrical power generated by a wind turbine has been examined by varying pulley diameters of 100 mm, 125 mm, and 150 mm using different turbine–generator pulley ratios. The results indicate that the highest torque and power were achieved using a diameter variation of 175 mm to 50 mm, producing electrical power of 5.8 watts and torque of 0.2 Nm. In contrast, the 100 mm to 50 mm variation produced the lowest torque of 0.056 Nm and electrical power of 1.5 watts, corresponding to the lowest shaft rotation and power output (Amin et al., n.d.).

Previous studies have also observed the average electrical power produced by a system with pulley diameter variations of 175 mm and 50 mm. Measurements indicated an average rotational power output of 5.8 watts. However, it is important to note that the magnitude of electrical power generated is influenced by several key factors that determine the final output. One significant factor is the size or diameter of the pulley used in the system. Pulley diameter is directly related to changes in rotational speed and overall system efficiency. Variations in pulley diameter between 175 mm and 50 mm are therefore critical factors affecting electrical power output. Differences in pulley size may lead to significant changes in system rotation and overall performance. In addition to pulley diameter, other factors such as pulley material, internal friction, and mechanical conditions also affect the electrical power produced. These factors may influence energy conversion efficiency and the effectiveness of power transmission. Furthermore, a larger pulley diameter on the turbine side results in higher generator rotational speed, enabling the generator to produce greater electrical power (Herlambang et al., 2021).

In other previous research, separation speed and separation effectiveness were analyzed as the main parameters. The study focused on comparing the use of pulleys with different diameters and their impact on separation speed and effectiveness. The use of a pulley with a diameter of 4 inches produced the most optimal results, achieving a separation speed of 30.6 kg per hour and a very high separation effectiveness of 99.3 percent. These results indicate that a 4-inch pulley is capable of facilitating highly efficient motion, resulting in the desired separation speed and the most effective separation performance in the study.

However, the use of a 2-inch pulley showed less optimal performance. Although it still produced a relatively adequate separation speed of 26.28 kg per hour, separation effectiveness slightly decreased to 98.6 percent. This suggests that a 2-inch pulley may not be sufficiently capable of generating efficient motion, thereby reducing separation effectiveness. Meanwhile, the use of a 6-inch pulley yielded less satisfactory results, with a separation speed of 21.6 kg per hour and separation effectiveness of 98.3 percent. These significant differences indicate that a 6-inch pulley has a negative impact on separation speed and effectiveness in the system. Based on these findings, it can be concluded that a pulley with a diameter of 4 inches provides the most optimal performance in improving separation speed and effectiveness. These results highlight the importance of proper equipment selection and appropriate pulley sizing to ensure maximum performance in separation processes (Ngatoil Hakim, 2022).

Based on the identified problems and previous studies, this research conducts an analysis of power output in relation to variations in pulley diameter, with the expectation that it can contribute to addressing energy crisis issues and land limitations resulting from increasing population density.

RESEARCH METHOD

This study employed an experimental research approach to examine the effect of pulley diameter variation on the electrical power generated by a vertical axis wind turbine of the Savonius type with three blades. The experimental method was selected because it allows direct observation of cause-and-effect relationships between mechanical transmission components and turbine performance under controlled conditions. The focus of the study was placed on mechanical transmission behavior rather than aerodynamic modification, ensuring a clear analytical boundary.

The experimental setup consisted of a Savonius vertical axis wind turbine integrated with a generator through a belt and pulley transmission system. The turbine blades were designed with a fixed geometry, and no changes were made to blade shape, material, or blade arrangement throughout the experiment. This design choice ensured that any variation in performance could be attributed solely to changes in pulley diameter rather than to aerodynamic or structural differences.

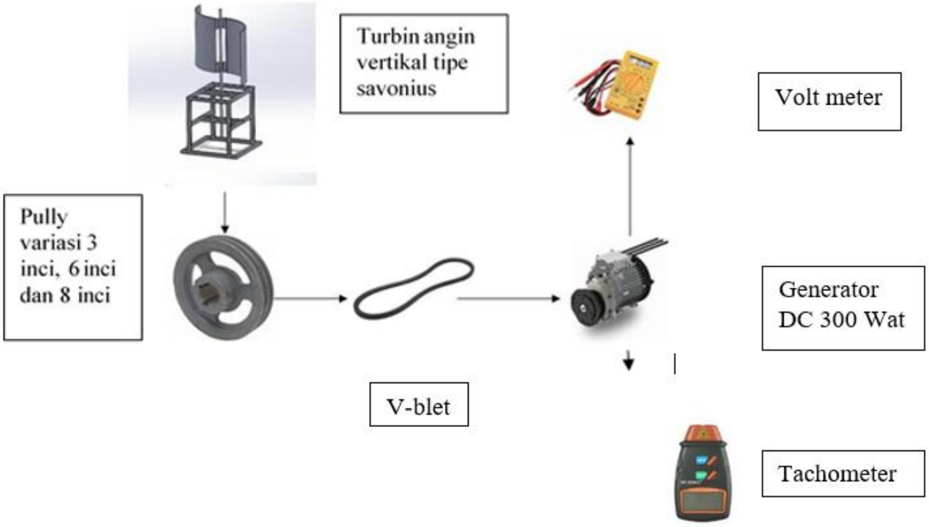

Figure 1. Figure of the Research Schematic

Pulley diameter variation was applied on the turbine side while maintaining a constant pulley size on the generator shaft. Several pulley diameters were tested sequentially to observe their influence on rotational speed, torque behavior, and electrical power output. Each pulley configuration was installed carefully to maintain proper belt alignment and tension, minimizing mechanical losses caused by slippage or misalignment during operation.

Wind flow for the experiment was generated under controlled conditions to simulate low to moderate wind speeds typically found in urban and semi-urban environments. The turbine was allowed to reach stable rotational conditions before measurements were taken. This stabilization period was essential to ensure that the recorded data reflected steady-state performance rather than transient behavior during startup or deceleration.

Electrical measurements were conducted by recording voltage and current output from the generator during turbine operation. These parameters were measured using calibrated electrical instruments to ensure data reliability. Electrical power output was determined based on the measured voltage and current values, allowing for a consistent comparison across different pulley configurations.

Mechanical performance was assessed through rotational speed observations of the turbine and generator shafts. Rotational speed data provided insight into how pulley diameter influenced speed amplification within the transmission system. This information was essential for understanding the relationship between mechanical transmission characteristics and electrical energy conversion efficiency.

To improve data validity, each experimental condition was repeated multiple times under similar operating conditions. The results from repeated trials were then averaged to reduce random measurement errors and improve consistency. This repetition strengthened the robustness of the findings and ensured that observed trends were not influenced by isolated anomalies.

The collected data were analyzed descriptively and comparatively to identify performance differences among pulley variations. The analysis focused on identifying trends rather than complex statistical modeling, as the objective of the study was to provide practical engineering insight into pulley selection for small-scale Savonius wind turbine systems. The methodological framework adopted in this study supports clear interpretation and practical applicability for renewable energy system design.

RESULT AND DISCUSSION

Measurement Results of Wind Turbine Rotation with Three-Inch Pulley

Table 1. Measurement Results of Wind Turbine Rotation with Three-Inch Pulley

Average Wind Speed (m/s)	Rotational Speed (RPM)	Current (A)	Voltage (V)	Power (W)
3.2	61.7	2.72	2.54	7
3.5	80.4	3.61	3.43	12.38
3.8	98.3	4.56	4.14	18.87
4.2	127.23	4.31	5.67	24.45
4.5	145.53	4.94	6.28	31.01

For the three-inch pulley configuration, the maximum power output reached 31.01 watts at the highest average wind speed, accompanied by a rotational speed of 145.53 RPM. Despite variations in rotational speed across testing conditions, the results show a consistent increase in power output with increasing rotation. The turbine generated a torque of 12.60 Nm, indicating efficient mechanical energy transfer. Overall, the three-inch pulley configuration demonstrates favorable transmission performance for improving generator output under low to moderate wind speed conditions.

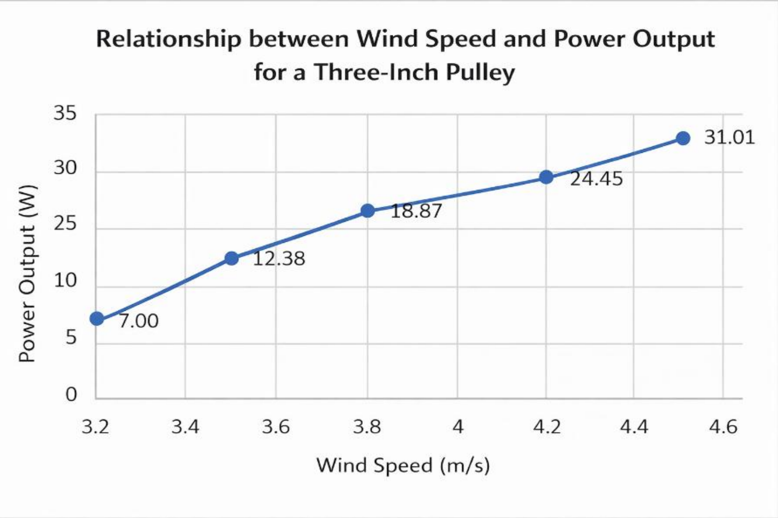

Figure 2. Performance graph of the three-inch pulley on the generated power

The graph illustrates a positive relationship between wind speed and power output for the three-inch pulley, showing a steady increase in generated power as wind speed rises.

Measurement Results of Wind Turbine Rotation with Five-Inch Pulley

Table 2. Wind Turbine Test Data for Five-Inch Pulley Variation

Average Wind Speed (m/s)	Rotational Speed (RPM)	Current (A)	Voltage (V)	Power (W)
3.2	49.8	1.72	1.56	2.68
3.5	64.3	2.73	2.6	7.09
3.8	91.7	4.2	3.86	16.21
4.2	118.33	5.02	4.69	23.58
4.5	136.53	6.23	4.68	29.14

For the five-inch pulley configuration, the results show that the maximum electrical power output reached 29.58 watts, obtained at the highest average wind speed with an average rotational speed of 136.53 RPM based on repeated measurements. Although variations in rotational speed were observed under different testing conditions, the overall results indicate a consistent increase in power output as rotational speed increases. Under this configuration, the turbine generated a torque of 10.25 Nm, reflecting effective mechanical energy transfer from the turbine shaft to the generator.

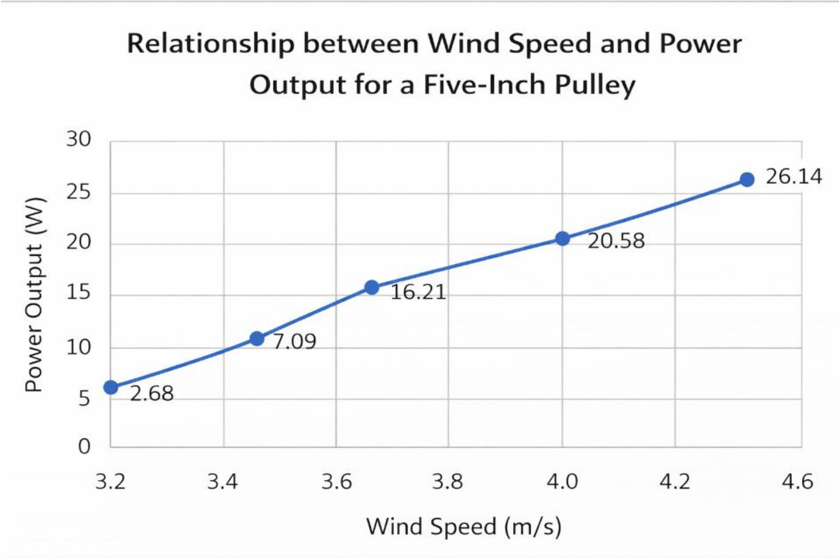

Figure 3. Performance graph of the five-inch pulley on the generated power

The graph shows a steady increase in power output as wind speed rises for the five-inch pulley configuration, indicating a positive relationship between wind speed and generated electrical power.

Measurement Results of Wind Turbine Rotation with Eight-Inch Pulley

Table 3. Wind Turbine Test Data for Eight-Inch Pulley Variation

Average Wind Speed (m/s)	Rotational Speed (RPM)	Current (A)	Voltage (V)	Power (W)
3.2	70.7	3.58	3.52	12.6
3.5	84.4	3.8	3.62	13.75
3.7	91.3	4.13	3.97	16.36
4.2	110.4	5.42	4.03	19.28
4.5	119.3	6.01	4.92	21.56

For the eight-inch pulley configuration, the results indicate that the maximum electrical power output reached 21.56 watts. This value was obtained at the highest average wind speed, with an average rotational speed of 119.3 RPM based on repeated measurements. Although variations in rotational speed were observed across different testing conditions, the overall trend shows a consistent increase in power output with increasing rotational speed. Under this configuration, the turbine generated a torque of 9.4 Nm, indicating effective mechanical energy transfer from the turbine shaft to the generator.

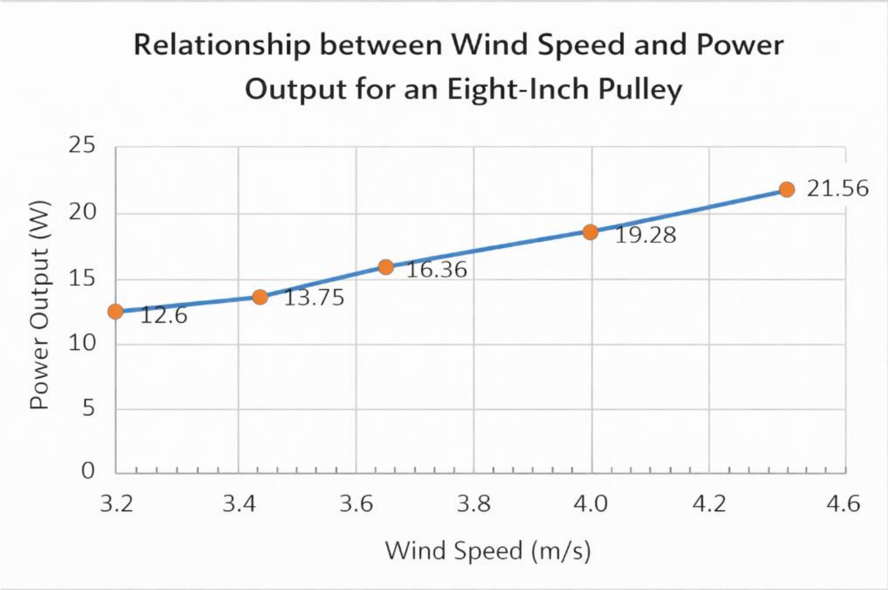

Figure 4. Performance graph of the eight-inch pulley on the generated power

The driving pulley has a significant influence on the performance of the driven generator. In general, higher rotational speed generated by pulleys with different diameters affects the power output produced by the generator. Rotational speed plays a major role in determining the electrical power generated. In the case of a wind generator using a three-bladed Savonius turbine, an advantage lies in its relatively stable torque characteristics, which enable the power produced from pulley rotation to remain optimal (Zulfikar et al., 2019).

CONCLUSION

This study concludes that pulley diameter variation plays a crucial role in influencing the electrical power output of a Savonius-type vertical axis wind turbine with three blades. The experimental results demonstrate that differences in pulley size significantly affect rotational speed, torque characteristics, and overall transmission efficiency between the turbine and the generator. Smaller pulley configurations tend to provide higher rotational speed at the generator shaft, resulting in more effective electrical power generation under low to moderate wind speed conditions. Conversely, larger pulley configurations show reduced rotational speed and lower power output due to increased mechanical load and transmission losses.

The Savonius turbine configuration used in this study exhibits stable torque characteristics, which support consistent mechanical energy transfer and contribute to reliable generator performance across varying wind conditions. This stability allows the transmission system to operate efficiently, even when wind speed fluctuates. The findings highlight the importance of optimizing mechanical transmission components rather than focusing solely on aerodynamic design when improving small-scale wind energy systems.

Overall, proper pulley selection is essential for maximizing energy conversion efficiency and ensuring optimal generator performance. The results of this study provide valuable practical insight for the design and development of compact wind energy systems suitable for urban and limited-space environments. Future research may further explore alternative transmission mechanisms and material variations to enhance system durability and long-term efficiency.

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