

Design Optimization and Performance Enhancement of Small-Scale Vortex-Induced Turbines for Sustainable Energy Generation

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Abstract

This study explores the development and evaluation of a vortex bladeless wind turbine prototype designed to harness wind energy in low wind speed conditions, making it suitable for regions like Malaysia. The prototype features a 2-meter tall, 0.2-meter diameter cylindrical structure on a flexible shaft that uses vortex-induced vibrations to generate mechanical energy. Testing in a wind tunnel with airflow from 1 m/s to 10 m/s, along with field tests around UTHM, demonstrates the turbine's effectiveness at low to moderate wind speeds. The generated vibrations are converted into electrical energy using an electromagnetic induction system. Analysis of the test results, including oscillation frequency, voltage, and efficiency, shows promising performance where traditional turbines underperform. Enhancements based on these findings have further optimized the turbine's performance.

1. Introduction

Electricity is a vital component of modern society, influencing nearly all aspects of life, from education and communication to home life and business operations. It powers our daily routines, enabling conveniences such as lighting, refrigeration, and entertainment while supporting critical functions like healthcare systems, public safety, and industrial production. Through its role in technologies like radio, television, email, and the Internet, electricity enhances communication and fosters global connectivity, driving innovation and economic growth (1). Furthermore, electricity is indispensable in modern transportation systems, powering trains, electric vehicles, and urban infrastructure, which collectively underpin the functioning of contemporary urban and rural settings.

Given its importance, the pursuit of sustainable electricity generation is crucial in addressing global challenges such as climate change, environmental degradation, and energy security. Presently, coal remains the most widely used source of electricity worldwide due to its affordability and abundant reserves (2). However, coal combustion releases significant quantities of harmful pollutants, including lead, mercury, sulfur dioxide, nitrogen oxides, particulates, and heavy metals, which are detrimental to both human health and the environment (3). The contribution of coal-fired power plants to greenhouse gas emissions exacerbates global warming, making the transition to cleaner energy sources imperative.

To reduce dependence on coal and other fossil fuels, countries worldwide are investing in renewable energy. Malaysia, endowed with favorable geographical and climatic conditions, has made strides in developing its renewable energy capacity, particularly through hydroelectric power. As the largest contributor to Malaysia's renewable energy mix, hydroelectricity harnesses the country's abundant rainfall and river systems, providing a reliable and relatively low-emission energy source (4). However, the development of large-scale hydropower projects is often accompanied by challenges, such as environmental concerns and the displacement of communities.

Wind energy represents another promising avenue for diversifying Malaysia's energy portfolio. Traditional wind turbines, towering between 40 and 90 meters, capture the kinetic energy of the wind and convert it into electricity using aerodynamic principles. While these large structures are efficient in areas with consistent wind patterns, their size and land requirements can limit their deployment in densely populated or ecologically sensitive areas (5). Research and development are addressing these limitations by exploring smaller, more adaptable turbine designs and offshore wind farms, which offer significant potential for Malaysia's coastal regions. As technology evolves, wind energy could rival hydroelectricity as a key renewable energy source in Malaysia, contributing to the nation's transition to a sustainable energy future (6).

This shift toward renewable energy aligns with global commitments to sustainable development, reducing environmental impacts, and ensuring energy security for future generations. By investing in technologies like wind and hydroelectric power, Malaysia can not only meet its growing energy demands but also position itself as a leader in the renewable energy sector (7).

2. Methodology

The VIT prototype, designed using SolidWorks 2019, consists of a thin, flexible cylindrical structure mounted on a solid base. The prototype includes 14 key parts made from various materials such as plywood, PVC pipes, and 3D-printed plastics.

The VIT prototype includes the following parts:

- Base plate and body made from plywood and concrete.
- Fixed and flexible rods made from PVC.
- Various connectors and covers made from ABS and PLA plastics.

Each component is carefully designed and fabricated to ensure the smooth functioning of the prototype. The electrical system includes proper wiring, an inverter to convert DC to AC power, and components for energy storage and conversion. Proper wiring ensures efficient operation and accurate data collection.



Fig. 1 Testing at 3 different places

The VIT prototype was tested around the UTHM aerodynamics laboratory. Due to low natural wind speeds, a wind tunnel was used to obtain electric current data. Initial tests faced wiring issues, impacting results. Proper operation of the wind tunnel required safety equipment and experienced operators. The prototype was tested at the UTHM football field and road site, where wind speeds ranged from 0.8 m/s to 3.0 m/s. The open space allowed wind to cause vibrations in the prototype, generating small amounts of energy. Both modified and unmodified prototypes were tested to gather data on vibrations and voltage. Safety measures included using safety glasses, earmuffs, and proper tools. Accurate measurement tools like wind speed meters and stopwatches ensured reliable data collection.

2.2 Assembly part circuit

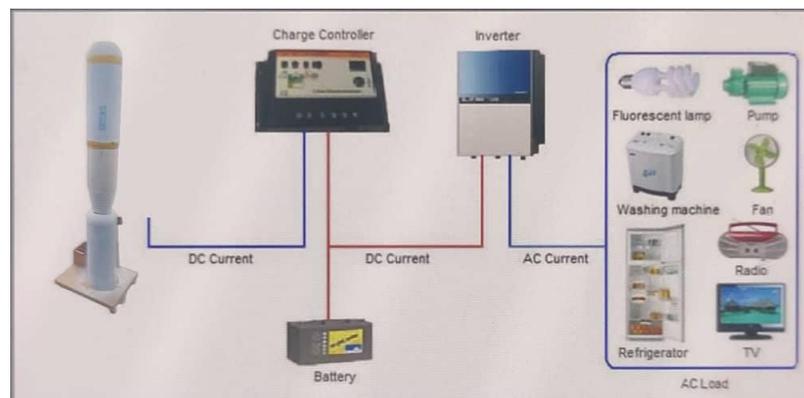


Fig. 1 Flow diagram prototype

The installation of a system involves careful arrangement of the base, flexible and permanent rods, mast-rod connector, copper coil holder, wiring, battery connection, magnet holder, cap, inner magnet ring, lower mast part, outer magnet ring, and screws. The base is arranged straight, and the copper coil holder is placed on fixed rods. The wiring process begins with wires connected to copper coils and directed through the holes in the fixed rod to the base of the mast. The battery connection is disconnected, and the charger controller is connected to the battery. The assembly then includes the magnet holder, cap, and inner magnet ring above the copper coil holder. The lower mast part is trimmed to make room for the outer magnet ring, and the outer magnet ring is carefully placed. Four screws are used to secure the lower mast part through the mast-rod connector. The inverter is connected to the battery wire, and the assembly is completed with a functional and integrated system.

3. Result & Discussion

Table 1 Origin oscillation vs wind speed (8)

Wind Speed(m/s)	No. of Oscillation				Time Taken(s)	Frequency of Oscillation(Hz)
	1	2	3	Average		
1	23	20	24	22.33	20	1.12
2	24	26	25	25.00		1.25
3	26	25	25	25.33		1.27
4	24	23	26	24.33		1.22
5	25	26	24	25.00		1.25
6	26	25	26	25.67		1.28
7	26	27	26	26.33		1.32
8	23	24	27	24.00		1.23
9	24	24	24	24.00		1.20
10	25	24	23	24.00		1.20

Once the prototype modified, we may see an increase in oscillation frequency as well as a change in no oscillation rises put on by the body pole's weight. This modification happens when the body's middle structure is modified to a lightweight material such as v-shaped plastic making the body lighter in order to develop the prototype structure.

Table 2 Enhanced oscillation vs wind speed

Wind Speed(m/s)	No. of Oscillation				Time Taken(s)	Frequency of Oscillation(Hz)
	1	2	3	Average		
1	25	25	24	24.67	20	1.23
2	25	26	26	25.67		1.28
3	26	27	27	26.67		1.33
4	27	28	27	27.33		1.36
5	27	28	27	27.33		1.36
6	27	29	28	28.00		1.40
7	29	27	28	28.00		1.40
8	29	29	30	29.33		1.46
9	30	28	29	29.00		1.45
10	29	30	29	29.33		1.46

The data obtained during testing is displayed in tables. Based on the previous table. With an enhanced vortex, the origin of the vortex changes, increasing both the maximum and minimum. When the mast gets better from its origin mast, the result was an increase in oscillation.

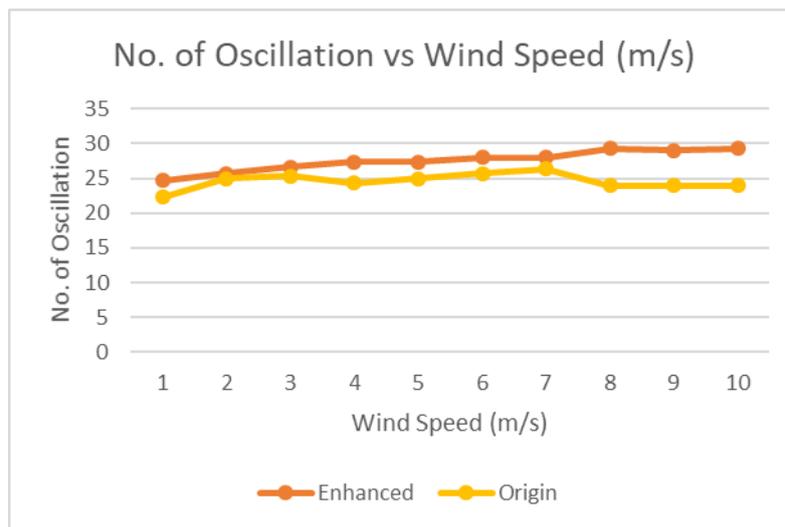


Fig. 3 Oscillation Against Wind Speed

A comparison of the number of oscillation against wind speed before and after can be observed in the graph. The enhanced vortex's maximum graph shows a maximum oscillation of 30, while the original vortex's maximum oscillation was 26. In addition, the graph shows a 15% increase in oscillation over the original vortex. The difference may be observed when the centre structure is modified to use plastic instead of PVC pipes, resulting in more oscillation and vibrating.

3.1 The experiment in various locations.

Table 3 Data experiment different site

Location	Voltage (V)	Current (A)	Wind Speed (m/s)
Football Field	0.055	23.40	2.4
Road side	0.080	25.80	2.6
Wind tunnel	0.105	26.10	2.5

Experiments have been conducted in several places around UTHM and found that voltage, current and wind speed change according to the area and environment that affects the vortex.

Table 4 The data collection of each location enhanced vortex

Location	Voltage (V)	Current (A)	Power Output (W)	Wind Speed (m/s)	Power Input (W)
Football Field	0.055	23.40	1.287	2.4	8.459
Roadside	0.080	25.80	2.064	2.6	10.759
Wind Tunnel	0.105	26.10	2.7405	2.5	9.57

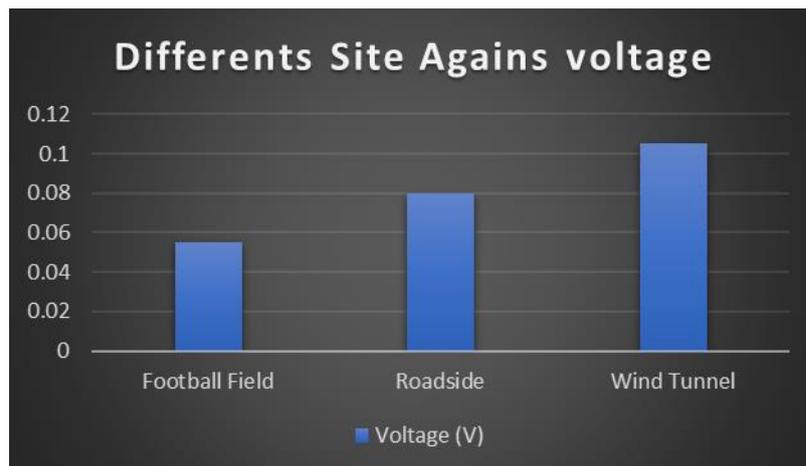


Fig. 4 Different site again voltage

The wind tunnel lab demonstrated the highest voltage measurement and highest rate volt, generating power output of 2.74 W at a wind speed of 2.5 m/s. This indicates the wind tunnel lab's ability to maintain steady air flow, which is crucial for optimal wind turbine power generation. The football field had the lowest voltage value and current, with a power output of 1.287 W, due to irregular wind patterns. The roadside location had moderate values, with a voltage of 0.080V and a current of 25.80 A at a wind speed of 2.6 m/s, generating a power output of 2.064 watts.

This suggests that while roadside wind conditions were less reliable than those in a wind tunnel, they were more stable compared to a football field. The significant difference in power output and voltage measurements among different locations underscores the importance of wind constancy in wind energy installations. Areas with more consistent wind patterns, such as wind tunnels, generally yield higher power

output and voltage production. However, changes in wind conditions, such as those observed at the football field, could significantly impact wind energy production. These findings underscore the importance of selecting suitable locations with reliable wind resources for wind energy projects to optimize efficiency and production.

Table 5 Data collection using origin VIT

Location	Voltage (V)	Current (A)	Power Output (W)	Wind Speed (m/s)	Power Input (W)
Football Field	0.023	13.40	0.308	2.4	8.475
Roadside	0.050	15.80	0.790	2.6	10.759
Wind Tunnel	0.080	16.10	1.288	2.5	9.570

The data from Table 10 had been collected from the experiment that been conducted using origin prototype VIT before enhancing the prototype. The data had been collected from 3 different places surrounded UTHM campus which is football field, roadside and wind tunnel lab.

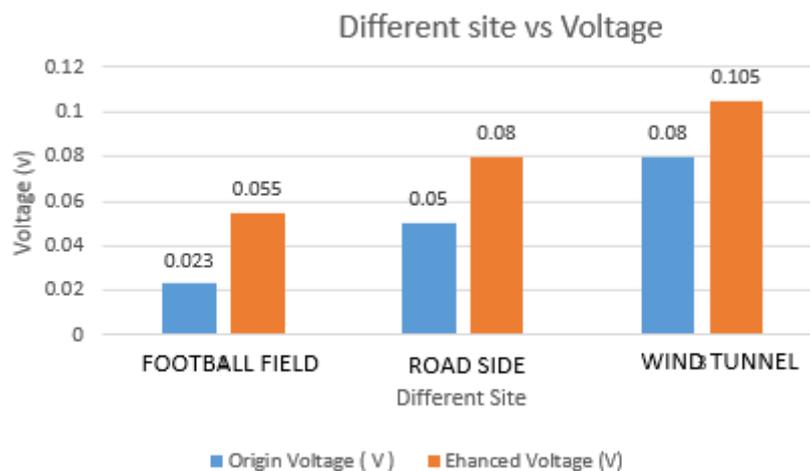


Fig. 5 Comparison different site origin vs enhanced

The comparison between the original voltage and the enhanced prototype voltage that has been developed is shown in Figure 28. As can be seen in the illustration, the voltage value on the football field has significantly increased by around 50%, rising from 0.023 V to 0.055 V. This suggests that the improved prototype produces positive results. In addition, the voltage value at the roadside has increased by nearly 30%, increasing from 0.05 V to 0.08 V. In addition, the wind tunnel exhibits an increase of up to 25%, with the voltage increasing from 0.08 V to 0.105 V. It is possible that the changing of several parts within the mast and flexible rod contributed for those changes. The change in weight that occurs within the mast is a significant factor that contributes to the acceleration of the vibrations and oscillations.

4. Conclusion

The experiment aimed to determine the most effective way to operate a turbine system induced by vortices using various sensors. The results showed that wind tunnel sites had the highest voltage rate, producing an output of 0.105 V and a power output of 2.74 W. Football field locations had the lowest voltage rate, producing an output of 0.055 V and a power output of 1.28 W. The enhanced prototype demonstrated greater effectiveness than the original VIT, demonstrating better performance. The improvement depends on wind speed and weather conditions at each location. The project received commendation for its positive environmental impact, despite the significant investment in time and work. The innovation resulted in efficient conservation of electrical energy and power harvesting from wind-induced vibrations, reducing carbon emissions and improving public health and safety. This demonstrates its potential as an economical and environmentally friendly alternative for conventional energy sources.

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References

- [1] S, L. (2010, March 8). *Importance of electricity*. The Hindu. <https://www.thehindu.com/features/kids/Importance-of-electricity/article16544961.ece>
- [2] Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Sustainable energy transition for renewable and low carbon grid electricity generation and supply. *Frontiers in Energy Research*, 9. <https://doi.org/10.3389/fenrg.2021.743114>
- [3] Admin. (2023, May 27). The History of Electricity and its Impact On Modern Society. *International Journal of Research (IJR)*. <https://internationaljournalofresearch.com/2023/04/04/the-history-of-electricity-and-its-impact-on-modern-society/>
- [4] Tang, K. H. D. (2019). Hydroelectric dams and power demand in Malaysia: A planning perspective. *Journal of Cleaner Production*, 252, 119795. <https://doi.org/10.1016/j.jclepro.2019.119795>
- [5] Wilson, R., & Lissaman, P. (1974). Applied Aerodynamics of Wind Power Machines. *Renewable Energy*. <https://doi.org/10.4324/9781315793245-89>.
- [6] Prabhu, H. J. (2021, July 6). *Aerodynamics of wind turbines* [Slide show]. SlideShare. <https://www.slideshare.net/slideshow/aerodynamics-of-wind-turbines/249624828>
- [7] Hosseini, S. E., & Wahid, M. A. (2014). The role of renewable and sustainable energy in the energy mix of Malaysia: a review. *International Journal of Energy Research*, 38(14), 1769–1792. <https://doi.org/10.1002/er.3190>
- [8] Samsudin, M. I. S., & Mohd, S. (2022). Development of A Small-Scale Vortex-Induced Wind Turbine. *Progress in Aerospace and Aviation Technology*, 2(1), 10-18.