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Design of a 1-phase Axial Flux Type Generator with a Variation of Winding on a Star-Shaped Stator

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Abstract

A single-phase axial flux generator with a star-shaped stator is designed to investigate the optimal utilization of rainwater energy as a renewable energy source. In the experimental setup, the number of coils and their diameters were varied. Specifically, configurations of 25 and 50 coils with a 0.4 mm diameter, as well as 25 and 40 coils with a 0.5 mm diameter, were fabricated. Generator performance was evaluated under both load and no-load conditions at rotational speeds ranging from 600 rpm to 2000 rpm. The test results indicate that, for a single-phase axial generator operating at a 2.4 W output condition, an increase in the number of windings significantly affects the induced voltage, while the stator winding count directly influences the magnitude of induced voltage, current, and power. Furthermore, test results with different winding variations, using a 4.8 V 0.5 A (2.4 W) light bulb as the load, demonstrate that an increase in winding count leads to an enhancement of electrical output

Keywords: *Generator Axial Flux, Winding, Stator, Voltage*

Abstrak

Potensi air hujan sebagai energi terbarukan masih kurang dimanfaatkan sebagai sumber energi. Penting untuk menciptakan teknologi yang memanfaatkan energi air hujan dengan lebih efisien. Untuk mengeksplorasi pemanfaatan energi air hujan yang optimal, diperlukan sebuah generator fluks aksial 1 fase dengan stator berbentuk Bintang. Eksperimen yang dilakukan dengan mengatur jumlah lilitan dan diameter. Dirancang 25 lilitan dan 50 lilitan untuk diameter 0,4 mm, serta 25 lilitan dan 40 lilitan untuk diameter 0,5 mm. Performa generator akan dievaluasi dengan pengujian pada kecepatan 600 rpm hingga 2000 rpm, dalam kondisi berbeban dan tanpa beban. Hasil uji menunjukkan bahwa peningkatan jumlah lilitan mempengaruhi tegangan yang diinduksikan oleh generator dan kuantitas tegangan, arus, dan daya yang diinduksikan dipengaruhi oleh jumlah lilitan stator untuk generator aksial 1 fase yang beroperasi pada kondisi output 2,4W. Hasil pengujian, dengan menggunakan beban bola lampu 4.8V 0.5A atau 2.4W, dengan variasi belitan yang berbeda dan menunjukkan peningkatan jumlah belitan menghasilkan peningkatan daya listrik.

Kata kunci: *Generator Axial Flux, Lilitan, Stator, Tegangan*

Introduction

The amount of rainfall peaks when the rainy season begins. When there is enough rainfall to make hydropower a viable renewable energy source, it is a promising renewable energy option [1]. In order to make rainwater an environmentally friendly and sustainable energy source, technology that can maximize its energy must be developed. Currently, the utilization of rainfall as a renewable energy source is not at its best. Water-based power plants can be used to generate hydropower by utilizing this enormous water potential [2].

Nevertheless, a power generation system with an installed generator is necessary to fully utilize this potential energy. Generators can serve as a solution for electrical issues by producing electricity. The majority of power generators on the market today run at high rpm, however because of their limited flow and slow speed, renewable energy sources like wind and water can only run the generator at low rpm. A permanent magnet generator (AFPM) that runs with minimal rotating flux must therefore be designed and tested [3]. The generator comprises stator and rotor parts, with the stator part made up of copper coils and the rotor part made up of permanent magnets. It operates based on Faraday's law [4]. The rotor and stator are positioned perpendicularly to the axis, which gives this generator its axial type name [5].

Permanent magnet generators are an option for low head pico hydro power plants since they don't require DC excitation current and have an easy maintenance schedule [6]. Permanent magnet generators require adjustments to their windings, magnets, magnetic flow, and number of turns in order to increase power, voltage, and speed. Additionally, the wire's diameter can be changed [7]. Alterations to the winding of the stator coil will impact how the strong magnetic field penetrating it is dispersed thereby increasing the induced voltage [8]. These generators undergo different design variations to enhance their performance [9]. The background information above is in favor of using rainwater as a sustainable and environmentally beneficial energy source. In order to capture rainfall energy, this project creates a 1-phase Axial Flux generator featuring a star-shaped stator. The generator explores the evolution of rainfall energy usage by using a star-shaped stator with a maximum voltage of 12 V and varying winding numbers and diameters.

Literature Studies

A generator is a machine or device that can produce electrical energy from mechanical energy [10]. The rotor components of generators require mechanical energy to operate. Supporting components such as arduino allow to be used when needed [11]. A prime mover like a motor or other power sources like wind or water can provide the necessary mechanical energy. Primary drives such as motors or other resources such as wind or water can provide the necessary mechanical energy. Such motors can be used as a medium in electricity distribution systems as well [12]. According to Faraday's study, an electromotive force (EMF) or voltage can be induced at the end of a wire or conductor coil by a magnetic field that varies over time [3]. EMF, or electromotive force, is the energy used to charge and produce voltage in an inactive battery and supply energy in voltage units from a power source, such as a battery. EMF is a voltage measurement; the letter E stands for it. It represents the maximum potential difference between two points of the battery when current flows from the power source without any resistance. Although it might initially seem that EMF induces current flow, this is not entirely accurate. One part of EMF is the electrical potential provided by active devices, such batteries. Rather, it characterizes the total energy applied to each group of targets inside the circuit [13].

There are various groups of permanent magnets that have been implemented in different electromagnetic applications to create magnetic fields, such as Alnico magnets, ferrite, SmCo magnets, and NdFeB magnets. NdFeB magnets, also known as neodymium magnets, are considered the strongest [14]. Iron, boron, and neodymium Permanent magnets are finding more and more uses in systems technology. To fully capitalize on their potential, though, it's crucial to take into account pragmatic design considerations [15]. Implementing neodymium magnets in machinery is a more effective option for electricity generation [8]. The axial permanent magnet (AFPM) flux generator is a type of electrical machine capable of producing electrical energy with perpendicular flux flow direction. Since permanent magnets generate the AFPM generator's magnetic field, an external excitation field source is not necessary. Additionally, this magnetic field is oriented in the axial direction or parallel to the generator shaft [16]. Variations such as a stator with a torus-shaped iron core or without an iron core, as well as the number of coils, indicate the stator section of this axial flux generator. The generator's rotor is made up of permanent magnets that produce the primary magnetic field and a magnetic stand. The permanent magnets are glued or embedded into the disc to make it sturdy and vibration-resistant. The surface area of the permanent magnets used determines how much magnetic flux the permanent magnets produce to enter the stator coils and produce electromotive force (EMF).

$E =$ □ x □ x □□ ....(1)

Description:

E = Induced voltage
B = Fluk magnetics (Wb)
l = Magnetic width
v = magnetic field speed (rpm)

Wave-shaped stators with twelve poles are called star-shaped stator coils. It is assumed that all types of windings are equivalent in terms of the induced back electromotive force (emf), because (emf) induction is only a function of the length of the conductor placed in the stator slot, regardless of how the end winding is formed and placed outside the stator. Generally, stator winding forms vary in types, patterns, and number of poles depending on the needs of the generator / motor engine designed. However, there are differences among winding types that are not considered in the law of (emf) induction [17].

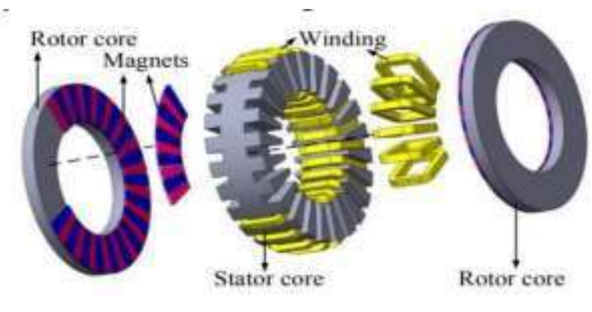


Figure 1 Axial Flux Permanent Magnet Topology.

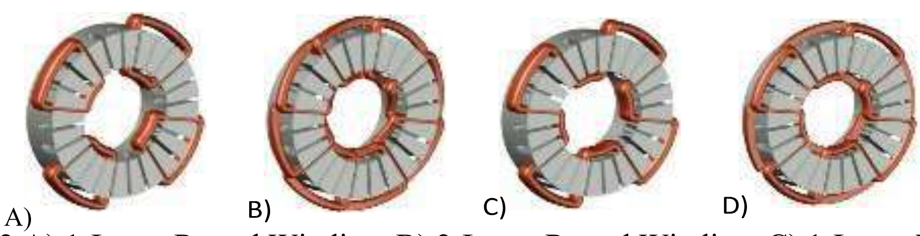
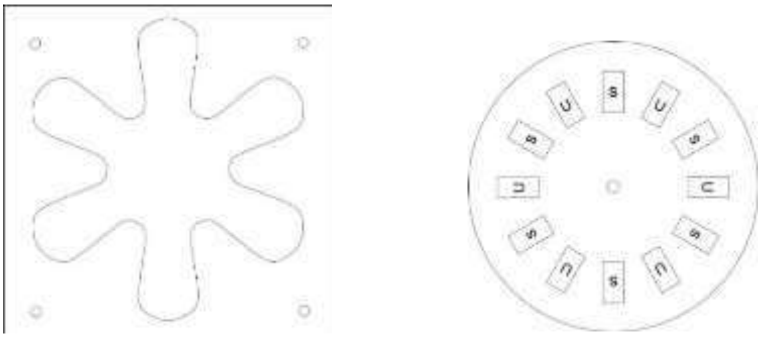


Figure 2 A) 1-Layer Round Winding, B) 2-Layer Round Winding, C) 1-Layer Wave Winding, D) 2-Layer Wave Winding

Method

Part of the methodology employed in this study included a survey of the literature on generators, axial flux generators, permanent magnets, and waveform stators. The literature review states that the design concept entailed determining goals, objectives, and challenges. These included defining the problem, setting goals, establishing boundaries, and identifying research interests. The material has also been proofread for accuracy in word choice, grammatical accuracy, and the absence of filler words. Third, the design of a prototype Axial Flux generator utilizing Neodymium magnets as the initial driving force of the generator and a star-shaped wave stator as the means to generate electrical energy. This covers material selection, construction and generator design, and construction. Fourth, putting the prototype together in line with the concept. Lastly, the prototype will be tested to ascertain system performance. The last objective is to create research reports and publications that analyze the axial flux generator prototype's performance.



(a) (b)

Figure 3 (a) Design of Stator with Star Shape, (b) Design of a rotor with 12 poles

The prototype design can be seen in Figure 3 (a) and (b). The details of the machine, equipped with the position of each part, are listed as follows:

a. Neodymium (NdFeB) magnets with dimensions of 5 × 10 × 20 and a total of 12 poles were used and their specifications are shown in Table 1 the speed is controlled by a DC motor at 600 - 2000rpm.
b. The stator has a star-shaped design and uses two rotors.
c. The generator's output voltage passes through the diode function to convert it from AC to DC.
d. 2mm acrylic medium for making the rotor and stator of a 1-phase generator.
e. Air gap 5mm
f. The load implemented consumed 4.8V at a current of 0.5A, resulting in a power consumption of 2.4W.

Table 1 Specifications of the Magnet

Specifications	Description
Type	Neodymium
Size	5×10× 20 mm
Flux Densities	0,54T
Quantity of polar pairs	12 Pole

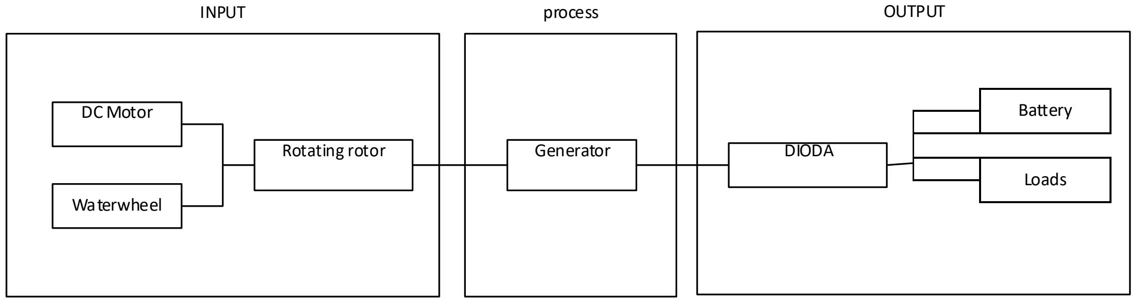


Figure 4. Block Diagram of a Single-Phase Axial Flux Type Generator.

The rotor inside the generator is rotated by motion or kinetic force given by either the DC motor or the water wheel, as shown in the block diagram above. Motion and kinetic energy cause the generator's rotor to move during the Process stage, which results in the intersection of magnetic flux. An induced electromotive force (EMF) is then produced as a result of these changes in magnetic flux over time. The output of the generator produces an unstable AC voltage, which needs to be rectified and converted from Vac to Vdc by passing it through a diode. The resultant voltage, which has passed through the diode, can either be stored in a battery or be used directly.

Results and Discussion

Multiple tests have been conducted on the generator, encompassing both loaded and unloaded scenarios. The formula employed for these tests is as follows:

$$E = \square\ x\ \square\ x\ v$$

Description:

$\square = 1{,}2\,.\,\frac{1}{(1+0{,}6)}$

$\square = 0{,}75\ T$

$\square = 1\ \times 2$

$\square\ = 2\square\square^2$

v = 2000 rpm

$E = 0{,}75 \times 2 \times 2000$

$E = 3000\ \square V = 3\ V$

The above formulation is used to measure, calculate, and analyze the measurement data. Here are the results of the measurements that have been carried out.

a. Testing with no load

The generator test results were obtained by rotating the rotor using a DC motor/drill and measuring the Vdc generator output using a multimeter. The table below shows the measurement results.

Tabel 1 Testing the Output of the Generator with No Load

RPM	25 Coil 0,4 mm		50 Coil 0,4 mm		25 Coil 0.5 mm		40 Coil 0,5 mm	
	Volt	Amper	Volt	Amper	Volt	Amper	Volt	Amper
600	0,9	0	1,98	0	0,9	0	1,16	0
800	1,16	0	2,48	0	1,22	0	1,68	0
1000	1,54	0	2,89	0	1,68	0	2,1	0
1200	1,74	0	3,58	0	1,76	0	2,38	0

1400	2,02	0	4,04	0	2,14	0	2,92	0
1600	2,28	0	5,65	0	2,57	0	3,48	0
2000	3	0	6,3	0	3,05	0	4,2	0

Table 2 demonstrates that an induced voltage of 3.05 V for 25 windings and 4.2 V for 40 windings is produced by a winding with a 0.4 mm diameter, and an induced voltage of 6.3 V for 50 windings and 3 V for 25 windings by a winding with a 0.5 mm diameter. This suggests that the number of rotations affects the induced voltage that the generator releases. In a similar vein, it is possible to argue that the induced voltage increases at 25 revolutions when the diameter ratio is between 0.4 and 0.5 mm. The higher the induced voltage that the generator releases, the more turns and larger the winding's diameter.

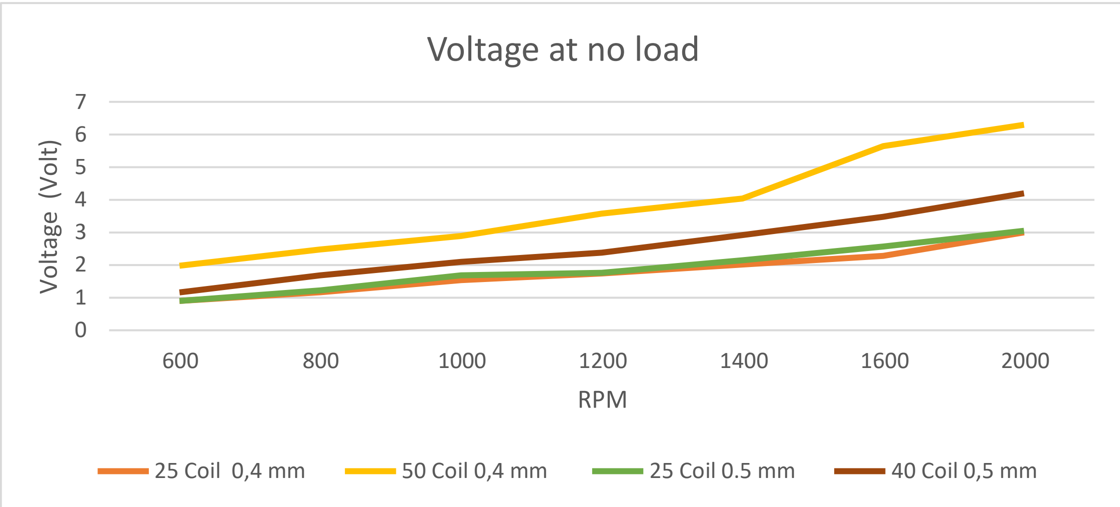


Figure 5. Graph of Voltage Induced by Generator without Load

The test results are plotted on the graph in Figure 2, which shows a clear relationship between the generated voltage value and the operating RPM. All lines rise between 600 and 2000 revolutions per minute, indicating a direct correlation between the induced voltage and the revolving RPM.


Figure 6. Image for Testing Generator Performance

b. Testing with load

When a 2.4 W lightbulb is used as the load for assessing the generator's performance, the following table 4 shows the results:

Tabel 2 Testing generator output with a load

RPM	25 Coil 0,4 mm		50 Coil 0,4 mm		25 Coil 0,5 mm		40 Coil 0,5 mm	
	Volt	Amper	Volt	Amper	Volt	Amper	Volt	Amper
600	0,03	0,03	0,42	0,05	0,03	0,02	0,37	0,05
800	0,14	0,03	0,63	0,09	0,05	0,03	0,64	0,07
1000	0,29	0,05	1,08	0,12	0,19	0,04	0,96	0,08
1200	0,46	0,06	1,51	0,15	0,3	0,05	1,28	0,1
1400	0,64	0,07	1,85	0,18	0,5	0,06	1,56	0,15
1600	0,88	0,09	2,3	0,21	0,69	0,08	1,96	0,17
2000	1	0,1	3,35	0,31	1,1	0,1	2,73	0,24

The voltage, current, and induced power measurement results of the generator under a 2.4 W light bulb load are displayed in Table 4. The table demonstrates the direct proportionality between the rise in RPM and the increases in voltage, current, and power. Furthermore, under 2.4 W load conditions, it is evident from the winding variation that the quantity of stator windings influences the voltage, current, and induced power of the 1-phase axial generator.

Figure 7 Testing a 1-Phase Axial Flux Generator with a Star-Shaped Stator and a Load

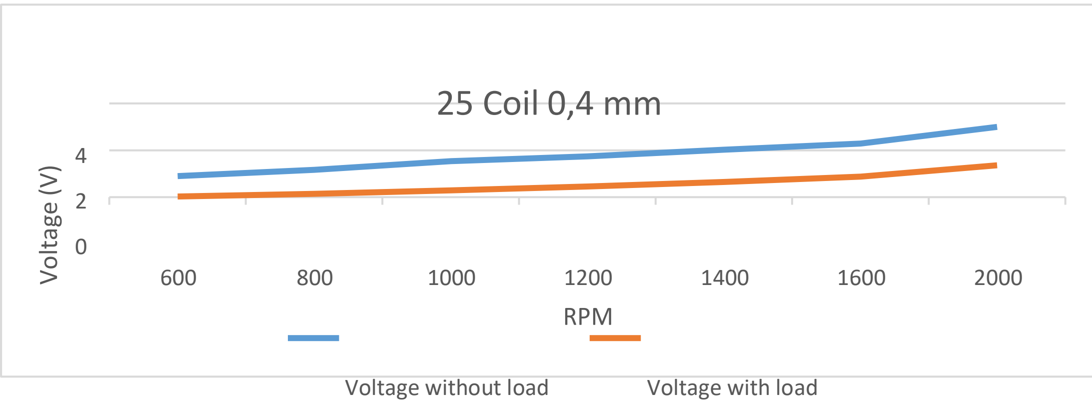


Figure 8. Voltage Graph of 25 turns 0.4mm Without Load and With Load

The figures in Figures 8 and 9 demonstrate how the number of turns—25 and 50 in this case—has a notable impact on the voltage produced. This leads to the conclusion that there is a positive correlation between the number of turns and the voltage that is induced and supported by the data in the figures.

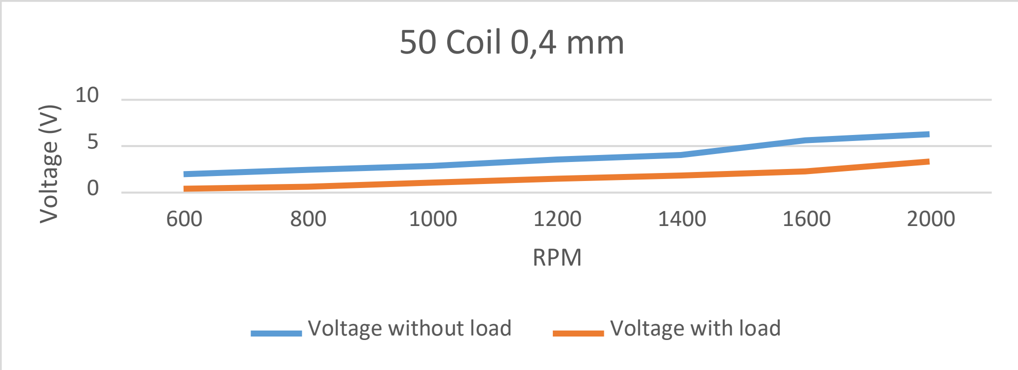


Figure 4 Voltage Graph of 50 turns 0.4mm Without load and with load

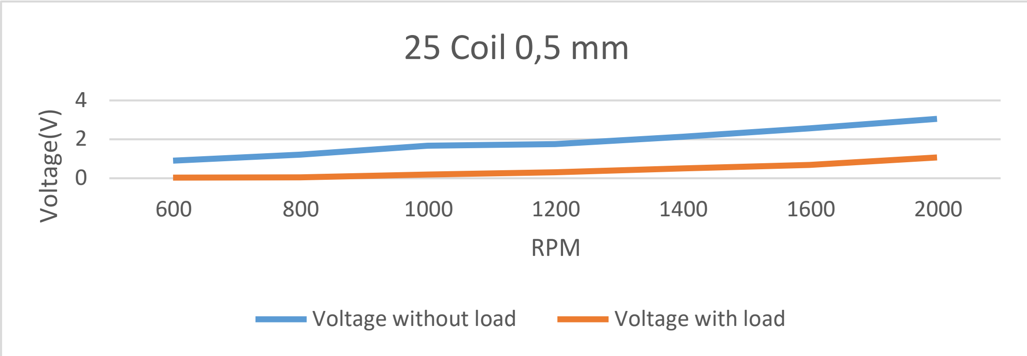


Figure 5 Voltage Graph of 25 turns 0.5mm Without Load and With Load

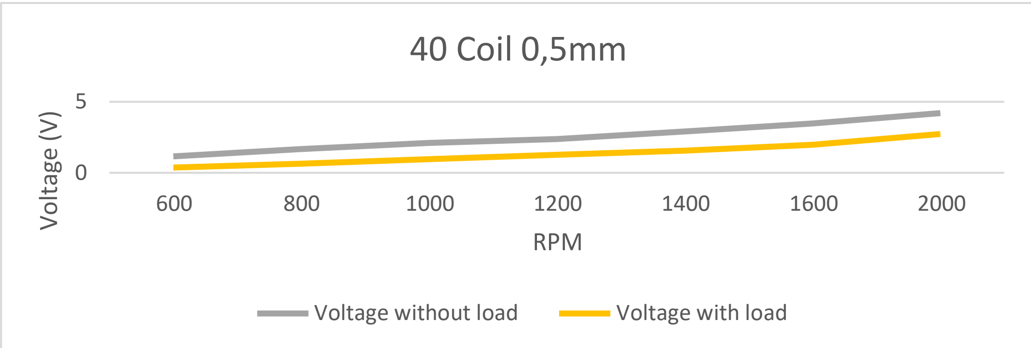


Figure 6 Voltage Graph of 40 turns 0.5mm Without Load and With Load

As shown in Figures 8 and 10, there is a difference in the diameter of the winding between 0.04 mm and 0.05mm. Based on this, it can be concluded that the increase in the diameter of the winding is directly proportional to the induced voltage produced.

Conclusions

Based on the test results in this study, it can be concluded that a number of voltages above 1 volt can be obtained when testing without a load at 800 rpm in 25 and 50 windings with a diameter of 0.4mm and 25 and 40 windings at a diameter of 0.5mm. While utilizing a load necessitates 2000 rpm in order to attain a voltage over 1 volt, there is a positive correlation between rpm and voltage increase when comparing the voltage across 25 windings with diameters of 0.4 and 0.5. The lowest voltage at 25 turns of 0.4mm diameter is 0.8V for no load and 0.03V with load, while the highest voltage occurs at 50 turns of 0.4mm diameter with 2000 rpm, yielding 6.3 V for no load and 3.35 V with load. The higher/greater the voltage created, the higher the required RPM, according to the link between RPM and voltage (VoltBased) on this study, further research is advised since it is believed that the rpm is excessive and does not match the force of motion generated by water, which is why this design tool had to be made. By maximizing the voltage output at lower rpm, increasing the number of windings and the width of the windings will maximize the permanent magnet axial flux generator as a more potent and efficient tool for turning renewable energy into usable form in the real world.

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