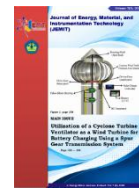




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Utilization of a Cyclone Turbine Ventilator as a Wind Turbine for Battery Charging Using a Spur Gear Transmission System

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Abstract

This study investigated the use of a cyclone turbine ventilator-type wind turbine for battery charging through a spur gear transmission system. The study aimed to determine the relationship between wind speed and turbine speed, investigate the effect of the driven-gear tooth ratio on generator speed, and evaluate the efficiency of the wind turbine in converting wind energy into electrical energy. Three driven gears with 10, 15, and 20 teeth were used, while the drive gear had 80 teeth. The experiment was conducted at Tanjung Tua Beach, Bakauheni, South Lampung, on January 8, 2023, from 12:00 p.m. to 3:00 p.m. The battery voltage increased by a total of 5 V during the 3-hour charging period, during which the three gear ratios were used alternately. The highest turbine efficiency was 1.843%, obtained when the 10-tooth driven gear was used. The results indicate that the gear-tooth ratio affects the transmission of turbine speed to the generator and consequently influences the electrical output and charging performance. The cyclone turbine ventilator-type wind turbine with a spur gear transmission system therefore has potential as a small-scale renewable energy system for battery charging.

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Abstrak

Penelitian ini bertujuan untuk memanfaatkan turbin angin tipe cyclone turbine ventilator untuk pengisian aki menggunakan sistem transmisi spur gear. Penelitian dilakukan untuk mengetahui hubungan antara kecepatan angin dan kecepatan turbin, menganalisis pengaruh rasio jumlah gigi gear driven terhadap kecepatan generator, serta menentukan efisiensi turbin angin dalam mengonversi energi angin menjadi energi listrik. Penelitian menggunakan tiga variasi gear driven dengan jumlah gigi 10, 15, dan 20, sedangkan gear drive memiliki 80 gigi. Pengujian dilakukan di Pantai Tanjung Tua, Bakauheni, Lampung Selatan, pada 8 Januari 2023, pukul 12.00–15.00 WIB. Hasil penelitian menunjukkan bahwa tegangan aki meningkat sebesar 5 V selama proses pengisian selama 3 jam dengan penggunaan ketiga rasio gigi secara bergantian. Efisiensi turbin tertinggi diperoleh sebesar 1,843% ketika menggunakan gear driven dengan 10 gigi. Hasil tersebut menunjukkan bahwa rasio jumlah gigi memengaruhi transmisi kecepatan turbin ke generator, sehingga turut memengaruhi keluaran listrik dan kinerja pengisian aki. Dengan demikian, turbin angin tipe cyclone turbine ventilator yang dilengkapi sistem transmisi spur gear berpotensi digunakan sebagai sistem energi terbarukan skala kecil untuk pengisian aki.

1. Introduction

The current need for electrical energy has become one of the important energies for human life, and its usage is increasing. The use of fossil fuels to generate electricity is not efficient due to the environmental pollution it produces. In addition, the supply of fossil fuels is gradually decreasing. To overcome dependence on fossil energy,

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conversion, conservation, and the development of new renewable energy sources are necessary. This development must consider energy, economics, and ecology. Therefore, alternative energy sources must be able to produce large amounts of energy at a low cost and without causing environmental damage (Culp, 1991).

Indonesia has a large potential for renewable energy sources to achieve its primary energy target, including wind energy with a potential of 94.3 GW, geothermal energy of 28.5 GW, bioenergy with a potential of 32.6 GW for PT Bio and 200 thousand Bph for BBN, solar energy with a potential of 207.8 GWP, wind energy with a potential of 60.6 GW, and ocean energy with a potential of 17.9 GW (Kementrian ESDM, 2019).

Wind turbines are a system that can convert wind energy (mechanical) into electrical energy. The wind energy that blows on the blades of the fan turbine generates a drag force that causes the turbine to rotate (Jamaludin, 2019). One of the important components of a wind turbine in converting mechanical energy into electrical energy is the generator. Wind turbine generators have specific specifications, namely the ability to generate electricity at low speeds (Nurtjahmulyo, 2010). Wind turbines use the speed of the wind to rotate the blades, which can then be converted into electrical energy. However, wind speed is not always constant (Supardi et al., 2016).

The weakness of renewable wind energy sources is the changing direction and speed of the wind. According to Sugiono et al. (2014), changes in wind direction and speed can be anticipated by using a vertical-axis wind turbine so that wind direction from any direction can be utilized by the wind turbine. The wind energy potential in Indonesia has an average speed ranging from 3.5 to 7 m/s (Saputra, 2016). The utilization of wind energy can be carried out in flat or highland areas and can even be applied at sea (Priyambodo and Agung, 2019). An instrument is needed to adjust wind energy results to convert them into electrical energy, namely by using multistage transmission (Sukandi et al., 2018).

Research on the use of cyclone-type wind turbines to convert renewable wind energy into electricity has been previously conducted. Parameters that can affect the performance of cyclone-type turbines include room temperature, inclination angle, and the number of blades (Karim and Sartika, 2018), as well as using additional transmission systems to accelerate the rotation of the generator, such as using belts to transmit from the turbine to the generator (Tumembow and Siwi, 2021), and using multistage spur gear transmission systems to transmit from the turbine to the generator (Budiprayitno et al., 2020).

Based on the above explanation, this study was conducted to create and utilize a cyclone-type wind turbine using a multistage spur gear transmission system to determine and analyze the relationship between wind speed and turbine speed. The variable used in this study is the gear ratio between the number of teeth on the gear driven and the generator speed. This study also analyzed the electrical characteristics of the generator (voltage (V), current (I)), the increase in battery voltage during charging using the generator through a solar charge controller, as well as analyzing the power generated by the generator and wind and the efficiency that can be produced by the turbine in converting renewable wind energy sources into electrical energy. The gear ratio used in this study is 10 teeth, 15 teeth, and 20 teeth.

2. Research Methods

This research was conducted in the Basic Electronics Laboratory of the Physics Department, Faculty of Mathematics and Natural Sciences, Lampung University, from September 2022 to January 2023. The study aimed to determine the power generated by the wind on the turbine and generator to activate a 12VDC 10W LED light. Thus, the power generated by the wind and the generator can be used to measure the efficiency of the turbine in converting wind energy into electricity.

Some parameters measured in this research include wind speed, turbine speed, generator speed, voltage and current of the generator, and battery voltage. There are two variables in this study, namely independent variables and dependent variables. Independent variables in this research include wind speed, the number of gears, and the diameter of the gear driven. Meanwhile, dependent variables in this study include the speed of the fan turbine, generator speed, voltage, and current.

The procedures in this research consist of several stages, including research preparation, designing and creating tool designs, testing the tool, and data collection. The research method used is quantitative because it involves the collection of numerical data, statistical analysis of data, and the generalization of results (conclusions drawn from the obtained data).

2.1 Research Preparation

In the research preparation stage, a literature review was conducted from various sources such as journals, books, websites, and theses on previous research as a basic reference for this study.

In this stage, equipment preparation was also carried out such as hand grinders, measuring tape, drill machines, lathe machines, multimeters, screwdrivers, pliers, anemometers, and tachometer sensors.

Meanwhile, the materials used in this study are threaded iron rods, cyclone wind turbines, pillow block bearings, DC generators, gears, bolts and nuts, solar charge controllers, and batteries.

2.2 Cyclone Turbine and Spur Gear System Design

In the design stage of the cyclone turbine system, Autodesk Fusion 360 software was used. The cyclone turbine used has 24 blades with a blade area of 0.040861 m² each. The total diameter of the cyclone turbine is 66 cm and the overall height of the turbine system is 1 m.

At the head of the turbine, a threaded iron rod is used as the shaft, with a length of 1 m and a diameter of 1.4 cm. The threaded iron rod is then mounted and secured to the head of the turbine using several bolts at the top and bottom of the turbine head.

The body of the turbine has a chimney-like shape with a height of 50 cm and a diameter of 35 cm. There are two sections on the body of the turbine, each with a width of 9 cm, and a distance of 15 cm between the top and bottom sections.

Pillow block bearings are installed at the top and bottom sections to support the load of the turbine head and maintain the rotation of the turbine head shaft. The design of the cyclone wind turbine system in this study is shown in Figure 1.

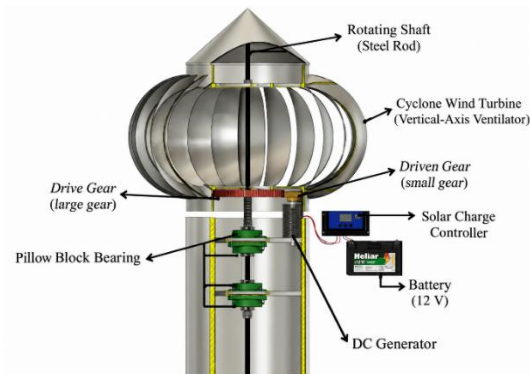


Figure 1. Cyclone wind turbine system design

Next, the design of the spur gear was carried out using *Camnetics Gear Treq 2021* software. This software is a plug-in for *Solidworks* and *Autodesk Inventor* software. It can instantly create any gear by inputting the desired gear ratio, one example of which is the spur gear.

The variable in this study is the gear ratio on the gear driven, which is 10, 15, and 20 teeth, while the driving-gear tooth ratio remains constant at 80 teeth. An example of the design of the gear and complete information in this study is shown in Figure 2 and Table 1.

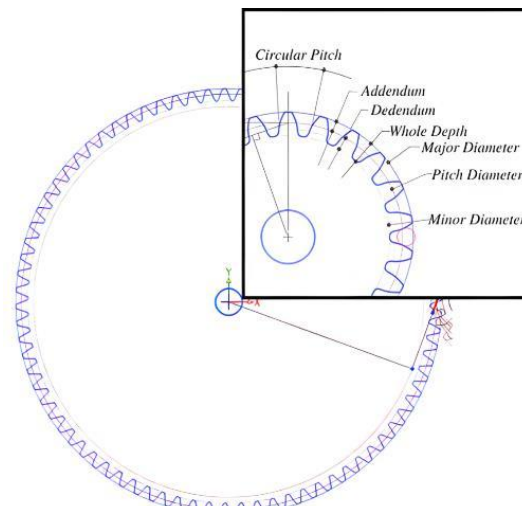


Figure 2. Design of the 80-tooth drive gear

Table 1. Spur gear design information

No.	Parameter	Gear Drive with an 80-tooth gear ratio (mm)	Gear Driven with a 10-tooth gear ratio (mm)	Gear Driven with a 15-tooth gear ratio (mm)	Gear Driven with a 20-tooth gear ratio (mm)
1	Circular Pitch	7.97965	7.97965	7.97965	7.97965
2	Pitch Diameter	203.200	25.400	38.100	50.800
3	Major Diameter	208.280	30.480	43.180	55.880
4	Minor Diameter	196.850	19.050	31.750	44.450
5	Addendum	2.540	2.540	2.540	2.540
6	Dedendum	3.175	3.175	3.175	3.175
7	Whole depth	5.715	5.715	5.715	5.715
8	Thickness	20	25	25	25

2.3 Testing and Data Collection

During the testing and data collection phase, it was conducted for 3 hours. In the first hour, equipment testing and data collection were carried out using a gear ratio of 80:10 for a 5-minute interval.

Then, in the second hour, equipment testing and data collection were carried out using a gear ratio of 80:15 for a 5-minute interval as well.

In the final hour, equipment testing and data collection were continued using a gear ratio of 80:20 within the same 5-minute interval as the others.

3. Results and Discussion

Research on the production and utilization of cyclone wind turbine using spur gear transmission for battery charging has been conducted. This study aims to determine the relationship between wind speed and the speed of the cyclone turbine that has been made, as well as the relationship between the ratio of driven gear teeth and the generator speed.

Additionally, this research also aims to determine the electrical characteristics such as voltage (V) and current (I) values, as well as the relationship of battery voltage during the charging process using each ratio of driven gear teeth.

Therefore, the amount of power generated by the wind and generator can be used to measure the efficiency of the turbine in converting the renewable energy source of wind into electricity.

The research was conducted at Tanjung Tua Beach on Sunday, January 8th, 2023. Data collection was carried out for 3 hours, starting from 12:00 PM to 3:00 PM.

Data collection using a gear ratio of 80:10 was conducted for one hour, from 12:00 PM to 1:00 PM, followed by data collection using a gear ratio of 80:15 from 1:05 PM to 2:00 PM, and data collection using a gear ratio of 80:20 was conducted from 2:05 PM to 3:00 PM.

The wind speed was measured using an anemometer. Meanwhile, the measurement of the turbine and generator speed was carried out alternately using a tachometer with a laser target point on one of the turbine blades and on the "konde" of the driven gear.

Furthermore, the measurement of the voltage and current generated by the generator was carried out alternately using a digital multimeter with a load in the form of a 12 VDC 10 W LED lamp. Meanwhile, the measurement of the battery voltage was observed on the solar charge controller screen.

3.1 The Effect of Wind Speed on Turbine Speed

The speed generated by the turbine tends to increase significantly with the increase of wind speed when using each ratio of gear driven. The constantly changing wind speed at every moment causes the turbine speed to be different for each use of the gear-driven ratio.

The highest turbine speed was 408.9 rpm, obtained using the 20-tooth driven gear. This result may be associated with the lower mechanical loading and different rotational characteristics of the transmission configuration. However, the contribution of gear inertia cannot be confirmed without measurements of gear mass, geometry, and torque (Halliday, 1992).

Also, in the case of rotating objects like gears, the kinetic energy is important and the moment of inertia of an object plays a significant role in storing kinetic energy. The larger the mass and radius values of the gear, the greater the moment of inertia of the object, and the larger the moment of inertia and speed of the object when rotating, the greater the kinetic energy value contained in the object.

According to Tang et al. (2008), in their study, explained that the influence of turbine inertia moment can affect the average output power of wind turbines. Turbine inertia can affect the dynamic response of a wind turbine to changes in wind speed and may influence the resulting power output.

Based on simulation results in the study, it is also explained that the average frequency of wind speed affects the output power. When the wind experiences rapid speed changes, these factors increase, resulting in a greater power reduction in wind turbines.

The graph of the data and the linear regression analysis of the relationship between wind speed and turbine speed are shown in Figure 3. Meanwhile, the analysis of the minimum, maximum, and average values of turbine speed is shown in Table 2.

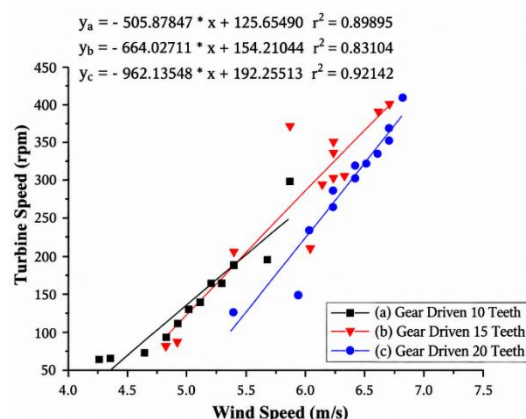


Figure 3. Graph of the relationship between wind speed and turbine speed

Table 2. Analysis of minimum, maximum, and average turbine speeds

The ratio of the number of teeth on gear driven	Turbine minimum (rpm)	Wind speed (m/s)	Time	Turbine maximum (rpm)	Wind speed (m/s)
10	61.8	4.3	12:20	297.8	6
15	81.5	4.9	13:10	400	6.9
20	124.2	5.5	14:05	408.9	7

3.2 The Effect of Gear Driven Gear Ratio on Generator Speed

All changes in the generator speed when using each gear ratio of gear driven increase significantly with the increase in turbine speed.

Although the speed produced by the turbine is smaller compared to when using the other two gear ratios, the highest generator speed is achieved when using the gear driven with a gear ratio of 10 or with an 80:10 ratio between the gear drive and gear driven, which is 2127.8 rpm.

This is due to the larger gear ratio compared to the other two gear ratios. According to Sa'diyah et al. (2022) in equation 1, the larger the gear ratio between gear drive and gear driven, the larger the angular speed on the gear driven.

Therefore, gears with gear ratios of 80:15 and 80:20 can only produce lower generator speeds than 80:10.

$$n_A \omega_A = n_B \omega_B \quad (1)$$

The graph of data and linear regression analysis of the relationship between the gear tooth ratio and the generator speed is shown in Figure 4. Meanwhile, the analysis of the minimum, maximum, and average values of the generator speed is shown in Table 3.

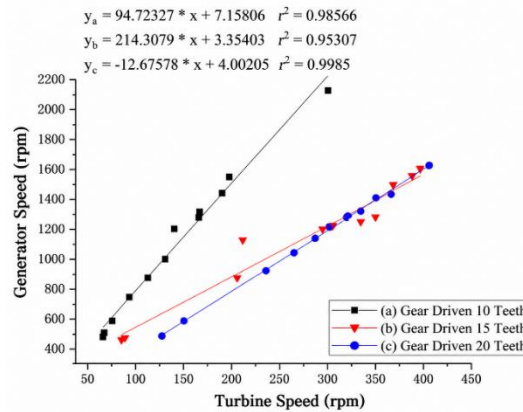


Figure 4. Graph of the relationship between gear driven gear ratio and generator speed

Table 3. Analysis of minimum, maximum, and average generator speeds

Ratio of the number of teeth on gear driven	Generator minimum (rpm)	Turbine (rpm)	Time	Generator maximum (rpm)	Turbine (rpm)	Time	Average generator speed (rpm)
10	474.1	61.8	12:20	2127.8	297.8	12:50	1090.76
15	453.2	81.5	13:10	1604	400	13:45	1146.53
20	477.5	124.2	14:05	1621.6	408.9	14:50	1144.41

3.3 The Effect of Generator Speed on Voltage and Current Produced

The generator voltage increased significantly but not regularly with the increase in generator speed when using each gear ratio of the gear driven.

This is due to the smaller gear ratio of the gear driven compared to the other 2 gear ratios, causing the generator to spin faster and produce a higher voltage. The highest generator voltage was obtained when using the gear driven with a gear ratio of 10, which is 9.8 V.

The graph of the data and linear regression analysis of the relationship between generator speed and the voltage produced are shown in Figure 5. Meanwhile, the analysis of the minimum, maximum, and average values of the generator voltage is shown in Table 4.

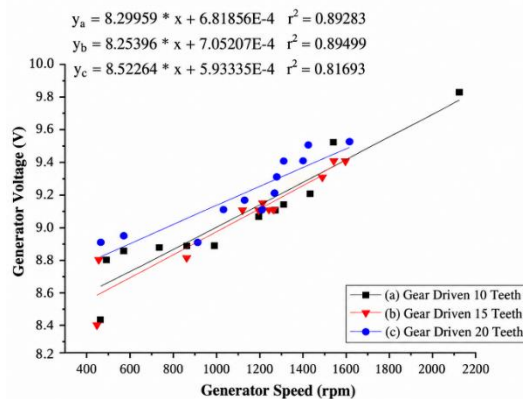


Figure 5. Graph of the relationship between generator speed and the voltage produced

Table 4. Analysis of minimum, maximum, and average generator voltage

Ratio of the number of teeth on gear driven	Generator voltage minimum (V)	Generator speed (rpm)	Time	Generator voltage maximum (V)	Generator speed (rpm)
10	8.43	474.1	12:20	9.8	2127.8
15	8.4	453.2	13:10	9.4	1604
20	8.9	477.5	14:05	9.52	1621.6

Meanwhile, the generator current experiences a drastic increase at some points of the generator speed, resulting in a graph that almost curves upwards. The highest current value measured by the multimeter is 0.15 A.

The graph of data and polynomial regression analysis of the relationship between generator speed and the current it produces is shown in Figure 6. Meanwhile, the analysis of the minimum, maximum, and average values of the generator current is presented in Table 5.

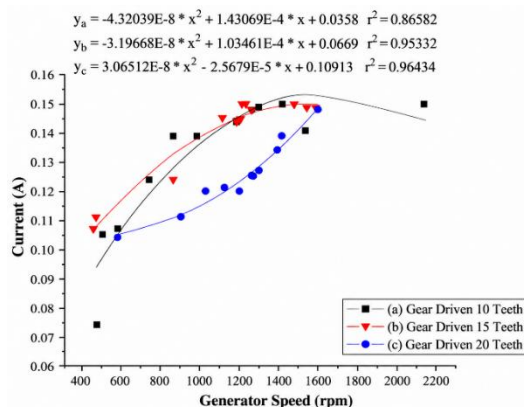


Figure 6. Graph of the relationship between generator speed and current produced

Table 5. Analysis of minimum, maximum, and average generator current

Ratio of the number of teeth on gear driven	Generator current minimum (A)	Generator speed (rpm)	Time	Generator current maximum (A)	Generator speed (rpm)
10	0.074	474.1	12:20	0.150	3238.8
15	0.107	453.2	13:10	0.149	1604
20	0.104	581.7	14:10	0.148	1621.6

3.4 Battery Charging

The battery voltage during the charging process experienced a significant increase. The initial battery voltage before charging was 7.7 V.

After 60 minutes of charging using gear driven with a gear ratio of 10, the battery voltage increased by 0.7 V. Continuing with gear driven with a gear ratio of 15 for 60 minutes, the battery voltage increased by 1.6 V. Then, using a gear driven with a gear ratio of 20 for 60 minutes, the battery voltage increased by 2.7 V.

Therefore, the total increase in battery voltage during the 180-minute or 3-hour charging process was 5 V. The increase in battery voltage during the charging process using the generator through the solar charge controller is shown in Figure 7.

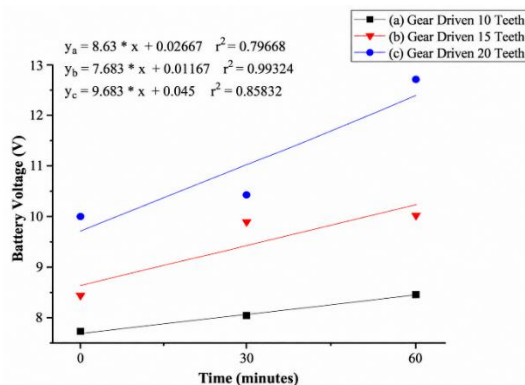


Figure 7. Graph of battery voltage during charging

3.5 Analysis of Wind Power, Generator Power, and Equipment Efficiency

In this study, an analysis of the power generated by the generator was performed based on the voltage and current data produced by it. The power can be calculated using equation 2, with $P_{Generator}$ = generator electrical power (W), $V_{Generator}$ = generator voltage (V), and $I_{Generator}$ = generator current (A).

$$P_{Generator} = V_{Generator} I_{Generator} \quad (2)$$

Meanwhile, in this study, an analysis of the power generated by the wind turbine was also conducted. The power generated by the wind can be calculated using equation 3, where P_{wind} = power generated by the wind (W), ρ = air density (average ρ air = 1.2 kg/m³), A = area of the turbine blade (0.040861 m² × 24 blades = 0.588408 m²), v_{wind} = wind speed (m/s).

In this study, it was assumed that the wind was evenly distributed across each turbine blade and had the same speed.

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

Thus, the calculation results of generator power using equation 2 and wind power using equation 3 are plotted in Figure 8. Meanwhile, the analysis of the minimum, maximum, and average values of generator and wind power is shown in Table 6.

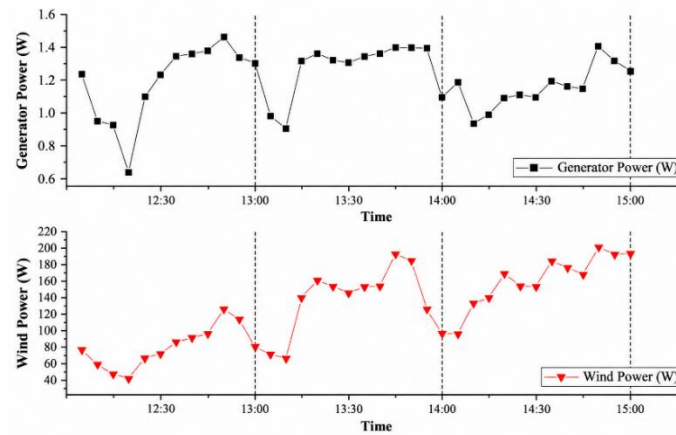


Figure 8. Graph of power generated by the generator and wind

Table 6. Analysis of minimum, maximum, and average generator and wind power

Power	Ratio of the number of teeth on gear driven	PMin (W)	Time	PMax (W)	Time
Generator	10	0.62	12:20	1.47	12:50
Generator	15	0.9	13:10	1.4	13:55
Generator	20	0.93	14:10	1.41	14:50
Wind	10	46.78	12:20	127.1	12:50
Wind	15	69.23	13:10	193.3	13:45
Wind	20	97.9	14:05	201.82	14:50

Based on the calculation results using equations 2 and 3, the power generated by the generator is smaller compared to the power generated by the wind. This is because the generator used is a small-scale generator, so the power it generates is not as large as the power generated by the wind, which has reached its maximum operating point.

Therefore, the efficiency of the cyclone wind turbine using a spur gear transmission system in converting renewable wind energy into electricity can be calculated using equation 4, where η = efficiency of the system (turbine) (%), $P_{Generator}$ = generator power (output) (W), and P_{Wind} = wind power (input) (W).

$$\eta = \frac{P_{Generator}}{P_{wind}} \times 100\% \quad (4)$$

According to the calculation results using equation 4 to determine the efficiency of the cyclone wind turbine in converting renewable wind energy into electrical energy, the efficiency of the turbine decreases as the wind speed increases.

This is because the power generated by the generator cannot match the power generated by the wind speed. Although there is a slight increase in wind speed, it can significantly affect the power generated by the wind, while the increase in the generator's power is not as significant.

The highest turbine efficiency occurred when using a gear driven with a gear ratio of 10, which is 1.843%. This is because the gear ratio between the gear drive and the gear driven is greater, allowing the generator to rotate faster and generate a larger current during charging.

The efficiency calculation results using equation 4 are then plotted in Figure 9, while the analysis of the minimum, maximum, and average turbine efficiency values are shown in Table 7.

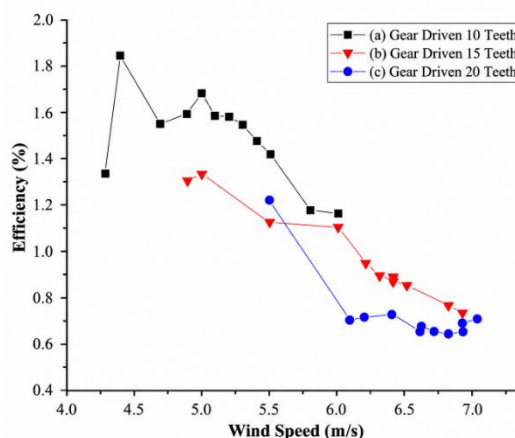


Figure 9. Graph of the relationship between wind speed and turbine efficiency

Table 7. Analysis of minimum, maximum, and average turbine efficiency

Ratio of the number of teeth on gear driven	Minimum turbine efficiency (%)	Wind speed (m/s)	Time	Maximum turbine efficiency (%)	Wind speed (m/s)	Time
10	1.156	4.3	12:20	1.843	6	12:50
15	0.724	4.9	13:10	1.328	6.9	13:45
20	0.645	5.5	14:05	1.218	7	14:50

4. Conclusion

The cyclone turbine ventilator equipped with a spur gear transmission system increased the battery voltage by 5 V during the 3-hour charging process. Among the tested configurations, the 80:10 drive-to-driven gear ratio produced the highest measured generator speed and the highest calculated wind-to-electrical conversion efficiency of 1.843%. The results indicate that the driven-gear tooth ratio influences the rotational speed transmitted to the generator and affects the electrical output of the system. However, the calculated efficiency depends on the accuracy of the swept-area determination and the theoretical wind-power estimation. Further experiments involving repeated measurements, uncertainty analysis, and direct measurement of mechanical shaft power are required to establish the performance of the system more reliably.

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