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

NG KAI JUN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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

NG KAI JUN

A report submitted
in fulfilment of the requirements for the degree of
Bachelor of Mechanical Engineering with Honours

Faculty of Mechanical Engineering

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

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 : ....

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 outweigh 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 lelurus tunggal dan berkembar akan dikaji melalui simulasi praktikal pada model sistem penjana ombak mini. Keberkesanan penjana lelurus tunggal pada jarak yang berbeza dan penjana lelurus 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 lelurus tunggal yang terbaik dan juga jarak sela bagi penjana lelurus 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 lelurus tunggal menjana voltan elektrik yang lebih tinggi berbanding dengan penjana lelurus berkembar. Ini sebab penjana lelurus yang lebih akan mengurangkan kuasa purata yang dihasilkan setiap penukar tenaga gelombang, membawa kepada pengurangan jumlah penjanaan voltan elektrik. Ini terbukti dengan perbandingan jumlah penjanaan voltan purata tertinggi, di mana penjana lelurus tunggal menjana 1.34mV pada 70RPM manakala penjana lelurus berkembar menjana 0.65mV pada 50RPM. Ini menunjukkan bahawa jumlah penjanaan voltan purata tertinggi oleh penjana lelurus tunggal adalah 107.69% lebih tinggi dairpada penjana lelurus berkembar. Jumlah penjanaan voltan yang tertinggi dengan menggunakan penjana lelurus tunggal ialah 1.8mV pada jarak penjana lelurus A, x*, 35cm pada 70RPM. Jumlah penjanaan voltan yang tertinggi dengan menggunakan penjana lelurus berkembar ialah 0.8mV pada jarak jurang penjana lelurus,* x*, 28cm pada 50RPM dan jarak jurang penjana lelurus,* x*, 38cm pada 90RPM. Ujikaji pada penjana lelurus tunggal menunjukkan perbezaan yang ketara dalam jumlah penjanaan voltan bergantung pada lokasi penjana lelurus, sedangkan untuk penjana lelurus berkembar, perbezaan adalah minimum antara pelbagai jarak jurang penjana lelurus. Secara keseluruhannya, bagi penjana lelurus tunggal, coraknya menunjukkan bahawa apabila jarak penjana lelurus tunggal A, x, meningkat, jumlah penjanaan voltan meningkat. Secara umumnya, bagi penjana lelurus 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

LIST OF FIGURES

LIST OF APPENDICES

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	–	*projek sarjana muda* (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.