Comparison of Energy Conversion Performance of Vertical and Horizontal Axis Wind Turbines in Wind Power Plant

Ni Made Karmiathi[1], I Nyoman Sugiarta[2], I Nyoman Mudiana[3], Agus Supranartha[4], and Ni Wayan Rasmini[5]

[1,2,3,4,5] Electrical Engineering Department, Politeknik Negeri Bali, Bali, Indonesia
made.karmiathi@pnb.ac.id

Abstract. Indonesia has ample renewable energy potential, with wind energy primarily available in coastal areas or on islands. According to the National Energy Council, Indonesia's wind energy potential reaches 154.9 Gigawatts (GW). However, its use for electricity generation is still very limited, accounting for only about 0.102% or 157.41 Megawatts (MW). To promote the development of wind energy in line with the Strategic Research Plan (RENSTRA) of Bali State Polytechnic 2021-2025, this study conducted a comparative analysis of the energy conversion performance of two types of wind turbines: horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT) at the Renewable Energy Laboratory, Department of Electrical Engineering, Bali State Polytechnic, Bukit Jimbaran. A blower was simulated as a wind energy source. The energy conversion performance of HAWT and VAWT was tested under various wind conditions by adjusting the blower's rotation speed and its distance from the turbines. The results showed that under low and unstable wind speeds (blower distance of 200cm with low and medium speeds), VAWT performed better than HAWT. Conversely, under stable wind speeds (blower distance of 100cm with low, medium, and high speeds), HAWT demonstrated superior performance, producing output voltages of 9.2V, 13.65V, and 14.18V, respectively, compared to 0.44V, 2.48V, and 3.18V.

Keywords: Horizontal Axis Wind Turbine, Vertical Axis Wind Turbine, Wind Energy

1 Introduction

Wind energy has been used for centuries to turn windmills and to power sailing vessels, but it's only in the past few decades that wind has been used to generate electricity. Wind is geographically variable as an energy resource. Wind is thus a variable and uncertain energy source, dependent on a range of complex atmospheric and topographic conditions (Spiru & Simona, 2024). Average wind speeds are higher on the oceans than on land, and consistently higher in flat areas compared with mountainous regions (Earle, 2021).

A. A. N. G. Sapteka et al. (eds.), *Proceedings of the International Conference on Sustainable Green Tourism Applied Science - Engineering Applied Science 2025 (ICOSTAS-EAS 2025)*, Advances in Engineering Research 280,
https://doi.org/10.2991/978-94-6463-878-3_55

Wind energy accounts for about 25% of installed renewable energy (Singh et al., 2022). Based on 2019 data, China and the US have the highest installed wind capacity. Still, Denmark has the highest proportion of wind-generated electricity at 48%, followed by Ireland (33%), Portugal (27%), Germany (26%), the UK (22%), and Spain (20%) (Energy, 2019).

Indonesia has significant wind energy potential, especially in coastal and island regions. The 2022 Indonesian Energy Outlook by the National Energy Council (DEN) estimates this potential at 154.9 GW (Surhayati et al., 2023). Despite this, current wind power capacity is only 157.41 MW, about 0.102% of the potential, with a target of 255 MW by 2025. The main reason for this underutilization is insufficient detailed research into wind energy resources (Surhayati et al., 2023). To enhance wind power usage in Indonesia, it is essential to conduct more comprehensive resource assessments, advance turbine technology, and promote government incentives, streamlined licensing, and public awareness efforts.

To contribute to wind energy research for electricity in Indonesia, this study examines the performance of wind turbines in generating electrical power under different wind speeds through simulations at the Renewable Energy Laboratory, Department of Electrical Engineering, Bali State Polytechnic, Bukit Jimbaran. Two types of wind turbines are used in this study: (1) Horizontal axis wind turbine (HAWT): The turbine's rotational axis runs parallel to the wind stream and the ground. The rotor, generator, and gearbox are mounted at the back of the blades. (2) Vertical axis wind turbine (VAWT): The turbine’s rotational axis is perpendicular to the ground. The rotor, generator, and gearbox are positioned at the base. We are exploring which type of wind turbine might be the best fit for specific locations with their unique wind conditions. Our goal is to help identify the most suitable wind turbine options to harness the wind's power effectively.

In this simulation, a blower will be used as a wind energy source for two wind turbines, i.e., HAWT and VAWT, each rated at 300 watts. Different wind speed conditions are simulated by adjusting the distance of the blower to the wind turbine and the blower rotation speed. Voltage and rotational speed measurements will then be taken for both the HAWT and VAWT under these conditions.

Many scientific studies have compared the energy conversion performance of HAWTs and VAWTs, as referenced in several works (Fadil et al., 2017; Herlina et al., 2024; Johari et al., 2018; Kashem et al., 2021; Nader & Jendoubi, 2018). These studies show that HAWTs generally have higher efficiency than VAWTs, particularly in regions with steady wind directions. VAWTs, capable of capturing wind from any direction, are better suited for areas with variable wind patterns. While HAWTs require higher wind speeds to start generating power, VAWTs can operate at lower wind speeds, making them more effective in locations with light or fluctuating winds.

Nevertheless, this study remains essential as an effort to enrich research on renewable energy, especially wind energy, which aligns with the Bali State Polytechnic's 2021-2025 strategic research plan and aims to support the development of learning tools for students in the field of wind energy conversion.

2 Methodology

This study took place at the Renewable Energy Laboratory, Department of Electrical Engineering, Bali State Polytechnic, Bukit Jimbaran, from May to June 2025. A quantitative method was used to collect and analyze data systematically.

To ensure thorough investigation and reliable results, the work steps in this research include literature review, system component preparation and assembly, simulation and measurement, data analysis, and conclusion.

2.1 Literature Review

Various written sources, such as books, journals, scientific articles, and other relevant materials related to the research topic, have been collected and reviewed to establish a theoretical basis and framework for this study.

2.2 System Component Preparation and Assembly

The system components used in the simulation in this study consist of:

a) Blower, SFG5-4 750W, which functions as a source of wind energy, as shown in Figure 1a.
b) Charge controller, which operates to regulate the electrical output of a wind turbine to safely and efficiently charge a battery bank or directly serve the load, as shown in Figure 1b.
c) Horizontal Axis Wind Turbine 300W, as shown in Figure 2a.
d) Vertical axis wind turbine 300W, as shown in Figure 2b.

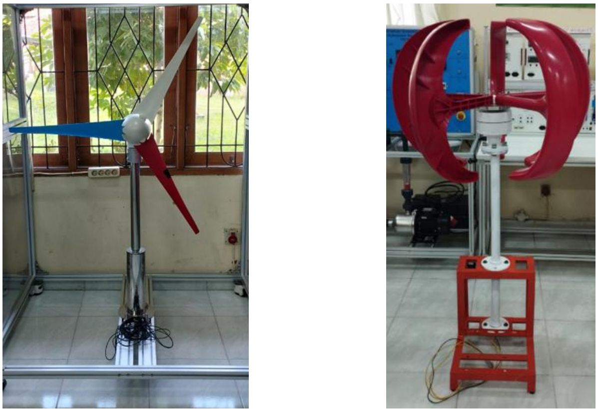
The measurement tools used in this study include:

a) Voltmeter to measure the output voltage of HAWT and VAWT.
b) Tachometer to measure the speed of the blower and wind turbine.
c) Stroboscope to measure the speed of the blower and wind turbine.

(a)

(b)

Figure 1. (a) Blower, (b) Charge Controller 600W



(a) (b)

Figure 2. (a) Horizontal Axis Wind Turbine 300W, (b) Vertical Axis Wind Turbine 300W

2.3 Simulation and Measurement

This study simulated different wind conditions by changing the distance between the blower and the wind turbine, as well as the blower speed. Subsequently, the energy conversion performance of both horizontal and vertical wind turbines was assessed.

2.4 Data Analysis

After collecting all the research data, the next step is data processing and analysis, which aims to convert the raw data into useful information for concluding.

3 Result and Discussion

3.1 Result

The simulation comparing the wind energy conversion performance between HAWT and VAWT into electrical energy is shown in Figure 3. A blower is simulated as a wind energy source. To create different wind speed conditions, the blower is placed at varying distances (short, long) from the wind turbine and operated at various speeds (low, medium, high). HAWT and VAWT are the objects of energy conversion comparison. Wind turbine rotation speed and output voltage were measured after being regulated by the charge controller.

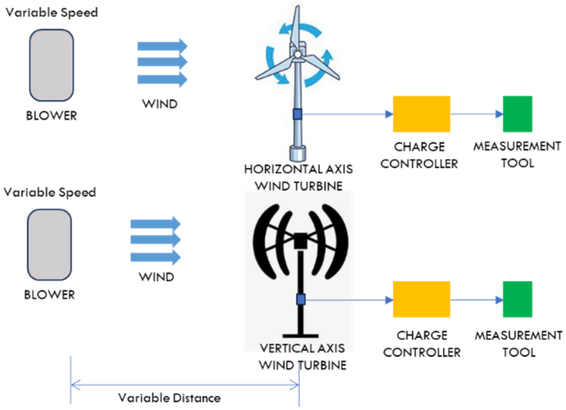


Figure 3. Simulation Diagram

The following were the results of simulation measurements under various wind speed conditions:

A1. Blower distance to wind turbine is 200cm (long), with a speed of 1315 rpm (low). The measurement results are shown in Table 1.

Table 1. Data Measurement of Rotation Speed and Output Voltage of HAWT and VAWT with a Distance of 200cm to the Blower and Blower Speed 1315rpm

	Horizontal Axis Wind Turbine		Vertical Axis Wind Turbine	
	Speed (rpm)	Output Voltage (Volt)	Speed (rpm)	Output Voltage (Volt)
Minimum	0	0.00	39	0.60
Maximum	0	0.00	39	0.90
Average	0	0.00	39	0.70

HAWT is showing no movement on its blade, while VAWT is showing an average speed of 39 rpm and an output voltage of 0.7 volts.

A2. Blower Distance to Wind Turbine 200cm (Long), with Speed 1528 rpm (Medium). The measurement result is shown in Table 2.

Table 2. Data Measurement of Rotation Speed and Output Voltage of HAWT and VAWT with a Distance of 200 cm to the Blower and Blower Speed 1528rpm

	Horizontal Axis Wind Turbine		Vertical Axis Wind Turbine	
	Speed (rpm)	Output Voltage (Volt)	Speed (rpm)	Output Voltage (Volt)
Minimum	0	0.00	67	1.40
Maximum	0	0.00	67	2.00
Average	0	0.00	67	1.78

HAWT is showing no movement on its blade, while VAWT is demonstrating an average speed increase of 67 rpm and output voltage of 1.78 volts.

A3. Blower Distance to Wind Turbine 200 cm (Long), with Speed 1828rpm (High). The measurement result is shown in Table 3.

Table 3. Data Measurement of Rotation Speed and Output Voltage of HAWT and VAWT with a Distance of 200 cm to the Blower and Blower Speed 1822rpm

	Horizontal axis wind turbine		Vertical axis wind turbine	
	Speed (rpm)	Output voltage (Volt)	Speed (rpm)	Output voltage (Volt)
Minimum	1190	12.10	76	1.70
Maximum	1298	13.20	76	2.60
Average	1251	12.56	76	2.29

HAWT has an average speed of 1251 rpm and an output voltage of 12.56 volts, while VAWT has a maximum average speed of 76 rpm and an average output voltage of 2.29 volts.

B1. Blower distance to wind turbine is 100 cm (short), with a speed of 1315 rpm (low). The measurement results are shown in Table 4.

Table 4. Data Measurement of Rotation Speed and Output Voltage of HAWT and VAWT with a Distance of 100 cm to the Blower and Blower Speed 1315rpm

	Horizontal axis wind turbine		Vertical axis wind turbine	
	Speed (rpm)	Output voltage (Volt)	Speed (rpm)	Output voltage (Volt)
Minimum	944	8.90	33	0.20
Maximum	953	9.40	33	0.70
Average	948	9.20	33	0.44

HAWT has an average speed of 948 rpm and an output voltage of 9.20 volts, while VAWT has an average speed of 33 rpm and an average output voltage of 0.44 volts.

B2. Blower Distance to Wind Turbine 100 cm (Short), with Speed 1528 rpm (Medium). The measurement result is shown in Table 5.

Table 5. Data Measurement of Rotation Speed and Output Voltage of HAWT and VAWT with a Distance of 100cm to the Blower and Blower Speed 1528rpm

	Horizontal axis wind turbine		Vertical axis wind turbine	
	Speed (rpm)	Output voltage (Volt)	Speed (rpm)	Output voltage (Volt)
Minimum	1362	13.30	89	2.3
Maximum	1366	13.90	89	2.7
Average	1364	13.65	89	2.48

HAWT has an average speed of 1364 rpm and an output voltage of 13.65 volts, while VAWT has an average speed of 89 rpm and an average output voltage of 2.48 volts.

B3. Blower Distance to Wind Turbine 100 cm (Short), with Speed 1822 rpm (High). The measurement result is shown in Table 6.

Table 6. Data Measurement of Rotation Speed and Output Voltage of HAWT and VAWT with a Distance of 100cm to the Blower and Blower Speed 1822 rpm

	Horizontal axis wind turbine		Vertical axis wind turbine	
	Speed (rpm)	Output voltage (Volt)	Speed (rpm)	Output voltage (Volt)
Minimum	1393	14.0	124	3.00
Maximum	1397	14.4	124	3.30
Average	1396	14.18	124	3.18

HAWT has the best average speed of 1396 rpm and the best output voltage of 14.18 volts, while VAWT also has the best average speed of 124 rpm and the best average output voltage of 3.18 volts.

3.2 Discussion

If the average value of the simulation results in tables 1 to 3 and Tables 4 to 6 is compiled, the results can be presented in tables 7 and 8, respectively.

Table 7. Average Rotation Speed and Output Voltage of HAWT and VAWT with Distance 200 cm to the Blower and with Three-Stage Blower Speed.

No.	Blower distance (cm)	Blower speed (rpm)	Horizontal axis wind turbine		Vertical axis wind turbine	
			Avg. Speed (rpm)	Avg. Output voltage (Volt)	Avg. Speed (rpm)	Avg. Output voltage (Volt)
1	Long	Low	0	0	39	0.7
2	Long	Medium	0	0	67	1.78
3	Long	High	1251.4	12.56	76	2.29

Referring to Table 7, we see some significant results. At a distance of 200 cm from the blower to the wind turbine (WT), which we call "long" configuration, the HAWT was unable to rotate or stay inactive at low and medium blower speeds, producing no electricity. It only activates when the blower speed is increased to the high setting of 1822 rpm. At this point, the turbine rotates at 1251 rpm, producing an impressive average output voltage of 12.56V. In clear contrast, the VAWT consistently converts wind energy into electrical power at low, medium, and high blower speeds, with its output voltage gradually increasing from 0.44V to 2.48V and 3.18V, respectively.

Table 8. Average Rotation Speed and Output Voltage of HAWT and VAWT with a Distance of 100 cm to the Blower and with a Three-Stage Blower Speed

No	Blower distance (cm)	Blower speed (rpm)	Horizontal axis wind turbine		Vertical axis wind turbine	
			Avg. Speed (rpm)	Avg. Output voltage (Volt)	Avg. Speed (rpm)	Avg. Output voltage (Volt)
1	Short	Low	948	9.20	33	0.44
2	Short	Medium	1364	13.65	89	2.48
3	Short	High	1396	14.18	124	3.18

Turning to Table 8, we find additional compelling evidence: when the blower is positioned just 100 cm from the wind turbine (we call this a "short" configuration), both the HAWT and VAWT demonstrate remarkable efficiency in harnessing wind energy across all three blower speed levels: low, medium, and high. Yet, the HAWT stands out, achieving higher average voltages of 9.2V, 13.65V, and 14.18V, surpassing the VAWT's outputs of 0.44V, 2.48V, and 3.18V, respectively. This clear distinction showcases the superior performance of the HAWT, highlighting its powerful capabilities in energy generation.

The results of this study indicate that HAWT has higher conversion performance than VAWT in high and stable wind speed conditions. Conversely, VAWT demonstrates more effective energy conversion than HAWT in low and less stable wind speed conditions. These findings align with previous results, studies that showed by Fadil et al. (2017), Herlina et al. (2024), Johari et al. (2018), Kashem et al. (2021), Nader & Jendoubi (2018).

4 Conclusion

Based on the results from the results and discussion section, it can be concluded that under low and unstable wind speeds, with the blower placed 200cm from the wind turbine and operating at low to medium speeds, the Vertical Axis Wind Turbine (VAWT) performs better than the Horizontal Axis Wind Turbine (HAWT). Specifically, it is more efficient at converting wind energy into electrical energy, producing output voltages of 0.7V and 1.78V. Under stable wind speed conditions across low, medium, and high ranges (with the blower 100cm from the wind turbine and blower speeds set to Low, Medium, and High), the HAWT outperforms the VAWT by generating output voltages of 9.2V, 13.65V, and 14.18V, respectively, compared to 0.44V, 2.48V, and 3.18V.

References

Earle, S. (2021). Solar and Wind (Chapter 9.1). In *Environmental Geology* (p. 222). https://environmental-geol.pressbooks.tru.ca/chapter/solar-and-wind/.

Energy, U.S.D. of. (2019). *Approximate wind energy penetration in leading wind markets in 2019, by select country*. Statista. https://www.statista.com/statistics/217804/wind-energy-penetration-by-country/.

Fadil, J., Soedibyo, & Ashari, M. (2017). Performance comparison of vertical-axis and horizontal-axis wind turbines to get optimum power output. *QiR 2017 - 2017 15th International Conference on Quality in Research (QiR): International Symposium on Electrical and Computer Engineering*, *2017-December*. https://doi.org/10.1109/QIR.2017.8168524.

Herlina, Agustina, S., Sariman, Pratama, M. A., & Azhary, M. I. (2024). Preliminary study on wind turbines for power on floating net cages. *Jurnal Asimetrik: Jurnal Ilmiah Rekayasa & Inovasi*, *6*, 341–350. https://doi.org/10.35814/asiimetrik.v6i2.6869.

Johari, M. K., Jalil, M. A. A., & Shariff, M. F. M. (2018). Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). *International Journal of Engineering and Technology(UAE)*, *7*(4). https://doi.org/10.14419/ijet.v7i4.13.21333.

Kashem, S. B. A., Chowdhury, M. E. H., Majid, M. E., Ashraf, A., Hasan-Zia, M., Nashbat, M., Kunju, A., & Esmaeili, A. (2021). A comprehensive review and the efficiency analysis of horizontal and vertical axis wind turbines. *European Journal of Sustainable Development Research*, *5*(3). https://doi.org/10.21601/ejosdr/11001.

Nader, N. A., & Jendoubi, A. (2018). Study of a vertical-axis wind turbine for low-speed regions in Saudi Arabia. *International Conference on Fluid Flow, Heat and Mass Transfer*. https://doi.org/10.11159/ffhmt18.139.

Singh, U., Rizwan, M., Malik, H., & García Márquez, F. P. (2022). Wind energy scenario, success and initiatives towards renewable energy in India—A review. *Energies, 15*(6), 2291.

Spiru, P., & Simona, P. L. (2024). Wind energy resource assessment and wind turbine selection analysis for sustainable energy production. Scientific Reports, 14(1), 10708.

Surhayati, Pratiwi, N. I., Pambudi, S. H., & Wibowo, J. L. (2023). *Oulook Energi Indonesia 2023*. 36. https://suaraenergi.com/wp-content/uploads/2024/01/Buku-Outlook-Energi-Indonesia-2023-2033-suaraenergi.com.pdf.