



Harnessing the Power of Ocean Waves: A Case Study of NAHRIM-WEC

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Abstract

This report presents a case study of the NAHRIM-WEC (Wave Energy Converter) system, which is an electric power generation system that uses ocean waves as its primary source. The report provides an overview of the system's main components, including a floating structure system and an electric induction system that uses magnetostrictive concepts, including a charge amplifier. The report also describes the development of the NAHRIM-WEC prototype, which was designed to harness the energy of ocean waves and convert it into electricity. The prototype was tested in the field to evaluate its performance and efficiency in generating electricity from ocean waves. It is very important to ensure the overall WEC structure is watertight because extreme and unpredictable weather at sea can cause the WEC structure to sink suddenly, and seawater can accelerate chemical reactions that lead to the corrosion of electrical circuits if it enters. Future research should focus on improving the efficiency of the system and reducing its cost. The results of the sea trials were generally positive, with the prototype demonstrating a high level of efficiency in generating electricity from ocean waves. The potential of the NAHRIM-WEC prototype to revolutionize the way of generating electricity and provide a sustainable and environmentally friendly source of renewable energy was also discussed. The system is capable of providing a significant source of renewable energy, helping to reduce our dependence on fossil fuels and protect the environment. Furthermore, this report also highlights the challenges and limitations of the NAHRIM-WEC system and the need for further research and development. To improve the efficiency of the Wave Energy Converter (WEC), consider redesigning the floating structure to have a wider and larger shape to increase stability. Optimizing the winding configuration and increasing the number of turns in critical parts will increase the voltage and current induced and need to be studied more deeply. Further testing should be conducted to evaluate the system's performance under different weather conditions and in different ocean environments. Overall, the NAHRIM-WEC prototype is a significant development in the field of renewable energy. The system has the potential to provide a sustainable and environmentally friendly source of electricity, which could help reduce our dependence on fossil fuels and protect the environment. The NAHRIM-WEC system could become a significant source of renewable energy, helping to address the challenges of climate change and promoting sustainable development.

Introduction

Global energy demand is on the rise, necessitating a greater focus on renewable energy sources. Among these, wave energy stands out as a promising option with the potential to significantly contribute to electricity generation. According to the Intergovernmental Panel on Climate Change (IPCC), wave power has long been recognized as a key renewable energy source. The IPCC report provides estimates for the world's total potential of ocean wave energy resources, obtained through various methods. The theoretical maximum is approximately 30,000 terawatt-hours per year (TWh/yr), equivalent to about 20% of the world's energy consumption in 2019. However, practical limitations related to technology and economics result in an exploitable resource that is nearly ten times less than the theoretical maximum (IPCC, 2018).

Wave energy offers several advantages. It is a clean and renewable source that does not produce harmful pollutants or greenhouse gases, unlike fossil fuels. Additionally, wave energy exhibits greater predictability and consistency compared to other renewables like wind and solar power. Waves containing harvestable energy can generate electricity up to 90% of the time, surpassing the performance of wind or solar devices [1].

The ever-growing number of ideas and concepts regarding the optimal use of the wave energy resource characterises the development of wave energy converters (WECs). Generally, WECs can be classified by where they are: offshore, nearshore, and onshore. The primary operating principles of WECs are another factor in classifying them [2]. The classification method employed by IEA—Ocean Energy Systems [3] is shown in Figure 1.

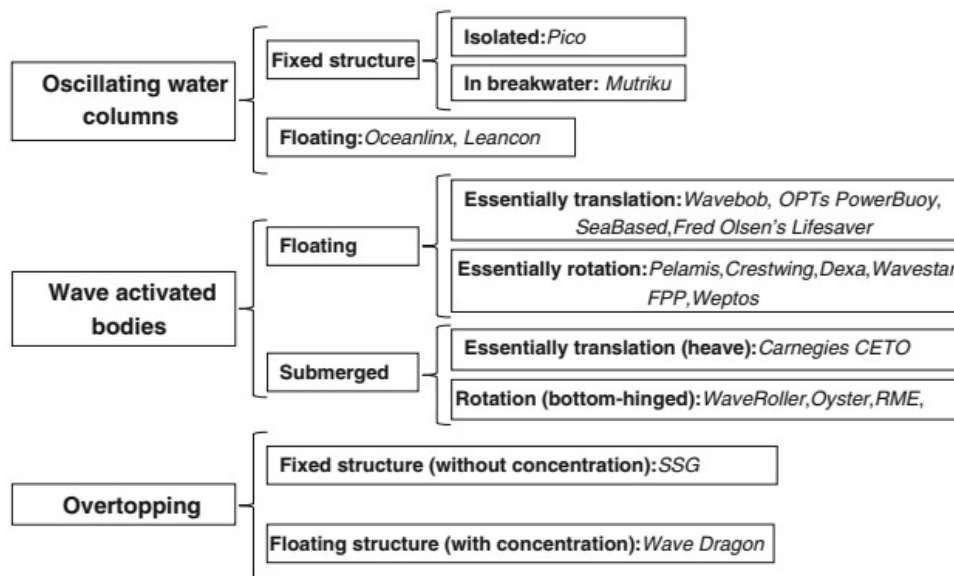


Fig. 1: Classification of wave energy technologies

The process by which the energy received by the main converter is converted into useful electricity is commonly referred to as the power take-off (PTO) of a wave energy converter. The PTO system is crucial because it influences the wave energy converter's mass, size, and structural dynamics in addition to directly affecting how well the absorbed wave power is converted into electricity. As a result, there are many distinct kinds of PTO systems, each with its benefits and drawbacks in terms of effectiveness, control, complexity, and cost.

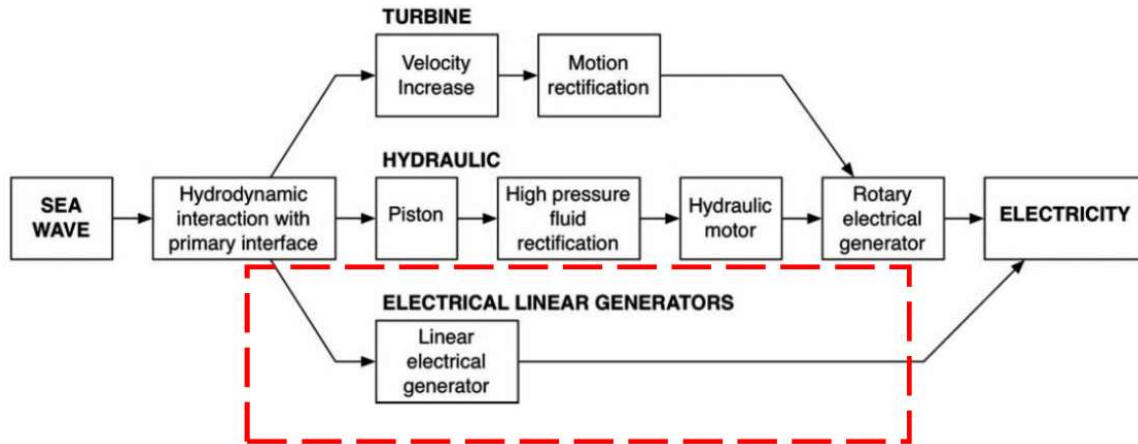


Fig. 2: Power Take Off mechanism of WEC [4]

A typical PTO mechanism is shown in Figure 2, with the dotted box indicating linear electrical generators as used in NAHRIM-WEC.

Background

The NAHRIM-WEC is an electric power generation system that uses ocean waves as its primary source. Conceptually, it falls under the classification of wave-activated bodies (WABs), which encompasses a very large field of WEC concepts. The system consists of several main components, such as a floating structure and an electric induction system that use magnetostrictive concepts, including a charge amplifier. The system is designed to be environmentally friendly and sustainable, with the potential to provide a significant source of renewable energy.

The floating structure is initially designed to be stable and durable in harsh ocean environments. It consists of a buoyant structure that is anchored to the seabed and a mooring system that keeps the NAHRIM-WEC unit in place. The buoyant structure is designed to move up and down with the motion of the waves and, in the process generates mechanical energy that is converted to another form of energy by the electric induction system, which also acts as the WEC's PTO mechanism.

Consequently, the electric induction system uses magnetostrictive concepts to convert mechanical energy into electrical energy. The system consists of a charge amplifier that amplifies the electrical charge generated by the magnetostrictive material, which is then converted into usable electrical energy. Therefore, the NAHRIM-WEC's PTO, as explained in Figure 2 earlier, can also be categorized as a linear electrical generator.

The motivation behind the NAHRIM-WEC prototype development is to harness the energy of ocean waves and convert it into electricity. Therefore, the prototype was tested in the field to evaluate its performance and efficiency in generating electricity from ocean waves. The sea trials was conducted by a team of experts from NAHRIM, who monitored the performance of the prototype and collected data on its energy output.

The NAHRIM-WEC system offers substantial environmental advantages. The system is engineered to be ecologically conscious and enduring, with the capacity to offer a substantial supply of sustainable energy. The system is environmentally friendly as it does not emit harmful pollutants or greenhouse gases, which are known to contribute to climate change. This makes it a perfect substitute for fossil fuels. The system also possesses the capacity to diminish our reliance on fossil fuels and safeguard the environment.

Methodology

Model development

The development of the NAHRIM-WEC prototype involved several stages. The first stage was the design and construction of the prototype (Figure 3), which was based on the principles of magnetostriction. The prototype was designed to be stable and durable in harsh ocean environments, and it consisted of a floating structure system and an electric induction system that used magnetostrictive concepts, including a charge amplifier.

The floating structure system is made of fiberglass, with two numbers of U-shaped tubes arranged on top. The floating structure is designed with a hollow space inside and equipped with two safety light sockets. The floating structure is also designed with a closed electronic component storage box, which is built-in onto its platform. The electric generator is an important element that consists of two cylindrical tubes, each containing a magnet that moves horizontally along the cylinder. The movement of the magnet crossing the coil will cause the magnetic field to be cut, which will cause an electric current to be induced in the coil. For WEC preparation, the cleaning process was carried out, including the process of removing water and small debris trapped in the floating structure before the sea trials was conducted.

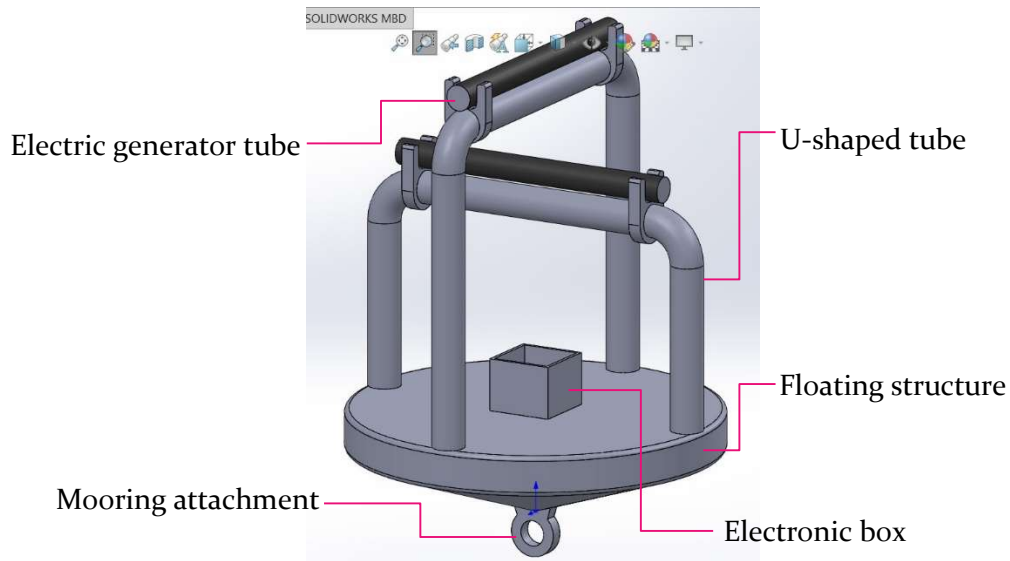


Fig. 3 : 3D CAD model of NAHRIM-WEC

Within the electric generator tube, the induced current and voltage will be directed to the electronic box that has a data logger that will record sea trials data. The electronic circuit contains several main components, such as dry battery cells, power banks, data loggers (Arduino), display screens, HOBO G-loggers, and SD cards to record data. These components have been arranged in an orderly and systematic manner before being tested using a multi meter to measure the voltage and current induced by the electric generator tube. The WEC installation phase begins by installing the electric generator tube on the floating structure crossbar in series. Figure 4 (a-c) and Figure 5 (a-c) show the preparation of electronic components and the installation of a customized data logger for data collection purposes.

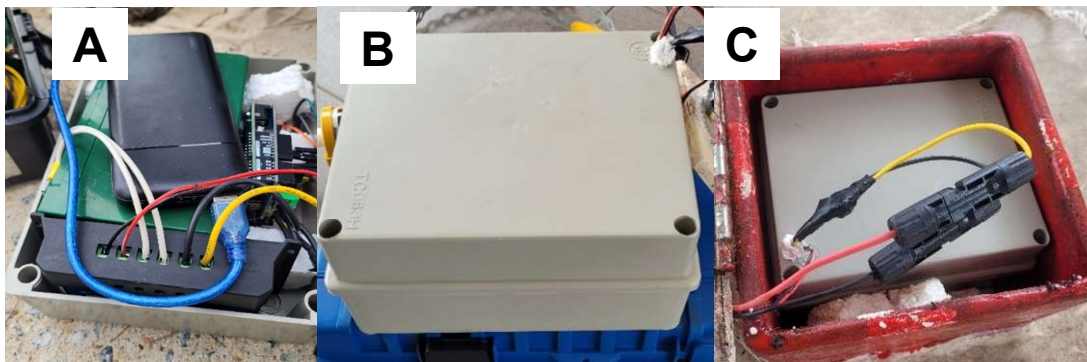


Fig. 4 (a) (b) (c): The preparation of electronic components

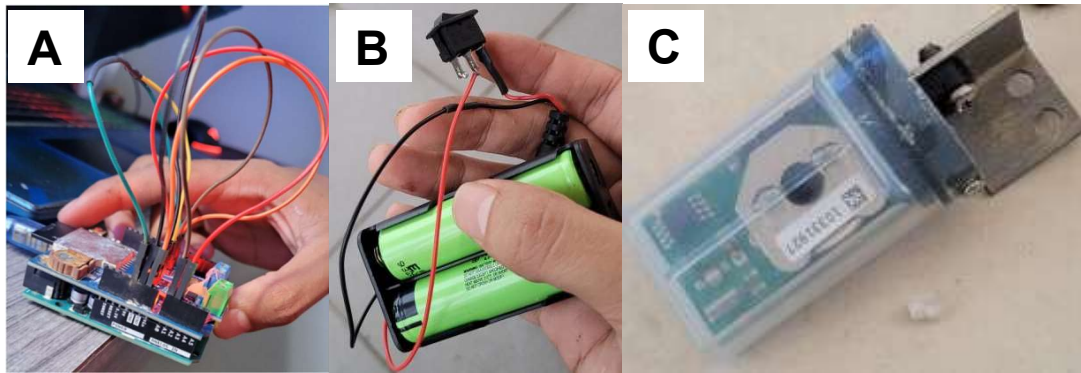


Fig. 5 (a) (b) (c): The installation of custom data logger for data collection purposes

Laboratory test

The primary goal of a laboratory test is to examine specific aspects of a technology or to verify their validity. Experimental testing of a WEC model can be conducted in three distinct environments: a controlled and wet environment (commonly known as tank or basin testing), a controlled and dry environment (commonly known as test bench testing), and an uncontrolled wet environment (commonly known as sea trials). Due to the substantial increase in complexity, time, and costs of tests as the model size and environmental complexity increase, it is often more appropriate to study system variables using smaller simulations [5]. Therefore, during the development of WECs, there will be a consistent modification in the physical parameters of the model and the testing environment.

Figure 6 (a-c) shows the WEC prototype being tested in a controlled environment at NAHRIM's laboratory. The laboratory wave basin is equipped with a multi-element wave generator capable of creating artificial waves. These waves vary in amplitude, wavelength, and frequency, mimicking the diverse conditions encountered in natural oceans. The test aims to expose the NAHRIM-WEC prototype to these simulated waves. As the waves propagate through the basin, the WEC system's response is closely monitored. Researchers observe how it interacts with the waves, measures energy conversion efficiency, and maintains stability. Sensors and probes were strategically placed within the basin to record critical data points. These include the prototype's power output, mechanical stress, and structural stability. By analyzing this data, researchers gain insights into the system's performance and identify areas for improvement prior to sea trials.



Fig. 7: WEC prototype tested in a controlled environment at NAHRIM wave basin

Field test or sea trials

The third stage was the field test or sea trials, which was conducted in an open ocean environment. Sea trials can be conducted to achieve various objectives, which can significantly impact the capabilities of the WEC prototype and the chosen test location. In addition to the data obtained from the sea trials, the construction of the WEC and the knowledge gained from its operation and maintenance are also extremely valuable.

The site selected for sea trials of the NAHRIM-WEC is near the coast of Pantai Melawi, Bachok in the state of Kelantan (Figure 8). Some of the main objectives for sea trials are (i) demonstrate the technology in real ocean conditions and (ii) to measure, verify and validate loads, motions and power performance calculations and estimations. The team of experts from NAHRIM inspect the structure physically before the sea trials was executed (Figure 9).

Consequently, Figure 10(a-b) and 11 shows the site deployment of WEC and WEC on-site testing, respectively.

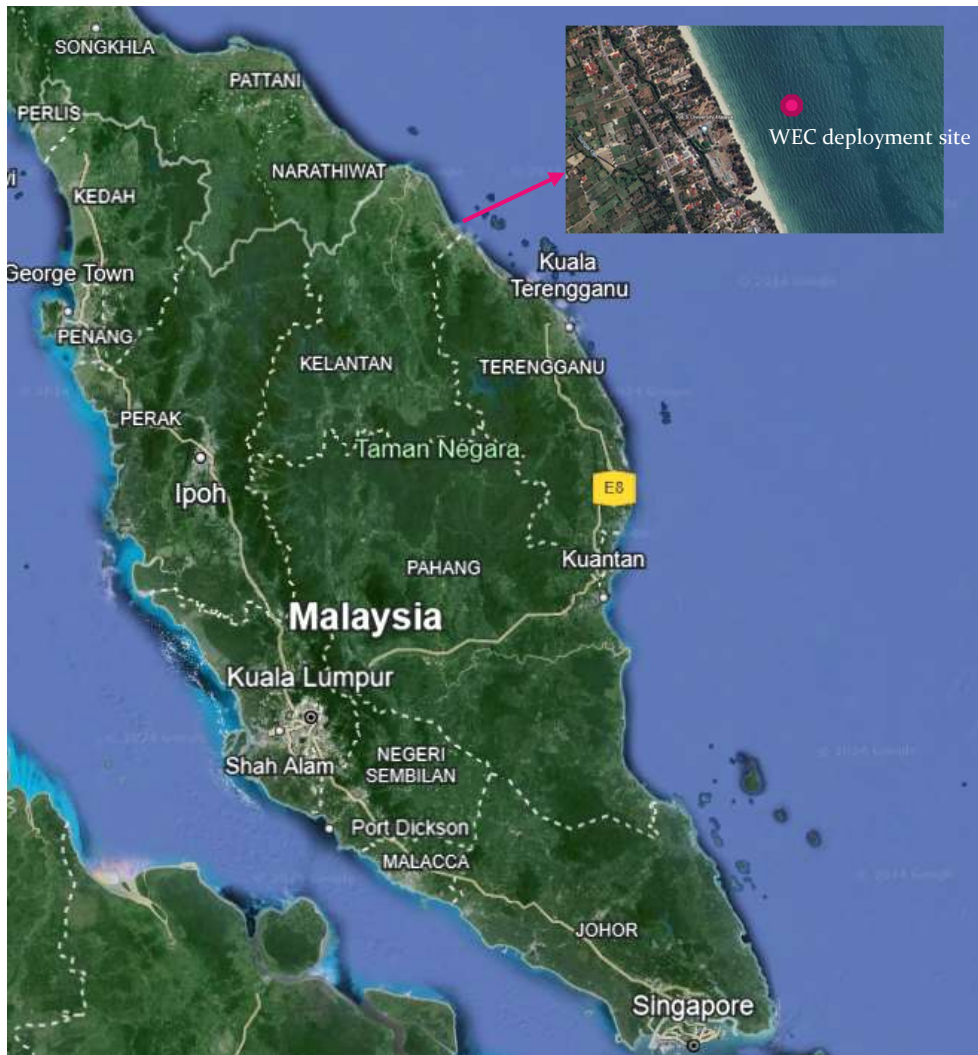


Fig. 8: Location of sea trials near Bachok, Kelantan



Figure 9: The NAHRIM-WEC (Wave Energy Converter) in preparation for the sea trials

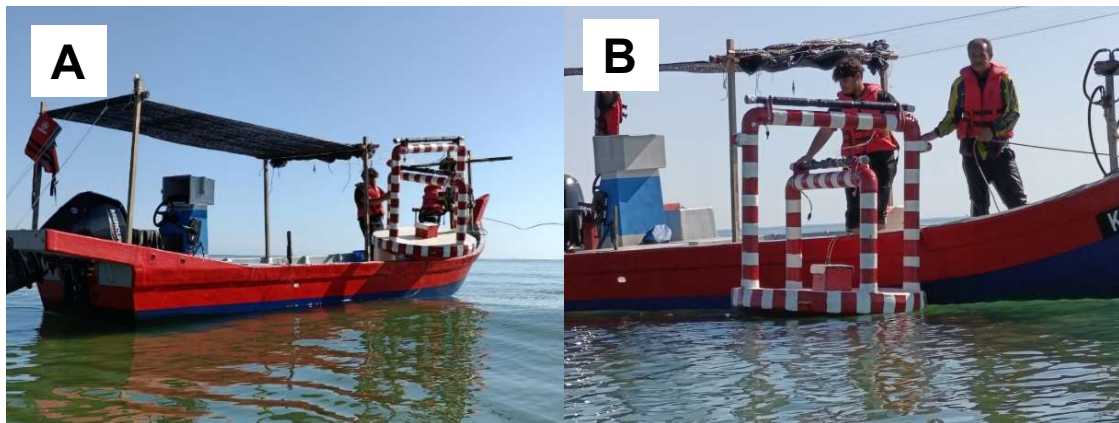


Fig. 10 (a) & (b): Deployment of WEC



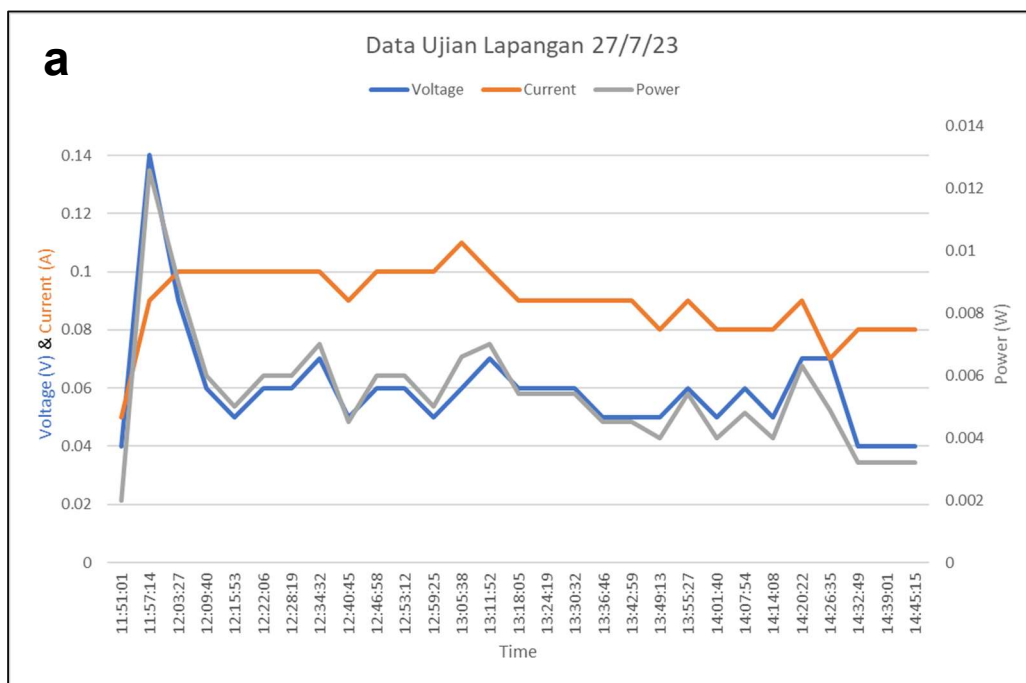
Fig. 11: WEC on-site testing

Results

The WEC generates power by converting the kinetic energy of ocean waves into electrical energy. The power generated by the WEC can be calculated using the formula.

$$\text{Power (W)} = \text{Current (A)} \times \text{Voltage (V)}$$

The voltage and current induced by the WEC during the sea trials are shown in Figure 11. When the WEC was in the designated location, the voltage and current reached stability throughout the sea trials, except for slight fluctuations in the graph. This is because the sea level is decreasing and the breaking waves will move slowly towards the WEC, causing small spikes in the graph. Then the WEC will be moved away from the breaking waves to a deeper sea level where the waves are not as strong, causing a slight decrease in the graph before it stabilizes again. This process is repeated until the end of the sea trials, and the WEC is brought back to the beach to be loaded into the IOES. There is a sudden drop at the end of the graph because the WEC is no longer in the water.



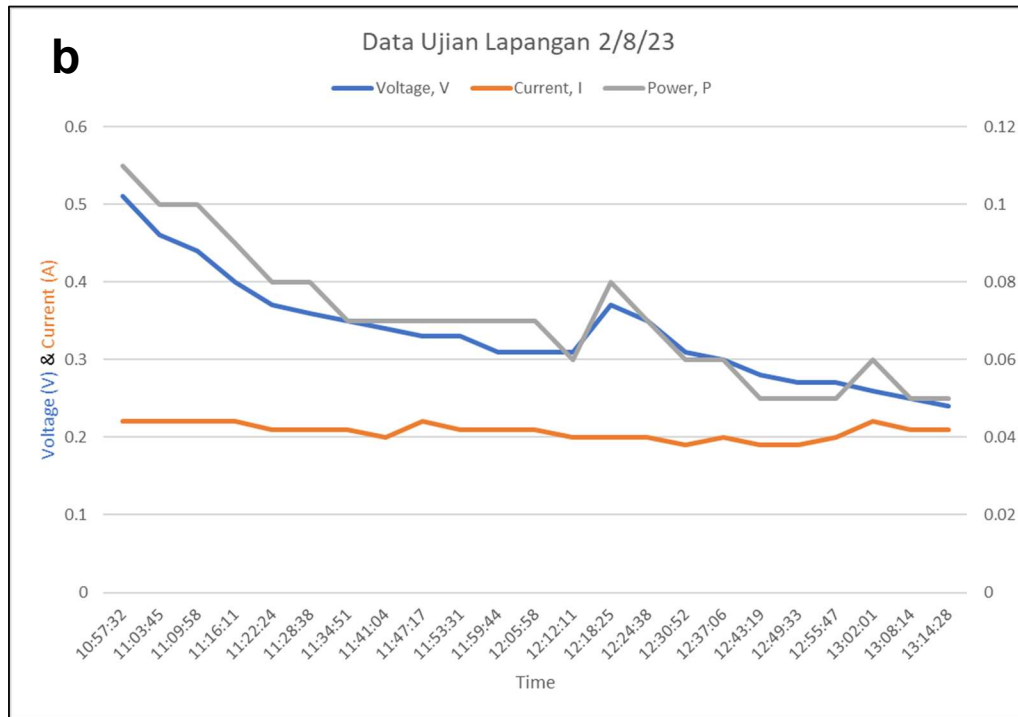


Figure 8: Sample of voltage and current induced during the field test

a) 27th July 2023 b) 2nd August 2023

The WEC generated an average voltage of 0.0205 V/hour, an average current of 0.0309 A/hour, and an average power of 0.0019 W/hour during the sea trials on July 27th. The WEC generated an average voltage of 0.14709 V/hour, an average current of 0.09088 A/hour, and an average power of 0.03087 W/hour during the field test on August 2nd. The results illustrate the capacity of the WEC to produce electricity from ocean waves and offer a sustainable and eco-friendly form of renewable energy.

Discussion

Sea trials are generally very expensive and time-consuming, as they require heavy equipment, and some wave conditions only occur sporadically. Moreover, various problems might occur, and different parameters have to be tested, retested, and optimized. This usually leads to a vast amount of discrepancy in the recorded performance of the device, which should be clearly marked—especially in the early stages of testing. The methodology thereby accepts incomplete and interrupted data series from sea trials. [6]

The sea trials results are promising, but further research and development are needed to improve the efficiency of the system and reduce its cost. The report highlights the need for future research to focus on improving the efficiency of the system and reducing its cost.

When a wave-activated body's motion is limited to one degree of freedom, its PTO operates at its most efficient level. In the absence of PTO interaction, the wave-activated body will always opt to go in the path of least resistance. Additionally, by restricting its motions to a single degree of freedom, the PTO system's complexity and the number of possible load instances are decreased. Its efficiency is maximised, and control is made easier because the precise motion of the wave-activated body is known.

The report also recommends that further testing be conducted to evaluate the system's performance under different weather conditions and in different ocean environments. The challenges and limitations of the NAHRIM-WEC system must be addressed to ensure that the system can be deployed on a large scale.

Recommendations

Upon completion of the sea trials and data collection, various recommendations have been made to enhance the efficiency of the Wave Energy Converter (WEC) and maximise its future potential. The following is a list of improvement suggestions that can be considered to enhance the efficiency of the WEC:

- i. Enhancing the floating structure's stability through design improvements: It is recommended to explore the possibility of redesigning the floating structure with a broader and more expansive shape in order to enhance its stability. The risk of the floating structure capsizing or submerging in water can be mitigated even when the WEC is deployed in an area with turbulent waves. Feasible strategies to enhance the stability of the floating structure encompass optimising weight distribution, adjusting the centre of gravity, and incorporating stabilising fins.

- ii. Utilising tubes with a low coefficient of friction: Employing tubes that have undergone vacuum sealing and are fully enclosed will diminish the air resistance exerted on the magnets as they move within the tube. Energy losses caused by friction can be minimised by employing advanced materials and employing manufacturing techniques that result in smooth surfaces with low friction coefficients.
- iii. Enhancing the number of copper wire turns: To maximise the voltage and current induced, it is necessary to thoroughly investigate the optimisation of the winding configuration and the increase in the number of turns in crucial sections.
- iv. Ensuring the overall WEC structure is waterproof is crucial due to the potential for sudden sinking caused by severe and unpredictable sea weather. If salty seawater infiltrates electrical circuits, it can expedite chemical reactions that result in corrosion.

Conclusion

The NAHRIM-WEC prototype is an electric power generation system that uses ocean waves as its primary source. The system's main components include a floating structure system and an electric induction system that uses magnetostrictive concepts, including a charge amplifier. The prototype was tested in sea trials to evaluate its performance and efficiency in generating electricity from ocean waves. The results of the sea trials were positive, with the prototype demonstrating a high level of efficiency in generating electricity from ocean waves.

In conclusion, the NAHRIM-WEC prototype is a significant development in the field of renewable energy. The system has the potential to provide a sustainable and environmentally friendly source of electricity, which could help to reduce our dependence on fossil fuels and protect the environment. Whilst the sea trials results are encouraging, further research and development are needed to improve the efficiency of the system and reduce its cost.

References

- [1] IPCC. (2018). *Special Report on Renewable Energy Sources and Climate Change Mitigation*. Retrieved from <https://www.ipcc.ch/report/renewable-energy-sources-and-climate-change-mitigation>
- [2] <http://www.emec.org.uk/marine-energy/wave-devices/>. Accessed 15 December 2023
- [3] http://www.ocean-energy-systems.org/ocean_energy/waves/. Accessed 10 December 2023
- [4] Drew, B., A.R. Plummer, and M.N. Sahinkaya, A review of wave energy converter technology. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, 2009. 223(8): p. 887-902
- [5] Holmes, B.: *Ocean Energy : Development and Evaluation Protocol—Part 1 : Wave Power*. HMRC—Marine Institute, pp. 1-25 (2003)
- [6] Pecher, A., and Kofoed, J.P. *Handbook of Ocean Wave Energy*, *Ocean Engineering & Oceanography*. DOI 10.1007/978-3-319-39889-1