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Preliminary Study on Wind Turbines for Power on Floating Net Cages

Studi Awal tentang Turbin Angin untuk Daya pada Keramba Jaring Apung

Herlina*, Sri Agustina , Sariman, M. Akbar Pratama, M. Ichsan Azhary
Jurusan Teknik Elektro, Fakultas Teknik Universitas Sriwijaya, Jalan Raya Palembang Prabumulih KM 32, Inderalaya, South Sumatera, Indonesia.

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Abstract

Focus of this primary study is to investigate how efficient horizontal-axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT) are in preserving floating net cages. The expansion of the aquaculture sector, which is increasingly dependent on advanced technologies like monitoring and data processing systems in open waters, need a reliable energy source. The investigation was carried out by manipulating wind speed, battery charging duration, and electrical load for both types of wind turbines in simulated field circumstances. Based on the test results, HAWT outperforms VAWT in generating a greater battery voltage and achieving a more consistent charging period at the same wind speed. The smallest voltage rise in HAWT is 2.2 m/s with a 5-minute 0% charging time and the maximum is 1.2 m/s with a 15-minute 38.1% charging time. While the VAWT demonstrates better stability under specific load conditions, the HAWT can generate substantial power throughout a wide range of wind speeds. This renders HAWT more appropriate for utilization in dynamic maritime applications, such as floating net cages.

Keywords: wind turbine, power, battery charging, load variation, floating net cages.

***SDGs*:**

7 AFFORDABLE AND CLEAN ENERGY

Abstrak

Fokus utama penelitian ini adalah untuk menyelidiki seberapa efisien turbin angin sumbu horizontal (*Horizontal Axis Wind Turbines*/HAWT) dan turbin angin sumbu vertikal (*Vertical Axis Wind Turbines*/VAWT) dalam menunjang keramba jaring apung. Perluasan sektor akuakultur, yang semakin bergantung pada teknologi canggih seperti sistem pemantauan dan pemrosesan data di perairan terbuka, membutuhkan sumber energi yang andal. Investigasi dilakukan dengan memvariasikan kecepatan angin, durasi pengisian baterai, dan beban listrik untuk kedua jenis turbin angin yang disimulasikan di lapangan. Hasil pengujian menunjukkan bahwa HAWT lebih unggul dalam menghasilkan tegangan baterai yang lebih tinggi dan durasi pengisian yang lebih seragam dibandingkan dengan VAWT pada kecepatan angin yang sama. Kenaikan tegangan terkecil dalam HAWT adalah 2,2 m/s dengan waktu pengisian 0% selama 5 menit dan maksimum adalah 1,2 m/s dengan waktu pengisian 38,1% selama 15 menit. Meskipun VAWT unggul dalam stabilitas arus pada kondisi beban tertentu, HAWT mampu menghasilkan daya yang signifikan pada berbagai kecepatan angin. Hal ini membuat HAWT lebih cocok untuk digunakan dalam aplikasi maritim yang dinamis, seperti keramba jaring apung.

Kata Kunci: turbin angin, daya, pengisian baterai, variasi beban, keramba jaring apung.

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*Correspondence Author
email : herlinawahab@unsri.ac.id

1. INTRODUCTION

Aquaculture has emerged as a prominent industry in meeting the growing worldwide demand for fishery products and animal protein sources. Floating net cages (FNC) are a very effective and environmentally friendly technique for aquaculture, which involves using open bodies of water for the cultivation of fish. This approach enables the production of a significant amount of fish while minimizing the negative effects on the environment, in contrast to traditional aquaculture systems (Suryawan, Sunardi and Heru, 2019). Nevertheless, the functioning of floating net cages necessitates a dependable and enduring energy supply to facilitate diverse operations including as aeration, automated feeding, and environmental monitoring systems (Wang *et al.*, 2023; Zhang *et al.*, 2023).

Many research have examined wind turbines and floating net cages. An offshore floating wind turbine and fish cage farming technology combined electricity generation and steady fish farming in medium-deep waters (Pinguet *et al.*, 2020). Another research described a floating net cage based on an offshore fan composite cylinder foundation that combined wind power generation with floating net cage culture to minimize expenses, increase income, and improve structural stability (Lei *et al.*, 2024). The researchers also discovered a floating body for a polygonal deep-sea fishing net cage, a link structure for a wind turbine set, and an interface for a mooring system (Li *et al.*, 2020). In the context of floating net cages, the need for sustainable energy sources is very important to maintain optimal operations (Fan *et al.*, 2023). Utilizing wind turbines as a sustainable energy source holds great potential in addressing these energy requirements. Wind turbines offer an environmentally friendly and enduring energy option, particularly in distant or hard-to-access areas where traditional power lines are not feasible (Khan *et al.*, 2021). These studies show that wind energy generation and floating platform aquaculture can work together.

Wind energy is a highly promising form of clean energy. Wind turbines possess the capacity to transform the motion-driven energy of the wind into energy for electrical use, which may be utilized for many purposes (Summerfield-Ryan and Park, 2023; Yasmeen *et al.*, 2023). Two main types of these turbines are HAWT and VAWT (Al-Rawajfeh and Gomaa, 2023). HAWT is known for its high efficiency in stable and strong wind conditions, while VAWT has the advantage of simpler design and the ability to capture wind from various directions, making it more flexible for fluctuating wind conditions (Das *et al.*, 2017; Fadil, Soedibyo and Ashari, 2017).

Although several studies have explored the use of renewable energy in aquaculture, investigations that specifically discuss the use of wind turbines for floating net cages are still limited. Renewable energy studies have neglected wind turbines for floating net cages (FNCs) in aquaculture. This study fills that gap. The study examines how HAWTs and VAWTs transform energy from the wind into FNC power using a unique way. This study assesses the energy conversion efficiency of both types of turbines, the stability and viability of wind energy systems for FNCs, and the benefits and drawbacks of integrating them via battery charging and variations in load. Including charging intervals of 5, 10, and 15 minutes is intended to assess the effectiveness of battery charging over several time frames and replicate real-life scenarios where wind conditions may vary. This test allows researchers to understand the wind turbine's power delivery performance to the battery over different time intervals, reflecting likely operating situations in the field. Prior studies highlight the significance of assessing the charging efficiency across various time intervals to gain insights into the actual performance of turbines in practical scenarios (Blanford *et al.*, 2018). LED light loads of 5, 10, and 15 watts were chosen to assess the wind turbine's power output stability and efficiency throughout various load conditions. These loads also represent a spectrum of potential energy requirements in real-world scenarios. This test assesses the turbine's performance in scenarios characterized by fluctuating power demand, guaranteeing its ability to fulfill diverse power requirements (Salih, Taha and Alawsaj, 2012).

The findings should help develop more sustainable and efficient aquaculture methods, promoting environmentally friendly worldwide fisheries output.

2. METHODOLOGY

This chapter will present the research flowchart, wind turbine theory, and the materials and equipment utilized in this study.

2.1. Flowchart of the Research

This study aims to determine the most effective turbine configuration regarding use in floating net cages through experimental methods. This method comprises two primary tests: battery charge and variations in loads. The initial test involved charging the batteries for 5, 10, and 15 minutes to assess the charging efficiency of both VAWT and HAWT. For another test, we altered the loading conditions by employing LED lights with power outputs of 5, 10, and 15 watts. This was done to evaluate the capacity of both types of turbines to produce and maintain a steady supply of electricity at different load levels. The objective of this technique is to provide a thorough comprehension of the performance and efficiency of each turbine under different operating situations. This will help in selecting the most optimal and efficient turbine type for utilization in floating net cages.

The procedures taken in this study are illustrated in the flowchart in Figure 1. This research will be carried out using two test conditions. The first condition involves testing the wind turbine with battery charging. In this condition, the turbine will be equipped with a battery system and monitoring equipment to gather data on wind speed, turbine output, and battery charging status. The second condition involves testing the wind turbine with varying loading. In this condition, the turbine will be equipped with a system that varies the load to collect data on wind speed, turbine output, and loading performance. A comprehensive analysis will be carried out to assess the efficacy of battery charging and turbine performance under different loads. Subsequently, the findings will be evaluated against the established benchmark, documented in a report, and presented.

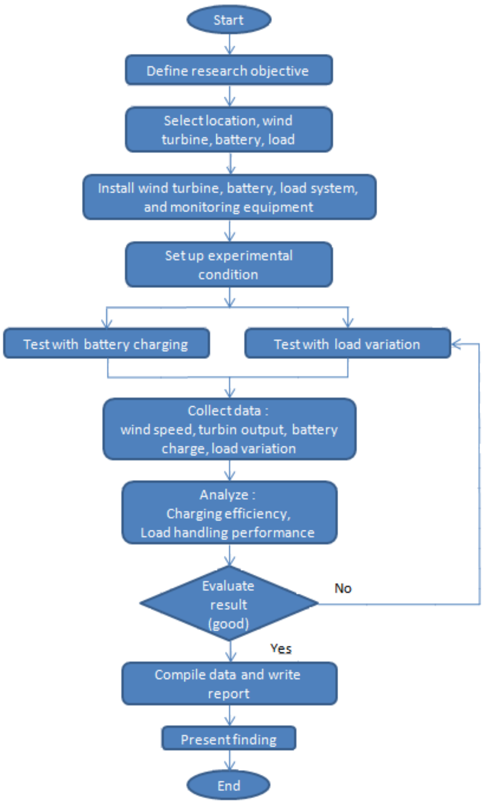

Figure 1. Flowchart of the research.

2.2. HAWT and VAWT Wind Turbine

VAWT and HAWT wind turbines are the main types. Savonius turbines and other VAWTs are favored in cities because of their geographic interface and uneven conditions of the wind (Nambiar, Tripathi and Pant, 2023). Although historically HAWTs have been more efficient than VAWTs, the latter have advantages such as the ability to start on their own and work efficiently under low-speed prevailing winds (Al-Rawajfeh and Gomaa, 2023; Azadani, 2023). Studies comparing the efficiency of HAWTs and VAWTs in different meteorological conditions have shown that HAWTs tend to work with greater efficiency in certain regions (Adebayo *et al.*, 2019; Pietrykowski *et al.*, 2023). VAWTs, like the one used in a system for energy generation with a DC motor and battery, are designed to utilize the energy of the air efficiently (Bezrukovs *et al.*, 2020).

Overall, both types of wind turbines play crucial roles in generating electricity from wind power, each with its own set of advantages and suitable applications. The conversion process in wind turbines is essentially identical, as depicted in the accompanying diagram.

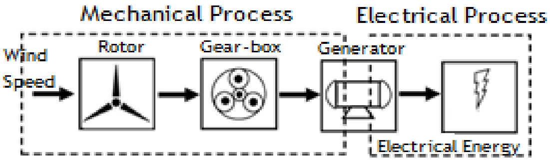

Figure 2. Conversion of energy in wind turbines.

The mechanical and electrical processes are the two primary phases of the energy conversion process in a wind turbine, as depicted in the Figure 2. The turbine rotor transforms the movement energy of the wind to mechanical force, beginning with the velocity of the wind. Transmission transmits mechanical energy to enhance rotor rotation speed for generator use. The generator generates electricity from mechanical energy. Finally, a generator's electricity serves numerous applications. This procedure demonstrates the conversion of kinetic energy from the wind to electric power through a sequence of mechanical and electrical conversions.

The performance of vertical (VAWT) and horizontal (HAWT) wind turbines can be determined using the following fundamental formulas. The equation representing the amount of wind power available in the turbine sweep area is as follows (Al-Rawajfeh and Gomaa, 2023):

$$P_{wind} = \frac{1}{2}\rho A v^3 \qquad (1)$$

where:

P_{wind} = available wind power (watt)

ρ = air density (kg/m^3), the value around 1,225 kg/m^3 at sea level and 15^0 C

A = turbine swept area (m^2)

v = wind speed (m/s)

A wind turbine generates a fraction of the available wind power as electrical power. This is decided by the power coefficient Cp, which stands for the turbine's aerodynamic efficiency.

$$P_{turbine} = \frac{1}{2}\rho A v^3 C_p \qquad (2)$$

where:

$P_{turbine}$ = the turbine's power (in watts).

Cp = power coefficient, which varies depending on the design and operating conditions of the turbine (usually a maximum of about 0.59 according to the Betz limit).

2.3. Research Tools and Materials

The instruments employed in this investigation include HAWT, VAWT, blower 260 Watt, multi-meter, anemometer, tachometer, 12 VDC battery, test circuit, and LED bulbs with power ratings of 5 Watts, 10 Watts, and 15 Watts. The following are images of HAWT and VAWT used as research objects.


(a) HAWT (b) VAWT

Figure 3. Wind turbines.

From Figure 3, we can see the specifications of the HAWT and VAWT used, namely: Both the VAWT and the HAWT have a rated wind generator capacity of 600 W and operate at a voltage of 24 V. Each turbine is equipped with 5 blades and designed to work with a battery that has a rated voltage of 24 V. The HAWT includes additional specifications with a breaking voltage of 30 V and a recover voltage of 27 V.

Subsequently, voltage and current measurements are conducted in three different scenarios: unloaded conditions, charging the battery, and varying the load. This is conducted to evaluate the efficiency and effectiveness of both HAWT and VAWT.

3. RESULTS AND DISCUSSION

This part contains an exposition of the data acquired during the investigation. It includes wind speed data from both the HAWT and VAWT turbines, as well as current and voltage measurements taken at different wind speed conditions. The data will be analyzed, and the findings of the measurements and calculations will be discussed. Additionally, an analysis will be conducted for each condition.

3.1. Data Collection

The data collection was conducted under two specific scenarios. Firstly, the wind turbine outlet was utilized for battery charging, with variations in charging 5 minutes, 10 minutes, and 15 minutes. The variance in time is determined by the battery capacity and the alternating usage schedule of the laboratory, which is shared with other research teams. (2) Loading conditions, which involve changes in LED bulb loads of 5 watts, 10 watts, and 15 watts, are also affected by the available load in the laboratory. Data collection occurred in the engineering department of Sriwijaya University, Palembang campus, and the Electrical Machines Laboratory of Sriwijaya University, Inderalaya. To simplify the process of gathering data, a 240-watt blower is employed as a replacement for the natural wind source. The blower offers three distinct speeds: 1, 2, and 3. Measurements were conducted over three days for the HAWT and three days for the VAWT. The wind speed measurements and their corresponding outputs are displayed in Table 1 and Table 2.

Table 1. HAWT Data.

Speed	Wind Speed (m/s)	Voltage (V)	Current (A)
1	1.2	11.0	0.85
2	2.2	12.4	0.86
3	3.4	13.5	0.87

Table 2. VAWT Data.

Speed	Wind Speed (m/s)	Voltage (V)	Curren t (A)
1	4.6	4.1	0.3
2	3.9	3.8	0.29
3	4.1	3.7	0.29

Analysis of the data from the two tables reveals notable disparities between HAWT and VAWT in relation to wind velocity, voltage, and current. The wind speed in a HAWT rises from 1.2 m/s to 3.4 m/s, corresponding to rise in voltage from 11.0 V to 13.5 V and current from 0.85 A to 0.87 A.

On the other hand, VAWT exhibit more wind velocity, but generate lower levels of voltage and current. Specifically, the wind velocity varies between 3.9 m/s and 4.6 m/s, and the voltage goes from 3.7 V to 4.1 V, and the current remains steady at 0.29-0.3 A. This illustrates that while VAWT functions at elevated wind velocities, its efficacy in transforming wind energy into electricity is inferior to that of HAWT, as seen by the diminished voltage and current.

3.2. Battery Charging Results

This section provides the battery charging outcomes for HAWT and VAWT. To achieve an equivalent wind speed, a blower is employed as the source of wind, and the duration for charging the battery is set at 5, 10, and 15 minutes. In this scenario, the voltage of the battery is monitored both prior to and following the charging process.

Figure 4. Battery charging measurement.

Figure 4 depicts the procedure of obtaining voltage and current data while charging the battery. Table 3 and Table 4 display the measurement results.

Table 3. HAWT wind turbine battery charging data.

Speed	Wind Speed	Battery Voltage (volt)		Charging Time (minutes)		
		Start	End	5	10	15
1	1.2	2.1	2.9	2.3	2.7	2.9
2	2.2	2.9	3.6	2.9	3.2	3.6
3	3.4	3.6	4.6	3.7	4.1	4.6

The data from Table 3 and Table 4 reveals a consistent pattern in the relationship between wind speed, battery voltage, and charging time.

In general, as the wind speed increases from 1.2 m/s to 3.4 m/s, the battery voltage tends to increase from 2.1 V to 3.6 V in Table 3 and from 1.3 V to 3.1 V in Table 4.

Table 4. VAWT wind turbine battery charging data.

Speed	Wind Speed	Battery Voltage (volt)		Charging time (minutes)		
		Start	End	5	10	15
1	1.2	1.3	2.3	1.5	1.8	2.3
2	2.2	2.1	3.1	2.3	2.5	3.1
3	3.4	3.1	4.3	3.4	3.8	4.3

In addition, longer charging times (15 minutes) consistently produce higher battery voltages compared to shorter charging times (5 or 10 minutes) in both tables. For example, at a wind speed of 3.4 m/s, the battery voltage increases from 3.7 V (10 minutes) to 4.6 V (15 minutes) in the table 3 and from 3.4 V (10 minutes) to 4.3 V (15 minutes) in Table 4. These findings show that wind turbines can produce higher battery voltages at higher wind speeds and longer charging times.

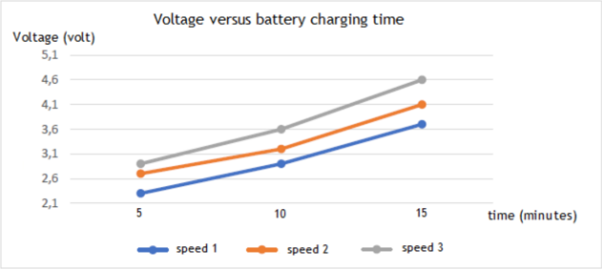

Figure 5. Battery charging graph using HAWT.

The Figure 5 depicting the relationship between voltage and battery charging time using a (HAWT) demonstrates that the voltage consistently rises as the charging time progresses, regardless of the three varied speeds. When the speed is set to 1, the voltage first measures around 2.5 V and gradually rises to approximately 3.5 V over a period of 15 minutes. When the speed is set to 2, the voltage initially measures around 2.6 V and gradually increases to approximately 3.8 V over a period of 15 minutes. At a velocity of 3, the voltage first measures approximately 2.7 V and then rises to almost 4.5 V after a span of 15 minutes.

The Table 6 illustrates a positive correlation between wind speed and battery voltage throughout the charging process. Specifically, when wind speed increases from speed 1 to speed 3, the battery voltage experiences a notable increase. At low wind speeds (speed 1), the rise in battery voltage is somewhat sluggish; but, at medium (speed 2) and high (speed 3) wind speeds, the voltage increase is considerably swifter and more substantial. These findings indicate that wind turbines have a higher level of efficiency in converting wind energy into electrical energy when the wind speeds are higher. This aligns with the test results that demonstrates a larger increase in voltage at higher wind speeds. Wind turbines with higher wind speeds are more suited for applications that necessitate fast and efficient battery charging.

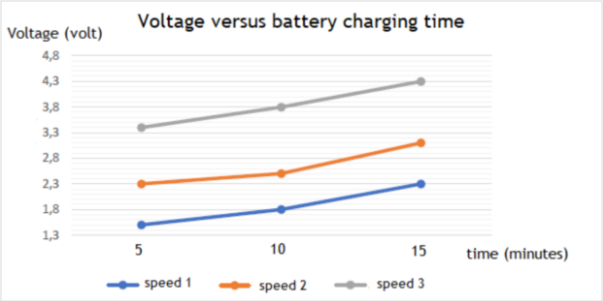

Figure 6. Battery charging graph using VAWT.

The literature contains pertinent research that offers useful insights into the battery charging efficiency of wind turbine systems, particularly about fluctuating wind speeds and charge durations. The study conducted by Worasinchai and Kowitkulkrai, aimed to assess the efficacy of a small-scale wind turbine system in charging batteries (Worasinchai and Kowitkulkrai, 2021). The study shows that the charging efficiency of the system can fluctuate based on varying wind speeds. The study emphasized the substantial impact of wind speed on the system's charging performance. The outcomes of this research provide a vital basis for improving our comprehension of how to maximize the efficiency of wind turbines for increased renewable energy output, especially in the context of floating net cage installations.

3.3. Load Variation Results

The next test is with load variations. The load used is an LED lamp with variations of 5, 10 and

15 Watts. Voltage and current measurements are carried out in two conditions, namely without load and load variations at wind speeds at speeds 1, 2, and 3. The measurement data obtained for HAWT can be seen in Figure 7 and Table 5.

Figure 7. Battery charging graph using HAWT.

Table 5. HAWT test data with loading variations.

Parameters	**Wind Velocity (m/s)**		
	Speed 1	**Speed 2**	**Speed 3**
No load voltage (V)	11.05	12.41	13.50
No load current (A)	0.85	0.86	0.87
Loading (Watt)	**Voltage (Volt)**		
5	8.6	9.5	10.8
10	8.2	9.5	9.4
15	8.1	8.6	9.7
Loading (Watt)	**Current (Ampere)**		
5	0.52	0.55	0.62
10	0.23	0.52	0.61
15	0.46	0.56	0.54

The experimental data obtained from the HAWT test as shown in Table 5, with different loads, demonstrates a direct correlation between wind speed and both voltage and current. As wind velocity increases from speed 1 to 3, voltage and current rise both when the turbine is idle and when it is loaded. The open-circuit voltage rises from 11.05 V to 13.50 V, but the current remains relatively constant at approximately 0.85-0.87 A. At a power consumption of 5 Watts, the voltage increases from 8.6 volts to 10.8 volts, and the current increases from 0.52 amperes to 0.62 amperes. At power levels of 10 watts and 15 Watts, both the voltage and current exhibit a rising pattern, but with lesser fluctuations.

Based on the provided data, Figure 8 and Figure 9 illustrate the correlation between current, voltage, and load variations on the HAWT wind turbine.

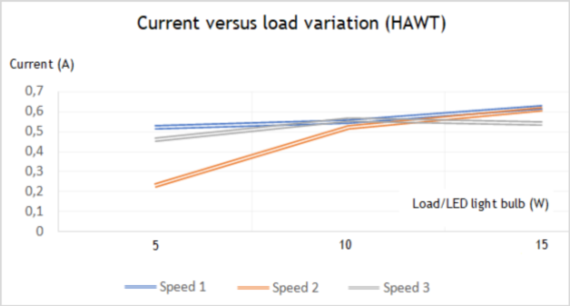

Figure 8. Current and load variation on HAWT.

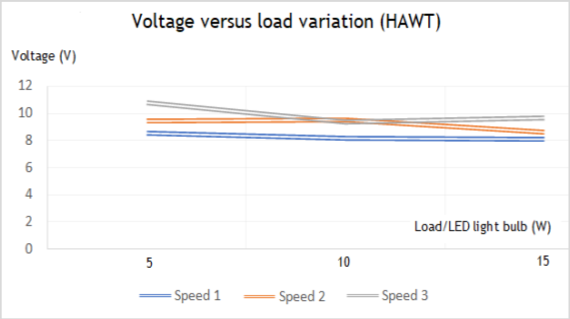

Figure 9. Voltage and load variation on HAWT.

In Figure 8 and Figure 9, HAWT current and voltage fluctuations with load show various tendencies. The “current versus load variation” graph indicates that load increases current, peaking at Speed 3 wind speed. Lower wind speeds (Speed 1 and Speed 2) enhance current, although less than Speed 3. In contrast, the "Voltage versus load variation" graph decreases voltage with load. At the highest wind speed (Speed 3), the voltage starts high and lowers slightly with load, although it remains greater than at lesser speeds (Speed 1 and Speed 2). This indicates that while the HAWT produces more current at higher wind speeds, the voltage decreases slightly as the load increases, demonstrating efficiency varies with load and wind speed.

Table 6 shows the results of voltage and current measurements under no-load conditions and load variations on the VAWT. The VAWT test data indicate that the voltage and current produced by the turbine grow as the wind speed rises, but their overall magnitudes are lower than those of the HAWT. No-load voltage rises from 7.8 V to 8.56 V, whereas current rises from 0.2 A to 0.43 A.

Table 6. VAWT test data with loading variations.

Parameters	Wind Velocity (m/s)		
	Speed 1	Speed 2	Speed 3
No load voltage (V)	7.8	8.17	8.56
No load current (A)	0.2	0.32	0.43
Loading (Watt)	**Voltage (Volt)**		
5	3.2	4.8	6.1
10	3.2	4.5	4.5
15	3.1	4.5	5.6
Loading (Watt)	**Current (Ampere)**		
5	0.2	0.24	0.44
10	0.23	0.32	0.26
15	0.19	0.26	0.43

During periods of increased wind speed, the voltage and current of the system experience an upward trend. However, these changes exhibit more fluctuations compared to those observed in the Horizontal Axis Wind Turbine (HAWT). As an illustration, when subjected to a 5-watt load, the voltage rises from 3.2 volts to 6.1 volts, while the current increases from 0.2 amperes to 0.44 amperes. When subjected to a 15-Watt load, the voltage fluctuates between 3.1 volts and 5.6 volts, while the current fluctuates between 0.19 amperes and 0.43 amperes. This demonstrates that while the VAWT can enhance power production at elevated wind speeds, its ability to generate consistent voltage and current is inferior to that of the HAWT, particularly under heavy loads.

Based on the provided data, Figure 10 and Figure 11 illustrate the correlation between current, voltage, and load variations on the VAWT wind turbine. The data at Figure 10 shows that VAWTs' voltage decreases with load. At 1 m/s wind speed, the no-load voltage is 7.8 V, but 5 W decreases it to 3.2 V. Wind speeds of 2 and 3 m/s behave similarly. At the Figure 11, the current versus load variation pattern depends more on wind speed. At 1 m/s wind speed, the current increases from 0.2 A at no load to 0.44 A at 5 W, but at 2 m/s, it reduces from 0.32 A (no load) to 0.26 A (10 W load) before increasing again at 3 m/s. This analysis shows that the applied electrical load significantly affects turbine performance, lowering voltage and varying current depending on wind speed and load level.

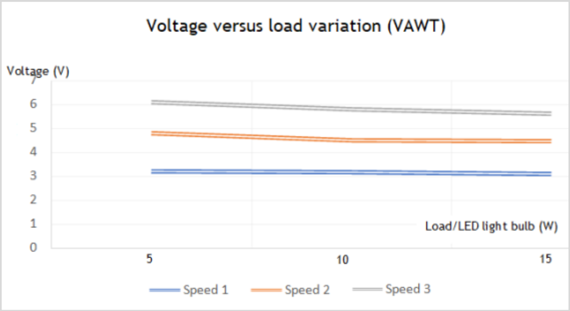

Figure 10. Voltage and load variation on VAWT.

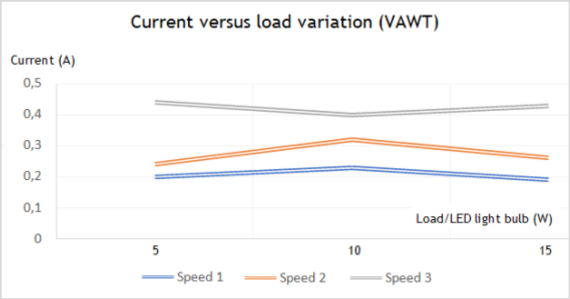

Figure 11. Current and load variation on VAWT.

Compared to a floating HAWT, a floating VAWT can minimize energy costs, making it ideal for offshore applications (Borg and Collu, 2015). VAWTs offer advantages such as lower inclining moment, higher torque, and reduced support structure costs, making them a viable option for floating platforms (Koppenol, 2016). The aerodynamic forces generated by VAWTs on the support structure differ significantly from HAWTs, impacting static and dynamic responses, with VAWTs experiencing increased motion in specific frequency ranges (Nielsen, Hanson and Skaare, 2008). Although HAWT have been extensively researched and used in offshore settings, the progress in developing floating VAWT is still at a preliminary stage (Marten *et al.*, 2017). VAWT may improve wind power plant output and dependability for deep-water floating systems, according to multi-criteria experiments. This makes them a viable option as an alternative for offshore wind farms.

4. CONCLUSION

According to the provided data, it appears that HAWT is a more appropriate choice for installing in floating net cages as opposed to VAWT. The HAWT and VAWT battery charging experiments show a consistent voltage increase pattern with wind speed and charging period. In HAWT, the minimum voltage rise is 2.2 m/s with a 5-minute 0% charging time, while the maximum is 1.2 m/s with a 15-minute 38.1% charging time. VAWT has a minimum voltage rise of 9.5% at 2.2 m/s and a charging time of 5 minutes and a high of 76.9% at 1.2 m/s and 15 minutes. This shows that both types of wind turbines convert wind energy into electricity more efficiently at higher wind speeds and longer charging times. The experimental results indicate HAWT and VAWT performance differences with varied loads and wind speeds. HAWT's minimum voltage increase is -30.7% at 2.2 m/s with a 10 watt load, and its highest current increase is 100% at 1.2 m/s. VAWT has a minimum voltage increase of -60.3% at 1.2 m/s with a 5 watt load and a maximum current increase of 69.2% at 3.4 m/s with a 10 watt load. HAWT is more stable than VAWT, especially when voltage and current increase at varied loads and wind speeds, indicating improved electrical energy efficiency.

In addition, HAWT have superior efficiency in producing large amounts of power, which is crucial for supplying energy to monitoring, surveillance, and data processing devices located inside the cage. HAWT is a more dependable option to meet the energy needs of applications like floating net cages because it can produce a higher and more consistent voltage at varying wind speeds, even though VAWT exhibits better current stability at different loads.

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