Development of Linear Permanent Magnet Generator for Wave Energy

By

Iskandar Bin Saaidi

Supervise by Dr. Taib Bin Ibrahim

DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme

in partial fulfilment of the requirement

for the Degree

Bachelor of Engineering (Hons)

(Electrical and Electronics Engineering)

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Development of Linear Permanent Magnet Generator for Wave Energy

By

Iskandar Bin Sa'aidi

A project dissertation submitted to

Electrical and Electronics Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfilment of the requirements for the

BACHELOR OF ENGINEERING (Hons)

(ELECTRICAL AND ELECTRONICS ENGINEERING)

Approved:

Dr. Taib Ibrahim

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Iskandar Bin Sa'aidi

ACKNOWLEDGEMENT

At a very first, I would like to express my gratitude to God for giving me the strength to complete this project. Then, I would like to thanks to my parents and all my family members who give me support and advise when I am in problem.

I would like to thank my supervisor, Dr Taib Ibrahim for giving the guidance and sharing his knowledge throughout the project. I also would like to thank lab technician, Mr. Shaiful who always assists me for prototype fabrication.

My appreciation also goes to Universiti Teknologi PETRONAS especially Electrical and Electronics Engineering Department, by providing me the good facility and equipments for me to accomplish my project. I would also like to thank PETRONAS for sponsoring my studies in Universiti Teknologi PETRONAS.

Last but not least, I offer my regards to those who support me especially all my friends and staff in Electrical and Electronic Engineering department for contributing their assistance and ideas for this project.

ABSTRACT

This project is about the development of linear permanent magnet generator for wave energy. Wave energy is one of renewable energy that has a potential as a source of energy. The objective of this project is to fabricate a linear permanent magnet generator to be use at the oil platform by attaching the generator to the platform stand. Currently, the oil platform stands is not fully utilized because it has a potential for electricity generation by using sea wav. The project begins with research in wave energy potential and the available methods for wave energy harvesting. There are four methods available for wave harvesting which are overtopping sea wave, attenuator, terminator oscillating water column and point absorber. All of the methods will be analyze to find the appropriate method for an oil platform application. A proposed design is build based on the chosen method based from the research. Based on the proposed design, prototype is divided into several main parts which are rotor, stator and floatation device. Detail steps of fabrication of the prototype are included inside this paper. Lastly, the prototype is tested to get the efficiency of the operation and the amount of electricity being generated. Based on the result of the test conducted, the performance of the generator is analyzed and several recommendations are suggested for further improvement of the prototype. This paper is hopefully will attract interest for more research and development of device for wave energy harvesting.

Table of content

Contents

List of figures

List of Tables

List of Abbreviation

EMF	Electromotive Force
OWC	Oscillating Water Column
WEC	Wave Energy Converter
TFM	Transverse Flux Permanent Magnet Machine
NeFeB	Neo-Dymium-Iron-Born
EPEW	Engine for Producing Energy from Sea Wave
TLSM	Tubular Linear Synchronous Machine

CHAPTER 1

INTRODUCTION

1.1 Project Background

Energy is being categorized into two groups which are renewable energy and un-renewable energy. Un-renewable energy is an energy that is from a raw material such as petroleum, coal and nuclear material. Most of the un-renewable energy will produce pollution and waste that can affecting the health of the public for example smoke, heat or the worst which is the nuclear waste and this kind of energy is running low nowadays. Renewable energy is natural energy that will never run out and example for these kinds of energy such as solar energy, wind energy, biomass energy, geothermal energy and wave energy. Most popular and highly use renewable energy is by using solar and wind energy while wave energy is still under development. Sea wave that continuously propagate is consider as a mechanical energy and this can be use to generate electricity. There are several reasons why the author chooses to pursuit in using the sea wave energy as a method of power generation. The major reason is because almost 70% of earth is cover with sea water and it is such a waste if this available, clean and redundant energy is being ignored by mankind. In Malaysia alone, two major seas are covering Malaysia which is Straits of Malacca and South China Sea. This Final Year Project (FYP) is related to development of linear permanent magnet generator in order to harvest the wave energy to generate electricity.

1.2 Problem Statement

The oil platform mostly situated at the open sea and has good potential to generate electricity by using the wave energy. The location of the platform which is situated in the middle of the sea surrounded by continuous sea level movement can be use as a resource for generate electricity. But, the oil platform stands until today is not fully utilized therefore it can be used to attach a generator that capture the wave energy and generate electricity.

1.3 Objective

The main objective of the project is to develop a linear generator to harvest the sea wave energy to generate electricity by attaching the generator to the platform stand. To achieve this main objective, several main goal must be achieve to ensure smoothness of the project:

a) To conduct a literature review on various technologies for sea wave conversion.
b) To design an appropriate wave energy conversion system based on literature review being done on various technologies for sea wave conversion.
c) To test the fabricated prototype for its functionality and electricity generated

1.4 Scope of Study

In effort to ensure the project to be successful, several area of study needs to be completed by the author which is included in this paper such as:

a) Chapter 1: Understanding the project background, problem that is trying to be solved and the main objective of the project.
b) Chapter 2: Research about the potential energy in sea wave, available method of sea wave energy conversion and design a system for harvesting wave energy based on research that had been done.
c) Chapter 3: This topic consist of fabrication process for each component of the prototype
d) Chapter 4: Test the prototype to measure the electricity being generated.
e) Chapter 5: Finding of the research is summarized in this chapter.

CHAPTER 2

LITERATURE REVIEW

This chapter discuss on the wave energy and various method of harvesting wave energy. The proposed design of the prototype author planned for fabrication based on the method of wave conversion that the author had chosen is introduced.

2.1 Wave Energy

Waves are caused by the wind blowing over the surface of the ocean. In many areas of the world, if the wind blows with enough consistency and force it can provide continuous waves. This cause a tremendous energy in the ocean waves available as a source of generator prime mover. This tremendous energy is extract by wave power devices extract energy directly from the surface motion of ocean waves or from pressure fluctuations below the surface. Unfortunately, the wave power varies in different parts of the world and wave energy cannot be harvest effectively everywhere. Wave-power rich areas of the world include the western coasts of Scotland, northern Canada, southern Africa, Australia, and the north-western coasts of the United States. Figure 1 and Figure2 showed the distribution of wave energy in the world. Ocean energy is a yet unexploited renewable energy source on our planet. Preliminary surveys show that marine power has a potential to supply a significant part of the future European energy needs [1]. Large portions of the world's potential wave energy resources are also found in sheltered waters and calmer seas, which often exhibit a milder, but still steady wave climate. Examples are the Baltic, the Mediterranean and the Black Sea [2][3].This does not mean there is no potential for Asian country to generate electricity by using sea wave.

Using a direct use of wind energy exploitation of wave energy offers great advantages in generating electricity. By the interaction of wind and free water surface an energy concentration takes place [5]. Mechanical oscillation stored in sea waves due to the wind energy which is interchanged through wide surface areas of the oceans [5]. Based on concept of generator, mechanical energy can be converted into electrical energy by using generator. Tidal wave, pressure of air due to wave oscillation, direct contact between mechanical part of generator with the sea wave itself are the example of mechanical energy that can be found in the ocean. There are several compelling arguments for using the wave energy technology [2][6]:

i.) By its high power density it is one of the lowest cost renewable energy sources.

ii.) The wave energy is more predictable than solar and wind energy, offering a better possibility of being dispatched to an electrical grid system.

iii.) The conversion of ocean wave energy to electricity is believed to be one of the most environmentally benign ways to generate electricity; hence it does not render any waste that has to be stored or destroys the environment.

iv.) The wave energy conversion devices can be located far enough away from the shore (offshore) that they are generally not visible.

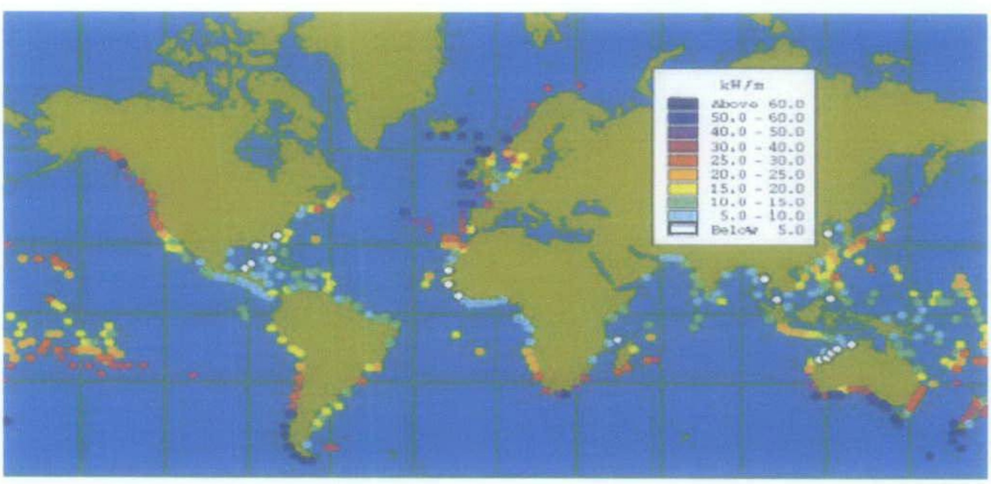


Figure 1: Wave power density measured in kilowatts (kW) per meter (m) [4]

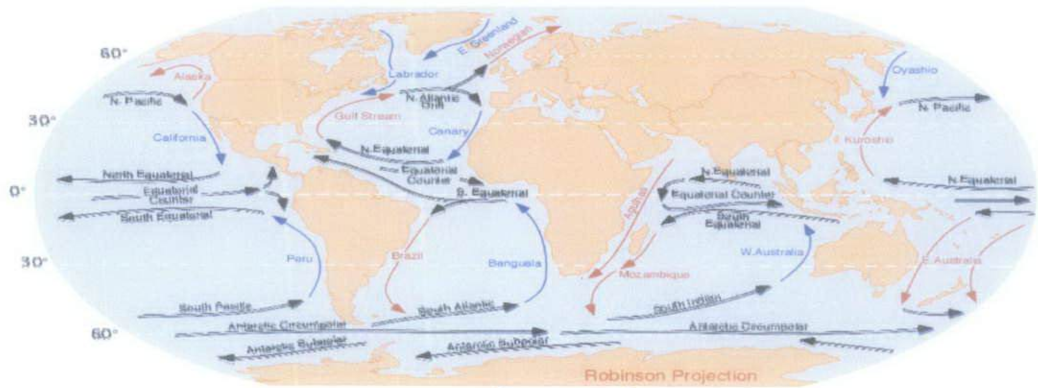


Figure 2: Map of Surface Ocean Currents [4]

Based on numerous research reports, capturing wave energy inevitably needs large capital investments and can have some impacts on the environment, which must be taken also into account although waves represent a free and clean source of energy [2]. The installation of any wave generator must not affecting the sea condition such as damaging the coral reef, the marine life population and not endanger any ship or marine life travelling in the open sea.

Sea wave is a mechanical energy and it can be converted to electricity. Wave is like a sinusoidal signal which has a negative and positive cycle. The highest part of the wave is called crest while the lowest part of wave is called trough. The distance of vertical high from the trough to the crest is called wave height and from the sea level to the crest or trough is called amplitude. When wave approach shallow water, it will change its shape causing the wavelength decrease but the height increase because of resistance from the bottom.

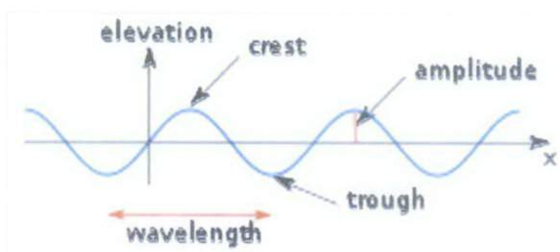


Figure 3: Wave properties [7]

2.2 Method of Harvesting the Wave Energy

There are four methods to generate electricity from the sea wave which are:

i. Overtopping Sea Wave
ii. Attenuator
iii. Terminator Oscillating Water Column (OWC)
iv. Point Absorber

2.2.1 Overtopping Sea Wave

An effective way to harvest sea energy is by using the sea water to be store in water reservoir as potential energy which is achieved in some overtopping devices like the Wave Dragon and the Tapchan [8]. Wave Dragon is an offshore wave energy converter based on overtopping sea wave concept. The main structure consists of a ramp where the waves are overtopping and led to a reservoir. Hydro turbines produce energy leading the water back to the sea as shown in Figure 4. Two reflectors are focusing the waves towards the ramp as shown in Figure 5 and Figure 6.

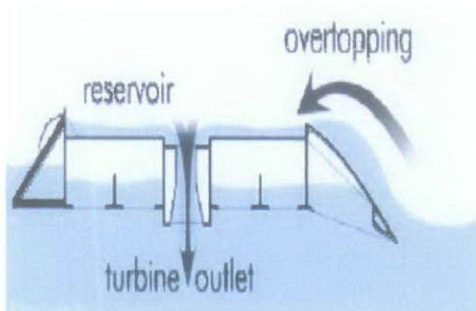


Figure 4: The basic principle of Wave Dragon loading the reservoir via ramp [9]

Figure 5: Wave Dragon [9]

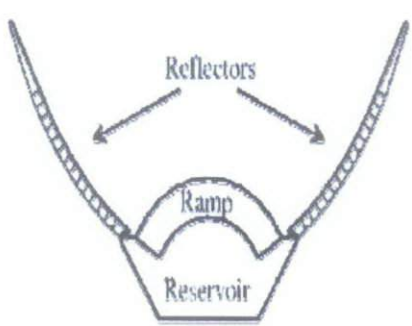


Figure 6: Main component of the Wave Dragon from above [10]

The plant "Wave Dragon" is a floating device using the potential energy in overtopping waves to produce power [9]. A water reservoir is placed on top of the Wave Dragon will lead the water back to the sea pass through the hydro turbines to produce electrical power. To maximize the power production in consideration of the wave height, it is important to control the level, heal and trim of the reservoir [10]. Here the amount of overtopping water and the amount of potential energy is conflicting. Controlling the level, the heel and the trim of the Wave Dragon is possible through pressure adjustments in air chambers and the pressures in the air chambers may be individually controlled by an air fan through an array of valves. An anchor is use to fastened the Wave Dragon making it possible to turn the ramp towards the dominant wave direction. The reservoir water is led through a turbine as shown in Figure 4. The Wave Dragon floats on closed and open air chambers [9]. The open air chambers are used to adjust the floating level and controlling the floating level is a part of optimization for the overtopping sea wave. Another way to optimize the generated electricity produce Overtopping Wave Energy Converter (OWEC) is by increasing the number of guided vanes [10] as shown in Figure 7.

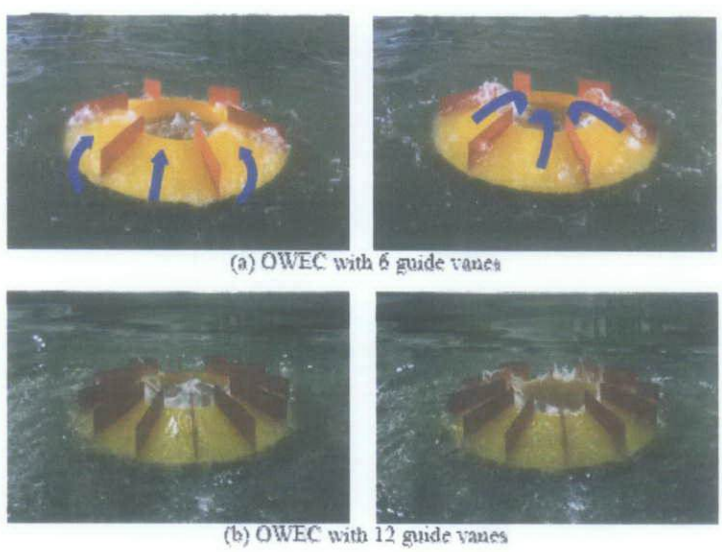


Figure 7: OWEC with vanes [10]

2.2.2 Attenuator

Attenuator is an infinite array of evenly spaced groups of oscillating bodies they have the same directional orientation. The angle of wave incidence is arbitrary. Regular waves diffracted and radiated from the bodies interfere constructively into rays of plane waves propagating away from the array. The ratio between the wavelength and the interspacing between adjacent groups will determine the number of rays [11]. The maximum wave power absorbed by the array is derived under the assumption of linear theory and of unconstrained amplitudes of the oscillating bodies. The cylindrical parts drive hydraulic rams in the connecting sections and those in turn drive an electric generator. The devices send the electricity through cables to the sea floor where it then travels through a cable to shore as shown in Figure 8.

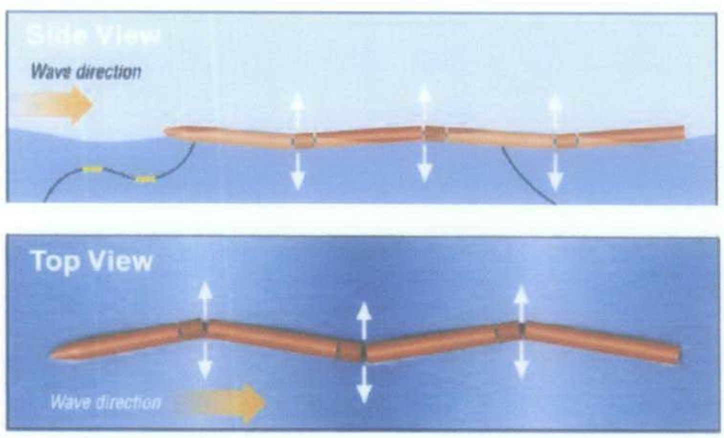


Figure 8 : Attenuator [7]

2.2.3 Terminator Oscillating Water Column (OWC)

OWC device utilize the relation between the wave motions and an air chamber to drive an air turbine appear to be among the most promising commercial devices in the short to medium term [12]. From the Figure 9 show the OWC device will depend on the oscillation of the wave to push out the air inside the chamber. As the after the air exit the chamber, it will cause the pressure inside the chamber less than the atmosphere pressure thus causing the air return back inside the chamber due to different pressure level. The process of in and out of the air inside the chamber wills causing the turbine to rotate thus electricity is generated.

These devices can be use as shore-mounted fixed devices, or moored floating structures. However, to use the OWC as shoreline converters will face some difficulties especially in term of location because they need specific site and are not likely play any significant part in the large-scale deployment of wave energy devices. These devices will be typically slack moored several kilometres offshore. Both brushed and brushless induction machines as well as permanent magnet machines have been considered for OWC devices. However, no clear consensus regarding the most suitable machine-type exists [12].

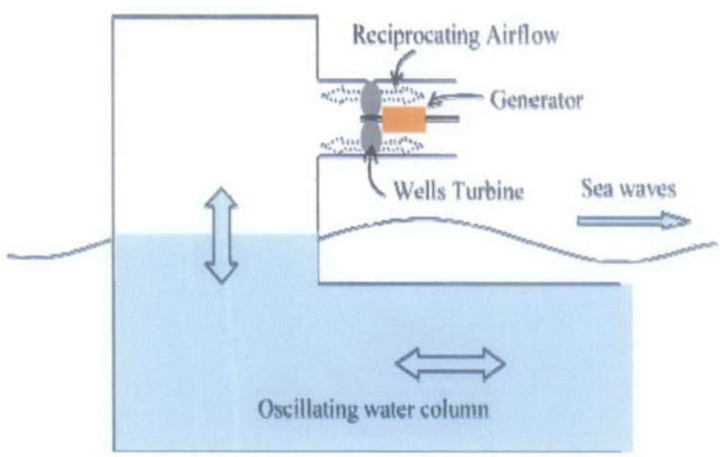


Figure 9: Floating OWC Device [12]

2.2.4 Point Absorber

One encouraging way to convert wave energy into electrical through direct drive is by using a linear permanent magnet (PM) generator where the rotor piston is driven by, for example, a point absorber [13]. There are two common type of magnet that been use for this type of generator which is Ferrite and NdFeB but as prices decrease, it has only recently become possible to use high remanence NdFeB magnets in technical applications. This help to develop a smaller magnet but with a high magnetic excitation to avoid heavier piston.

Using linear generator, the possibility to couple the motion of a point absorber directly to the generator can help to construct a simple configuration that eliminates the need of complex power take-off schemes. This, in turn, reduces the complexity of the plant and the need for maintenance [13]. Direct driven linear generators for wave energy converter (WEC) have been investigated by M.A. Muller in a number of articles [14, 15]. It is mainly the transverse flux permanent magnet machine (TFM) that has been investigated. The studies have shown that the TFM exhibits very good power to mass ratios but also that it suffers from high inherent synchronous reactance [14]. Another disadvantage of the TFM is the structure of the stator, which demands significant supporting structures to keep the cores in place [15].

The WEC consists of a buoy coupled directly to the rotor of a linear generator by a rope and the tension of the rope is maintained with a spring pulling the rotor downwards. The motion of rotor will follow the linear motion and approximately same speed as the waves. The relatively low speed implies that the reaction force developed between the rotor and stator to be very high. This shows that the directly driven generator must be larger than a conventional high-speed generator. Figure 10 and Figure 11 below show the configuration of the wave energy converter (WEC).

Figure 10: WEC device [13]

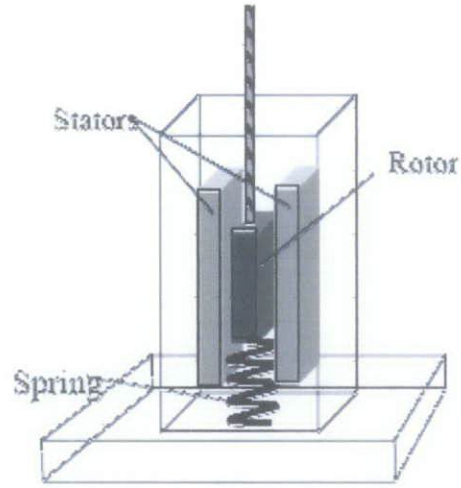


Figure 11: Inside of the WEC device [13]

The stator of the WEC consists of coil while the rotor consists of the rope, spring and magnet which act like a piston. There are two type of permanent magnet that can be use which is ordinary ferrite (Fe) magnets and high-energy Neo-dymium-Iron-Boron (NdFeB) magnets. The basic properties of the magnets are presented in Table 1. NeFeB magnets are considerably more expensive than Fe magnets and the relation of the kilo price is assumed to be 10:1 [13].

Table 1: Property of the magnet

Material	Neo-dymium-Iron-Boron	Ferrite Magnet
Remanence	1,32	0,3663
Relative permeability	1,06	1,06
Density (Kg/m^3)	7700	4700

2.3 Proposed Design

Based on the four available concepts for wave energy converter mention previously, each concept has different operating principles. Different operating principles meaning a different power take off systems for each concept [14]:

i. Oscillating water columns mostly have an air turbine that is driven by air inside the air chamber that drives rotating generators.
ii. Overtopping devices mostly have hydro turbines that drive rotating generators.

iii. Attenuator devices often use hydraulic power take off systems.
iv. Point absorber devices often have linear generator systems.

As for that, method that the author proposes to be use for harvest the sea wave energy is by using point absorber method. The justification of reason for the author chooses to use this method can be found below:

i. The generator construction by using this method is simpler and smaller in term of size compare to other method.
ii. This method can be use in an open sea which means no specific area needed for installing this device. For example, Oscillating Water Column (OWS) the device needs to be place near to onshore and the location choose to build the generator need to be modified to accommodate the generator requirement.
iii. The cost of production of generator using point absorber concept is less compare to other concept.
iv. Installation of generator using point absorber concept is less complicated.

But there are still several important disadvantage of point absorber method [8] that the author needs to be aware of which is:

i. The buoy, must be enough light not to drown in sea and be able to fluctuate by waves.
ii. WEC cannot absorb all energy of sea waves.
iii. Sea wave converting to electricity is, generator input is irregular and therefore voltage and current amplitude and frequency is irregular.

Figure 12 shows the propose design of the prototype that the author plan to fabricate. The linear generator that the author plans to fabricate is different from the WEC design. In WEC, the whole generator will be mounted into the base of the ocean while the author plan to let the generator part to be above the sea level by attach it to the platform stand. This way can help to ensure the problem of ensuring the casing for the generator to be tightly seal from water to protect the electrical component inside the generator and reducing the cost of installation because the generator do not need to be mounted to the sea base of the ocean.

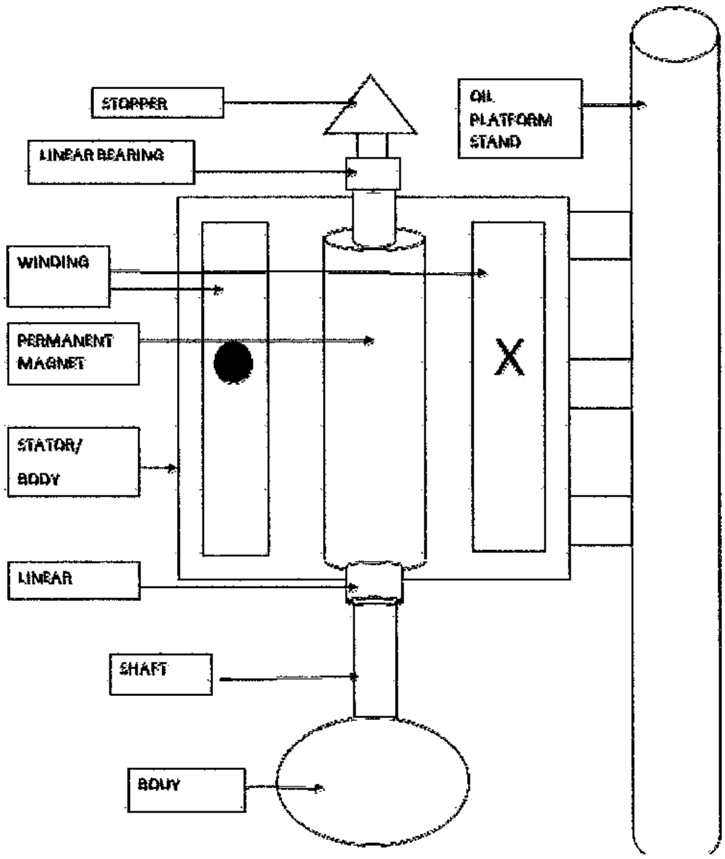


Figure 12: Proposed design for linear permanent magnet generator for wave energy

From Figure 12, show the design that the author would like to propose by using the concept of point absorber. The prototype will be using the permanent magnet that acts as a rotor and connected directly to the shaft. The shaft then is connected to the buoy. This buoy will absorb the sea wave propagation and causing the shaft to push the rotor up and down. To overcome the problem of friction, linear bearing is use to help the motion of the shaft. The hydrodynamic forces are significantly dependent on the buoy geometry and dimensions that is why the appropriate geometry has to be selected taking into account the energy spectrum of waves in the region of interest [16]. Due to this reason, the author would like to make some modification for the buoy. Instead of a ball shape buoy, the author plan to use a round floater such as use for swimming to capture more force from the sea wave. Figure 13 below show the propose shape of the buoy.

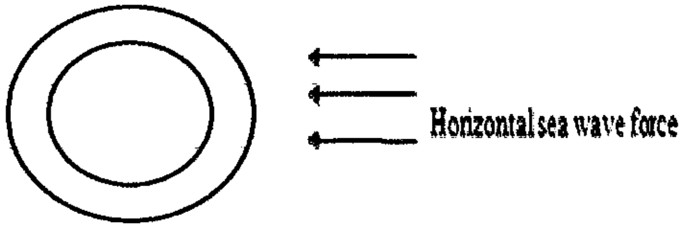


Figure 13: Propose shape of the buoy

2.4 Summary

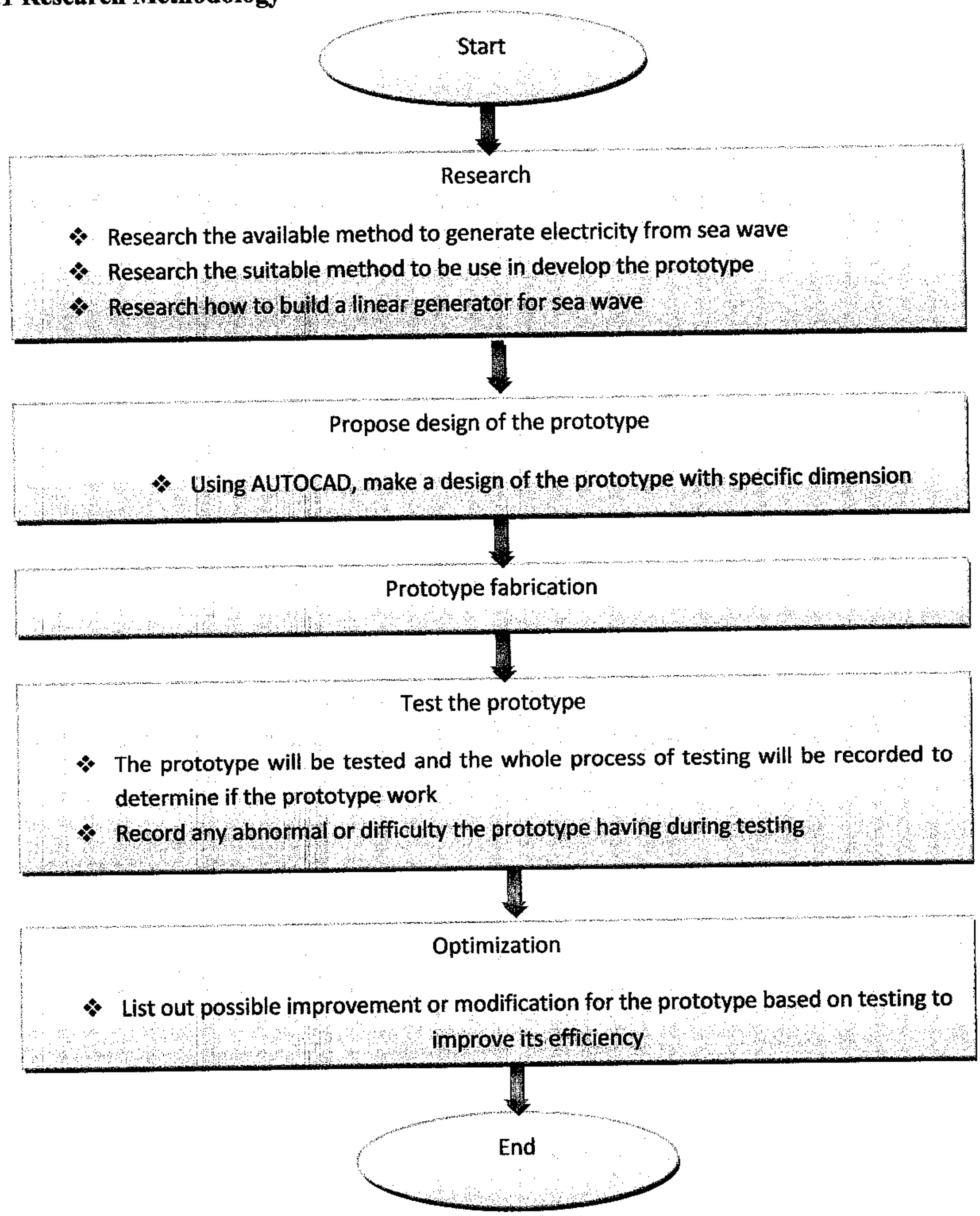
Four available concepts for wave energy conversion system such as overtopping sea wave, attenuator, terminator oscillating column and point absorber had been discussed. The proposed design is develop based on the research done. Based on the proposed design in Figure 12, the fabrication process can begin.

CHAPTER 3

METHODOLOGY

In this chapter, the fabrication process of the prototype is being explained in detail to help reader understand the design and how each fabricated components is crucial for prototype to function efficiently.

3.1 Research Methodology



3.2 Project Activities

The project activities that had been carried out:

1. Research about the method of generating electricity from the sea wave.
2. Choose the method that going to be use in the prototype.
3. Rough design of the prototype.
4. Estimated material needed for the project had been identified can be found in Table 2.
5. Research available segmented Ferrite magnet in the market and purchasing process.
6. Research available Mild steel pipe with diameter of 100 mm in the market and purchasing process.
7. Research available linear bearing in the market and purchasing process.
8. Research available aluminium pipe with diameter of 200 mm in the market and purchasing process.
9. Research available mild steel rod with diameter of 20 mm in the market and purchasing process.
10. Research suitable device to be use as buoy in the market and purchasing process.
11. Fabrication of prototype.

Table 2: Estimated material required

	Item
1.	Ferrite Magnet
2.	Insulated Copper Wire
3.	Cylindrical Casing (Aluminium and Mild Steel)
4.	Linear Bearing
5.	Shaft
6.	High Temperature Glue
7.	PVC Pipe

3.3 Software Required

The software required for the project is the AUTOCAD that is use to build the prototype dimension.

3.4 Tools Required

Proper tools and equipments is use in fabrication process to ensure the fabricated parts had the exact the dimension of the proposed design. List of equipments and tools can be found in Table 3.

Table 3: List of tools

Equipment	i. Drilling Machine ii. Smoothing Surface Machine iii. Electrical Saw iv. Metal Cutter Machine
Hardware	i. Parsimonious ii. Hammer iii. Hand Saw

3.5 Prototype Fabrication

The components for the prototype can be divided into three main parts which are the rotor, stator and floatation device. The prototype will be fabricated based on the dimension and design shown in Figure 12.

3.5.1 Rotor Development

The rotor will consist of several parts which are the rotor casing, the segmented magnet, two round caps for the casing and the shaft. Figure 14 shown that the segmented magnet that had been purchase to be use in developing linear permanent magnet generator.

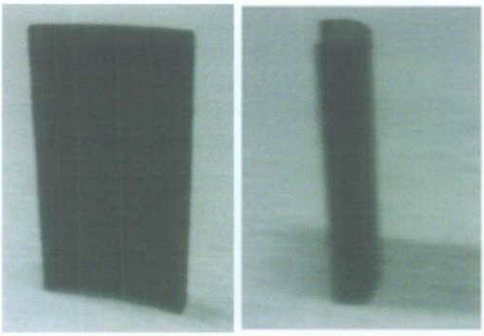


Figure 14: Segmented Magnet

The magnet that the author uses is a Ferrite magnet grade N35 with coating of Nickel. The dimension of the magnet can be found in the magnet specification at Figure 15.Based on the dimension of the magnet datasheet, a dimension test of magnet is conduct to avoid redesign of the prototype due to measurement error. Table 4 shown the result of the test:

Table 4: Segmented Magnet Dimension

Items	Measurement
Angle of the curve magnet	30 Degree
Circumference of curve magnet	26.46mm
Length	45mm
Thickness	3mm

Circumference formula: π x d

Total circumference for rotor casing: π x 100 mm = 314.16 mm^2

Number of segmented magnet needed to fill the circumference of the rotor casing:

314.16 mm^2 ÷ 26.46 mm = 11.87 = 12 pieces

Based on the measurement above, it will take 12 pieces of magnet to make a complete cycle.

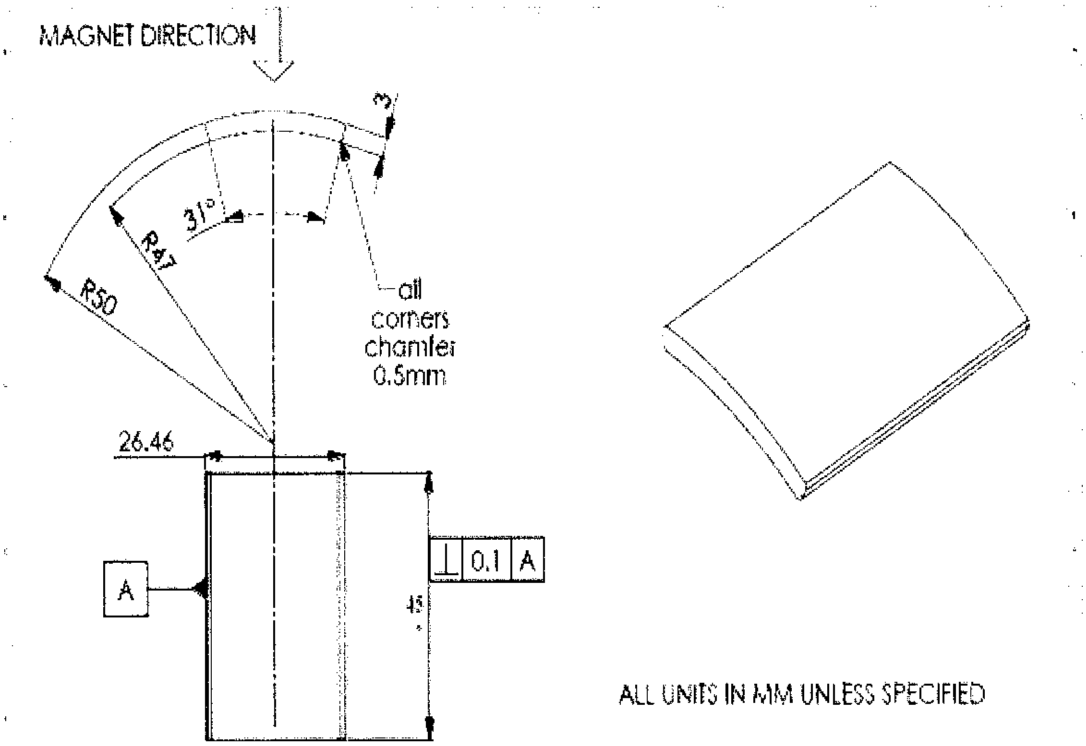


Figure 15: Magnet specification

Based on the magnet specification given by supplier, it shown the North-South pole of the magnet is shown as below:

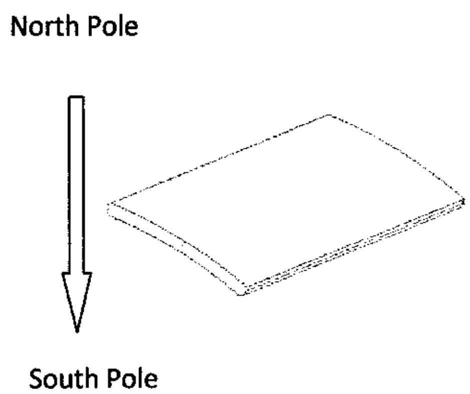


Figure 16 : Curve Magnet Polarity

But the problem is that the magnet push each other if the magnet is arrange to make a circular shape around the rotor casing.

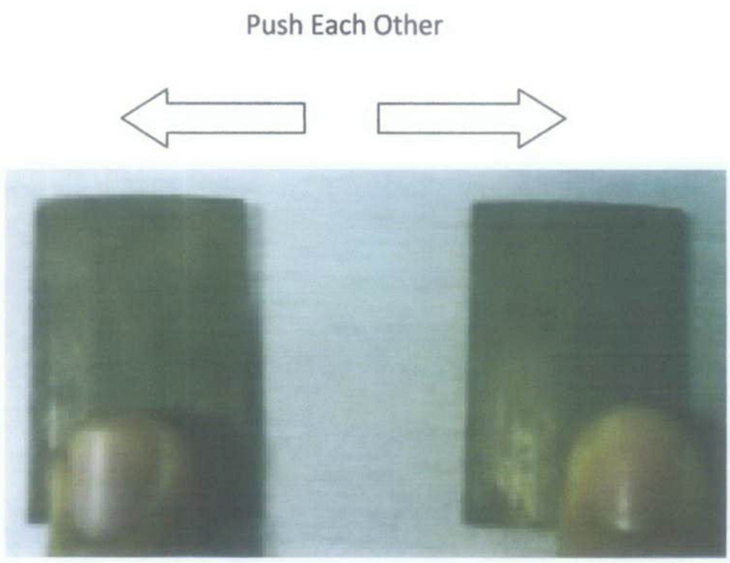


Figure 17: Magnet pushing each other

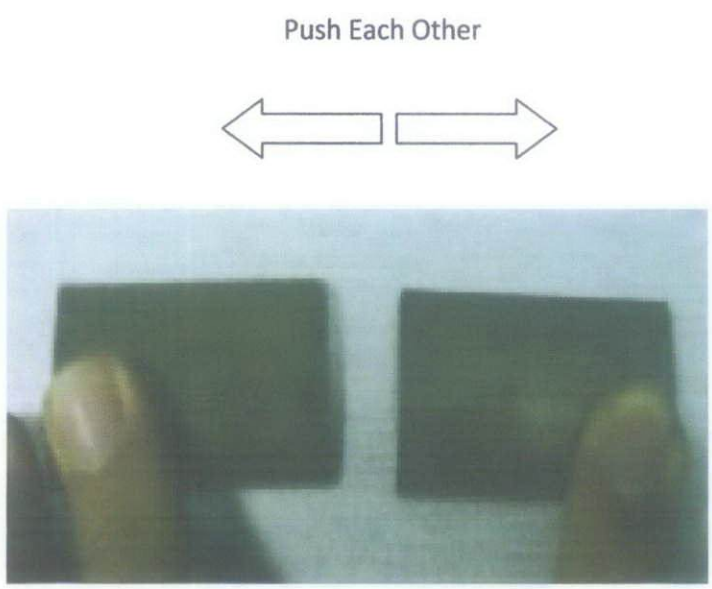


Figure 18: Magnet pushing each other

Both edge of the curve magnet have a same polarity causing the magnet pushing each other when nearing each other. This factor cause a new method need to be use to attach the 12 magnet together to make a full circle. As a solution, the magnet will be stick by silicone glue one at a time by using slot insertion method as shown in Figure 19.

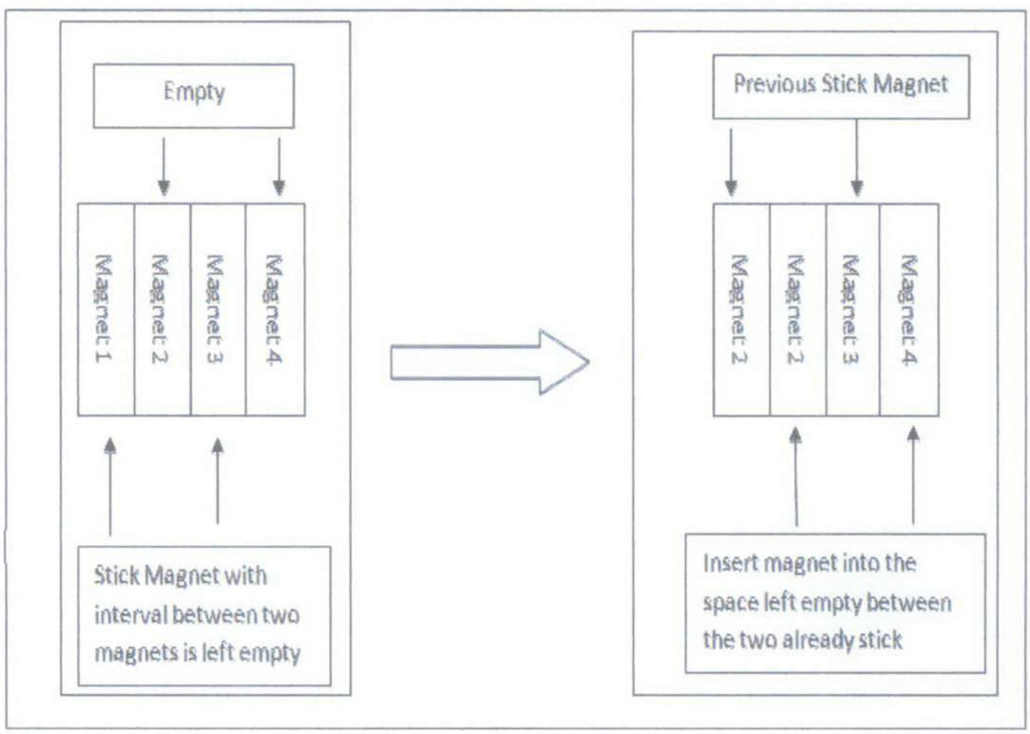


Figure 19: Slot Insertion Method

The slot insertion method help to slot in and help the magnet stick between each other. But the magnet still push each other during the waiting period for the glue to dry causing only 11 unit of segmented magnet is being able to be stick to the rotor body hence leaving a small gap between each magnet as shown in Figure 20.

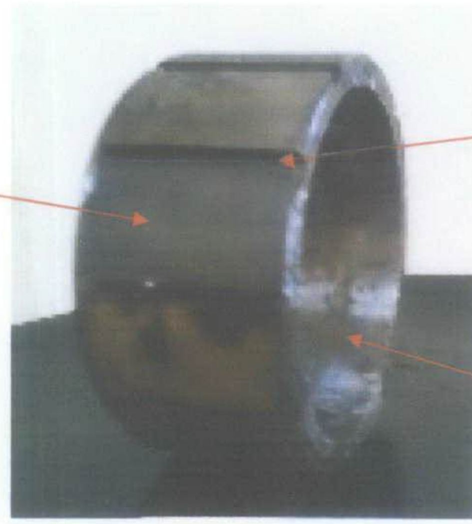


Figure 20: Complete rotor with magnet

Table 5: Dimension of components for rotor

Component	Dimension
Cap	• Round plate with dimension of 100 mm
Rotor Casing	• Cylindrical shape with radius 100 mm • Height of casing = 55 mm • Thickness = 5 mm
Shaft	• Height = 450 mm • Diameter = 20 mm

In development process of the rotor casing, the author faces several difficulties such as:

1. The material to be use for development of the rotor body is difficult to be found.
2. Suppliers do not sell the mild steel pipe in a small quantity hence a new mild steel pipe cannot be obtained.
3. The available mild steel pipe from the recycle site is in a bad condition and the prototype need to be used a body that is strong hence the option to buy from the recycle place is unacceptable.

As solution, the author had to use full cylindrical solid mild steel with 100 mm in diameter and weight about 3kg. To ensure the velocity of rotor is high, the mild steel weight needs to be reduced by removing the centre of the cylindrical. Based on the equipment available in the lab, several processes need to be done to remove the centre fill of the solid mild steel:

1. Facing process to remove the rust from the circular shape of top and bottom solid mild steel as shown in Figure 21.
2. Turning process to rid the rust from the surface of cylindrical solid mild steel as shown in Figure 22.
3. Drill a 25 mm hole in the centre of the solid mild steel as shown in Figure 23.
4. Grinding process which remove layer by layer of the inside the hole left by drilling process and will remove only 0.5mm for every cycle as shown in Figure 24. This process took the longest time to be complete.

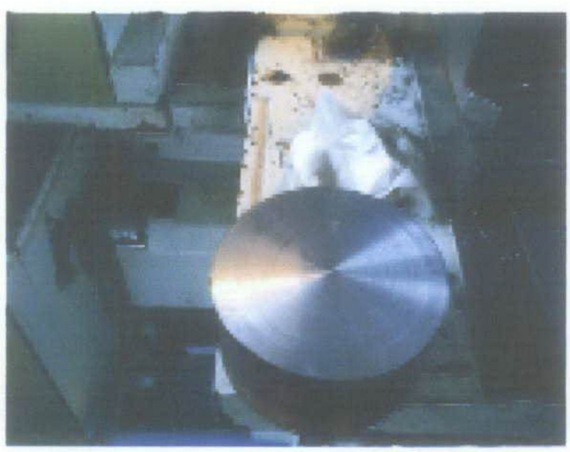


Figure 21: Solid mild steel after facing process

Figure 22: Mild Steel after Turning Process

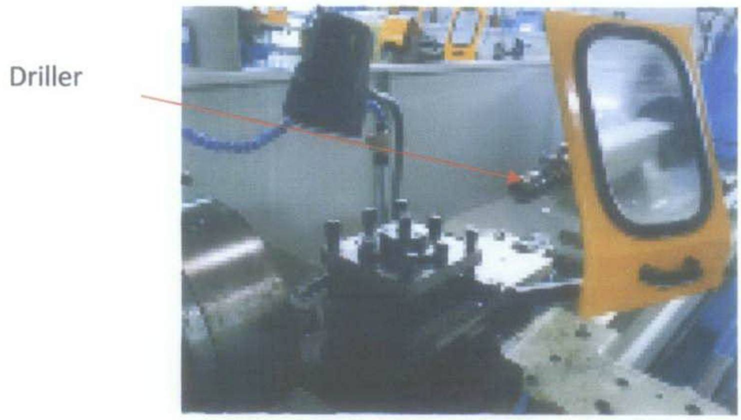


Figure 23: Drilling Process to the Centre of Solid Mild Steel

Figure 24: Grinding process

The cap for the rotor casing is made from a mild steel sheet. The mild steel sheet will be cut based on the round shape with the diameter of 100 mm. The rough side of the round shape of the rotor cap can be smooth by using smoothing surface machine as shown in Figure 25. After that, the cap needs to be drill to make a 20 mm hole which is for the shaft placement.

Figure 25:Smoothing the side surface of the cap

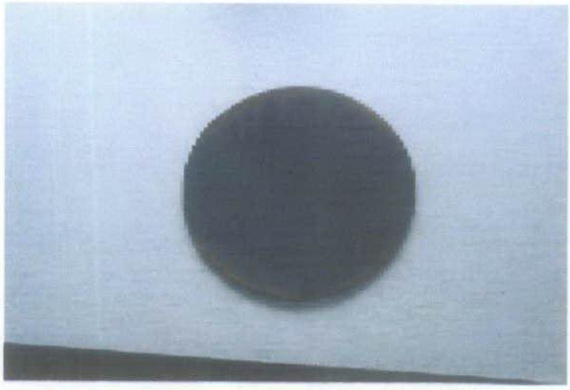


Figure 26: Finish round and smooth rotor cap

The shaft is originally is 30 mm in diameter and the turning process need to be done to ensure the shaft diameter will be 20 mm. The turning process is shown in Figure 27. The turning process for the shaft is risky because of the vibration cause by the machine rotation and that is the reason why the rotor length is only 450 mm. The effect of the vibration will cause the uneven surface which will affect the linear motion of the rotor and to ensure smooth movement between shaft and bearing, an uneven surface is not applicable.

Figure 27: Turning process for the shaft

After finished fabricating all components for the rotor, assembling process can proceed as shown in Figure 28. The finish fabricated rotor is shown in Figure 29.

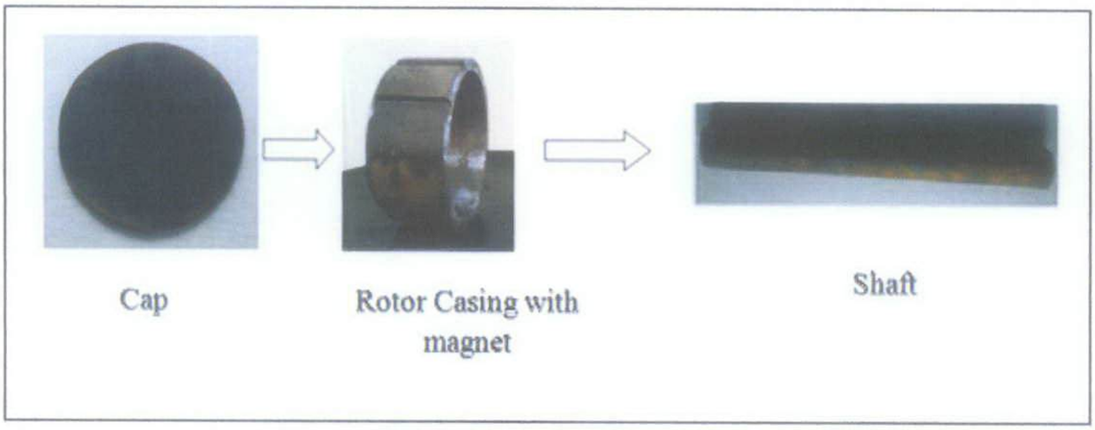


Figure 28: Combine all component of rotor

Figure 29: Completed rotor

3.5.2 Stator Development

The stator will consist of several parts which are the stator casing, copper winding, two round caps for the casing. Table 6 show the exact dimension of the stator component.

Table 6: Dimension for stator components

Component	Dimension
Stator Casing	• Diameter = 200mm • Height = 110 mm • Thickness = 8 mm
Copper Wire	• Diameter = 0.5 mm
Stator Cap	• Diameter = 200 mm

The stator casing is made from aluminium and the casing do not go through the same process as the rotor casing because there is an available supplier that sell the aluminium pipe in a small dimension. The cap for the stator will go through same process as the rotor cap.

Figure 30: Stator casing

To make a copper winding, there are several steps that need to be done. First, a solid a strong cylindrical shape material is use as the moulding based shape and in this case the PVC pipe is use. A cloth ribbon will be stick to the surface of the PVC pipe as shown in Figure 31. The ribbon will be use to tie the winding together. This is to ensure the winding will keep their cylindrical shape and avoid the copper wire to slip from its original place. The winding process is done after 700 turn of copper wire is wrapped around the PVC pipe.

Figure 31: Ribbon is attach to the PVC surface

Figure 32: Winding process in progress

After winding is finish, the PVC pipe will be stick to the bottom cap of the stator as shown in Figure 33.

Figure 33: Finish winding stick to the stator cap

After finish fabricating all components for the stator, assembling process for stator can proceed as shown in Figure 34.

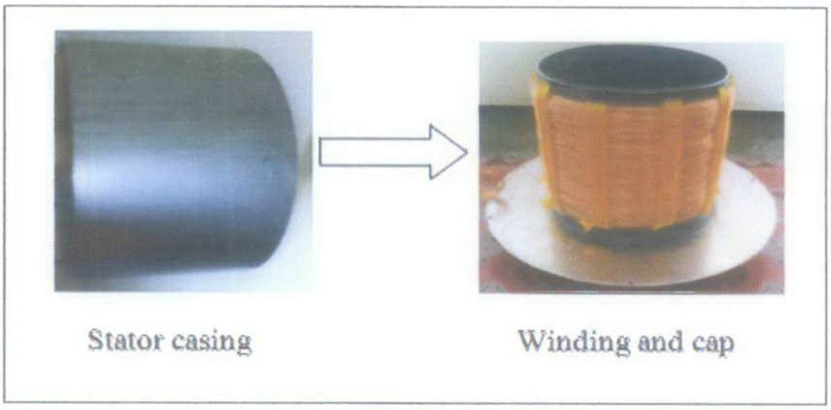


Figure 34: Combine all component of stator

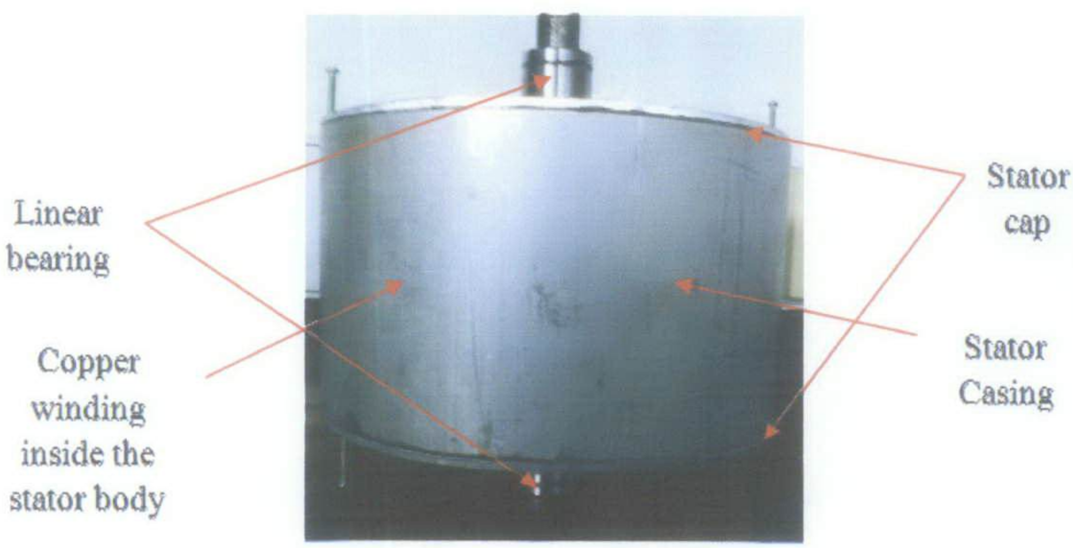


Figure 35: Completed stator

3.5.3 Floatation Device Assembly

The body to hold the floater is made from wood and four holes are made at the flat surface to allow rope to tie the floater with the wood structure. The shaft will be connected to the floater by insert the shaft into the 20mm hole available in the wood structure. Bolt and nat is not needed in this situation because the hole manage to grip and hold the shaft tighly.

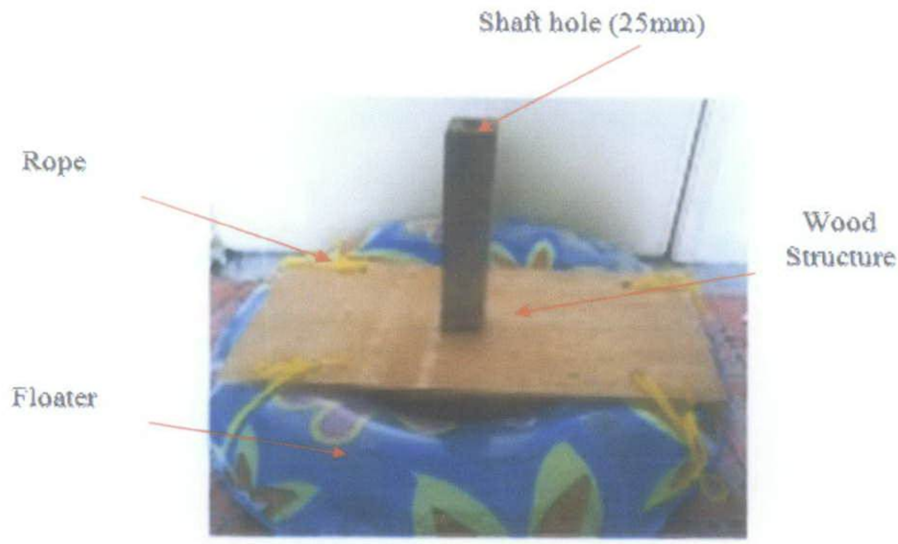


Figure 36: Finish fabricated floatation device

3.5.4 Linear Permanent Magnet Generator Prototype

The assembling of all main component of prototype is shown in Figure 38. The completed prototype is shown in Figure 38.

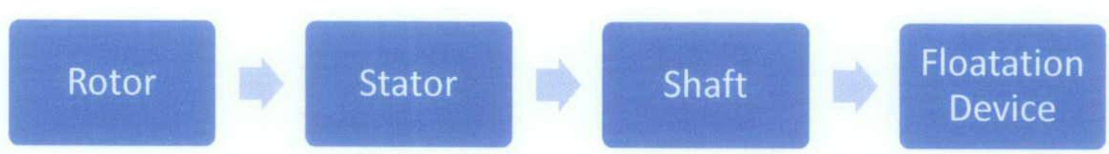


Figure 37: Assembling steps

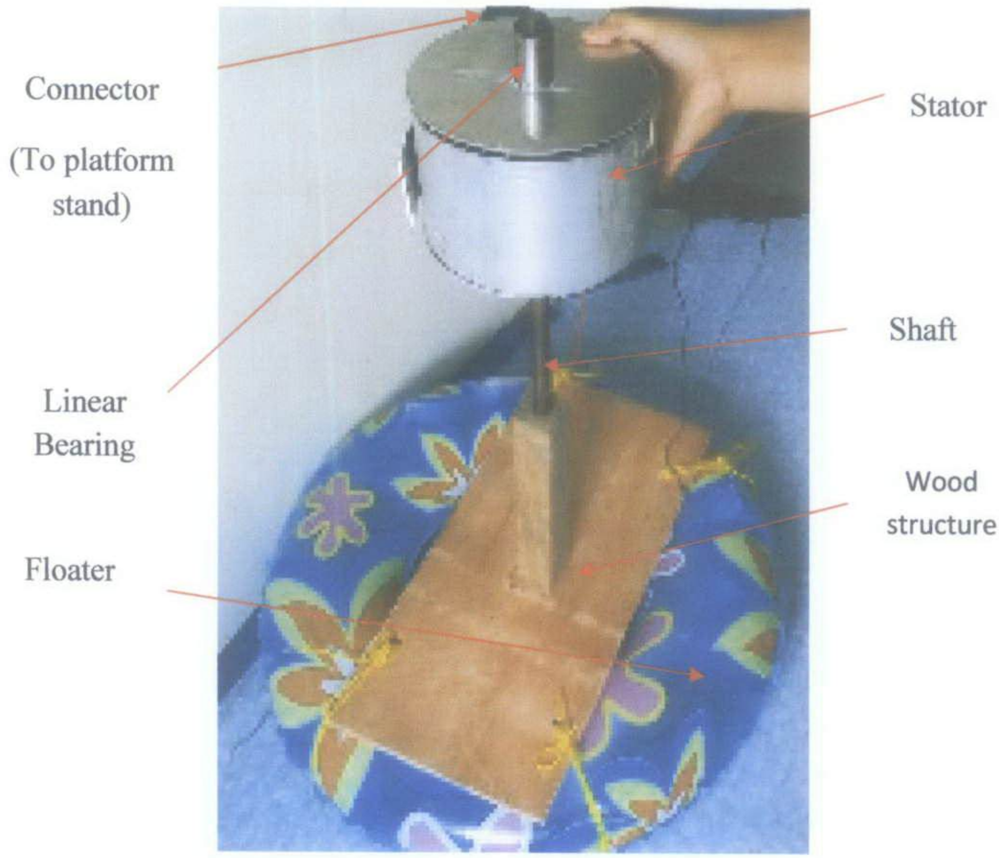


Figure 38: Finished prototype

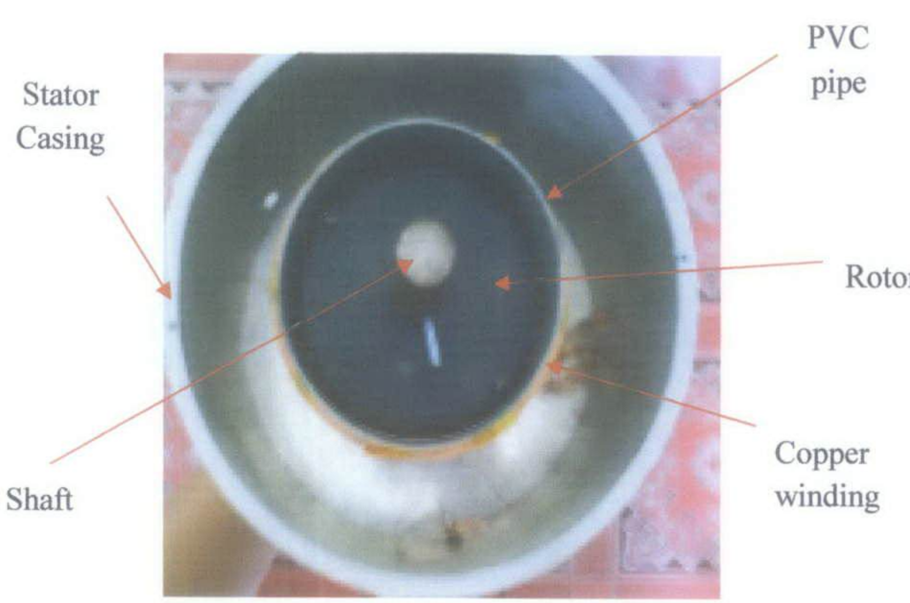


Figure 39: Inner part of finished prototype

3.5.5 Summary

The prototype manage to be fabricated although facing several obstacle such as difficulties to find suitable material for prototype, waiting period for material delivery and unforeseen problem such as the magnet against each other whenever they near each other. But with the help of supervisor and the technician, the fabrication of prototype manages to be done.

CHAPTER 4

RESULT AND DISCUSSION

This chapter show several test that had been carried out to test the functionality and to get the potential amount of electricity being generated by the prototype. Although the test is unable to be done using specific and scientific equipment, but the test is still carried out to prove the prototype be able to work in real situation.

4.1 Dynamic Test

Dynamic test is done to get the result generated by the prototype when it is given an outside force such as sea wave. Due to some problem, a proper test is unable to be conduct in the lab. As an alternative, the author is using a swimming pool as the medium to test the prototype functionality. This test is done to prove that the shaft able to move the rotor upward and downward when in the present of wave. The wave in the swimming pool is manmade wave which is done by several volunteers. During the testing, the manmade wave develop by volunteers during swimming manage to cause the shaft to move the rotor upward and downward hence generating small amount of electricity. In summary, the prototype manages to capture the wave and be able to use its mechanical energy to generate electricity.

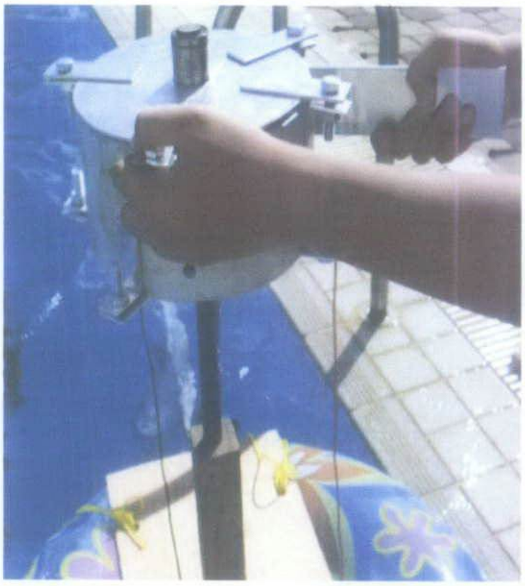


Figure 40: Dynamic test

4.2 Open Circuit Test

An experiment is carried out without using any load. The rotor is move manually by hand with the approximately 2 second for a complete cycle. This means that the frequency of the movement of rotor is 0.5 Hz. The test setup is shown in Figure 40. The result of this experiment is in Alternating Current (AC) is tabulated in Table 7.

Table 7: Result of open circuit test at 0.5 Hz

AC Current (range)	AC Voltage (range)
1.94mA – 19.94mA	90mV – 461mV

Figure 41: Test setup for open circuit test

4.3 Closed Circuit Test

An experiment is carried out with using a load which is a resistor with 8.8 ohm. The rotor is move manually by hand with the approximately 2 second for a complete cycle. This means that the frequency of the movement of rotor is 0.5 Hz. The test setup is shown in Figure 41. The result of this experiment is in Alternating Current (AC) is tabulated in Table 8.

Table 8: Result of closed circuit test at 0.5 Hz

AC Current (range)	AC Voltage (range)
1.10mA – 10.84mA	5mV – 11mV

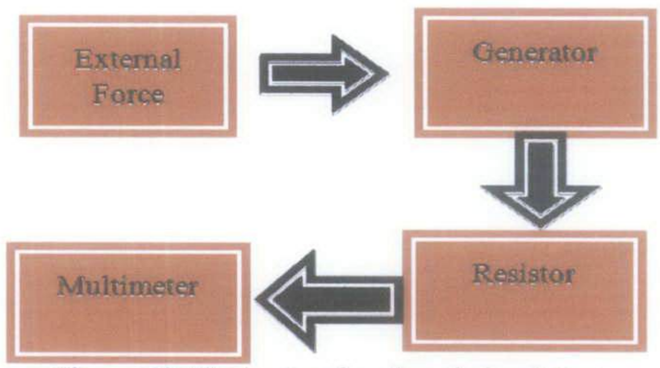


Figure 42: Test setup for closed circuit test

4.4 Summary

Based on the prototype performance during test, the prototype is able to operate and generate a small amount of electricity. The small amount of electricity produce is due to the small frequency that is applied during the test. It is believe that in higher frequency, the electricity generated will be higher. Hence, a proper test using a proper equipment during testing in necessary to get the real performance of the prototype.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As a conclusion, the research on all four available concept of wave energy converter help the author in determining the best concept to be use for the prototype that is going to be develop. In comparison of all the available methods, the author chooses to proceed with the concept of point absorber. The proposed design had been develop with exact dimension to help the fabrication process to be smooth. Based on economical factor, the material that is going to be use is below the budget given for the project to prove that an economical generator can be develop to harvest wave energy to generate electricity.

The prototype development starts with the research and gathering the materials that is going to be use. Next, the fabrication of prototype is being divided into three main parts which is the rotor, stator and floatation device. The finish fabricated part is then being assembled and ready for testing. The result of the testing will determine whether the prototype is functioning or not. During the test, the prototype is functioning with the movement of the shaft is smooth with the help of linear bearing and although the electricity generated from the test is low, it still show there is a possibility for further improvement of the prototype in the future.

As recommendation, the author would like to suggest several improvements to the prototype such as install oil lubrication at the bearing for smoother movement, install spring to increase the velocity of rotor movement and develop special floater that can capture wave energy more efficiently. Due to some obstacle such as difficulties of finding materials and waiting period for material arrival, the proper test is unable to be done in the wave tank. So, for future research a proper test must be conducted to get more accurate and precise data.

References

1. Callaghan, J., "Future Marine Energy Results of the Marine Energy Challenge: Cost Competitiveness and Growth of Wave and Tidal Stream Energy," Research Report, Carbon Trust, London (UK), 2006.

2. Szabo, L,Oprea, C, “Wave Energy Plants for the Black Sea – Possible Energy Converter Structures”, Clean Electrical Power, 2007. ICCEP '07. International Conference, October 2007.

3. Lawrence M Lerner, “Physics for Scientists and Engineers”, Jones & Bartlett Publishers, year 1997.

4. K. Nilsson,E. Segergren, and M. Leijon,” Simulation of Direct Drive Generators Designed for Underwater Vertical Axis Turbines ”, Fifth European Wave Energy Conference, September 2003.

5. Dr.-Ing. Harald Kayser Brundorf, “Energy Generation From Sea Waves”, Engineering in the Ocean Environment, Ocean '74, October 1974.

6. Previsic, M., Bedard, R., and Hagerman, G., "Offshore Wave Energy Conversion Devices," Electric Power Research Institute (EPRI) Report no. WP-004-US, 2004.

7. Technology White Paper on Wave Energy Potential on the U.S. Outer Continental Shelf Minerals Management Service Renewable Energy and Alternate Use Program U.S. Department of the Interior, Internet: http://ocsenergy.anl.gov (16 December 2011)

8. Ehsan Enferad, Murtaza Farsadi, and Shirin Enferad, “New method for Converting Sea Wave Energy”,ELECO 2009. International Conference, 2009.

9. Nielsen, K.M.; Pedersen, T.S, "A dynamic model for Control Purposes of a Wave Energy Power Plant Buoyancy System ", Control and Automation, 2009. ICCA 2009. IEEE International Conference on Digital Object Identifier, November 2009.

10. Zhen Liu; Yajun Liu; Jianhui Jiao, "Experimental Study on a New Offshore Wave Energy Converter", Power and Energy Engineering Conference (APPEEC), 2011 Asia-Pacific Digital Object Identifier, 2011.

11. Johannes Falnes, "Wave-power absorption by an Array of Attenuators Oscillating with Unconstrained Amplitudes ", Division of Experimental Physics, The Norwegian Institute of Technology, University of Trondheim.

12. O'Sullivan, D.L.; Lewis, A.W, "Generator Selection and Comparative Performance in Offshore Oscillating Water Column Ocean Wave Energy Converters", Energy Conversion, IEEE Transactions on Volume: 26, November 2006.

13. Oskar Danielsson, Karin Thorburn, Mikael Eriksson,Mats Leijon, "Permanent Magnet Fixation Concepts for Linear Generator", Division for Electricity and Lightning Research Department of Engineering Sciences, Uppsala University.

14. M.A. Mueller, N.J. Baker and E. Spooner, "Electrical Aspects of Direct Drive Energy Converters", Proceedings of the 4th European Wave Energy Conference, 2000.

15. M.A. Mueller and N.J. Baker, "A low speed reciprocating permanent magnet generator for direct drive energy converters", Conference publication, Power Electronics, Machines and Drives.

16. H. Polinder, M.A. Mueller, M. Scuotto, and M. Goden de Sousa Prado, "Linear generator systems for Wave Energy Conversion", Electrical Power Processing Group, EEMCS Faculty, Delft University of Technology.

APPENDICES

APPENDIX A

GANTT CHART FOR FYP 1

	ACTIVITIES/WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	**Literature Review**														
2	**Propose Design**														
3	**List of Material for Project**														
4	**Material Gathering**														
5	**Design Specification**														
	*build specification of the design using software														
6	**Extended Report**						Submit								
	*report preparation														
7	**Attach magnet with the shaft**														
8	**Make a body for the prototype**														
9	**Proposal Defend and Progress Evaluation**									Submit					
	*report preparation and dry run														
10	**Interim Draft Report**													Submit	
	*report preparation													Submit	
11	**Interim Final Report**														Submit

APPENDIX B

GANTT CHART FOR FYP 2

	ACTIVITIES/WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13		14
1	**Finding Required Material for Rotor Body**															
2	**Find Suitable Size of Linear Bearing**															
3	**Rotor Body Manufacturing**															
4	**Cap Manufacturing**															
5	**Find Required Shaft for Prototype**															
6	**Progress Report Submission**								Submit							
7	**Attach magnet with the Rotor**															
8	**Make a body for the Stator**															
9	**Make a Cap for Stator body**															
10	**Pre-EDX**											Submit				
11	**Make Copper Winding inside the Stator**															
12	**Draft Report**													Submit		
13	**Assemble of all component of the Prototype**															
14	**Final Report**														Submit	
15	VIVA															Submit