UNIVERSITI MALAYSIA PERLIS

DOUBLE ROTATIONAL AXIAL GENERATOR FOR PICO HYDRO POWER GENERATION

Nur Irwany Ahmad
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Technical Report

TECHNICAL REPORT

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ACKNOWLEDGMENT

In the name of Allah, the Most Gracious and the Most Merciful.

Alhamdulillah, I would like to thanks to Allah S.W.T, the Most Merciful, and all praises to Allah for His blessing in completing this project. I would also like to show appreciation to SBJ Technologies for giving me opportunity to study renewable energy issues provided and my appreciation also to all academic staff and technician at Universiti Malaysia Perlis (UniMAP) for their help upon for consultation, comments, opinion and assists to complete the project. I would like to thanks my family for the never-ending supports to finish this project. Also, thanks to all beloved friends for their encouragement in completing this project.

Thank you very much.

PREFACE

This technical report introduced to the theory and practical of the project. Malaysia is now heading for uses of renewable energy for daily use. Most residents now use one of renewable energy, which is solar energy to generate electricity on electrical appliances. Pico hydro is one of the most efficient renewable energy sources. It is particularly suited to small-scale applications. However, the conventional operation that using a single set of rotating waterwheel turbine limiting the rotation of the generator’s stator. In this project, the objective is to develop an axial generator below than 1 W by using two waterwheel type turbines for simple pico-hydro system. More output power was generated by the axial flux generator, which combines the use of permanent magnets and set of windings. AutoCAD software are used as drafting design before it was created in the hardware version. This project used the waterwheel water turbines as the prime mover and flowing of water to move waterwheel turbines and generate electricity. Hence, this project successfully to generate a power based on the speed and strength of the magnet. Finally, the data was presented and analyse in the final report.

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter describes about introduction of this propose prototype, problem statement, objectives and scope of project.

1.2 Introduction

Hydro is renewable energy source that is clean, free, and easy to be found. Everyday throughout the world, pico-hydro capture the energy of water and converting it to electricity. The conventional operation usually uses a single of waterwheel, thus limiting the rotation of the generator’s stator. This condition will cause the generated output voltage is limited. The purpose of this project is to develop and implement of an axial generator for pico-hydro power generation with double rotation of waterwheel that has ability to function in both right and left side. The design of generator has two waterwheels which rotate in opposite direction each other. The proposed prototype is targeted to operate in double rotation. Therefore, the waterwheels need to be easily to rotate by installing the bearing as smooth as possible.

To ensure the prototype function well, an axial flux generator is built from permanent magnet and coils winding in order to meet the expectation in harnessing enough water for power generation. The composition of the corresponding magnet can generate a magnet field which effectively using Printed Circuit Board (PCB) layers would facilitate the capture voltage caused by changes in the magnet field.

1.3 Problem Statement

The efficiency of pico-hydro is really important. Normally, a conventional single waterwheel will limit the power output. Output power, speed, and efficiency of water turbines are affected by the curvature angle of the blade. This is because the energy of water flowing is absorbed by the blade of turbines [1].

Thus, through this project, double waterwheel is used to enhance the output power and efficiency of water turbines.

Induction machine operating as a stand-alone self-excited single-phase induction generator for generation of electrical energy from renewably energy sources [2]. There only have a single rotation which is only the rotor that rotate while stator remain static. Single rotating of generator limits the rotation and directly limit the output voltage. By changing number of turns and size of wires in the auxiliary stator winding, considerable improvement of performance characteristics of the generator was obtained as regards no-load and load voltage of the stator windings as well as stator winding currents of the generator [2].

For solving the problems, double rotation of generator is designed. This design is multifunctional because the generator has two waterwheel water turbines which rotate in opposite direction each other. Hence, the percentage that the coils cut the magnetic fields increase and increase the output voltage.

1.4 Objective

The objectives of the project are:

i. To develop a double rotation axial axis generator.
ii. To construct a water turbine with double rotating waterwheel that can rotate in both rotations.
iii. To evaluate the performance of the prototype that produce double output power.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Chapter 2 introduce and provide a brief description of major components in implemented Double Rotational Axial Generator for Pico-Hydro Power Generation and included several factors that will contributed to an efficiently functioning generator. This section also provides an in-depth look into the importance to the overall operation of the Pico hydro turbine.

2.2 Pico-Hydro Theory

Pico-hydro is the hydro electricity generation with the highest electric output of five kilowatts. The need for Pico hydroelectricity around the globe is that it essentially and at no fuel cost allows energy generation. The evolving appeal of electrical vitality is forcing people to scan for different accessible vitality assets. The gears used as part of Pico's hydroelectricity age with its small and conservative plan, so that it can be easily introduced in a relatively small area [3].

New Pico small scale hydro innovation have influenced it more conservative energy to source in the developing nation. Pico small scale hydrometry is mostly introduced in country and hilly areas. Figure 2.1 demonstrates a case of Pico smaller scale hydro framework utilized as a part of hilly area.

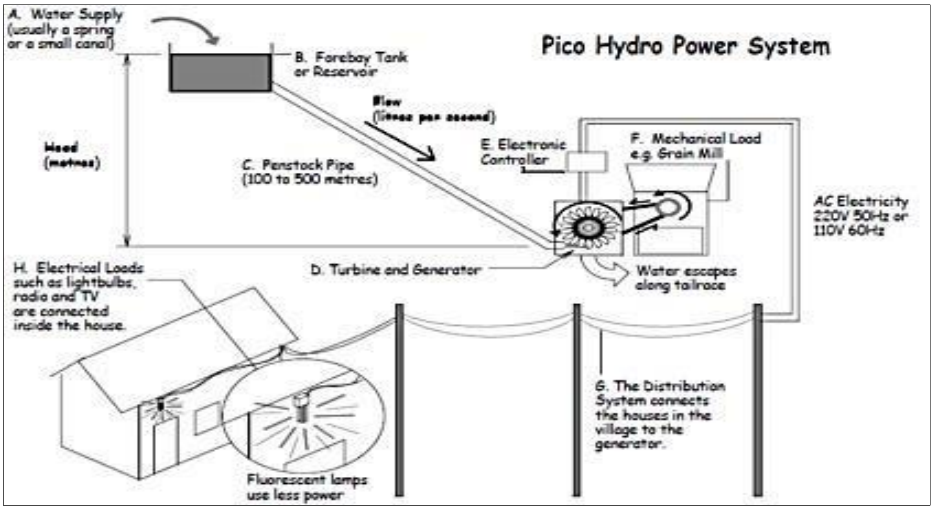


Figure 2.1: Pico hydro system [3].

Innovative work on the Pico hydro system had established interests, particularly in Asian nations. This could have been primarily due to the need to enlarge from non-renewable sources of energy, such as coal, the need to diversify choices for better access to rural groups and the common impediment that the geology is pushing against major improvements. The fundamental power conditions related with the system are appeared in conditions beneath, where the formula for power input, Pin and power output, Pout are;

Pin = $H \times Q \times g$ (2.1)

Pout = $H \times Q \times g \times \eta$ (2.2)

Pin is equal to Input power (Hydro power).

Where, Pout = Output power (Generator output), H = Head (meter), Q = Water flow rate (m/s), g = gravity (9.81 m/s2) and η = efficiency.

As per it, water stream accessible was regularly more than that required since the streams for pico hydro are little. Likewise, they gave half productivity to assess the potential output power when in doubt of the thumb. This deals with the losses in the pipe (or penstock) and in the generator. To decide the head, net (static) head and net (dynamic) head must be considered. Net head is the vertical separation between the highest point of the penstock and the point where the water hits the turbine. Net head is gross head short the weight or head losses because of contact and turbulence in the penstock. Head losses rely upon the sort, breadth, and length of the penstock channelling, and the quantity of curves or elbows. Net head can be utilized to appraise control accessibility and decide general achievability yet net head is utilized to compute the genuine power accessible.

There are numerous strategies for head estimation. One of the easiest and most handy techniques for head estimation is by utilizing a water-filled tube and adjusted weight check. Through this strategy, the weight check perusing in psi can be changed over to head in meters utilizing condition. $H = 0.704p$ where, H = Head (meters) while p = Pressure (psi). The water weight speaks to the net leader of the framework that is valuable to ascertain the real power accessible. The most basic of stream estimation for little streams is the basin strategy. In this technique, water is permitted to stream into a pail or barrel and the time it takes for the compartment to fill recorded. The volume of the holder is known and the stream rate is basically acquired by isolating this volume by the filling time [4].

Pico Hydro System has six main components which are:

i. Water supply, penstock or tank.
ii. Turbine. iii.
iii. Generator.
iv. Charging circuit.
v. Battery.
vi. Electrical loads.

In particular, the water limits must be adjusted to the customer for the complete loss of water tanks. Pico hydro should have a turbine channel with a specific extreme target to ensure that this should be done with the main part.

In this system water (from lake and Small River) immediately set away in a store. This set away water is streams downhill through a pipe (penstock). The running water in the penstock has an enough unique essentialness to turns the sharp edge of a turbine which in this manner turns the rotor of a generator which conveys control. However, in this examination paper it is shown that house hold water supply also has enough motor kinetic energy to turn a little hydro turbine for energy generation.

The penstock plan and selection method displayed which approximates the general system includes selecting the material for the penstock pipe, assuring its distance across, calculating the aggregate head misfortune, thinking of the surge head, calculating the thickness and the factor of well-being as a safety measure. In this determination, the most important plan parameter is that the water speed should be in the middle of 2.5 m/s to 3.5 m/s. Throughout the event that the velocity is lower or higher, it can cause unfortunate experience in the yield of influence and in the more drawn out, it is inefficient along these lines [4].

The fundamental parts in the pico hydro framework are turbine, where the assignment was to change over water energy to rotational power so as to drive the generator. Impulse turbines by and large work best with medium head (over 10 m). Penstock of motivation turbine will change over pressurized the water into rapid water jets that exchange the motor kinetic energy of the jet by affecting the turbine sharp edges or containers causing pivot [5].

Impulse waterwheels, with the slightest complex outline, are most commonly used for hydro hydraulic systems of high head small scale. For the most part, the used of the water velocity to rotate the sprinter and release atmospheric pressure. These turbines are better suited to high head and low stream locations. High head hydro by and large gives the most practical undertakings, since the higher the head, the lesser the water required for a given measure of energy, so littler and subsequently less expensive hardware is required [6]. Figure 2.2 shows the operation of cross-flow water turbine.

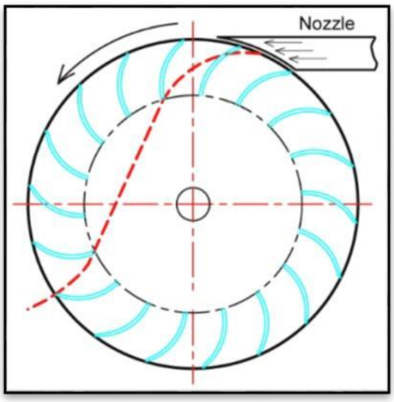


Figure 2.2: Cross-flow water turbine [6].

2.3 Magnetic Flux

Induction process occurs in the winding when there is a changing of the magnetic field in the conducting wire. The changing magnetic field can be improved either by increasing the strength of the magnetic field or the speed of the moving coil, so that the relative motion can occur between the magnetic field source and the moving coil. The process of induction is explained by the law of induction of Faraday.

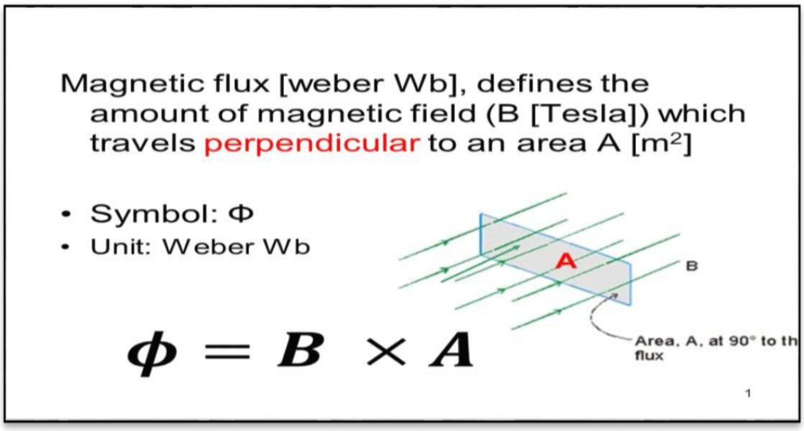


Figure 2.3: Magnetic flux through the coil [7].

The law states that in any closed circuit the induced electromotive force (emf) is equal to the change in the time rate of the magnetic flux through the circuit or in mathematical equation:

$$\Phi = \int_A B \, dA \qquad (2.3)$$

Where,

e = electromotive force (V)

N = numbers of turns

Φ = magnetic flux (Wb)

Magnetic flux can be described as the surface integral of B over a coil:

$$\Phi = \int_A B \, dA \qquad (2.4)$$

$$\Phi = BA \qquad (2.5)$$

Where,
B = magnetic field density (T)
A = the loop's cross-sectional area (m^2)

The magnitude of the magnetic field density received by the stator coils in an axial flux permanent magnet synchronous generator with double rotor plates is constant assuming no fringing effect occurs. The illustration can be seen in Figure 2.4 assumes B is constant, equation (2.4) can be simplified.

And substituting equation 2.5 to equation 2.3, following formula obtain:

$$e = N \frac{dA}{dT} \tag{2.6}$$

Parameter B is a vector and pointed to a particular direction. As the coil cut the magnetic field, induced voltage produced. An assumption is making that the north polarity rotor magnet result in positive e and south polarity rotor magnets the otherwise.

The air gap determined the strength of flux based on the magnetic flux concepts understanding of flux behavior. The air gap needed to separate the revolving rotor from the stator should be as small as possible to reduce the magnetizing power requirement, yet larger enough to prevent contact between the two despite manufacturing tolerances on their dimensions, or movement resulting from mechanical deflection and looseness in supporting bearings. Whatever gap is used, it must be uniform. A non-uniform gap causes increased noised and vibration [7]. Figure 2.4 and Figure 2.5 shows the magnetic field lines between magnets and air gap in the generator respectively.

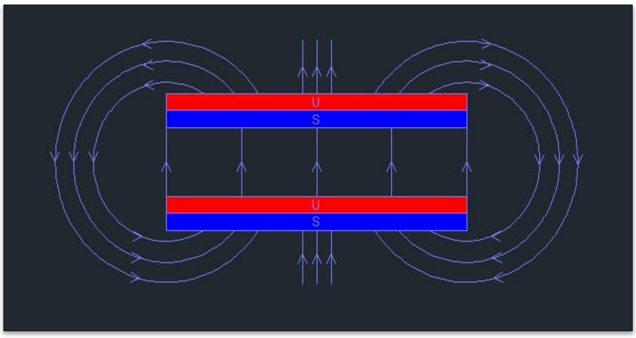


Figure 2.4: The magnetic field lines between magnets [7].

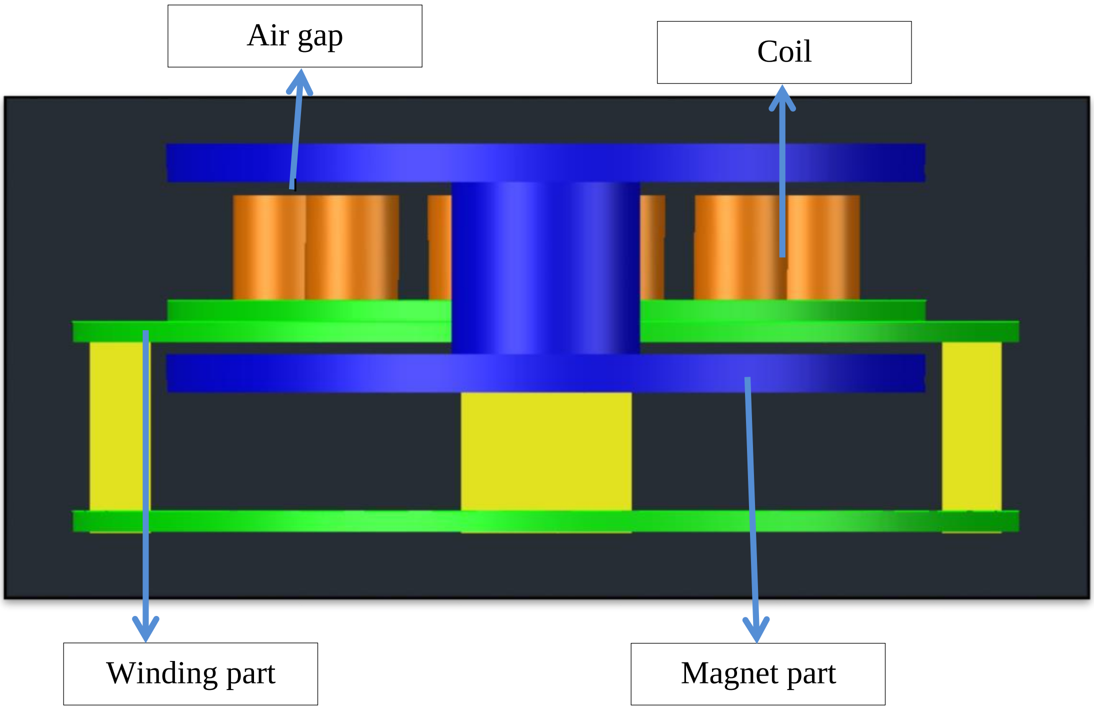


Figure 2.5: Air gap in the generator [7].

Electricity is not generated solely as a function of the field density. To fully describe the electromotive force the area in which the field is applied must be considered as it shows in Figure 2.6.

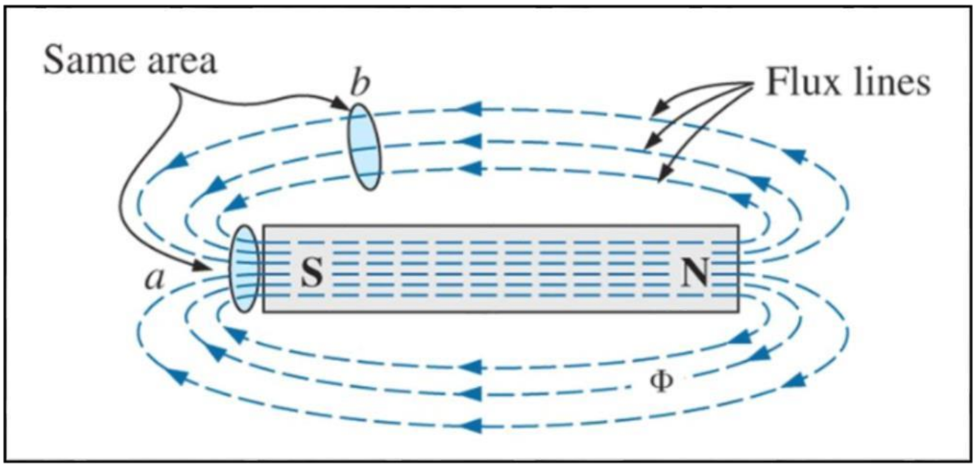


Figure 2.6: Flux distribution for a permanent magnet [7].

2.3.1 The Magnetic Flux through Coil

When a magnet is moved into a coil of wire, changing the magnetic field and magnetic flux through the coil, a voltage will be generated in the coil according to Faraday's Law. The induced magnetic field inside any loop of wire always acts to keep the magnetic flux in the loop constant.

Figure 2.7 shows the magnetic flux through a loop of area, A. Loop of area in Figure 2.7 can also be assume as the area of coil and it can be simplified:

$$\Phi = BA\cos\theta \tag{2.7}$$

Where;

θ = angle between the normal loop to the magnet field

B = magnetic field density (T)

A = cross-sectional area of the closed loop (m^2)

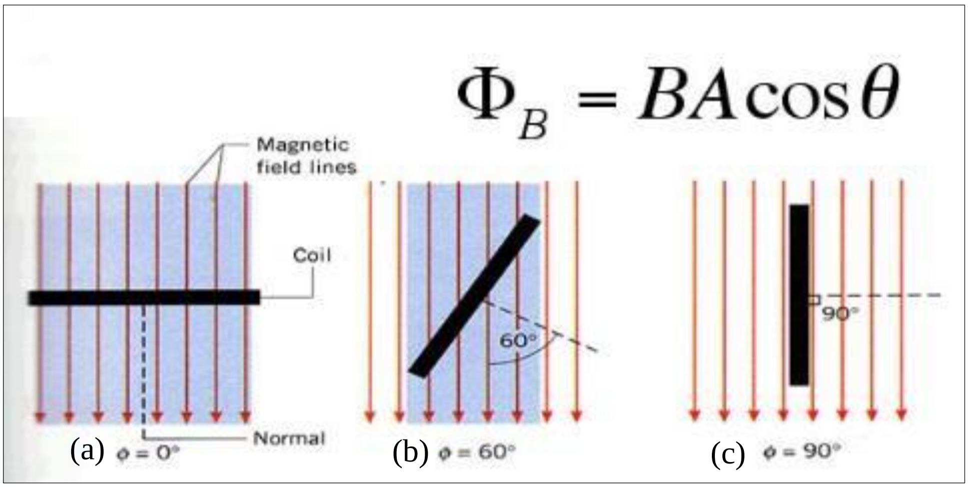


Figure 2.7: Magnetic flux through a coil of area, *A* [8].

According to Figure 2.7:

(a) The loop is perpendicular to the field; hence, θ = 0, and Φ = BA.

(b) For a general angle the component of the field that is perpendicular to the loop is B cos θ; hence, the flux is Φ = BA cos θ.

(c) The loop is parallel to the field; hence, $\theta = 90^\circ$, and Φ = 0.

Based on Figure 2.7, the placement of coil at (a), no field line will be produced. For at (b), the flux produced based on angle placement, θ. At (c) produced maximum field line through the coil. The voltage will be induced from coil when the coil cut the magnetic flux. The induced voltage will produce the induced current in the coil.

CHAPTER 3

METHODOLOGY

3.1 Overview

Previous chapter described the knowledge gathered regarding the project. The method of this purpose prototype of development of axial generator for Pico hydro power generation should be planned well to make sure it will successful implemented. This chapter explain about the method and flow that is used to implement this proposed prototype.

3.2 Flowchart

Figure 3.1 shows flowchart of the project. One of the objectives of this proposed prototype of development of axial generator for Pico hydro power generation, it is vital that the waterwheels have to be strength as possible to ensure it strong enough to rotate. Figure 3.2 shows the design concept of double rotation generator with double rotation axial water turbine.

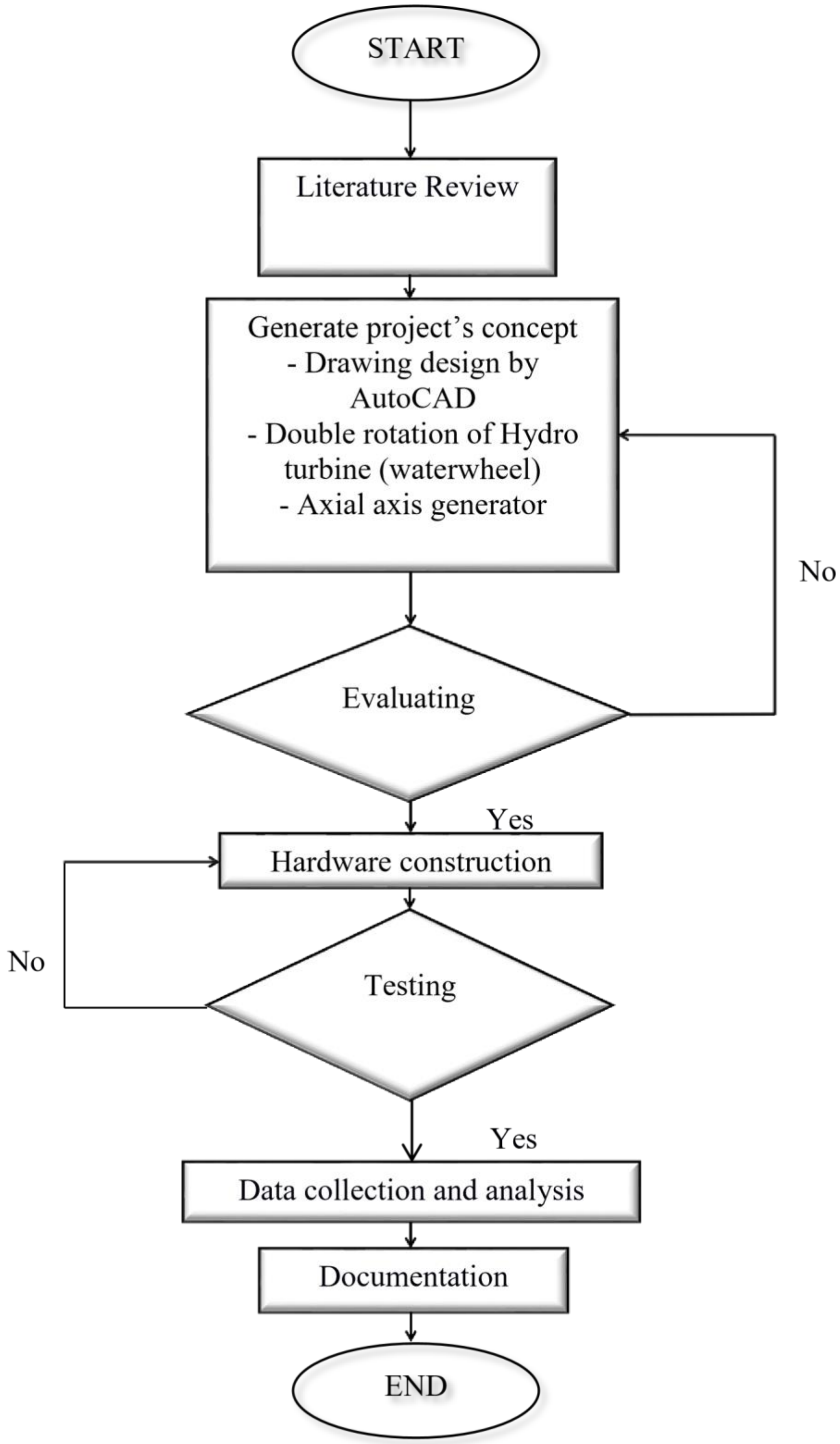


Figure 3.1: Flowchart of the project.

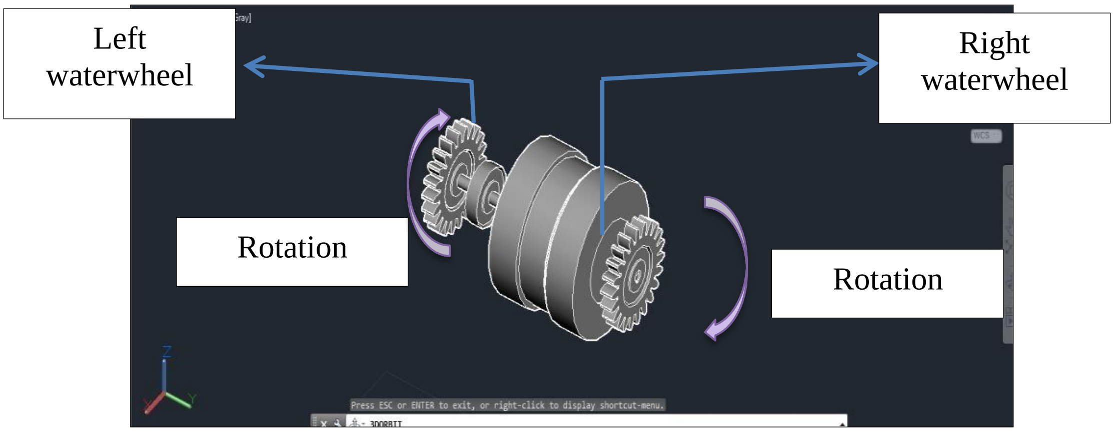


Figure 3.2: Initial design of axial generator for pico-hydro power generation.

In order to induce a voltage in copper wire, a nearby changing magnetic field must exist in the wire. In fact, the voltage induced not only depends on the magnitude of the field density but also in the winding part. The axial generator must be configured such both magnets and winding should be as close as possible. The configuration to ensure that the winding copper wire always actually occurs in the magnets strongest magnetic field, thereby allowing the process of inducing voltage in the winding.

The windings connected to the voltage measurement in a single phase. The number of windings will increase the voltage produced but will also increase the turns of the coil. Therefore, deep consideration must be given to the configuration.

Completing the design flow, the project proceeded development stage, where all parts must be assembled, installed and tested. The testing will be primarily focus on the water speed that rotates the waterwheels and the voltage that can be produced by the generator. Lastly, data on the tests conducted on the water turbine presented in the report and also in the presentation.

3.3 Material Selections

Table 3.1 shows the selections of material for axial generator for Pico hydro power generation. The selection of materials very important in order to archive the well results. This project may encounter problems such as imbalance of the waterwheel position or failure of waterwheel which directly lead failure in results to generate the desired voltage.

The projects should be design using a strongest and suitable materials. Therefore, the waterwheels can rotate smoothly. However, the other important element needs to be highlight is the costing of the project.

Table 3.1: Material selections for double rotating.

Categories	**Materials**	**Specification**	**Criteria that must be consider**
Shaft	Round stainless steel.	-Hold the waterwheels and as a shaft.	-Light weight. -Strong to be a shaft.
Blades	Pieces of prespex.	-Used for the blade to rotate the waterwheel : Left waterwheel = 8 fins Right waterwheel = 8 fins Total = 16 fins	-Strong to accept the water impact. -Easy to rotate.
Generator design part			
Waterwheel of magnet part			
Holder	Nylon bar	-Used for blade and magnet holder.	-Less friction.
Based	Prespex	-Prespex thickness: 5mm. Used for magnet holder. -Prespex thickness: 2mm. Used for base holder and magnet cover.	-Fit with the size of magnet. -Strong.
Bearing		-As an element that constraints relative movement to rotates the blades.	-Less friction. - Make the waterwheels easier to rotate.
Waterwheel of winding part			

Based	Perspex	-Prespex with high: 5mm. As a winding holder.	-As a winding holder to hold a winding part.
Winding part	Copper	-Winding part.	-The coils must be suitable diameter in order to insert in winding based.

3.4 Design Stage

Before starting the project, the waterwheels need to be designed roughly. Then, the design is upgraded by using AutoCAD software in order to see the real picture of the project. The AutoCAD software is used as the drafting tool to stimulate a real image in 3 dimensional (3D). There are three elements of design which are right and left waterwheels, winding part and frame. Figure 3.3 shows the full process of this project.

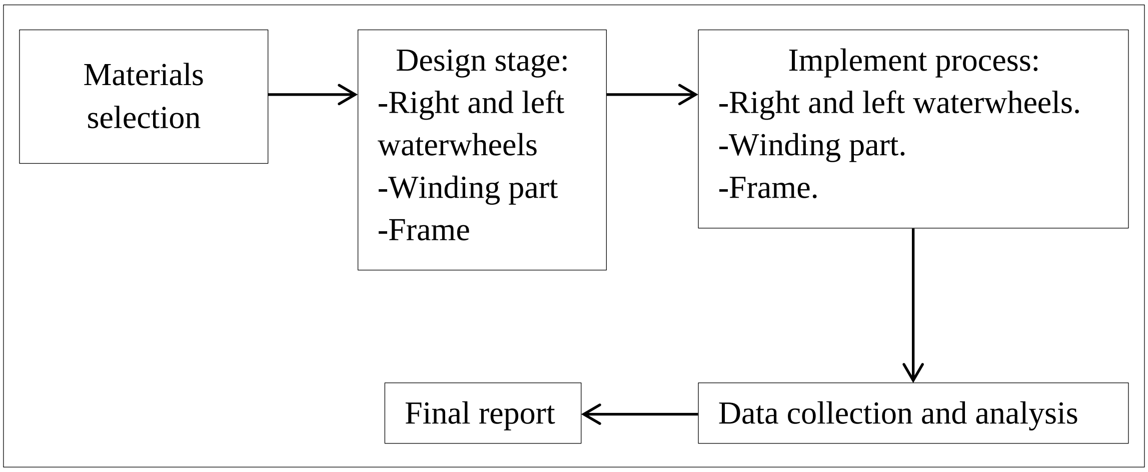
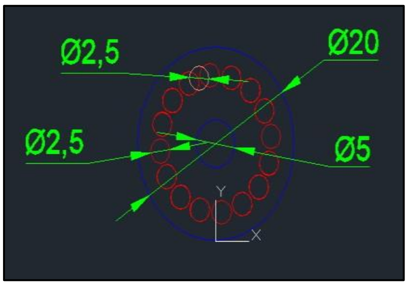


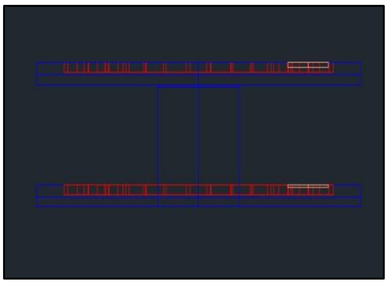
Figure 3.3: Planning process.

3.4.1 Magnet Parts

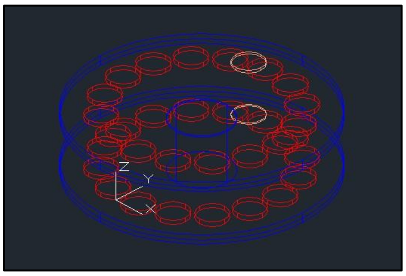
The development of axial generator that operate in double rotation condition consists of two main parts which were magnet part and winding part. Figure 3.4 shows the design of magnet holder. Perspex was used as a material for base and magnet holder. By referring to Figure 3.4, magnet holder was covered by Perspex and there are 16 holes for magnets per base, means total of magnet used is 32. The 5 mm thickness of perspex are used as a base of a magnet and 2 mm thickness of perspex used as a cover of magnet holder.



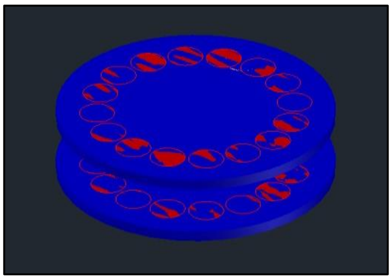
Top view



Side view



2D views



3D views

Figure 3.4: Magnet holder design.

3.4.2 Winding Parts

Figure 3.5 shows winding holder design in full view. There are 12 holes to place 12 of coils with the diameter and height of each coil is 2.5 cm and 2.0 cm respectively. Since all the parts will combine, hence the dimensions must be accurately respect to the magnet holder design to ensure it will rotate smoothly without any disturbance.

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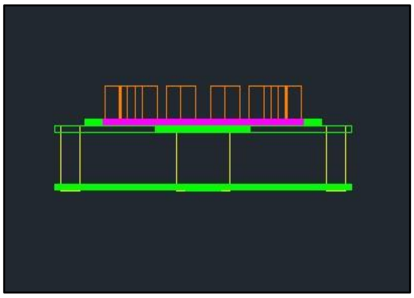
<tr><td>
</td><td></td></tr>
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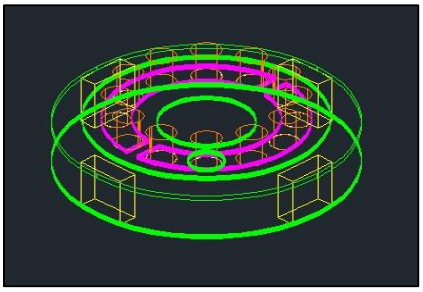
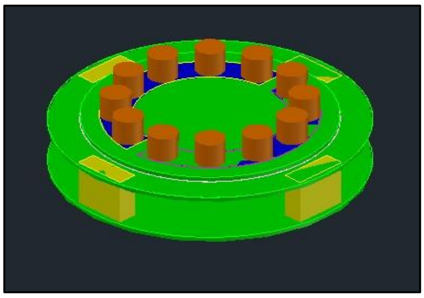
<tr><td></td><td></td></tr>
<tr><td>2D views</td><td>3D views</td></tr>
</table>

Figure 3.5: Winding part design.

3.4.3 Complete Design of Generator

Figure 3.6 shows the complete design of generator. The generator part consists a combination of winding part and magnet part. The output generator will be produced by cutting magnet flux. Hence, all the parameter and specification need to be highlighting to ensure the concept design is successful.

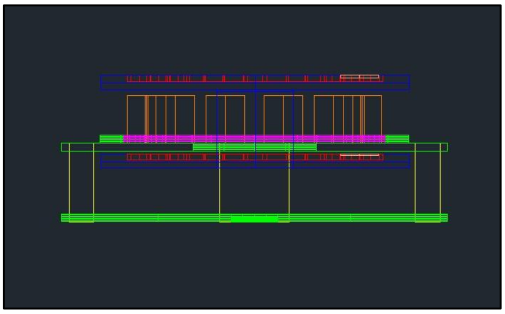
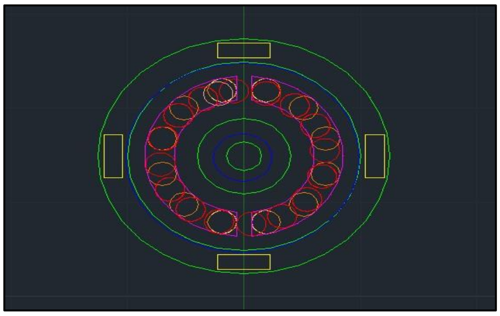
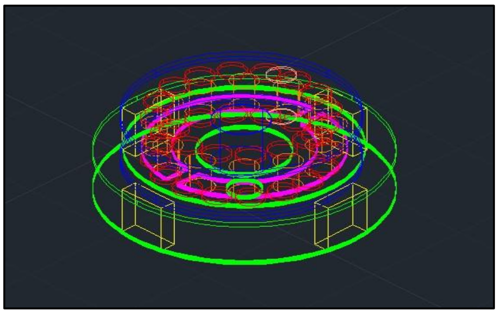
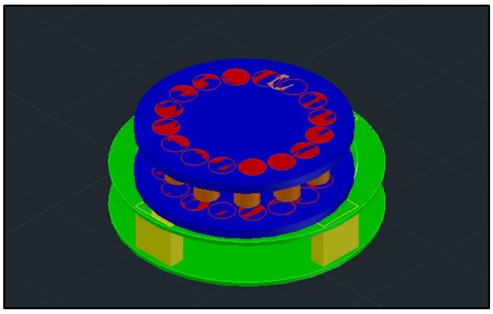
	
Top view	Side view
	
2D views	3D views

Figure 3.6: Generator design.

3.4.4 Winding Design

Every winding was designed by using fixed size which were:

i. Diameter = 2.5 cm

ii. Length = 2.5 cm

The thickness of coil wire is 0.6 mm. The number of turns was depending on the size of coil which is 2.5 cm long with diameter 2.5 cm. Since, the size was fixed, therefore the number of turns for 0.6 mm coil is estimated 400 turns.

The measurement of inductance reading is stated in Chapter 4, which is Table 4.1 for inductance reading of each coil for 0.6 mm (400 numbers of turn).

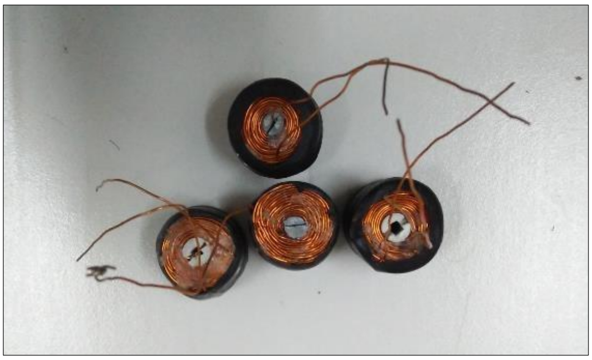


Figure 3.7: Coils.

3.5 Hardware Construction

This section will discuss the hardware construction process in order to complete this project. In this section too will shows a review of the project based on the drafting design and real prototype.

3.5.1 Hardware Construction Process

There are several method of engineering skills used to completely this project such as drilling process, cutting process, soldering, laser-cutting, laser-cut, and connection testing process. Table 3.2 shows summary of the hardware constructing process.

Table 3.2: Summary of hardware construction process.

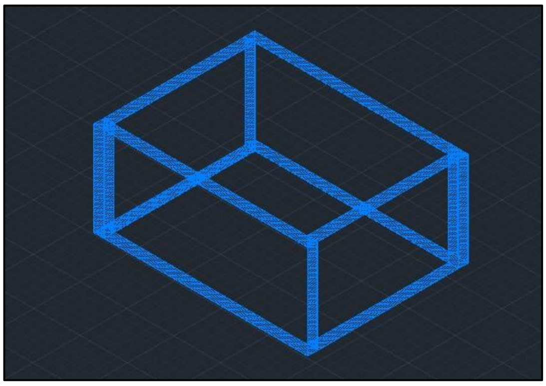
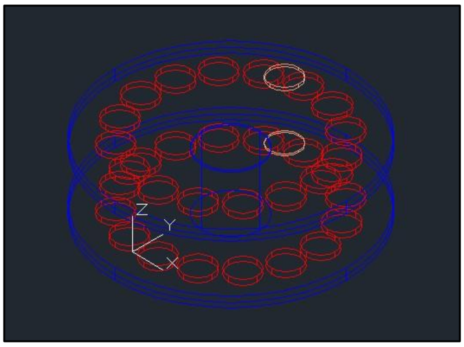
Method approach	Description	Explanation
Drilling	Drilling is a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials.	Holes throughout the Perspex was done by drilling a hand drill.
Cutting	Cutting is the separation or opening of a physical object, into two or more portions.	The nylon bar was cutting by using a hand saw.

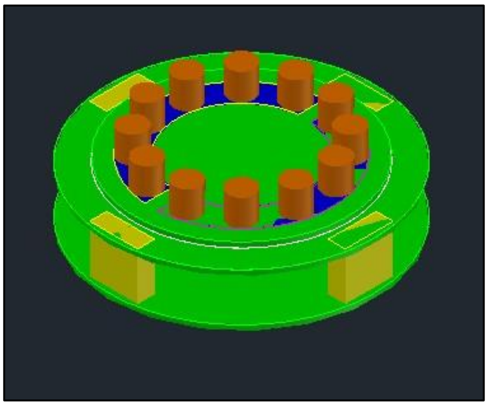
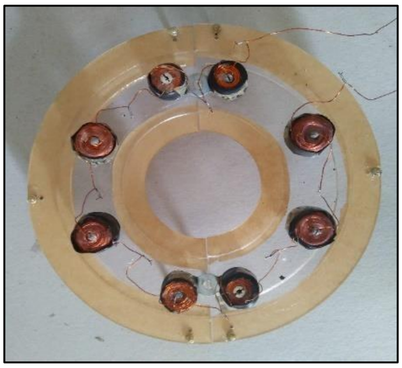
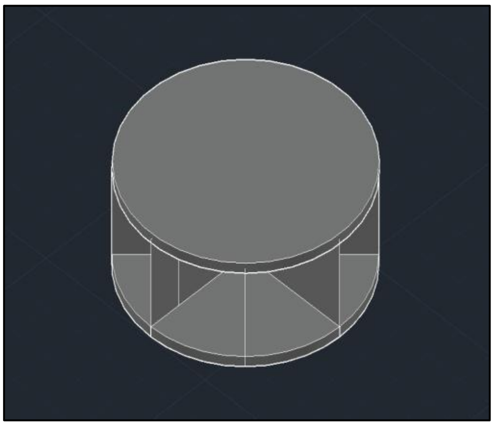
Soldering	Soldering is a process in which two or more items are joined together by melting and putting a filler metal (solder) into the joint.	The end of each coils are coupled together using solder.
Laser-cut	Laser cutting is mainly a thermal process in which a focused laser beam is used to melt material in a localized area.	Laser cutting process was used to make a precise and accurate shape of a perspex.
Connection testing using digital multi-meter.	Connection testing is a method to ensure accurate and relevant test results.	Used to check the connection of the copper wires and measuring current.

3.5.2 Review of the Project Based on the Drafting Design using AutoCAD and Real Prototype

Table 3.3 shows the views of AutoCAD design and real image. Since this prototype will be exposed to water, all the metal materials are from stainless steel such as shaft, bearing inside the waterwheels and frame.

Table 3.3: Review of the project based on the AutoCAD design and real image.

AutoCAD design	**Real image**
Frame	
	
Magnet holder	
	

Coil holder	
	
Waterwheels	
	

The main two factors that need to be highlight in implementing process which are balancing and alignment. To ensure are balance successfully, spirit level meter is used. Several stainless-steel flat washers with diameter 10 mm are placed in the middle of round bar to separate magnet and winding part. Grease used as lubricant in order to ensure the bearing in all part of prototype are spinning smoothly. Figure 3.8 shows the axial generator for pico-hydro power generator while doing the process balancing and alignment.

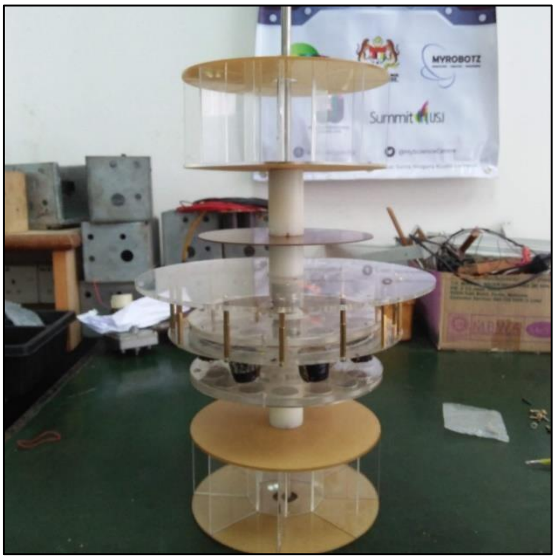


Figure 3.8: The axial generator for pico-hydro power generator while doing the process balancing and alignment.

Figure 3.9 shows an axial generator for pico-hydro power generator successfully implemented. All parts need to install carefully and tightly to ensure it will successfully on rotating when water sources are input. Plus, the development of axial generator for pico-hydro power generator needs to be design as strong as possible to ensure that is strong enough to face the water impact during of the operation. Both right and left waterwheel will rotate approximately in same speed and this will be proved that the waterwheels were stable and in order to produce about two times higher than the induced voltage of single waterwheel rotation.

Figure 3.9: An axial generator for pico-hydro power generator successfully implemented.

3.5.3 Problem Formulation to Calculate Velocity of Waterwheel

The calculation of waterwheels rotational per minute convert into velocity in unit meter/seconds, m/s. Alternatively, it can be measured how fast the water flow is moving through waterwheels by refer the radius of waterwheels is 10 cm which is 0.1 in meter and maximum rotational per minute left waterwheel is 357.47 rpm, it can be conclude in mathematical equation:

$$V = r \text{ x } Rpm\ x\ \frac{2\pi}{60} \tag{3.1}$$

Where;
V = velocity of waterwheel in m/s
r = radius in meter (*m*) *Rpm* =
rotational per minute

By referring the formula above, for the maximum velocity double rotation waterwheels can be simplified:

$$V = 0.1 \text{ x } 357.47\ x\ \frac{2\pi}{60}$$
$$= 3.74 \text{ m/s}$$

The value 3.74 m/s are approximately to 3.5 m/s for the maximum velocity double rotation waterwheels. All the velocity of waterwheels performance was presented in Chapter 4.

3.5.4 Experimental Setup

Figure 3.10 shows the experiment to prove the result output via oscilloscope. The tachometer used for measuring waterwheel speed. A digital multi-meter used for measure the voltage (V) and current (A) that produced from the prototype. Meanwhile the oscilloscope used to capture the waveform from output generated. All the data was presented in Chapter 4.

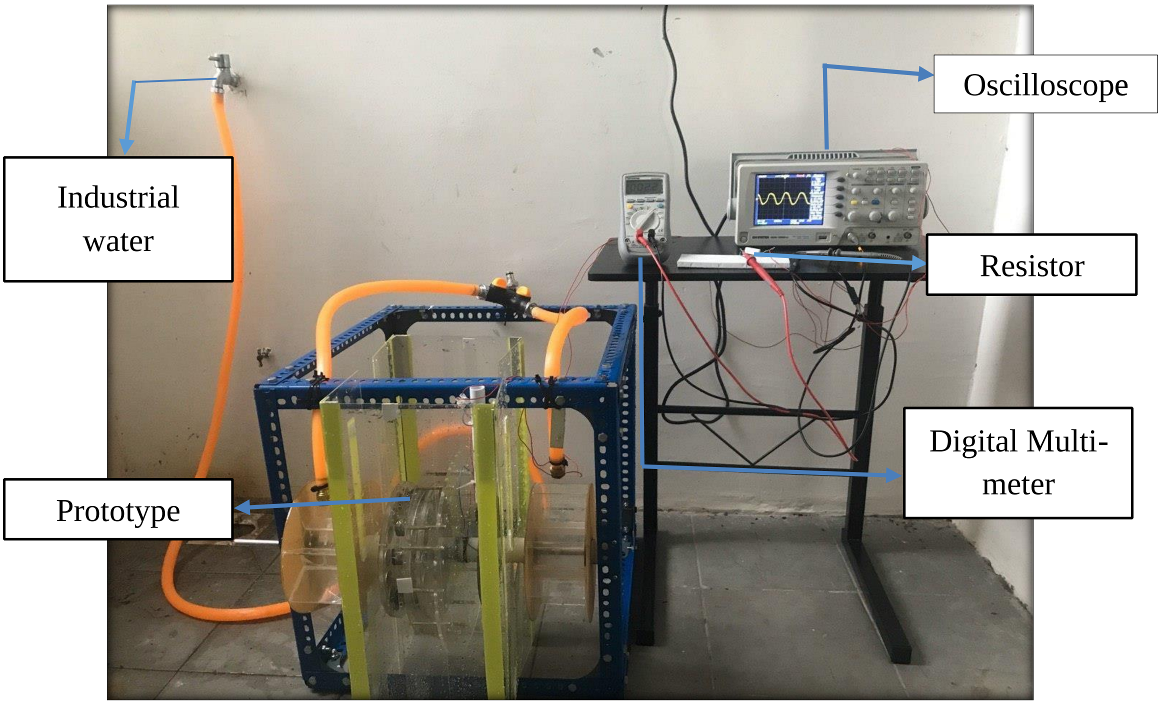


Figure 3.10: Experimental setup of the Double Rotational Axial Generator for Pico-Hydro Power Generation.

CHAPTER 4

RESULT AND DISSCUSSION

4.1 Overview

This chapter discussed about the result and analysis of the prototype. The data was taken by identifying the relationship between number of turns with different size of coil wire and the output voltage.

4.2 The Effect of Velocity of Water to the Rotational per Minute of Waterwheel

Since the meter for measuring water speed are not provided and take a costing, the water velocity in meter per second (m/s) is doing by calculation. The Tachometer are used in order to capture the rotational per minute (RPM). Table 4.1 shows the data of waterwheel speed in rotational per minute (RPM) and the velocity of the water while Figure 4.1 shows the graph speed of waterwheel in rotational per minute (RPM) against the velocity of the water. The data of rotational per minute (RPM) for both waterwheels is taken of average value.

Table 4.1: Waterwheels in rotational per minute (RPM) and velocity of water.

Velocity of water, m/s	Waterwheels speed, rpm	
	Left waterwheel (magnet part)	Right waterwheel (rotor part)
1.5	156.47	155.37
2	215.10	211.73
2.5	250.60	252.43
3	300.60	302.77
3.5	357.47	359.13

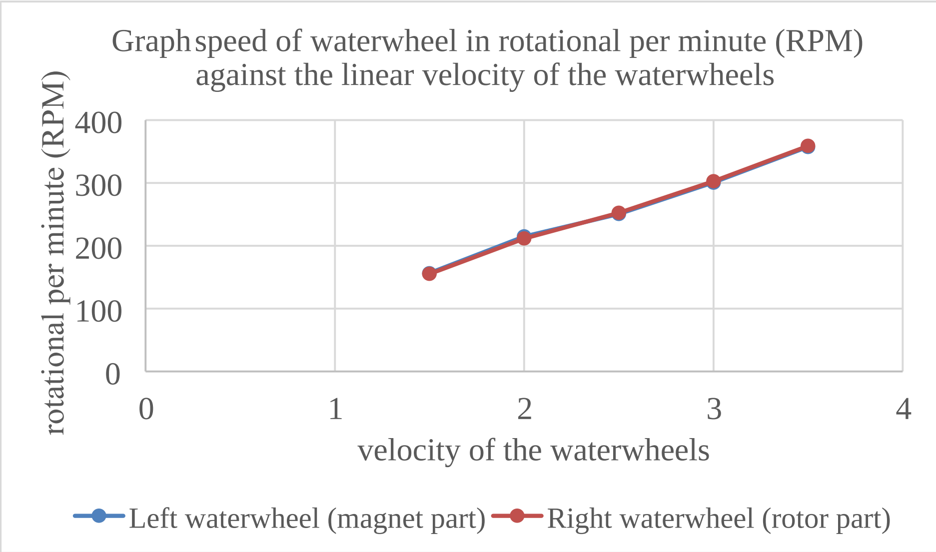


Figure 4.1: Graph speed of waterwheel in rotational per minute (RPM) against the velocity of the waterwheels.

Based on the data in Table 4.1, the waterwheels start rotated at 1.5 m/s which is the minimum speed the waterwheel can rotate. At the velocity of water 1.5 m/s, the waterwheel rotation is 156.47 rpm for left waterwheel (magnet part) while 155.37 rpm for right (rotor part) waterwheel. When the water velocity of water increases to 2 m/s, waterwheel rotation also increases to 215.10 rpm for left waterwheel and 211.73 rpm for right waterwheel. At velocity of water 2.5 m/s, rotation for left waterwheel increase to 250.60 rpm while for right waterwheel is 252.43 rpm. Next, for 3 m/s, the left waterwheel increases to 300.60 rpm and 302.77 rpm for right waterwheel. As the velocity of water increases. By referring to Figure 4.1, the rotation for left and right waterwheels are almost same. This shows that both waterwheels are stable. It is clearly showing that as the velocity of water increases, hence the rpm also will increase.

4.3 Output Captured from the Pico-Hydro Power Generation

Figure 4.2 shows the waveform for output captured from right waterwheel. The maximum rotational per minute for the left waterwheel at 357.47 rpm it produces voltage maximum, Vmax is 4.08V and voltage peak to peak, Vpp is 8.24V. While the frequency produced is 47.85 Hz. While, for the maximum rpm for right waterwheel at 359.13 rpm, it produces voltage maximum, Vmax is 3.84V and voltage peak to peak, Vpp is 7.76V. While the frequency produced is 43.63 Hz as it shown in Figure 4.3. Next, for the double rotation at same rpm from the both waterwheels, produced the voltage maximum, Vmax is 8.20V and voltage peak to peak, Vpp is 16.20V. While the frequency produced is 95.60 Hz. Figure 4.4 shows the output captured from double rotation of waterwheel.

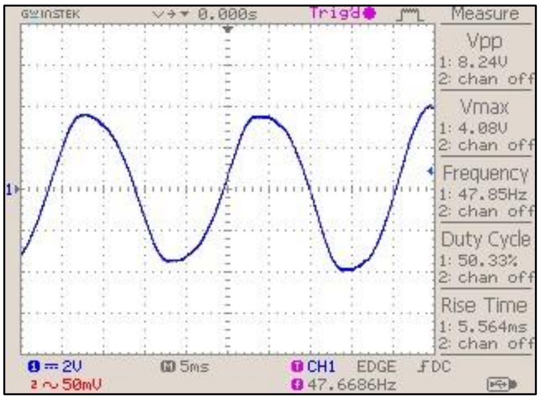


Figure 4.2: Output captured from left waterwheel.

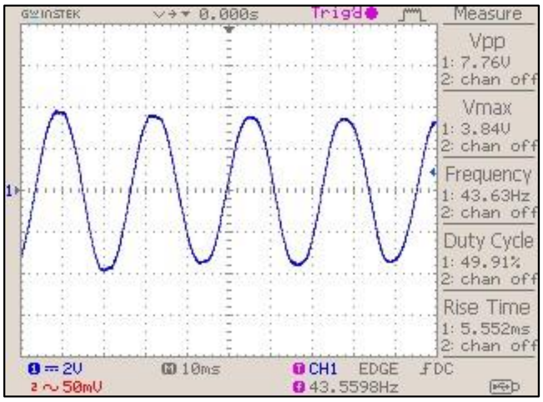


Figure 4.3: Output captured from right waterwheel.

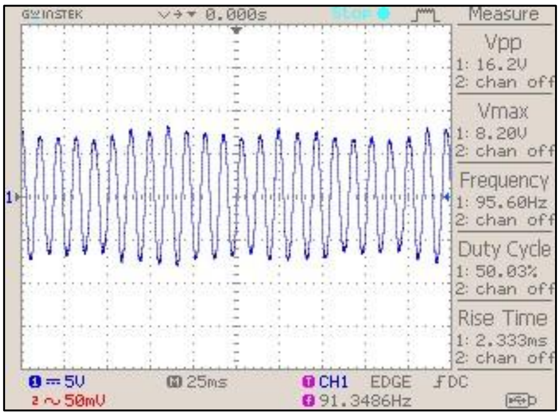


Figure 4.4: Output captured from double rotation of waterwheel.

4.4 The Effect of Waterwheel Rotational per Minutes (RPM) to the Voltage, Current, and Power

This part of analysis studied about the effect of waterwheel rotational per minute (RPM) from the both side of waterwheels and double rotation to the voltage, current, and power produced.

4.4.1 Left Waterwheel Performance

Table 4.2 shows the voltage, current, and power for the left waterwheel. This side of waterwheel are installed to the magnet part.

Table 4.2: The voltage, current, and power for the left waterwheel.

Left waterwheel			
RPM	**Voltage (V)**	**Current (uA)**	**Power (uW)**
156.47	2.03	0.8	1.62
215.10	2.54	1.2	3.04
250.60	2.95	1.5	4.42
300.60	3.77	1.9	7.16
357.47	4.00	2.2	8.80

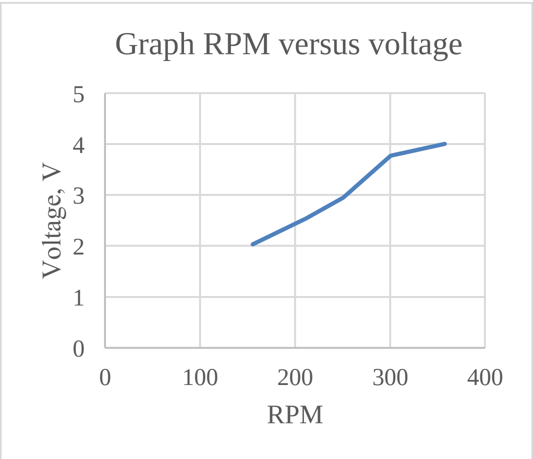


Figure 4.5: RPM versus voltage for left waterwheel.

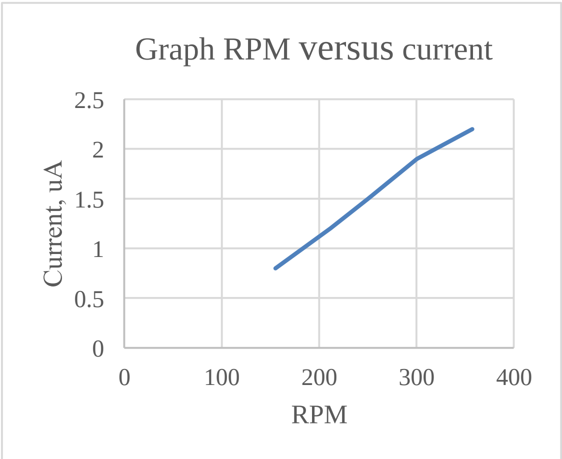


Figure 4.6: RPM versus current for left waterwheel.

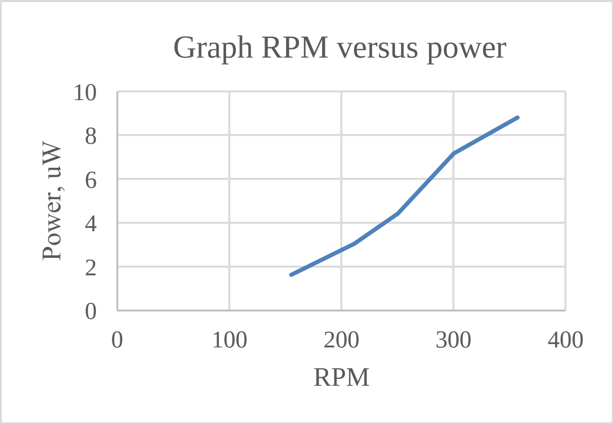


Figure 4.7: RPM versus power for left waterwheel.

According to the Table 4.2, at rotational per minute (RPM) in 156.47 rpm of the left waterwheel it produce voltage maximum, Vmax is 2.03 V, current is 0.8 uA and power is 1.62 uW. When the RPM increase which is at 250.60 rpm, Vmax and current also raise to 2.95 V and 1.5 uA, while the power boost to 4.42 uW. At the maximum RPM of left waterwheel which is 357.47 rpm, it produce uplift Vmax which is 4.00 V and current is 2.2 uA. While the power is 8.80 uW. Based on the graph shows in Figure 4.5 and Figure 4.7, it clearly shows that as the induced voltage high, the output power will be higher.

4.4.2 Right Waterwheel Performance

Table 4.3 shows the voltage, current, and power for the right waterwheel. This side of waterwheel are installed to the winding part.

Table 4.3: Voltage, current, and power for the right waterwheel.

Right waterwheel			
RPM	**Voltage (V)**	**Current (uA)**	**Power (uW)**
155.37	1.61	0.8	1.28
211.73	2.22	1.2	2.66
252.43	2.76	1.4	3.86
302.77	3.11	1.8	5.59
359.13	3.85	2.2	8.47

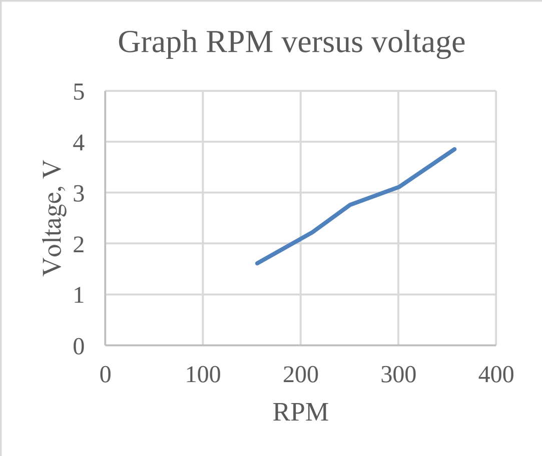


Figure 4.8: RPM versus voltage for right waterwheel.

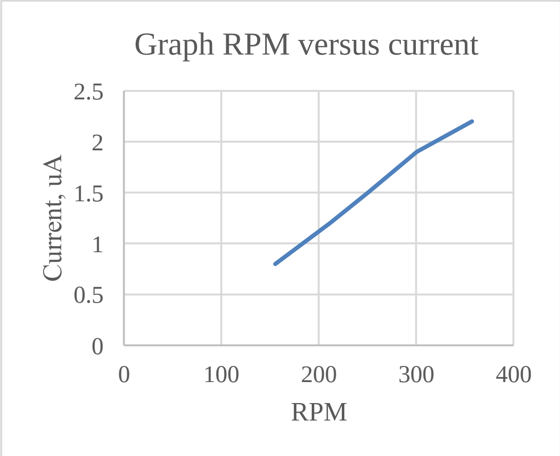


Figure 4.9: RPM versus current for right waterwheel.

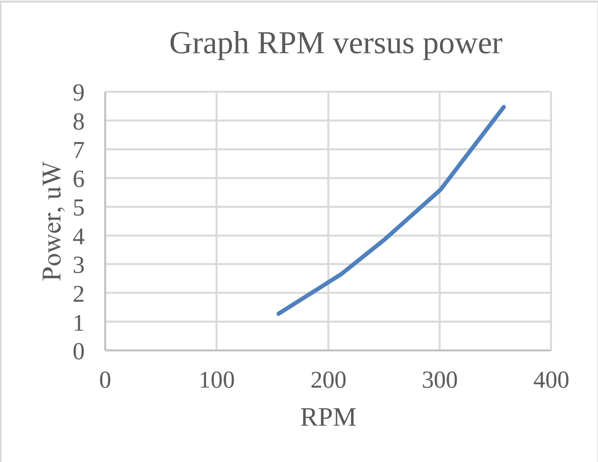


Figure 4.10: RPM versus power for right waterwheel.

According to the Table 4.3, at rotational per minute (RPM) in 155.37 rpm of the right waterwheel it produces voltage maximum, Vmax is 1.61 V, current is 0.8 uA and power is 1.28 uW. When the RPM increase which is at 252.43 rpm, Vmax and current also raise to 2.76 V and 1.4 uA, while the power boost to 3.86 uW. At the maximum RPM of right waterwheel which is 359.13 rpm, it produces uplift Vmax which is 3.85 V and current is 2.2 uA. While the power is 8.47 uW. Based on the graph shows in Figure 4.8 and Figure 4.10, it clearly shows that as the induced voltage high, the output power will be higher.

4.4.3 Double Rotation of Pico-Hydro Power Generation

Table 4.4 shows the voltage, current, and power for the double rotation. For the double rotation, both waterwheels are rotate with opposite direction.

Table 4.4: Voltage, current, and power for the double rotation.

Double rotation			
RPM	**Voltage (V)**	**Current (uA)**	**Power (uW)**
155.37 to 156.47	2.94	2.2	6.46
211.73 to 215.10	4.64	2.6	12.06
250.60 to 252.43	5.44	3.2	17.40
300.60 to 302.77	7.62	3.5	26.49
357.47 to 359.13	8.20	4.7	38.54

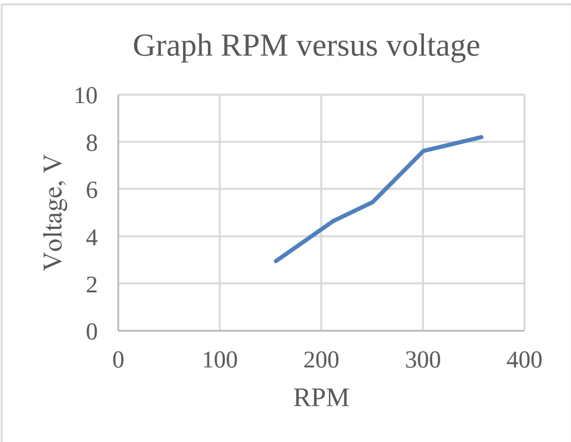


Figure 4.11: RPM versus voltage for double rotation.

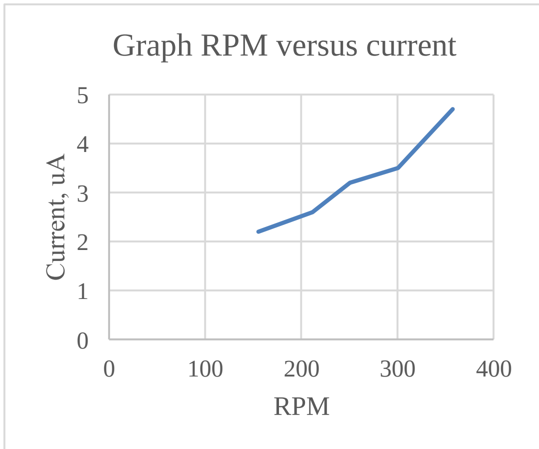


Figure 4.12: RPM versus current for double rotation.

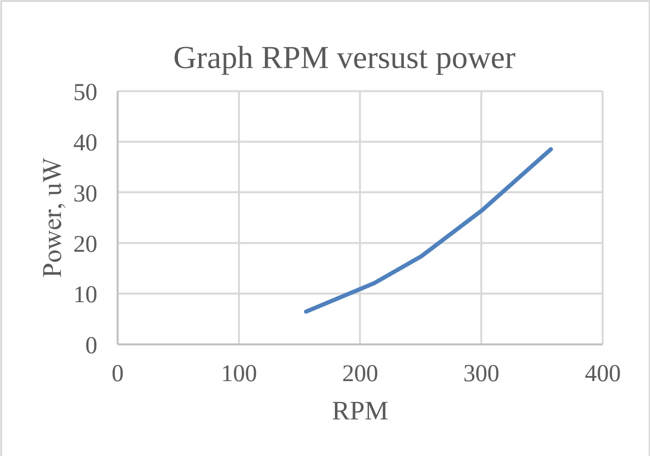


Figure 4.13: RPM versus power for double rotation.

According to the Table 4.4, at rotational per minute (RPM) in 155.37 to 156.47 rpm for double rotation, it produces voltage maximum, Vmax is 2.94 V, current is 2.2 uA and power is 6.46 uW. When the RPM increase which is at 250.60 to 252.43 rpm, Vmax and current also raise to 5.44 V and 3.2 uA, while the power boost to 17.40 uW. At the maximum RPM of double rotation which is 357.47 to 359.13 rpm, it produces uplift Vmax which is 8.20 V and current is 4.7 uA. While the power is 38.54 uW. Hence, it proved that double rotation of generator able to produce double output of power since the magnet and winding part are put nearly as the air gap small as possible [7]. Based on the graph shows in Figure 4.11 and Figure 4.13, it clearly shows that as the induced voltage high, the output power will be higher [8].

4.4.4 Summary of the Prototypes Performance

Based on all the data from the increase RPM for both waterwheels, it obviously shows that the voltage, current, and power output also raise up. The highest value from double rotation output was captured, for voltage maximum, Vmax is 8.20 V with voltage peak to peak, Vpp is 16.20 V. While, the frequency collected is 95.60 Hz. Figure 4.14 shows the graph induced average voltage maximum (Vmax) against the speed of waterwheel in rotational per minute (RPM) and Figure 4.15 shows the graph induced average current (uA) against the speed of waterwheel in rotational per minute (RPM). While, Figure 4.16 shows the graph induced average power (uW) against the speed of waterwheel in rotational per minute (RPM). Hence, the development of axial generator for Pico-Hydro power generation is achieved to produce double output of power.

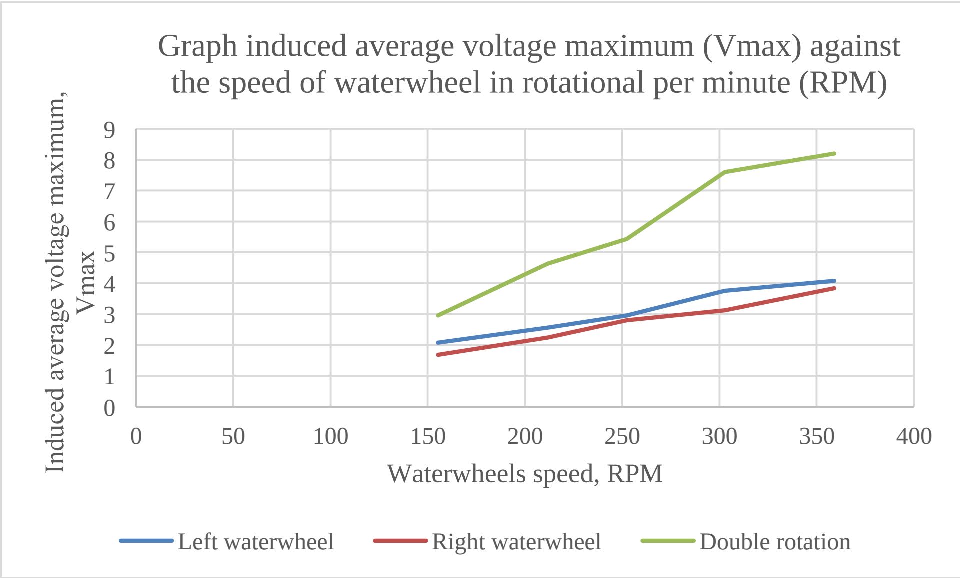


Figure 4.14: Graph induced average voltage maximum (Vmax) against the speed of waterwheel in rotational per minute (RPM).

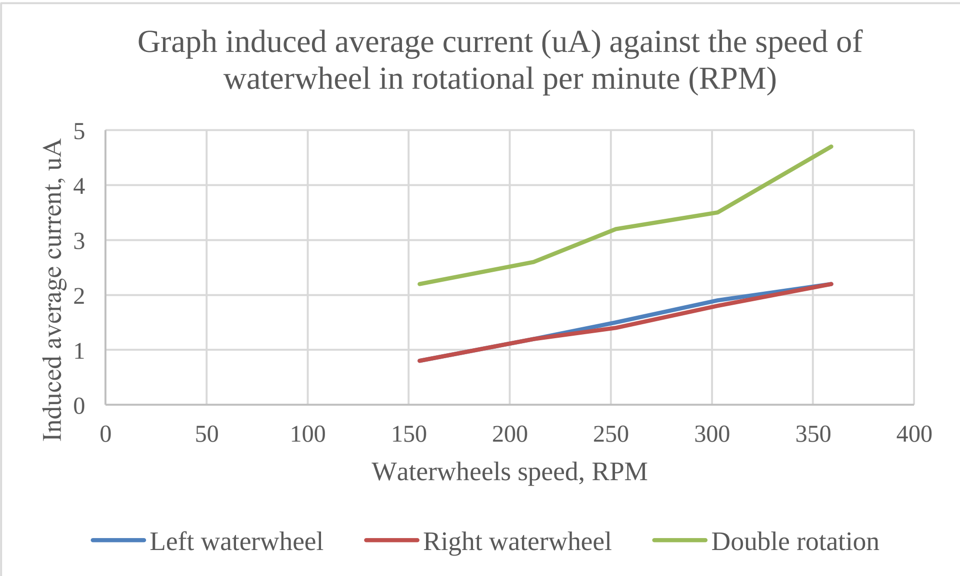


Figure 4.15: Graph induced average current (uA) against the speed of waterwheel in rotational per minute (RPM).

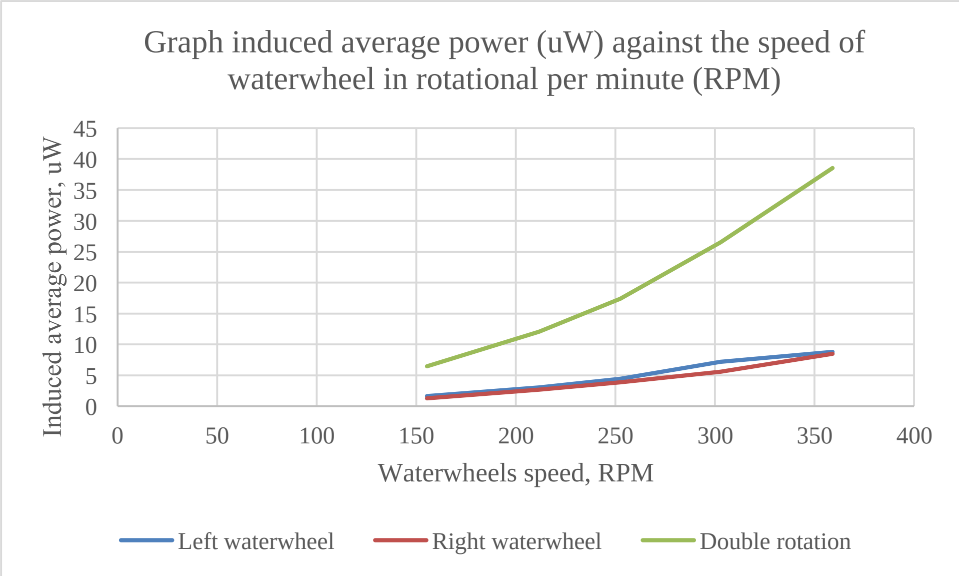


Figure 4.16: Graph induced average power (uW) against the speed of waterwheel in rotational per minute (RPM).

CHAPTER 5

CONCLUSION

5.1 Overview

This chapter consists of summaries about construction of development axial generator for Pico hydro power generation.

5.2 Summary of the Project

As a conclusion, double rotation axial axis generator was successfully developed and directly archived the first objective of this project. For axial axis generator, the value of inductances and magnetic strangeness will give an effect to the output produces. The greater number of turns of the windings to the cutting magnetic flux will produces higher output from generator prototype. Besides, the air gap between winding and magnets must be closed as possible to get higher cutting magnetic flux. An achievement from first objectives, pico-hydro power generation with double rotating waterwheel that can rotates in both rotations was successfully construct and achieved the second objectives of this project. From the results in Chapter 4, both right and left waterwheel rotates approximately in same speed and this proved that the pico-hydro power generation were stable. Finally, the performance of double rotation pico-hydro power generation have been evaluate and all the result ware presented in Chapter 4. All the objectives were achieved.

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