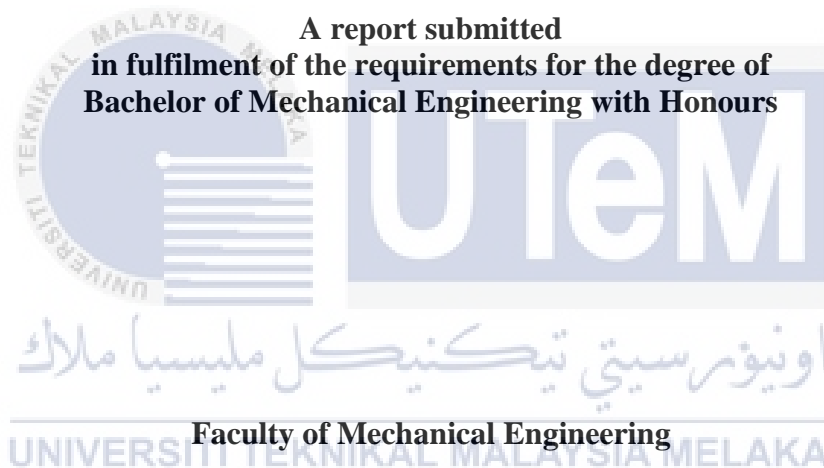


**PERFORMANCE OF MINI WAVE ENERGY HARVESTING SYSTEM
USING SINGLE AND DOUBLE LINEAR GENERATORS**

NG KAI JUN




UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this project report entitled “Performance of Mini Wave Energy Harvesting System Using Single and Double Linear Generators” is the result of my own work except as cited in the references.



Signature :

Name : Ng Kai Jun

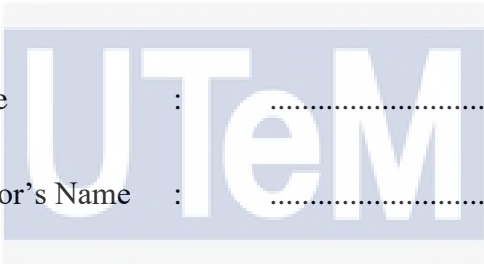

Date : 19 June 2021

اوتيمر سیتی تیکنیکل ملیسيا ملاک

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

APPROVAL

I hereby declare that I have read this project report and in my opinion, this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Honours.



Signature :

Supervisor's Name :

Date :
اونيورسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest gratitude to my project supervisor, Dr. Yusmady bin Mohamed Arifin, from the Faculty of Mechanical Engineering in Universiti Teknikal Malaysia Melaka (UTeM) for his constant support, motivation, and supervision in pushing me to strive forward in accomplishing this project report such that it obeys the requirements of the project report.

I would also like to thank the PSM coordinator, Dr. Fadhli bin Syahrial, for his concerns towards all students on issues related to the PSM subject, such that he constantly reminds us of the deadline of report submission so that students will not miss it, and also guide us with any problems related to report submission.

A great appreciation is also expressed towards Dr. Mohd Afzanizam bin Mohd Rosli and Dr. Fatimah Al-Zahrah binti Mohd Sa'at, that acts as my first and second panel respectively, for giving me sincere advice and constructive criticism that pushes me to perform better in this project.

I would also like to express my gratitude towards my uncle, Lee Wee Kiat, for his guidance in electric-related knowledge that helped me better understand the electrical components of the test rig, how to connect them and how to measure the electrical power.

Special thanks to my beloved father and mother, and all my peers for their moral support in the progress to the completion of my bachelor's degree. I am truly grateful for all the support I receive, and I believe that these supports play an important role in my success.

ABSTRACT

Waves are a natural phenomenon that packs a tremendous amount of energy as it travels a long distance with minimal to no loss of energy. Waves are caused by winds formed from the difference in environmental temperature in different locations around the globe. However, the energy packed in waves is lost as they crash into coastlines worldwide. In order to make use of the wave energy, wave energy conversion system is introduced. In this project, a wave energy conversion system using single and double linear generators was studied by practical simulation on a scaled-down model of a mini wave generator harvesting system. The effectiveness of single linear generator for different distances and double linear generators for different gap distances in producing electrical voltage was investigated with respect to different speed of wave generator. The setup that generates the highest electrical voltage was determined as the best location of single linear generator and best gap distances for double linear generators with relation to the specific speed of wave generator. The experiment was started off by running preliminary tests using a pre-built test rig. Modifications were performed wherever necessary to ensure the smoothness of the simulation. Results showed that single linear generator generates higher electrical voltage than double linear generators. This is because more linear generators reduce the average power generated per wave energy converter, hence a reduced total electrical voltage generation. This is proven with the comparison in the highest average total voltage generated, where single linear generator generated 1.35mV at 70RPM while double linear generators generated 0.65mV at 50RPM. This shows that the highest average total voltage generated by the single linear generator is 107.69% higher than the double linear generators. The highest total voltage generated with single linear generator is 1.8mV at distance of linear generator A, x , of 35cm at 70RPM. The highest total voltage generated with double linear generators is 0.8mV at gap distance of linear generators, x , of 28cm at 50RPM and at gap distance of linear generators, x , of 38cm at 90RPM. The experiment on single linear generator showed relatively significant difference in total voltage generated depending on the location of linear generator, whereas for double linear generators, the difference is minimal between various gap distances of linear generators. Overall, for single linear generator, the pattern showed that as distance of linear generator A, x , increases, the total voltage generated increases. In general, for double linear generators, as gap distance, x , increases, the total voltage generated increases. The change in depth of water in this test rig also does not influence the generation of electrical voltage as the strength of the waves outweighs the drag force on the tank bed.

ABSTRAK

Ombak merupakan suatu fenomena semula jadi yang mempunyai tenaga yang kuat dan berkebolehan untuk menempuh jarak jauh tanpa kehilangan tenaga. Ombak dihasilkan oleh angin yang terbentuk daripada perbezaan suhu persekitaran di lokasi berbeza di seluruh dunia. Namun, tenaga yang tersimpan dalam ombak itu hilang apabila ombak melanggar pantai di seluruh dunia. Bagi memanfaatkan tenaga ombak itu, sistem penukaran tenaga ombak diperkenalkan. Dalam projek ini, sistem penukaran tenaga ombak yang menggunakan penjana lurus tunggal dan berkembar akan dikaji melalui simulasi praktikal pada model sistem penjana ombak mini. Keberkesanan penjana lurus tunggal pada jarak yang berbeza dan penjana lurus berkembar pada jarak sela yang berbeza dalam menjana voltan elektrik akan dikaji dengan kelajuan penjana ombak yang berbeza. Cara pengaturan pelantar ujian yang menjana voltan elektrik yang paling tinggi akan ditentukan sebagai lokasi penjana lurus tunggal yang terbaik dan juga jarak sela bagi penjana lurus berkembar yang terbaik berhubung dengan kelajuan penjana ombak yang tertentu. Ujikaji bermula dengan menjalani ujian permulaan dengan menggunakan pelantar ujian sedia ada. Pengubahsuaian telah dilakukan di mana yang perlu untuk memastikan kelancaran simulasi. Hasil ujikaji menunjukkan bahawa penjana lurus tunggal menjana voltan elektrik yang lebih tinggi berbanding dengan penjana lurus berkembar. Ini sebab penjana lurus yang lebih akan mengurangkan kuasa purata yang dihasilkan setiap penular tenaga gelombang, membawa kepada pengurangan jumlah penjanaan voltan elektrik. Ini terbukti dengan perbandingan jumlah penjanaan voltan purata tertinggi, di mana penjana lurus tunggal menjana 1.34mV pada 70RPM manakala penjana lurus berkembar menjana 0.65mV pada 50RPM. Ini menunjukkan bahawa jumlah penjanaan voltan purata tertinggi oleh penjana lurus tunggal adalah 107.69% lebih tinggi daripada penjana lurus berkembar. Jumlah penjanaan voltan yang tertinggi dengan menggunakan penjana lurus tunggal ialah 1.8mV pada jarak penjana lurus A, x , 35cm pada 70RPM. Jumlah penjanaan voltan yang tertinggi dengan menggunakan penjana lurus berkembar ialah 0.8mV pada jarak jurang penjana lurus, x , 28cm pada 50RPM dan jarak jurang penjana lurus, x , 38cm pada 90RPM. Ujikaji pada penjana lurus tunggal menunjukkan perbezaan yang ketara dalam jumlah penjanaan voltan bergantung pada lokasi penjana lurus, sedangkan untuk penjana lurus berkembar, perbezaan adalah minimum antara pelbagai jarak jurang penjana lurus. Secara keseluruhannya, bagi penjana lurus tunggal, coraknya menunjukkan bahawa apabila jarak penjana lurus tunggal A, x , meningkat, jumlah penjanaan voltan meningkat. Secara umumnya, bagi penjana lurus berkembar, apabila jarak jurang, x , meningkat, jumlah penjanaan voltan meningkat. Perubahan kedalaman air di dalam pelantar ujian ini juga tidak mempengaruhi penjanaan voltan elektrik kerana kekuatan ombak melebihi daya seretan dasar tangki.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
ACKNOWLEDGEMENTS	i
ABSTRACT	ii
ABSTRAK	iii
TABLE OF CONTENTS	iv
LIST OF FIGURES	vi
LIST OF APPENDICES	xi
LIST OF ABBREVIATIONS	xiii
LIST OF SYMBOLS	xiv
CHAPTER	
1 INTRODUCTION	1
1.0 Background	1
1.1 Statement of The Purpose	3
1.2 Problem Statement	3
1.3 Objective	5
1.4 Scope of Project	6
2 LITERATURE REVIEW	7
2.0 Introduction	7
2.1 Location	7
2.1.1 Onshore	9
2.1.2 Nearshore	9
2.1.3 Offshore	10
2.2 Type of Wave Energy Converters	11
2.2.1 Attenuator	11
2.2.2 Point Absorber	12
2.2.3 Terminator	15
2.3 Operation Mode	16
2.3.1 Submerged Pressure Differential	16
2.3.2 Oscillating Wave Surge Converter	18
2.3.3 Oscillating Water Column	20
2.3.4 Overtopping Device	22
2.3.5 Bulge Wave Technology	24
2.3.6 Rotating Mass	25
2.3.7 Other WEC	26
2.4 Power Take-Off Methods	26
2.4.1 Hydraulic System	27
2.4.2 Air Turbine	29
2.4.3 Hydro Turbine	30
2.4.4 Direct Mechanical Drive System	32
2.4.5 Direct Electrical Drive System	33
2.5 Linear Generator	34
2.6 Faraday's Law of Induction	37
2.7 Capacitor	38

2.8	Halbach Array	39
2.9	Type of Buoy Setup	43
2.10	Power Fluctuation in Wave Energy Parks	44
2.11	Double-Sided Tubular Linear Generator	44
2.12	Four-Sided Permanent Magnet Linear Generator	48
2.13	Highlights for Advancement in Experiment	55
3	METHODOLOGY	56
3.0	Introduction	56
3.1	Gantt Chart	60
3.2	Test Rig	60
3.2.1	Test Rig Modification	62
3.3	Experimental Procedure	84
3.3.1	Single Linear Generator	84
3.3.2	Double Linear Generators	88
4	RESULTS AND ANALYSIS	91
4.0	Introduction & Preliminary Test Results	91
4.1	Single Linear Generator Results	99
4.2	Double Linear Generators Results	102
4.3	Comparison of Results between Single and Double Linear Generators	104
5	DICSUSSION	109
5.1	Results Tolerance	109
5.2	Insignificant Influence of Depth on the Voltage Generated	109
5.3	Removal of LED from Induced Current Circuit	110
5.4	Test Rig Issues	112
5.4.1	Dislodged DC Motor Gear Chain	113
5.4.2	Broken DC Motor Gear Track	114
5.4.3	Broken DC Motor Holder	115
5.4.4	Overheating of DC Motor	116
5.4.5	Leakage on Wave Generator	117
5.4.6	Imperfections on Wave Generator Setup	118
5.4.7	Horizontal Movement on Linear Generator	120
5.4.8	Improvement on Linear Generator	121
5.4.9	Location of Linear Generator B	122
5.4.10	Rotation of Float Caused by Oncoming Waves	123
6	CONCLUSION AND RECOMMENDATION	124
6.1	Important Knowledge from Literature Review	124
6.2	Conclusion	126
6.3	Recommendation for Future Research	128
	REFERENCES	129
	BIBLIOGRAPHY	135
	APPENDIX	139

LIST OF FIGURES

Figure 1.1: Waves hitting the coastline	4
Figure 2.1: Classification of wave energy locations	8
Figure 2.2: WEC power representation in different locations.....	8
Figure 2.3: Attenuator mechanism	12
Figure 2.4: Pelamis wave power device.....	12
Figure 2.5: Point absorber mechanism.....	13
Figure 2.6: Aquabuoy.....	14
Figure 2.7: Ocean Power Technology Powerbuoy.....	14
Figure 2.8: Salter's Duck mechanism	15
Figure 2.9: WEPTOS prototype during lab test	16
Figure 2.10: Archimedes Wave Swing mechanism.....	17
Figure 2.11: Archimedes Wave Swing.....	18
Figure 2.12: Oscillating wave surge converter mechanism.....	19
Figure 2.13: AW Energy WaveRoller	19
Figure 2.14: Aquamarine Power Oyster	20
Figure 2.15: Oscillating water column mechanism.....	21
Figure 2.16: Wavegen LIMPET	21
Figure 2.17: Overtopping device mechanism.....	22
Figure 2.18: Wave Dragon	23

Figure 2.19: Sea Wave Slot-Cone Generator	23
Figure 2.20: Bulge wave technology mechanism.....	24
Figure 2.21: Anaconda	24
Figure 2.22: Rotating mass mechanism.....	25
Figure 2.23: Wello Oy Penguin.....	25
Figure 2.24: Bombora.....	26
Figure 2.25: Wave energy conversion paths	27
Figure 2.26: Schematic diagram of a hydraulic system.....	28
Figure 2.27: Types of air turbines	30
Figure 2.28: Types of hydro turbines	31
Figure 2.29: Direct Mechanical Drive System	32
Figure 2.30: Direct Electrical Drive System	33
Figure 2.31: Tubular linear permanent magnet generator on Oregon State University's wave energy linear test bed	34
Figure 2.32: Planar linear permanent magnet generator in Archimedes Wave Swing.....	35
Figure 2.33: Halbach array superposition principle	39
Figure 2.34: (a)Ideal radial magnetized ring, and (b)Parallel magnetized arc segments	40
Figure 2.35: Magnetic flux density at outer permanent magnet radius, r_m , for standard magnet array	41
Figure 2.36: Magnetic flux density at outer permanent magnet radius, r_m , for Halbach array	42
Figure 2.37: Flux density distribution in air gap	45
Figure 2.38: Cross-section of TLPMG with Halbach array	46
Figure 2.39: Cross-section of DTLPMG	46
Figure 2.40: Cross-sectional geometry of TLPMG	47

Figure 2.41: Cross-sectional geometry of DTLPMG	47
Figure 2.42: Cross-section of tubular linear generator	49
Figure 2.43: Cross-section of four-sided linear generator	49
Figure 2.44: Magnetic flux repartition of tubular linear generator.....	50
Figure 2.45: Magnetic flux repartition of four-sided linear generator	51
Figure 2.46: Magnetic flux density repartition in the air gap.....	52
Figure 2.47: Coil flux for tubular and four-sided linear generator.....	53
Figure 2.48: Induced voltage by tubular and four-sided linear generator	53
Figure 3.1: Methodology Flow Chart.....	59
Figure 3.2: Schematic diagram of test rig.....	61
Figure 3.3: Modified wave generator track	63
Figure 3.4: Modified wave generator track attached to the tank wall	64
Figure 3.5: Cable tie used to prevent the top section of the wave generator from running out of track.....	65
Figure 3.6: Track with hook add-on to the existing right track.....	65
Figure 3.7: Bottom view of wheels on the wave generator being hooked by added-on track	66
Figure 3.8: Complete setup of the wave generator	67
Figure 3.9: Closer view of the motor track on the wave generator	68
Figure 3.10: Top view of DC motor gear (a)before and (b)after installation to its chain ...	69
Figure 3.11: Setup of DC motor	70
Figure 3.12: Stator of linear generator A.....	72
Figure 3.13: Stator of linear generator B	72
Figure 3.14: Translator and floater for linear generator	73
Figure 3.15: Schematic diagram of induced current circuit for single linear generator.....	74

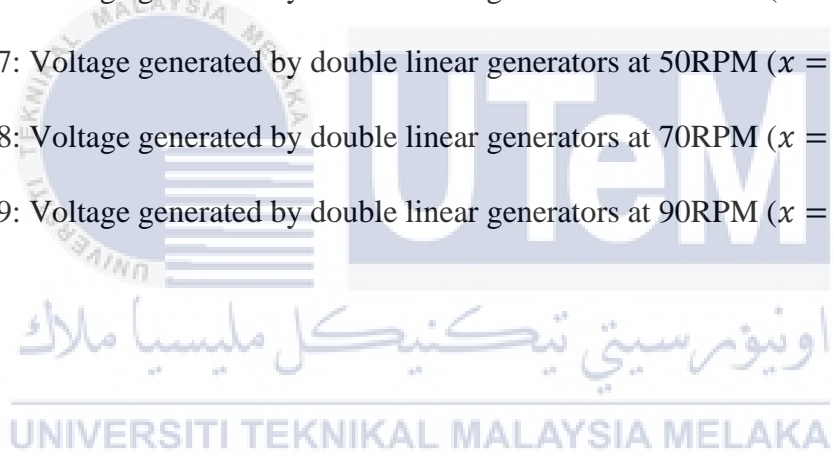
Figure 3.16: Setup of induced current circuit for single linear generator.....	75
Figure 3.17: Schematic diagram of induced current circuit for double linear generators ...	76
Figure 3.18: Setup of induced current circuit for double linear generators.....	76
Figure 3.19: Schematic diagram of speed control circuit.....	77
Figure 3.20: Position of permanent magnets to copper coils at datum for (a)linear generator A and (b)linear generator B	78
Figure 3.21: Types of wave generators	79
Figure 3.22: Type 1 wave generator.....	80
Figure 3.23: Wave generation observation setup for type 1 wave generator	81
Figure 3.24: Type 2 wave generator.....	82
Figure 3.25: Wave generation observation setup for type 2 wave generator	82
Figure 3.26: Reflective tape attached on a black duct tape wrapped around the gear shaft	85
Figure 3.27: Schematic diagram of mini wave energy harvesting system with single linear generator.....	87
Figure 3.28: Actual setup of single linear generator	87
Figure 3.29: Schematic diagram of the mini wave energy harvesting system with double linear generators	90
Figure 3.30: Actual setup of double linear generators.....	90
Figure 4.1: Method to measure wave height	92
Figure 4.2: Wave generated with type 1 wave generator at (a)50RPM, (b)70RPM, and (c)90RPM	93
Figure 4.3: Wave generated with type 2 wave generator at (a)50RPM, (b)70RPM, and (c)90RPM	94
Figure 4.4: Voltage generated for type 1 and type 2 wave generators at $x = 45\text{cm}$ for (a)50RPM, (b)70RPM, and (c)90RPM	97

Figure 4.5: Total voltage generated for type 1 and type 2 wave generators for different speed of wave generation at $x = 45\text{cm}$	98
Figure 4.6: Voltage generated by single linear generator at (a)50RPM, (b)70RPM, and (c)90RPM	101
Figure 4.7: Voltage generated by double linear generators at (a)50RPM, (b)70RPM, and (c)90RPM	103
Figure 4.8: Voltage generated at different distance x for (a)single linear generator and (b)double linear generators.....	108
Figure 5.1: Schematic diagram of induced current circuit for single linear generator with LED	110
Figure 5.2: Schematic diagram of induced current circuit for single linear generator with LED	111
Figure 5.3: Dislodged DC motor gear chain.....	113
Figure 5.4: Broken DC motor gear track.....	115
Figure 5.5: Broken DC motor holder.....	116
Figure 5.6: Wet cloth wrapped around DC motor.....	117
Figure 5.7: Frame of the wave generator.....	118
Figure 5.8: Hydraulic powered wave generator	119
Figure 5.9: Linear generator with cut out hole at closed bottom.....	121
Figure 5.10: Float with lateral surface facing oncoming waves.....	123

LIST OF APPENDICES

Appendix 1: Gantt Chart for PSM 1	139
Appendix 2: Gantt Chart for PSM 2.....	140
Appendix 3: Voltage generated for type 1 and type 2 wave generators at 50RPM ($x = 45\text{cm}$)	141
Appendix 4: Voltage generated for type 1 and type 2 wave generators at 70RPM ($x = 45\text{cm}$)	141
Appendix 5: Voltage generated for type 1 and type 2 wave generators at 90RPM ($x = 45\text{cm}$)	141
Appendix 6: Voltage generated by single linear generator at 50RPM ($x = 45\text{cm}$)	142
Appendix 7: Voltage generated by single linear generator at 70RPM ($x = 45\text{cm}$)	142
Appendix 8: Voltage generated by single linear generator at 90RPM ($x = 45\text{cm}$)	142
Appendix 9: Voltage generated by single linear generator at 50RPM ($x = 40\text{cm}$)	143
Appendix 10: Voltage generated by single linear generator at 70RPM ($x = 40\text{cm}$)	143
Appendix 11: Voltage generated by single linear generator at 90RPM ($x = 40\text{cm}$)	143
Appendix 12: Voltage generated by single linear generator at 50RPM ($x = 35\text{cm}$)	144
Appendix 13: Voltage generated by single linear generator at 70RPM ($x = 35\text{cm}$)	144
Appendix 14: Voltage generated by single linear generator at 90RPM ($x = 35\text{cm}$)	144
Appendix 15: Voltage generated by single linear generator at 50RPM ($x = 30\text{cm}$)	145
Appendix 16: Voltage generated by single linear generator at 70RPM ($x = 30\text{cm}$)	145

Appendix 17: Voltage generated by single linear generator at 90RPM ($x = 30\text{cm}$)	145
Appendix 18: Voltage generated by double linear generators at 50RPM ($x = 45\text{cm}$)	146
Appendix 19: Voltage generated by double linear generators at 70RPM ($x = 45\text{cm}$)	146
Appendix 20: Voltage generated by double linear generators at 90RPM ($x = 45\text{cm}$)	146
Appendix 21: Voltage generated by double linear generators at 50RPM ($x = 40\text{cm}$)	147
Appendix 22: Voltage generated by double linear generators at 70RPM ($x = 40\text{cm}$)	147
Appendix 23: Voltage generated by double linear generators at 90RPM ($x = 40\text{cm}$)	147
Appendix 24: Voltage generated by double linear generators at 50RPM ($x = 35\text{cm}$)	148
Appendix 25: Voltage generated by double linear generators at 70RPM ($x = 35\text{cm}$)	148
Appendix 26: Voltage generated by double linear generators at 90RPM ($x = 35\text{cm}$)	148
Appendix 27: Voltage generated by double linear generators at 50RPM ($x = 30\text{cm}$)	149
Appendix 28: Voltage generated by double linear generators at 70RPM ($x = 30\text{cm}$)	149
Appendix 29: Voltage generated by double linear generators at 90RPM ($x = 30\text{cm}$)	149



LIST OF ABBREVIATIONS

AC	–	alternating current
DC	–	direct current
DTLPMG	–	double-sided tubular-linear permanent magnet generator
LED	–	light-emitting diode
LG	–	linear generator
PVC	–	polyvinyl chloride
PSM	–	<i>projek sarjana muda</i> (bachelor's degree project)
RPM	–	revolutions per minute
TLPMG	–	tubular-linear permanent magnet generator
WEC	–	Wave Energy Converter

LIST OF SYMBOLS

A	–	Area, measured in cubic meter (m^2)
B	–	Flux density, measured in tesla (T)
C	–	Capacitance, measured in farad (F)
E	–	Voltage, measured in voltage (V)
F	–	Force, measured in newton (N)
f	–	Friction coefficient, dimensionless
J	–	Density of current in conductor, measured in ampere per cubic meter (A/m^2)
N	–	Number of loops of conductor coil
P	–	Power, measured in watt (W)
ρ_{Cu}	–	Conductor resistivity (copper), measured in ohm (Ω)
q	–	Electric charge, measured in coulomb (C)
φ	–	Magnetic flux, measured in weber (Wb)
r	–	Radius, measured in meter (m)
t	–	Time, measured in seconds (s)
v	–	Velocity, measured in meter per second (m/s)
x	–	Distance, measured in meter (m)

CHAPTER 1

INTRODUCTION

1.0 Background

Waves are a natural phenomenon that occurs on the surface of the ocean. On earth, 97% is covered by water bodies. 70% of the earth's surface is the ocean. The ocean is a huge reservoir of energy waiting to be harvested in the form of waves, water current, thermal resources, and tides (Singh, 2019). Waves, being one of the forms, comes from the generation of circular motion in the ocean caused by the winds produced from the difference in temperature throughout the globe. There are two types of waves present on the ocean, standing waves, and progressive waves. A progressive wave is a wave that is characterized by progressive forward motion, whereas a standing wave is a wave that oscillates vertically in a fixed point without any forward progression (Allaby, 2008).

Waves carry an overwhelming amount of energy in the form of kinetic energy and potential energy. Wave energy tends to be lost and absorbed by the environment as it hits the coast. The total amount of energy that can be generated by waves breaking around the world's coastlines can go up to 2 to 3 million megawatts (Khaligh and Onar, 2017). Thus, by placing electric generators onto the surface of the ocean, the wave energy will be able to be converted into electrical energy which can be used to power the electrical grid that channels electricity from as large as factories to as small as residential areas. The electric generators that convert wave energy to electrical energy are known as wave energy

converters (WEC). Wave energy carries kinetic energy that is dependent on the speed and duration of the wind that causes the wave formation, the depth and area of the water body affected by the wind, and the seabed condition. In order to produce an efficient wave energy harvesting system, many conditions need to be considered. This includes the sea conditions at all times, as well as the method of transmission of electricity through turbulent water bodies. The operating cost of a wave energy harvesting system may also be of higher cost than other power plants due to its complexity (Khaligh and Onar, 2017).

Wave energy has many advantages. Firstly, wave energy is produced through a natural phenomenon, thus it is considered clean and renewable energy where the environment is not harmed in any way. There are also no chemical reactions in the production of wave energy which leads to little environmental impact. Secondly, wave energy is more predictable and consistent than other renewable energy such as solar energy and wind energy. Thirdly, the energy contained within wave energy is of very high density, which means more energy can be converted. Wave energy also has the capability to travel very long distances with minimal to no loss in energy.

The challenges that arise when harvesting wave energy are that wave energy has a huge variation in the range of force and energy. Thus, the wave energy conversion system should be able to harvest energy from an average ocean climate and also survive harsh ocean storms. With all the absurd requirements that the system has to achieve, the system still has to remain economical for companies to build. Besides that, the energy conversion system should be able to meet the requirements imposed on the electrical grid network so that the power flow from the WEC to the electrical grid is maximized.

There are three fundamental technology designs that revolve around the concept of wave energy conversion, namely the attenuator, the point absorber, and the terminator. The Pelamis, the Ocean Power Technology's Powerbuoy, and the Salter's Duck are examples

of attenuator, point absorber, and terminator, respectively. Unlike other renewable energy harvesting technology, wave energy is very broad such that there are patents for more than 1000 wave energy conversion technologies with various designs. The installation location of the wave energy harvesting device can be broken into three categories: onshore, nearshore, and offshore (Blackledge *et al.*, 2013).

1.1 Statement of The Purpose

The purpose of this study is to determine the performance of single and double linear generators in harvesting mini wave energy and provide improvements in possible aspects.

1.2 Problem Statement

Wave energy is a result of constant wind motion that occurs due to a difference in temperature around the globe. This continuous wind motion is captured by the ocean and converted into wave energy. Wave energy carries a tremendous amount of energy as it travels a long distance with little to no loss in energy. However, this huge amount of energy that could amount to 2 to 3 million megawatts is wasted as waves hit coastlines worldwide. Wave energy conversion technologies are invented to harvest the tremendous amount of energy packed in waves. However, there are challenges to overcome where the WECs have to be able to harvest energy from an average ocean climate with huge variation in the range of force and energy, as well as being able to withstand harsh ocean storms. The WECs also have to remain economical to be built despite the absurd requirements it has to satisfy. The wave energy conversion system also has to fulfill the requirements

imposed on the electrical grid network in terms of power flow so that the energy received by the electrical grid is maximized.

In this project, a mini wave energy conversion system using single and double linear generators was studied on their performance. The optimum distance of the single linear generator, as well as the optimum gap distance for double linear generators, are variables studied on. The best location for single linear generator and the best gap distance for double linear generators were determined such that the electrical voltage produced are the highest.

With this study, a wave energy conversion system can be built on suitable coastlines worldwide with minimal cost and producing energy at higher efficiency. Figure 1.1 illustrates the scenario of ocean waves colliding into concrete walls causing energy to be absorbed and lost.



Figure 1.1: Waves hitting the coastline (Keegan, 2020)

1.3 Objective

The objectives of this project are as follows:

1. To investigate the effectiveness of single linear generator for different distances in producing electrical voltage.
2. To investigate the effectiveness of double linear generators for different gap distances in producing electrical voltage.



1.4 Scope of Project

The scopes of this project are as follows:

1. To determine the best location in obtaining the highest voltage accumulation for single linear generator. The best location of the single linear generator was determined by gradually bringing the linear generator closer to the wall at the end of the tank which decreases the depth of water from float to tank bed. The best location is the location where the voltage generated is the highest among all the other locations. This was also tested with varying speed of wave generator. The number of loops of copper coils around the linear generator was fixed.
2. To determine the best gap distance in obtaining the highest voltage accumulation for double linear generators. The location of linear generator closer to the wave generator was fixed. The linear generator closer to the wall at the end of the tank was moved away gradually from the fixed linear generator, starting off with a smaller gap distance. The best gap distance of double linear generators is when the electrical voltage generated is the highest. This was also tested with varying speed of wave generator. Both linear generators were similarly designed in terms of dimensions, the number of loops of copper coils, the number of magnets used, and the strength of the magnet used.