Design Of A Permanent Magnet Generator Using The Axial Flux Method

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Abstract

Electricity is a vital need in both the economy and industry. It can be said that the availability of electricity has a significant impact on the welfare of society and the workforce today. Electricity services in Indonesia, especially in West Kalimantan, are provided by the State Electricity Company (PLN). However, not all areas are covered by PLN services. Therefore, the purpose of this study is to design a permanent magnet generator using the axial flux method. This tool has the following specifications: Input voltage of 12 Volts and can produce an output of up to 220 Volts with a minimum of 2 Amperes. With a stator diameter of 16 cm and approximately 12 permanent magnets, it has approximately 1953 turns with 0.2 mm enameled wire and a distance between the stator and magnet of 0.8 m, the parameters of this tool are current, voltage, and frequency when supplied by an electric current load. From the results of the first experiment carried out, namely with a no-load voltage with an input voltage value of 12 Volts, a current voltage of 1.45 Amperes, a frequency of 50 Hz and producing an output voltage of 247.7 Volts, this tool was created with the aim of providing a solution for permanent magnet generators with the axial flux method, namely by adding a microcontroller feature that functions to control this tool when operating.

Keywords: Generator, Permanent Magnet, Axial Flux.

1. INTRODUCTION (Bold, 11pt)

Electricity is a crucial need in both the business and industrial sectors. It can be said that the availability of electricity significantly impacts the activities of Indonesian society today. The State Electricity Company (PLN) is responsible for electricity distribution in Indonesia, particularly in West Kalimantan. However, Indonesia has the potential to develop renewable energy generation. For example, electricity from generators is available in some regions, but this is only available to a select few. Therefore, a permanent magnet generator using the axial flux method has been developed to produce renewable energy as an alternative energy source to meet electricity needs.

In this implementation, several problems were identified, as follows, how can we design a permanent magnet generator using the axial flux method to generate alternative electrical energy,
how can we determine the number of turns and values for a permanent magnet generator using the axial flux method to achieve optimal voltage, current, and frequency.

According to Pattiapon D.R and Rikumahu J.J, Jamlaay M, (2019), a synchronous generator is a generator used to convert mechanical power into electrical force. This generator has its own separate field amplifier with a load of 0 – 240 watts, it turns out that the greater the load given to the generator, the generator rotation and output voltage produced from the generator decrease, so that the generator rotation must be stabilized again at 1500 rpm and the output voltage on each phase must be stabilized at 220 VAC. While the output voltage on the synchronous generator decreases from 252 VAC at zero load to 220 VAC at maximum load and the current increases. The disadvantages of this tool are such as high maintenance costs, more complex responses, and susceptibility to interference. Meanwhile, according to Haqq G.A.A, and Hardianto T., Sujanarko B., (2020), this single-phase permanent magnet generator with a power of 50 watts of dual rotor axial flux type uses Neoddymium Iron Boron magnets, the number of slots and poles for the design made is 12 slots and 24 poles. While the generator uses coils measuring 0.15 mm and 0.4 mm where each coil has 2000 turns for a size of 0.15 mm and for a size of 0.4 mm totaling 350 turns. The value produced on a 0.15 mm generator without load starts from 27.43 to 220 Volts with the condition that the larger the light will be dim because it is driven at 1000 rpm. When the condition is 0.4 mm, the value obtained without load is 6 to 60 Volts with the condition that the light is not bright, only dim or even goes out when the condition is 40 watts because it is driven at 1000 rpm. The drawback of this tool is in the control section when this tool is operating.

This research process was carried out using several reference sources for relevant research. Based on research by Pratama P.P., and Cahyadi W.H.W., (2021), entitled "Axial Flux Permanent Magnet Generator (AFPM)". A generator that can produce a voltage of 15 Volts and a power of 5.5 watts at a speed of 3000 RPM, even though it operates at a low rotation speed, one example is a multi-disc generator. In the design of this 1-phase AC multi-disc generator, Neodymium Iron Boron (NdFeB) magnets are used which are arranged with opposite poles on the opposite magnets. Tests were carried out with a rotation of 3000 RPM on the generator with a load of 8 parallels where each parallel has 7 LEDs connected in series. The generator output wave frequency was 400.6 Hz, a load voltage of 14.65 V, a load current of 13.704 mA, a power of 0.2008 W, and a torque of 6.39×10^{-4} Nm. The greater the load on the generator, the lower the voltage, while the greater the current, power, and torque. However, the drawbacks of this generator include the high cost of routine maintenance and the high risk of excessive

movement, which can affect the generator's performance and lifespan.

The research conducted by Pramurti A.R. and Suharyanto E.F. (2021) entitled "Permanent Magnet Generator with Radial Flux" discusses the effect of pulse torque on the generator's output voltage. The output voltage generated with the structural design is 0.25 MPa, while the pulse torque is 0.3 Nm, and the voltage is 144 volts. The smallest pulse torque value is obtained from the GMPFR design with a variation of the permanent magnet structure.

Previous research has identified several shortcomings, including relatively low efficiency, resulting in excessive heat generation, and the use of manual controls for measuring RPM and frequency.

This research provides a solution to improve device efficiency and allow for speed and frequency control using the Pzem004T sensor during operation.

Data collection on this tool can be done using a method, namely by providing a variable lamp load to see the results of the current, voltage and frequency on the generator, so that it can be seen through the results obtained during testing.

The data collection technique for this device involves providing a 12-volt input voltage and a 220-volt output voltage, with a 3-watt, 5-watt, 8-watt, 10-watt, and 15-watt lamp load. This is to observe the optimal current and voltage changes in the experimental results.

In carrying out the analysis of the results, experiments will be carried out, namely by measuring the results of the voltage, current and frequency, whether in each experiment changes are found in either voltage or current when a load is applied to the generator.

2. METHOD (Bold, 11pt)

2.1 Literature Review

• This research is based on a comprehensive review of prior studies on permanent magnet generators to establish a theoretical foundation and identify key research gaps.

• The study by Pratama P.P. and Cahyadi W.H.W., (2021) on an axial flux permanent magnet (AFPM) generator highlighted challenges such as high maintenance costs and risks associated with excessive movement.

• Haqq G.A.A., et al., (2020) discussed an axial flux permanent magnet generator for wind power, noting a key limitation was the low efficiency at high RPMs and the need for manual control.

• Pramurti A.R. and Suharyanto E.F., (2021) focused on the effect of cogging torque in a radial flux generator, which informed the design considerations for this study.

• Based on these findings, previous work had shortcomings, including low efficiency and a dependence on manual control. This study proposes using a PZEM004T sensor to enable automatic control and improve overall efficiency.

2.2 Supporting Theory and Systems Componets

Fundamental Principles

The working principle of the generator is based on Faraday's Law, which converts mechanical energy into electrical energy.

An axial flux generator has magnetic flux that is parallel to the axis of rotation, unlike a radial flux generator where the flux is perpendicular.

Electronic Components and Tools

Arduino Nano:
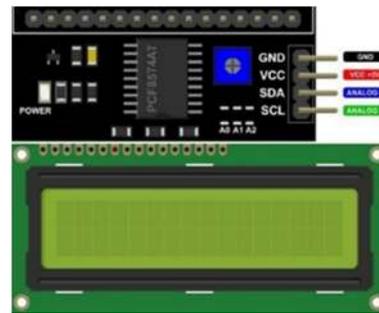Serves as the microcontroller for processing inputs and programming the system.
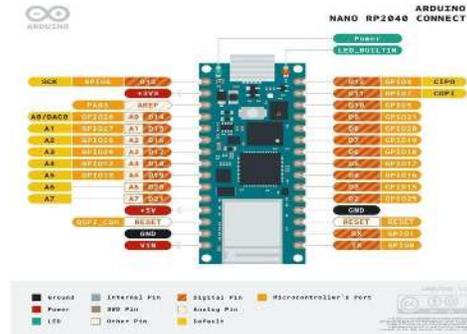
Source: (Pamarah, M., 2022)
Figure 2. 1 Figure 2 1 Arduino Nano Input/Output Pin

I2C LCD:
A display for showing data, using the I2C serial communication protocol to minimize pin usage.

Source: (Pradana, S., 2017)
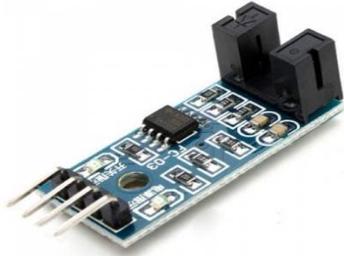Figure 2.2 I2C LCD Display

DC Motor:
Converts direct current into mechanical motion to drive the generator.

Source: (Khatimah, H,. 2022)
Figure 2.3 12V DC Motor Sensors:

An Optocoupler RPM sensor measures the motor's rotational speed, while a PZEM004T sensor measures electrical parameters like voltage, current, and power:

Source: (Donal, B,. 2024)
Figure 2.7 Optocoupler Sensor

Rotor and Stator Design
Rotor:
The rotor is the moving part that cuts the magnetic flux to create an electromotive force (EMF). Its design involves determining the number of poles, the distance between magnets, and calculating the overall circumference and flux density.
Stator:
The stator is the stationary part where electricity is generated. Its design calculations include the number of coils, the number of turns per coil, and the optimal wire diameter.

3. RESULTS AND DISCUSSION
3.1 Permanent Magnet Generator Tool Manufacturing Results
In creating and designing a permanent magnet generator with axial flux, the following documentation demonstrates the tool's shape:

Figure 3.1. GMPAF Design

3.2 Instrument Measurement Results
The instrument's measurement results show accurate, stable values, and meet technical specifications, making this magnet suitable for use. The following is an image of a magnetic field measurement:
Measuring the Magnetic Field Strength of the Rotor.
Based on the 24 magnets used, the first magnets measured were 12 magnets with the magnet code (S). These measurements can be seen in the table below:
Table 3.1 Magnetic Field Strength Data (S).

No	Kode Magnet	Angka Kuat Magnet (mT)
1.	S	163,93 mT
2.	S	167,98 mT
3.	S	185,12 mT
4.	S	171,80 mT
5.	S	172,93 mT
6.	S	165,77 mT
7.	S	167,08 mT
8.	S	176,26 mT
9.	S	173,00 mT
10.	S	106,04 mT
11.	S	158,54 mT
12.	S	185,64 mT

Meanwhile, the next measurement is with the magnetic code (N) of 12 magnets, and can be seen below:
Table 3.2 Magnetic Field Strength Data (N).

No	Kode Magnet	Angka Kuat Magnet
1.	N	165,63 mT
2.	N	175,92 mT
3.	N	173,75 mT
4.	N	174,20 mT
5.	N	168,00 mT
6.	N	176,15 mT
7.	N	177,74 mT
8.	N	170,68 mT
9.	N	173,00 mT
10.	N	106,04 mT
11.	N	174,44 mT
12.	N	180,44 mT

3.3 Voltage Measurement in Each Coil
The voltage in each coil was measured to determine the voltage across each coil and ensure that each coil functions optimally to produce the required power. Twelve coils were measured, as follows:
Table 3.3 Current Coil Data.

No	Input Tegangan	Input Arus	RPM	Arus Yang Dihasilkan.
1.	12 V	1,39 A	500 Rpm	20,4 V
2.	12 V	1,38 A	500 Rpm	20,5 V
3.	12 V	1,39 A	500 Rpm	20,9 V
4.	12 V	1,38 A	500 Rpm	20,9 V
5.	12 V	1,38 A	500 Rpm	20,8 V
6.	12 V	1,39 A	500 Rpm	20,7 V
7.	12 V	1,38 A	500 Rpm	21,1 V
8.	12 V	1,38 A	500 Rpm	21,8 V
9.	12 V	1,37 A	500 Rpm	21,3 V
10.	12 V	1,38 A	500 Rpm	21,0 V
11.	12 V	1,38 A	500 Rpm	21,5 V
12.	12 V	1.39 A	500 Rpm	20,3 V

3.4 Instrument Test Results.
Based on the tests conducted, this instrument was able to operate optimally and produce voltage in each measurement. Five trials were conducted during the test. The following is a picture of the instrument during testing:

a. No-Load Test.
No-load testing is carried out to determine the input voltage on the DC motor to help rotate the generator.
From the Power Supply image above, it can be seen that the current input is 1.45 Amperes and the voltage input is 12 volts, this value helps rotate the generator at a speed of 500 Rpm where the current and voltage affect the Rpm speed when it exceeds the specified limit.

No-load testing using an LCD monitor to display data such as RPM, Frequency, and Voltage, as shown in the image below:
The LCD display above shows a voltage output of 247.7 volts, a current of 10 amperes, a frequency of 50 Hz, and a rotational speed of 505 rpm. These values come from the sensor installed on the device.

Pengujian tanpa beban dengan menggunakan Osiloskop untuk menampilkan hasil pengukur data seperti tegangan, waktu dan frekuensi. Yaitu seperti gambar dibawah ini:
Dari gambar isoloskop diatas dapat dilihat nilai yang sudah ditampilkan dari layar monitor yaitu dengan tegana 100 volt dan arus 500 mv dengan frekuensi 50 Hz dan membutuhkan waktu 5 ms persatu putaran
Performance Data Analysis on Generator No-Load Voltage
The experimental analysis of the generator at no-load voltage can be seen in the table below:
Table 3.4 No-Load Data on the Tool

Jumlah Lilitan	Beban	Tegangan/Arus	Frekuemsi	Rpm
1952 Lilitan	Tanpa Beban	12 V / 1,45 A	50,2 Hz	505
1952 Lilitan	Tanpa Beban	247,7 V	50,4Hz	505
1952 Lilitan	Tanpa Beban	100 V/500 mV	50,2 Hz	505

The table above is the result of measuring the tool when the condition is no load and produces data as above.

4. CONCLUSION AND SUGGESTIONS
4.1 Based on the results of the experiments conducted, this device can be a source of alternative energy because it can produce electrical energy, although the current output is not yet optimal. This device still has shortcomings, namely in the voltage stabilizer (Voltage Stabilizer / Voltage Regulator) because the voltage produced is not yet capable of handling large loads.
4.2 Further research is recommended for better results.
Several components, such as a voltage stabilizer (Voltage Regulator), a frequency stabilizer (Frequency Stabilizer/Governor Control System), a rotor rotation distance stabilizer, and a generator output logbook are also recommended. This will ensure the device can produce optimal voltage, current, and frequency even under heavy loads.

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Design And Construction Of Line Follower Robot Prototype Based On Arduino Mega

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Abstract

The development of automation in the restaurant industry has led to the innovation of a waiter robot based on Arduino Mega 2560. This robot is designed to simplify food delivery to customers by integrating technology with service efficiency. It is equipped with a TFT LCD screen as an interface that allows users to provide direct instructions, and ultrasonic sensors that detect obstacles to prevent collisions during operation. The navigation system applies a line follower model, enabling the robot to move automatically along predefined paths. The research focuses on the design and implementation of the prototype, highlighting its functionality in ensuring safe and accurate food delivery. The results indicate that the system performs effectively in real-time restaurant service conditions. This innovation demonstrates the potential of robotic applications in enhancing service quality, reducing human workload, and contributing to the advancement of automated service solutions.

Keywords : *Arduino Mega, Waiter Robot, Line Follower*

1. INTRODUCTION

Service is an activity or a sequence of activities that occurs through direct interaction between a person and another person or a machine, and it provides customer satisfaction. It can also be defined as an effort to fulfill the needs of others, while serving refers to the act of assisting, preparing, or managing what someone requires. Along with the development of society, the demands for services have undergone significant changes. Increasing life needs, higher mobility, and busier lifestyles encourage people to use their time more efficiently to remain productive. This condition drives the emergence of various service providers, including restaurants as facilities that fulfill basic needs in the form of food In restaurants, service is commonly carried out by human waiters. However, their performance is often influenced by physical and psychological limitations such as fatigue, illness, and repetitive tasks. These limitations may lead to errors, including delays in delivering orders, incorrect table service, and a decline in customer interaction quality. If such issues continue, they can reduce customer satisfaction and damage the restaurant's reputation.

To overcome these problems, innovations in service delivery are required to optimize human resources, minimize work errors, and maintain consistent service quality. One promising innovation is the application of robotics in service automation. Initially, robots were developed for heavy, dangerous, repetitive, or dirty tasks, but technological advancements have expanded their roles into service sectors. Examples include nurse robots for patient care, rescue robots in disaster operations, housekeeping robots for daily household tasks, and window-cleaning robots for tall buildings. These cases highlight the opportunities for robots to support fast, accurate, and efficient restaurant services.

Several studies have examined the potential of service robots. Research developed a line follower-based waiter robot that could autonomously deliver food by following a programmed path. Meanwhile, another study. emphasized that waiter robots can improve time efficiency, reduce human workload, and minimize delivery errors. Based on these findings, the integration of robotics into restaurant services presents a promising solution to enhance customer satisfaction, accelerate service processes, and reduce long-term operational costs.

Therefore, this study aims to design and build a waiter robot based on the line follower method with the ability to deliver food to customer tables along predefined routes. The robot will be equipped with trays, sensors, and an integrated control system. This innovation is expected not only to improve efficiency in restaurant services but also to address human limitations and inspire further applications of robotics in the service sector.

2. METHOD

The research method consists of several stages including design, construction, and testing of the line follower waiter robot based on Arduino Mega 2560. The design stage begins with determining the specifications