Harnessing of Wave Energy using Axially Magnetized Linear Generator with Data Logger using Gizduino Microcontroller

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Abstract. This study focused on the design and construction of wave energy generation system. Wave energy is produced once the electric generators is placed parallel on the ocean surface and rides in different height of waves along the length of the device. It follows the concept of Faraday’s law of induction in the linear generator which an alternating current is induced in the loops of copper wire whenever the magnet slides back and forth through it. Using Axially magnetic type linear generator that will utilized the horizontal forces brought by the waves and placed on a waterproof floating boat with a data logger using microcontroller. The wave converter is deployed in a controlled and uncontrolled environment to observe the behaviour of the prototype and compared the measured parameters such as voltage, current, power, and energy at different time and wave height.

1. Introduction

With the discoveries and development of the renewable energy’s in the past decades, researchers have designed a variety of methods in harnessing energy that have been implemented for different applications [1-4]. Wave power is a relatively unknown solution to lessen the environmental impact of the conventional sources of energy, yet it is continuous, predictable and unlimited source of energy has the capability to be among the primary suppliers of the world’s future needs if we overcome some obstacles. So, the researchers are challenged how to convert power from wave motion that might yield significant electricity [5-6]. The main objective of this study is to harness wave energy using linear generator. Specifically, the research aims: (a) to develop a linear generator; (b) to develop a data logger for data storage; (c) to develop a waterproof casing for the integrated system; (d) to integrate the data logger to the linear generator; (e) to test the functionality of the integrated data logger and; linear generator; (f) to evaluate the wave energy conversion system in controlled and uncontrolled environment. The research compromises the design and construction of wave energy generation system. The linear generator of the system will only utilize the horizontal forces brought by the wave and it is an axially magnetic type linear generator. The energy conversion system will have a data logger module to store the data while the energy conversion system is deployed. The linear generator and the data logger will be placed inside a waterproof casing. The energy conversion system will be tested on a wave pool environment. The measuring devices and the data logger will have its own power source and its different configuration will not be covered in this study.
2. Methodology
A flow chart is illustrated on Figure 1 which serves as a guide in making the wave energy conversion system. Based on the flow chart, the first step to consider is finding previous and existing design of wave energy conversion system in order to create an improved and more efficient design. The linear generator design will be based on the computed parameters. The data logger module will be based on the design suitable for the Gizduino module. The obtained results will be compared based on the mathematical modelling that governs the principle of power that can be harvested on waves. Additional floaters will be added if the casing will not be able to float with the whole system.

![Flowchart of the study](image)

**Figure 1.** Flowchart of the study

2.1 Design of the linear generator
The linear generator was constructed based on the computed parameter on Tables 1, 2 and 3 respectively. The generated voltage and power are recorded and the percent difference between the theoretical output and the actual output is computed. The casing of the generator is tested to determine if it will be able to protect the equipment placed inside it in a controlled and uncontrolled environment.

2.2 Design of Wave Conversion System
Figure 2 is the proposed design of the wave energy conversion system that resembles a boat with two floaters at each side in order to add stability when deployed on the water.

| Description                  | Symbol | Result          |
|------------------------------|--------|-----------------|
| Number of phases             | phases | 1               |
| Number of turns              | Nturns | 700             |
| Number of poles              | P      | 4               |
| Magnetic field strength      | B      | 0.3265          |
| Wire radius (m)              | rwire  | 0.0002553       |
| Wire resistance (per 1m)     | reswire| 0.842           |
| Distance btwn poles (m)      | dpoles | 0.01            |
| velocity (m/s)               | vel    | 0.1             |
| winding radius (m)           | windrad| 0.01            |
| ideal min efficiency         | eff    | 0.5             |
| acceleration (m/s)           | g      | 9.8             |
2.3 Experimental Procedures

The prototype is tested on a controlled environment and an uncontrolled environment in which in this cases, a wave pool (Splash Island) and at the sea (Dalaroy Beach Resort). The prototype is deployed for 120 minutes in the wave pool for 2 trials and 120 minutes in the sea for 2 trials where the voltage, current and power is recorded via the data logger. The data gathered in the controlled environment will be compared to the projected wave power generated based on the mathematical model on equation (1). It was also correlated to the reference research [7]. Using the data on the output power of the prototype in both controlled and uncontrolled environment, the energy output can be calculated by getting the area under the curve of output power using the Simpson’s Rule given below on equation 2 [8].

\[
P = \frac{\rho g^2 H^2 T}{64\pi}
\]  

(1)
3. Results and Discussion

Figures 3 and 4 show the deployment of the prototype in the controlled and uncontrolled environment. The wave pool varies the types of wave and its height by changing the discharge pressure of the controlled environment. This part determines the projected wave power generated based on the mathematical model on equation 1. The result will then be compared to the results of the deployed prototype on a controlled environment.

Figure 5 shows the comparison of theoretical and actual voltages at a wave height of 3ft. It is obvious that the actual power is varying up and down because of the wave crest and trough. Looking at the regression line of the actual wave power, $y = 0.0233x + 90.926$, it can be seen that the slope of 0.023 is less than 1 which means that the line is almost horizontal and can be concluded that the average power output of the prototype is very slightly increasing (almost negligible slope). The graph above also shows that the slope of 0.023 is less than 1 which means that the line is almost horizontal and can be concluded that the average power output of the prototype is very slightly increasing (almost negligible slope). The graph above also shows that the regression line and theoretical value is almost the same and almost horizontal line wherein it can be said that the prototype has a stable power output over the span of 2 hours.

Calculating the area under the curve of actual power using the Simpson’s Rule, the energy produced by the wave energy converter at a wave height of 1ft is 9.52WHr. From these results, the researchers can say that the wave energy converter is effective in harnessing wave energy at a controlled environment.

Figure 6 shows the comparison of actual power produced at wave height of 1ft and 3ft in the span of 30 minutes. As seen above, the wave height of 3ft produces a higher power than the wave height of 1ft, the peak power output for a wave height of 1ft is 123.94mW while for a wave height of 3ft is 431.51mW. Throughout the 2-hour test, the power produced at a wave height of 3ft is always higher than the power produced at a wave height of 1ft. Therefore, the researchers could say that the prototype produces a higher power output at higher waves than at lower waves. Calculating the area under the curve using Simpson’s Rule, the energy produced for a wave height of 1ft is 9.52WHr and for a wave height of 3ft is 26.453WHr. With these results, it is obvious that the prototype produces higher energy output at a higher wave height than at lower wave height.
Based from the test conducted, the power output at uncontrolled environment is varying since the wave height are unpredictable. The varying results shows that the prototype is producing power no matter how small or big the wave is if the wave are continuous. Using the formula on equation 2, for the computations for the area under the curve, the energy produced for the trial 1 is 24.83WHR and for the trial 2 is 23.756 Whr. From these results, the researchers can say that the prototype is effective in harnessing wave energy.

4. Conclusions
The research proved the possibility of designing an Axially Magnetized Linear Generator with Data Logger using Gizduino Microcontroller that is capable of harnessing wave energy. The research includes a design of a wave energy conversion system that resembles a boat that can be easily deployed on the pool. The prototype will ride with the waves which will case the rotor of the linear generator, that is placed inside, to move linearly. The researchers integrate the designed linear generator to the data logger. The generator and data logging system are said to be operational as the percentage difference between the recorded data and the actual measurement is minimal. The percentage difference of less than 5% prove that the system is accurate and reliable in storing data parameters. The assessment and evaluation of the performance of the wave energy conversion system shows favourable results. The researchers conduct sets of experiments wherein the wave height of each experiment differs from the other. From the data gathered, the researchers concluded that the power and energy generated from the conversion of wave energy using axially magnetized linear generator is directly proportional to the wave height.

The researchers recommend the use of remote control that could deploy the boat in a longer distance to provide extra safety and less effort in placing it to the desired location. Various designs of linear generator can be considered such as transversely or radially magnetize linear generator. It can be tested and compared on which design will be more efficient and produce better results. To provide a real-time monitoring of the prototype it is recommended to use a wireless monitoring system that will allow the researchers to gather data in a remote way. It also prevents the removal of the boat cover every time the data is gather via memory card.

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