JURNAL TEKNIK MESIN (JOURNAL OF MECHANICAL ENGINEERING)

VOL. 14, NO. 02, June 2025
https://publikasi.mercubuana.ac.id/index.php/jtm/index
DOI : 10.22441/jtm.v14i2.15993

Design Analysis of Axial Flux Permanent Magnet Generator for Exhaust AC Version-3 Type B Output Wind Power Plant Prototype

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Abstract--*Outside AC exhaust wind power plant is one of the micro-scale renewable energies developed in the last five years. One of the main components of a power plant is a generator. The generator is a device that converts mechanical energy into electrical energy. An axial flux permanent magnet generator is believed to be the most appropriate generator for a power plant with a low-speed wind power source, such as outside AC exhaust. A design analysis needs to be done to produce an axial flux permanent magnet generator capable of producing 12vdc electric voltage, which will be used to charge the battery. This research uses the theoretical calculation analysis method on three rotor designs with different sizes and obtained rotor design 1 with the most considerable maximum flux value of 0.000998352 Wb. The calculation of the generator output planning signifies that to obtain an output voltage of 12 Vdc at a frequency of 20 Hz, 166 turns of wire are needed. The output of 12.8 Vdc was successfully generated after the generators were connected in series parallel at a frequency of 27.5 Hz. The wind speed entering the power plant inlet was 5.8 m/s, with generator one at a speed of 682 rpm, generator two at 749 rpm, and generator three at 888 rpm, which will then be used to charge the 12 Vdc battery. After a load test using a 12 Vdc 6Watt lamp on the designed axial flux permanent magnet generator, it can be seen that the voltage drop begins to occur at a frequency of 22.5 Hz when the current flow begins to rise. During the no-load test, at a frequency of 22.5 Hz, the measured DC voltage was 9.2 Vdc. Meanwhile, when testing with a 12 Vdc 6Watt lamp load at a frequency of 22.5 Hz, the measured voltage is 5 Vdc. There is a voltage drop of 4.2 Vdc. Furthermore, there is a voltage drop of 2.8 Vdc, 3.8 Vdc, 4.6 Vdc, and 5.2 Vdc at 25 Hz, 27.5 Hz, 30 Hz, and 32.5 Hz. This prototype of an outside AC exhaust wind power plant is expected to be useful for daily needs in the community*

Article History:
Received: July 14, 2022
Revised: January 20, 2025
Accepted: February 4, 2025
Published: May 24, 2025

Keywords: *Renewable energy, Wind power plant, AFPMG*

1. INTRODUCTION

1.1 Background

Electrical energy is an important element in the movement of human activities, both as household needs and industrial and commercial production needs. This is shown by the consistently high demand for electrical energy compared to other types of energy. The electricity demand growth in 2050 is projected to increase 9 times compared to 2018 [1].

Overall, the increase in electricity demand will impact per capita electricity income. Per capita electricity demand in 2025 will reach 2,030 kWh/capita (BaU), while per capita electricity demand in 2050 will reach 6,723 kWh/capita (BaU). This condition is still below the per capita electricity target contained in the KEN, which is 2,500 kWh/capita in 2025 and 7,500 kWh/capita in 2050. The development of electricity consumption per capita in all scenarios can be seen in Figure 1.

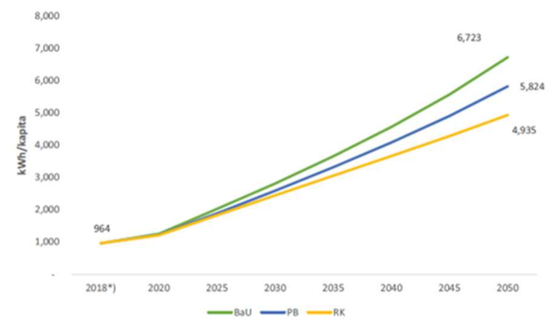

Figure 1. Electricity Consumption Development per Capita

To meet the demand for electricity in Indonesia in the coming year, the community can help by using their power plants on a micro scale for household needs. In general, power plants that can be used on a household scale are solar power plants with the help of solar panels. However, in the past few years, other energy uses have begun to be successfully developed on a micro scale for household purposes. In 2018, Anggun Febrianto and his team used wind power in the AC capacitor to generate electricity. The power plant built by Anggun Febrianto and his team can produce a voltage output of 7V and a power of 3.2W. In theoretical calculations where the generator rotates at a speed of 666 rpm and a frequency of 50 Hz, the voltage generated is 40.29V, while the voltage generated is 7V. There is a theoretical difference between the calculation and the measurement of 33.29 volts, so the actual power produced is only 17.37% of the expected voltage [2].

In 2020, Ali Raharjo and his team made improvements to the power plant made by Anggun Febrianto in 2018. The AC condenser wind power plant increased the voltage output to 14.82V, producing 7.3W of power. In theoretical calculations where the generator rotates at a speed of 300 rpm and a frequency of 60 Hz, the voltage generated is 34.54V, while in reality, the voltage generated is 14.82V. There is a difference in theoretical calculation with the actual measurement of 19.75 volts, so the actual voltage produced is only 42.86% of the expected voltage [3].

The increase in work performance from the power plant was significant and could still be developed by redesigning and improving. Based on the two designs of AC condenser wind power plants carried out previously, the author and his team will make improvements by designing and building a power plant and redesigning it.

The author analyzes the generator's design used in the designed power plant. Axial flux permanent magnet generators are believed to be the most appropriate type of generator to be applied to a power plant with a wind power source at speed [4]. The electrical energy produced will recharge a 12 Vdc battery, which can later be used for daily activities. Electrical energy output testing also needs to be carried out to determine the designed generator's characteristics.

A generator is a device that converts mechanical energy into electrical energy. The electrical energy produced by the generator can be in the form of AC electricity (alternating current electricity) or DC (direct electricity). This depends on the type of generator used in a power plant [5]

An AC generator is a generator that generates alternating current electricity. An AC generator is a type of simultaneous machine (synchronous engine) where the frequency of electricity produced is proportional to the number of poles and revolutions it has [6].

A DC generator is a dynamic electrical machine that converts mechanical energy into electrical energy. DC generators generate DC or direct current. [7].

A Permanent Magnet Generator (PMG) is a synchronous generator whose magnetic field is generated by a permanent magnet, not by a coil, so a permanent magnetic field generates the magnetic flux. Permanent magnet generators (PMGs) are generally used to convert the mechanical power output of steam, gas, water, and wind turbines into electrical power [8].

A permanent magnet generator stator is a field coil composed of several coils of e-mail wire coated with insulating material. The number of coils affects the output voltage quantity of the generator. The series relationship of several coils determines the voltage output of the generator to be 1 phase or 3 phase [9].

A rotor is a part of a rotating generator. The rotor is divided into two types from its construction: generating a magnetic field from DC and using a permanent magnet to generate a direct current when induced by winding. The rotor is placed opposite the coil on the stator. The rotor that rotates in front of the stator will later cause GGL in the stator coil [10].

2. METHODOLOGY

2.1 Flow Diagram

The research process can be seen through the flow chart below.

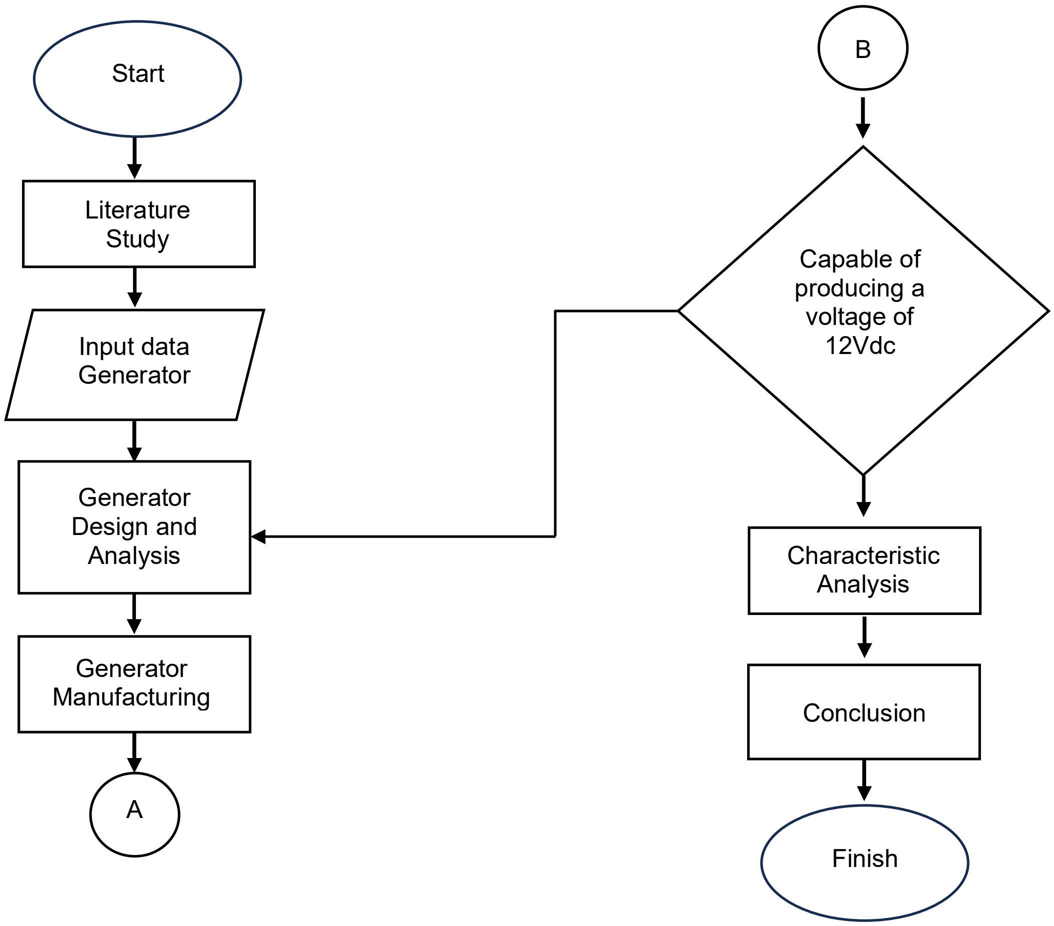

Figure 2. Research Flow Chart

2.2 Tools and Materials

a. Tools:
  1. Solidwork Software
  2. Soldering
  3. Cut Pliers
  4. Multimeter
  5. Tachometer
  6. Anemometer
  7. Variable Speed Driver
  8. Tarpaulin

b. Material:
  1. Email wire
  2. Acrylic
  3. Solder tin
  4. Neodymium Permanent Magnets
  5. Rectifier diodes

2.3 Rotor and Stator Design

Three different rotor designs are made with various sizes of neodymium magnets. The first design uses a 4x2 cm neodymium magnet, the second design uses a 3x2 cm neodymium magnet, and the third design uses a 2x1 cm neodymium magnet, which can be seen in Figure 3, Figure 4, and Figure 5.

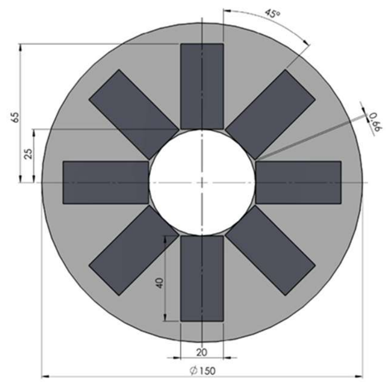

Figure 3. Rotor Design 1

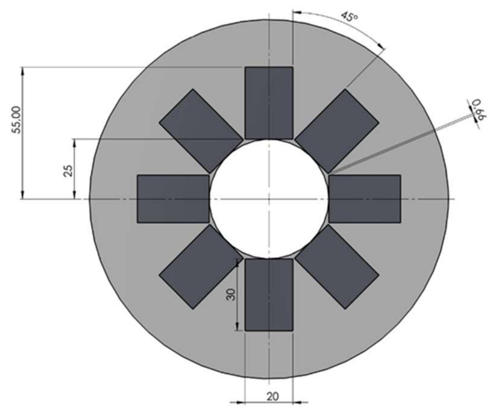

Figure 4. Rotor Design 2

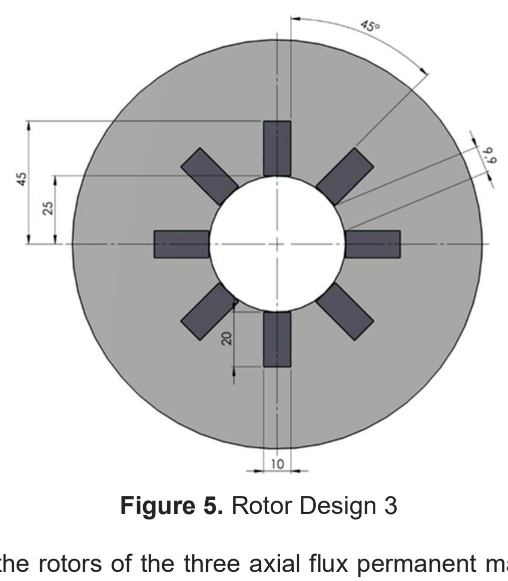

Figure 5. Rotor Design 3

The theoretical calculation of the rotors of the three axial flux permanent magnet generator variations was analyzed to find the maximum flux value (Ømax). With a considerable maximum flux value, for the generator to produce 12Vdc, the number of coil windings on the generator stator can be reduced to be more cost-effective.

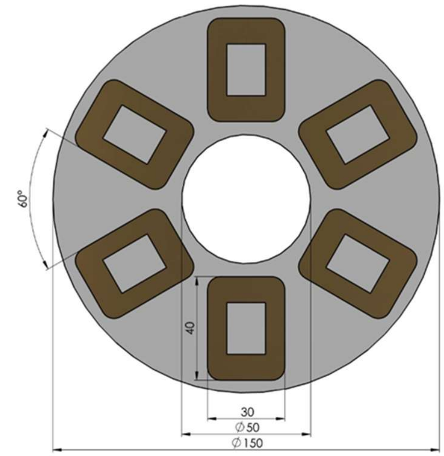

Figure 6. Stator Design

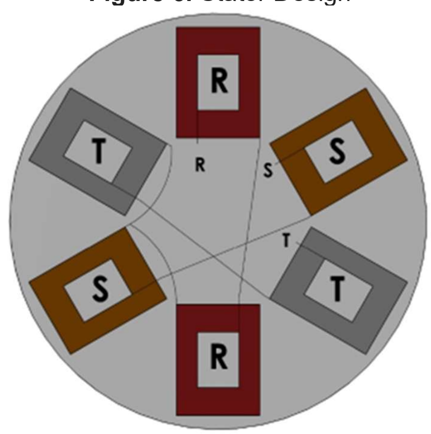

Figure 7. Wiring Stator

Figure 6 shows the design of a stator with a total of 6 coils. The designed generator is a 3-phase voltage generator using a star coil connection, where each group of copper wire coils (phase coils) is connected into one, as seen in Figure 7.

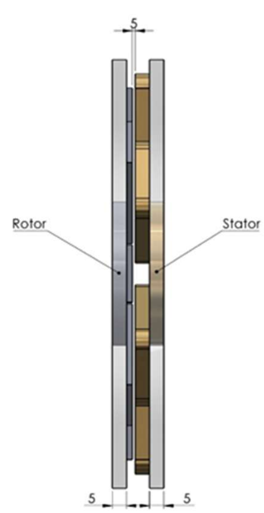

Figure 8. Couple Rotor Stator

Figure 8 shows the relationship between the rotor and stator with an air gap designed of 5 mm.

2.4 Generator Output Block Diagram

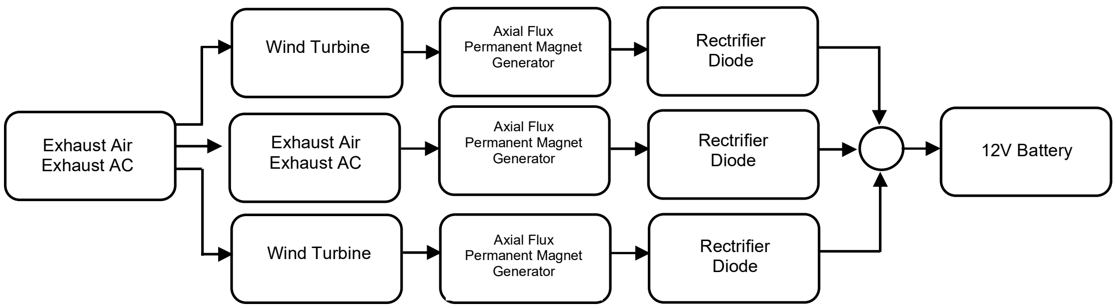

Figure 9. Generator Output Block Diagram

Figure 9 shows a representation of the generator output block diagram. The wind from the exhaust air conditioner will rotate the wind turbine. Wind turbines are connected to generators and generate AC voltage. The AC voltage is converted to DC voltage through a rectifier diode for battery charging. The DC voltage of each generator will be connected in series in parallel to produce greater power and then used to charge a 12V DC battery.

3. RESULT AND DISCUSSION

2.1 Analysis of Theoretical Calculations

It is known that the magnetic flux density of the N-52 neodymium magnet is 1.44 T, the magnetic thickness is 0.005 m, and the air gap width is 0.005 m. Then, the maximum flux density can be calculated through the following Equation (1):

$$B_{Max} = B_r \cdot \frac{l_m}{l_m + \delta} \quad (1)$$

$$B_{Max} = 1.44\,T \cdot \frac{0.005\,m}{0.005\,m + 0.005\,m}$$

$$B_{Max} = 0.72\,T$$

With the design of 3 different rotor designs, the area of the magnet can be calculated with variations in magnet size through Equation (2) in Table 1.

$$A_{magn} = \frac{\pi\,(r_0^2 - r_i^2) - \tau \quad (r_0 - r_1)N_m}{N_m} \quad (2)$$

Table 1. Magnetic Area Size

Design	r_o (m)	r_i (m)	τf (m)	A_{magn} (m^2)
Design 1	0.065	0.025	0.00066	0.001387
Design 2	0.055	0.025	0.00066	0.0009222
Design 3	0.045	0.025	0.0099	0.0003515

Once the maximum flux density value and the area of the magnet are known, the maximum flux can be calculated through Equation (3) listed in Table 2.

$$\emptyset_{max} = A_{magn} \times B_{max} \quad (3)$$

Table 2. Maximum Flux Value

Designers	Magnetic Area Size(m^2)	Maximum Flux Density	Maximum Flux (Wb)

	(T)		
Design 1	0,001387	0,72	0,000998352
Design 2	0,0009222	0,72	0,000663984
Design 3	0,0003515	0,72	0,00025308

The calculation analysis results in Table 2 show that the maximum flux value in Design 1 is 0.000998352 Wb. So, the only design used as a rotor in the AC exhaust power plant version-3 type B. Figure 10 shows the rotor of the generator that has been made.

Figure 1. Rotor Generator

2.2 Generator Output Planning Calculation
The voltage output to be generated is 12V DC. To get the output, the maximum voltage needed can be calculated using Equation (4)

$$V_{maks} = V_{outDC} + 1{,}4 \quad (4)$$
$$V_{maks} = 12 + 1{,}4$$
$$V_{maks} = 13.4\,V$$

After obtaining the maximum voltage, the rms voltage (Vrms) can be calculated using Equation (5)

$$V_{rms} = \frac{V_{maks}}{\sqrt{2}} \quad (5)$$

$$V_{rms} = \frac{13.4}{\sqrt{2}} = 9.48\,V$$

Equation (6) can be used to determine the number of wire windings required to generate a voltage of 12Vdc.

$$E_{rms} = \frac{2\pi}{\sqrt{2}}\,N.f.\emptyset_{max}.\frac{N_s}{N_{ph}} \quad (6)$$

Then,

$$N = \frac{E_{rms}\,.N_{ph}}{4.44\,.f.\emptyset_{max}.N_s}$$
$$N = \frac{9.48\,.\,3}{4.44.20, 0.000318816, 6}$$
$$N = 166\,coil$$

So, to produce a voltage of 12V DC at a frequency of 20 Hz without load, 166 wire windings are needed on the generator's stator. Figure 11 shows the generator stator that has been created.

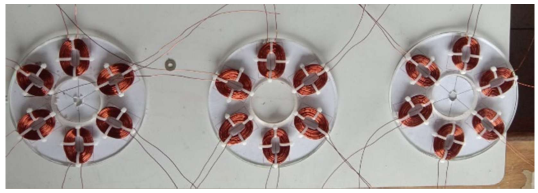

Figure 11. Stator Generator

2.3 No-Load Testing

The no-load test is carried out by varying the frequency of the variable speed driver, which then regulates the fan motor speed that blows the airflow into the inlet of the power plant.

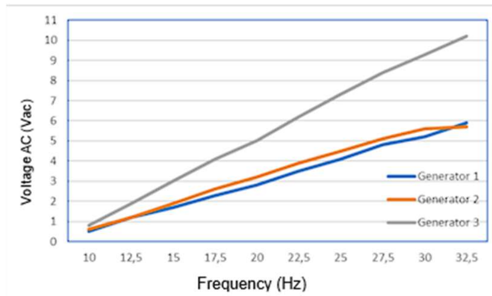

Figure 2. Frequency vs AC Voltage Graph

In Figure 12, you can see the frequency vs AC voltage graph. It is determined that 10 frequencies start from 10 Hz to 32.5 Hz, which can be adjusted using the Variable Speed Driver (VSD). The frequency set on the VSD then controls the rotation speed of the fan motor that blows wind on the generator. Each generator responds to gusts of wind and rotates at different rpm speeds. This causes the voltage produced to vary in each generator. The greater the frequency set at the VSD, the greater the wind gust that enters the power plant inlet until the greater the rotation in the generator, which causes the higher voltage generated. At the lowest frequency of 10 Hz, Generator 1 outputs a voltage of 0.5 V AC, Generator 2 outputs a voltage of 0.6 V AC, and Generator 3 outputs a voltage of 0.8 V AC. At the highest frequency of 32.5 Hz, Generator 1 outputs a voltage of 5.9 V AC, Generator 2 outputs a voltage of 5.7 V AC, and Generator 3 outputs a voltage of 10.2 V AC.

After the AC voltage is generated, the AC voltage output is turned into a DC voltage output using a full-wave rectifier diode. The magnitude of the DC voltage can be seen in Figure 13.

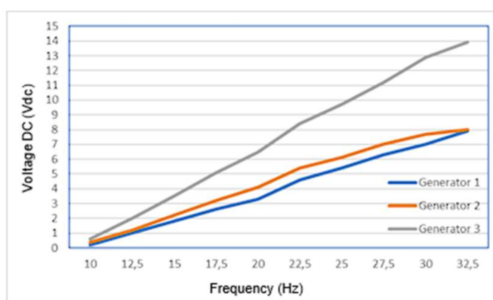

Figure 13. Frequency vs DC Voltage Chart

Like AC voltage testing, DC voltage testing is carried out by adjusting the frequency at VSD from 10 Hz to 32.5 Hz. Due to the rpm rotation of different generators, each generator's DC voltage produced is also different. At the lowest frequency of 10 Hz, Generator 1 outputs a voltage of 0.2 V DC, Generator 2 outputs a voltage of 0.4 V DC, and Generator 3 outputs a voltage of 0.6 V DC. Furthermore, at the intermediate frequency of 22.5 Hz, Generator 1 outputs a voltage of 4.6 V DC, Generator 2 outputs a voltage of 5.4 V DC, and Generator 3 outputs a voltage of 8.4 V DC. At the highest frequency, 32.5 Hz, Generator 1 outputs a voltage of 7.9 V DC, Generator 2 outputs a voltage of 8 V DC, and Generator 3 outputs a voltage of 13.9 V DC. A voltage increase occurs after the AC voltage is converted to DC voltage.

Furthermore, because the voltage in generator 3 is too large compared to generator one and generator 2, a series-parallel scheme produces a more maximum output. Generator 1 and Generator 2 are assembled in series and then parallel to Generator 3. The voltage output at the power plant when it is not overloaded can be seen in Figure 14.

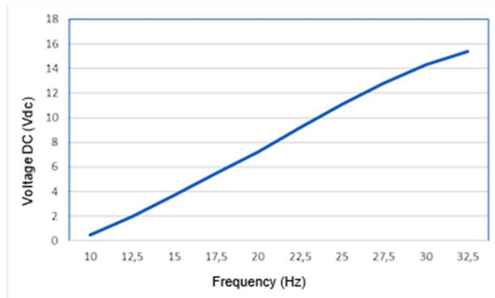

Figure 3. Series-Parallel DC Voltage Graph

From Figure 14, it can be seen that the amount of DC voltage generated after the three generators are connected in series-parallel. There is an increase in voltage compared to before it was assembled in series-parallel. At 10 Hz frequency, the voltage output is 0.5 V DC. At the frequency of 12.5 Hz, the voltage output is 2 V DC. At 15 Hz, the voltage output is 3.7 V DC. At 17.5 Hz, the voltage output is 5.5 V DC. At 20 Hz, the voltage output is 7.2 V DC. At 22.5 Hz, the voltage output is 9.2 V DC. At 25 Hz, the voltage output is 11.1 V DC at the frequency of 27.5 Hz, which 12.8 V DC emits. At a frequency of 30 Hz, the voltage output is 14.3 V DC. Finally, at 32.5 Hz, the voltage output is 15.4 V DC. The designed DC voltage, which is 12 Vrdc, can be generated at a frequency of 27.5 Hz with a wind speed that enters the inlet of the power plant of 5.8 m/s.

2.3 Testing with Load

Like no-load testing, this process is carried out by varying the frequency of the variable speed driver, which then regulates the fan motor's speed that blows airflow into the inlet of the power plant. However, the power plant's output is connected to the load, which is a 12 V DC 6-watt lamp.

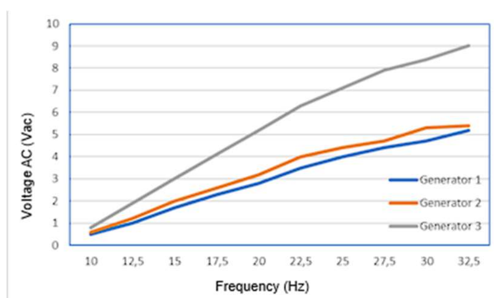

Figure 15. Frequency vs AC Voltage With Load Graph

It can be seen in Figure 15, the AC voltage generated after being loaded with a lamp load of 12 V DC 6 Watts. Just like in the no-load generator test, each generator responds to wind gusts and rotates at different rpm speeds. This causes the voltage produced to vary in each generator. The greater the frequency set at the VSD, the greater the wind gust that enters the power plant inlet until the greater the rotation in the generator, which causes the higher voltage generated. At the lowest frequency of 10 Hz, Generator 1 outputs a voltage of 0.5 V AC, Generator 2 outputs a voltage of 0.6 V AC, and Generator 3 outputs a voltage of 0.8 V AC. At the highest frequency of 32.5 Hz, Generator 1 outputs a voltage of 5.2 V AC, Generator 2 outputs a voltage of 5.4 V AC, and Generator 3 outputs a voltage of 9 V AC. No voltage change is too large in the AC voltage when given a lamp load of 12 V DC 6 W. This is especially true at low frequencies where the current has not been generated. The amount of current itself can be seen in Figure 16.

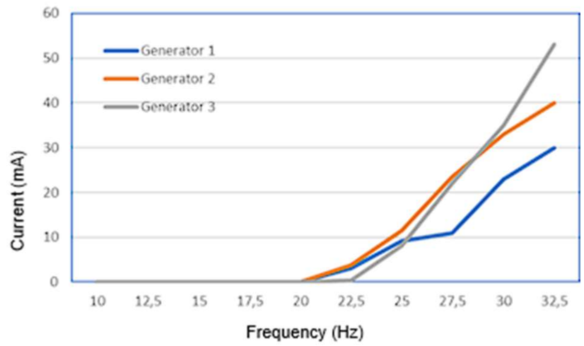

Figure 16. Frequency vs Current Graph

In Figure 16, it can be seen that the new current rises at a frequency of 22.5 Hz. At frequencies below 22.5 Hz, the multimeter meter cannot read the current that rises because the current is too small or below the instrument's limit. At a frequency of 22.5, generator 1 produces a current of 3 mA, generator 2 produces a current of 3.7 mA, and generator 3 produces a current of 0.3 mA. The current produced by generator 3 is tiny, but as the frequency increases, the current also increases. At a frequency of 32.5, generator 1 produces a current of 30 mA, generator 2 produces a current of 40 mA, and generator 3 produces a current of 53 mA. This occurred in line with the increase in AC voltage where generator three at high frequencies could spin faster than generators 1 and 2.

When the current rises, there begins to be a load on the voltage, so the voltage decreases. This can be proven in Figure 17.

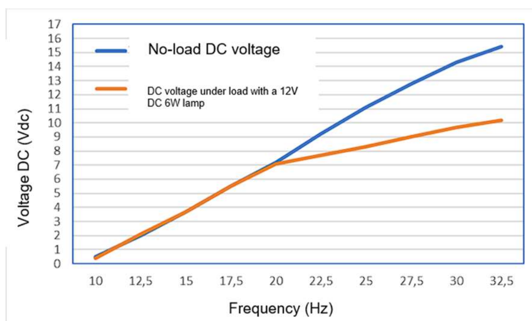

Figure 17. No-Load and With-Load DC Voltage Graphs

The test results of the no-load and loaded generators can be seen in Figure 17. At 22.5 Hz, the current starts to rise, as shown in Figure 16. When the current begins to rise, there is a decrease in voltage. At 20 Hz, where the current has not yet risen, the prevailing no-load DC voltage is 7.2 V DC, and the load DC voltage is 7.1. The voltage difference is not much different. However, when the current rises at a frequency of 22.5 Hz, the DC voltage without load is stable to 9.2 V DC, while the DC voltage when loaded is only 7.7 V DC. Continuing at the frequency of 27.5 Hz, the DC voltage without load is 12.8 V DC. In contrast, the DC voltage, when loaded, is 9 V DC. Until the highest frequency, 32.5 Hz, the DC voltage without load can rise by 15.4 V DC, while the DC voltage under load is only 10.2 V DC.

4. CONCLUSION

Based on the design analysis and testing of the tools that have been carried out, it can be concluded that:

1. Based on the analysis of the theoretical calculations carried out, the design rotor 1, with a size of 4x2 cm, is the rotor with the most considerable maximum flux of 0.000998352 Wb. The calculation of the generator output planning shows that to obtain a voltage output of 12 V DC at a frequency of 20 Hz, 166 wire windings are required. The output of 12.8 V DC was successfully generated after the generator was assembled in series and parallel at a frequency of 27.5 Hz.

The wind speed that entered the inlet of the power plant was 5.8 m/s, with the speed of generator one at 682 rpm, generator two at 749 rpm, and generator three at 888 rpm, which will then be used to charge the 12V DC battery.

2. After loading using a 12 V DC 6-watt lamp on the designed axial flux permanent magnet generator, it can be seen that the voltage drop begins to occur at a frequency of 22.5 Hz when the current flow begins to rise. During the no-load test, at a frequency of 22.5 Hz, the measured DC voltage is 9.2 V DC. During the test with a lamp load of 12 V DC 6Watt, at a frequency of 22.5 Hz, the measured voltage is 5 V DC. There is a voltage drop of 4.2 V DC. Subsequently, there is a voltage drop of 2.8 V DC, 3.8 V DC, 4.6 V DC, and 5.2 V DC at 25 Hz, 27.5 Hz, 30 Hz, and 32.5 Hz.

REFERENCES

[1] Suharyati, W. S. Hesti, P. J. Lastiko, and N. I. Pratiwi, *Outlook Energi Indonesia 2019*. Sekretariat General National Energy Council, 2019. [Online]. Available: https://www.esdm.go.id/assets/media/content/content-outlook-energi-indonesia-2019-bahasa-indonesia.pdf

[2] Anggun Febrianto, "Rancang Bangun Pemanfaatan Tenaga Angin Kondensor Air Condition Menjadi Tenaga Listrik." Universitas Mercu Buana, 2018.

[3] A. Raharjo, "Improvement Rancang Bangun Generator Listrik Tenaga Hembusan Angin Kondensor Dari Air Condition." Universitas Mercu Buana, p. 68, 2020.

[4] S. Rochman and A. Sujiwa, "Peningkatan Daya Output Generator Listrik Tipe AFMG Pada Putaran Rendah Menggunakan 3 Rotor dan 2 Stator," *Inovasi, Teknol. dan Pendidik. Guna Mewujudkan Indones. Sejah. di Era Ind. 4.0)*, 2018.

[5] W. Sunarlik, "Prinsip Kerja Generator Sinkron." Universitas Pawyatan Daha Kediri, 2017.

[6] A. Kadir, *Pembangkit Tenaga Listrik*. UI Press, 2010.

[7] H. S. Purnama, "Konstruksi Generator DC." Universitas Ahmad Dahlan, 2015.

[8] P. Hari and S. Walujo, "Prototipe Generator Magnet Permanen Axial AC 1 Fase Putaran Rendah Sebagai Komponen Pembangkit Listrik Tenaga Piko Hidro," *Techno, ISSN 1410 - 8607*, vol. 15, pp. 30–36, 2014, doi: 10.30595/techno.v15i2.91.

[9] H. Prasetijo, Ropiudin, and B. Dharmawan, "Generator Magnet Permanen Sebagai Pembangkit Listrik Putaran Rendah," *Din. Rekayasa*, vol. 8, no. 2, 2012.

[10] P. H. Alnur, "Perancangan dan Pembuatan Generator Tipe Magnet Permanen Flux Axial." Universitas Islam Indonesia, 2016.