International Journal of Marine Engineering Innovation and Research, Vol. 8(2), Jun. 2023. 272-278
(pISSN: 2541-5972, eISSN: 2548-1479)

Performance Analysis of a Point Absorber Wave Energy Converter in Nigerian West Coast; Gulf of Guinea

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(Received: 09 May 2023 / Revised: 10 May 2023 /Accepted: 31 May 2023)

***Abstract*— This paper presents a performance analysis of a point absorber wave energy converter (WEC) in the Gulf of Guinea along the Nigerian West Coast. The study aims to evaluate the device's efficiency and power output under different wave conditions in the Gulf, including extreme cases. To achieve this, an existing CAD model of a point absorber was reproduced in Auto-CAD and meshed in Ansys Aqua, to obtain the added mass and damping coefficient, it was finally imported in MATLAB where the simulation model was created using WEC-Sim software. The scatter diagram data from the region were analyzed, the probability of occurrence of each of the wave on the diagram was calculated and ranked, the top five conditions was fed in as input to the device. The results show that the device's efficiency is highest at a wave height of 2 meters and a peak period of 11 seconds. The power output is highest when the device resonates, this occur at a peak period and significant wave height of (4m & 15s). However, the efficiency decreases as power output increases. The study also confirms the device's suitability for the region, as it showed no abnormal behavior under extreme conditions. Further research is needed on optimizing the mooring line design and evaluating the cost-effectiveness of the device in the region.**

Keywords; Point Absorber; Newmarks-beta; WEC; WECSIM

I. INTRODUCTION

The utilization of wave energy can be effectively achieved through the use of Point absorber wave energy converters (WECs), which are devices that can move up and down with the waves. This motion is then transformed into electrical power via a power take-off system. Compared to other WECs, Point absorber WECs are preferred due to their ability to extract wave energy from various directions, their uncomplicated design that facilitates ease of maintenance, and their potential for scaling up [1].

The Gulf of Guinea, located in the southeastern region of the Atlantic Ocean, has been recognized as having significant potential for wave energy due to its proximity to the ocean [2]. The Nigerian West Coast is also found in this area and has been identified as a promising site for wave energy harvesting. In particular, the Lagos Deep offshore region, which has an average wave height of up to 4 meters, has been identified as one of the most attractive locations for converting wave energy [3].

This region's potential for high wave energy has piqued the interest of researchers and energy developers, making it a prime focus for wave energy converter deployment.

Several studies have highlighted the importance of wave energy converter performance for the economic feasibility of wave energy projects. To assess the effectiveness of wave energy converters, metrics such as power output, efficiency, and reliability are used [4]; [5]

Among the various types of wave energy converters, point absorbers have become a popular choice due to their high efficiency in converting wave energy into electricity [6].

With early Point absorbers are buoyant devices that move up and down with waves, generating power using a power take-off system that converts mechanical motion into electrical energy. Point absorbers are well-suited for the Nigerian West Coast because they can operate efficiently in moderate wave climates, which are common in the area [7].

Over time, point absorber technology has undergone various developments and trials, as documented by [8] and [9]. Initially, hydraulic systems were employed in the construction of point absorbers, but their performance was unsatisfactory due to their bulky size and low efficiency. Nevertheless, with the introduction of advanced power take-off systems, such as linear and direct-drive generators, the efficiency and reliability of point absorbers have been enhanced, as noted by [5]. Consequently, these advancements have increased the potential of point absorbers for the conversion of wave energy on the Nigerian West Coast.

The Nigerian West Coast within the Gulf of Guinea has notable wave energy potential, and the Lagos Deep offshore region exhibits some of the highest potentials in the area. To assess the efficacy of wave energy converters, it is critical to consider performance metrics like power output, efficiency, and reliability. One promising technology for wave energy conversion in the moderate wave climate of the Nigerian West Coast is point absorber technology. However, further research is necessary to comprehend the performance of point absorbers under extreme wave conditions in this region.

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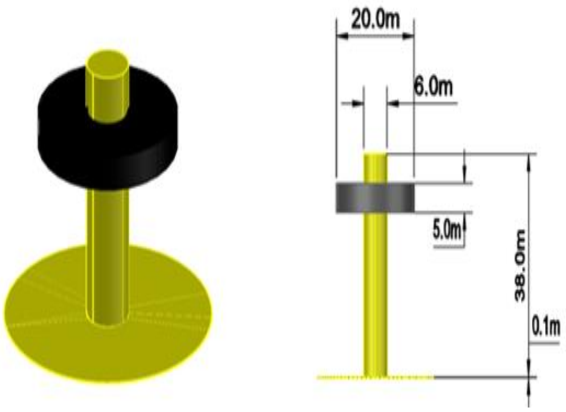

Figure 1: Reproduced CAD Model of the PAWEC

The objective of this investigation is to close this research gap by utilizing simulation models to evaluate the performance of a point absorber wave energy converter in the Nigerian West Coast, specifically in the Lagos Deep water region.

The aim of this research is to evaluate the performance of a point absorber wave energy converter (WEC) in the Gulf of Guinea along the Nigerian West Coast. To achieve this objective, scatter diagram data from the region will be analyzed to identify the most efficient and effective conditions for the WEC. Furthermore, the behavior of the WEC in extreme wave conditions will also be examined. However, this study will only employ numerical simulations, and no experiments will be conducted. To validate the accuracy of the simulations, data from a wave buoy deployed in the region will be used. By providing valuable insights into the potential of wave energy in the Gulf of Guinea, the findings of this research will inform the design and operation of future wave energy projects in the area.

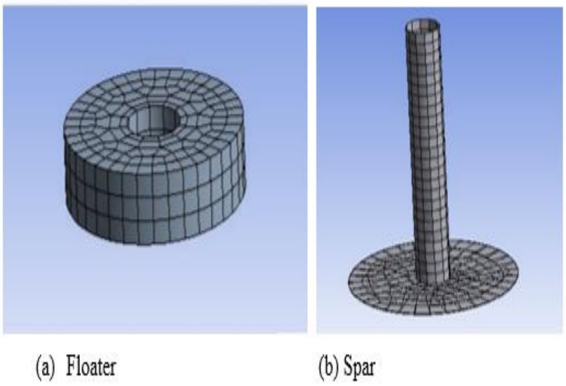

Figure 2: The Mesh CAD in Ansys Aqua

II METHOD

In order to In order to implement the performance analysis of the wave energy converter located in the Gulf, WEC-Sim (Wave Energy Converter SIMulator) software tool, was utilized. WEC-Sim is a freely available simulation tool that was developed by the National Renewable Energy Laboratory (NREL) and is highly regarded in the wave energy research community due to its capacity to model intricate WEC designs and simulate a wide range of operating scenarios. To create the simulation model in WEC-Sim. The point absorber's geometric CAD model was designed using AUTOCAD and meshed in Ansys Aqua to obtain the added mass and damping coefficient before importing it into WEC-Sim. The spectrum data obtained from the West Africa Swell Project Ewans et al (2004) was used to specify the wave climate in the Lagos Deep offshore region.

The specified wave climate was used to run the simulation model in WEC-Sim, resulting in output data that included the device's motion and power output over time. From these data, the device's performance metrics, such as efficiency, power output, and the impact of extreme wave conditions on its performance, were calculated. Additionally, Figure 1 shows the Computer Aided design of the model reproduced in Auto-Cad, Figure 2 presents the meshed model in Ansys Aqual, Table 1 presents the structural data, and Figure 3 presents the graphical user interface in MATLAB.

TABLE 1
STRUCTURAL DATA OF THE MODEL

	Mass(kg)	CG	Moment of Inertia (kg m^{2})
Float	727.01	-0.72	21,306,91
Spar	878.30	-21.29	94,407,091

The structural characteristics of the PAWEC is captured in table 1.

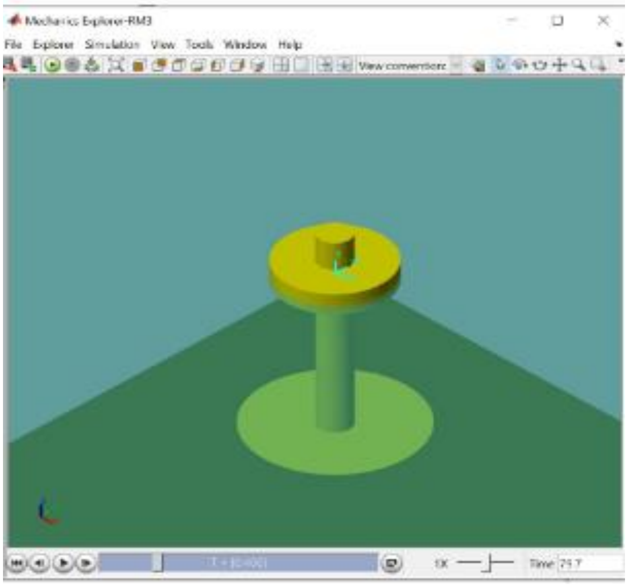

Figure 3 The Wec-Sim User Interface

A. Wave Spectrum Data for the Region

The wave spectrum data obtained from the West Africa Swell Project Ewans et al (2004). From the gulf in deep water Lagos is presented in Appendix A and B, Appendix A present the histogram of the directional significant Wave Height and Period at the region from 270 degrees to the 360 degrees. Appendix B present Histogram of significant wave height and period in the region.

B. Estimation of the Power Output

The Power output for the mechanical PTO can be calculated using equation 3.70 according to (R.So *et al*, 2015) this is valid for only mechanical PTO of the type used in this research.

$$P_{pto} = -C_{pto} \times \dot{Z}_R \quad (1)$$

Where;

C_{pto} = Force exerted by the PTO on the structure as discussed earlier,

$\dot{Z}_R$ = Difference in velocity between the two bodies i.e., the float and the spar.

C. Device Efficiency

The efficiency of the PAWEC is obtained using equation 2

$$\eta = \frac{P_{pto}}{P_{pt}} * 100 \quad (2)$$

Where;

P_{pto} = Power Take off power output

P_{pto} = Theoretical power output

The power output is the maximum power generated by the WEC for a given wave height and period while the power input (P_{in}) is the total power available in the area occupied by the WEC. It is given according to equation 3 for irregular waves (Buckham 2019).

$$P_{in} = \frac{1}{64\,\pi}\,\rho\, g^2 H_s^2 T_e \ \text{(W/m)} \quad (3)$$

For regular wave, it is given as equation 3.73

$$P_{in} = \frac{1}{32\,\pi}\,\rho\, g^2 H_s^2 T_e \ \text{(W/m)} \quad (4)$$

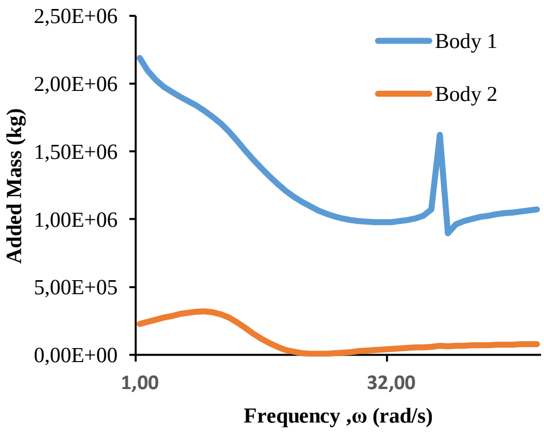

Figure 4; Added Mass for Uncoupled Heave

D. Probability of Occurrence

The equation for the probability of occurrence is given in equation 5, this equation is used to estimate the occurrence probability of each wava height and it associated period in the scatter diagram.

$$P_O = \frac{No\ of\ Occurance}{Total\ Occurance} \times 100 \quad (5)$$

Where;
P_O = Probability of Occurrence

III. RESULTS AND DISCUSSION

The results of the added mass and damping are shown in Figures 4 and 5, Ansys outputs frequency-based coefficients, *B* and *A*. The uncoupled added mass and radiation damping plotted against the frequency for both the spar and the floater, i.e., body 1 and 2 respectively, at a zero-degree direction. Only one direction is considered. This is because the PAWEC has a uniform geometry, and only the heave displacement was presented. This coefficient was gotten from Ansys Aqua and imported into the WecSim code, where it was used for the analysis.

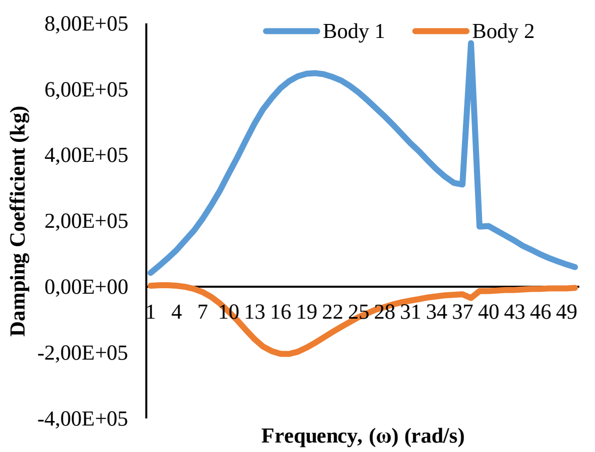

Figure 5: Damping for Uncoupled Heave

A. Target Parameter

The occurrence probability of each wave height and its associated period in the Scatter diagram of the region, as shown in Appendix A, has been determined and ranked in descending order. The resulting rankings are presented in Table 2, and the corresponding wave directions were extracted from Appendix B. Equation 5 was utilized to calculate the occurrence probability.

TABLE 2
TARGET PARAMETER

.S/N	Significant Wave Height (m)	Peak Period (s)	Probability of Occurrence	Occurrence	Direction (degree)
1	1	5	6.39	7448	293
2	2	7	5.44	6337	44
3	3	11	0.763	889	55
4	4	15	0.308	359	-
5	5	16	0.019	81	-
6	7	15	0.012	14	-
7	7	18	0.004	5	
8	7	11	0.003	4	

Considering sensitivity studies based on local data is crucial for obtaining direct information on the performance and efficiency of devices. In this study, data from the scatter diagram was used, focusing on the wave parameter with relatively higher energy content.

The power and efficiency variations for different conditions were summarized in Figures 6, 7, and 8. The highest power output was observed at 4 meters and 15 seconds, while the lowest was at 1 meter and 5 seconds. This can be attributed to the fact that the device oscillates more at a lower peak period, translating to more power, and makes more displacement at a higher wave height, which also contributes to power.

However, the efficiency was lower under these conditions due to the device pitching and yawing, leading to energy being expended on other modes of motion that do not contribute to power, as shown in Figure 7. The peak at 348.6 seconds in Figure 6 at PP & SH (4m&15s) could be due to resonance, where the wave frequency in the spectra was close to the PAWEC's natural frequency.

A similar condition was observed in PP & SH (5m & 16s) at around 290 seconds, but the power output was about half of the case in PP & SH (4m & 15s), which was the second highest. Figure 6 indicates that the PAWEC is most efficient at PP & SH (2m & 7s), while Figure 7 shows that power generation is highest at PP & SH (4m & 15s), primarily due to resonance. Unfortunately, this condition has a low probability of occurrence in the Gulf, being the fourth highest and occurring in one out of every 324 waves in the region. Although PP & SH (2m &7s) is the most efficient, given the enormous wave resources, the focus is on maximizing power output from the

PAWEC. Nonetheless, this supports the initial deduction that efficiency improves at lower wave height.

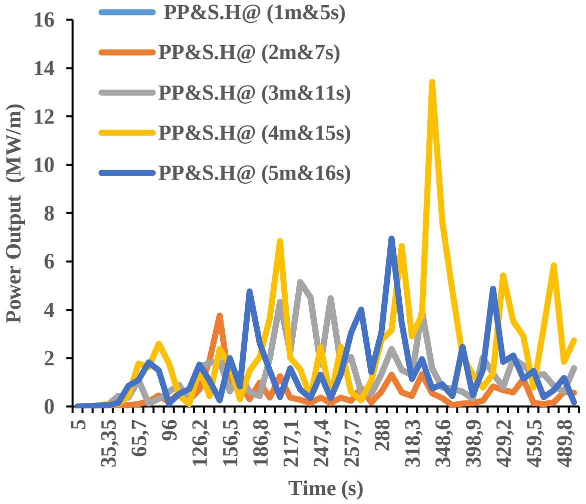

Figure 6: Variation in Power Output at Increasing Significant Wave Height and Peak Period Based on Scatter Diagram

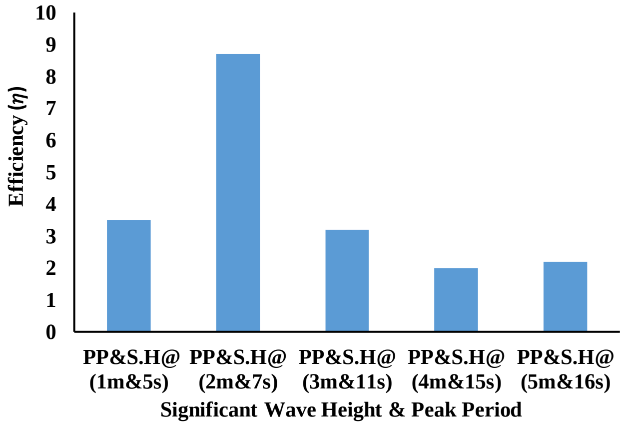

Figure 7: Variation in Efficiency at Increasing Significant Wave Height and Peak Period Based on Scatter Diagram

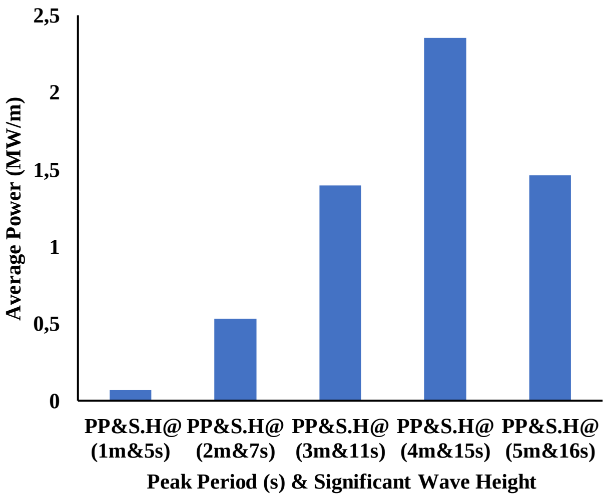

Figure 8: Variation in Wave Height and Peak Period Based on Scatter Diagram

B. Sensitivity Studies on the Extreme Cases

The scatter diagram displays the largest significant wave height as 7 meters. At a significant wave height of 7 meters, the peak period with the highest probability of occurrence is 15 seconds, while the peak periods range from 11 seconds to 18 seconds. Conducting a study to evaluate the performance of PAWEC under these extreme conditions is important. The study included three cases labeled as Desirable, More Probable, and Less Desirable based on their peak periods. The Desirable case (7 m and 11 sec) has the highest power output of 40 megawatts and is the most efficient, but it also puts a lot of strain on the PAWEC. The More Probable case (7 m and 15 sec) has a lower efficiency than the Desirable case, but a substantially larger power output than the Less Desirable case (7 m and 18 sec). Figure 9 displays the results. The study confirmed the suitability of the PAWEC for the region as no abnormalities were observed in any of the cases considered. The program ran smoothly without any abnormal motions of the PAWEC during the analysis. Although it only occurs four times a year, the Desirable case is the most efficient and has the largest power output.

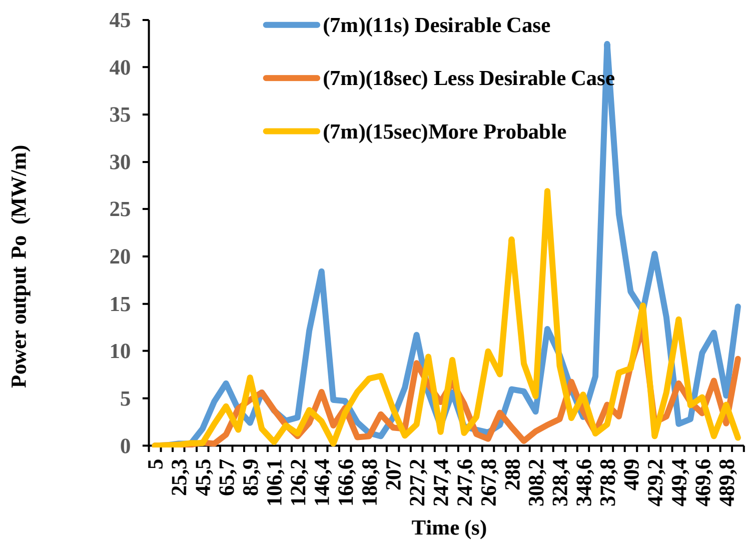

Figure 9: Performance at Extreme Cases

IV CONCLUSIONS

The The device's efficiency was shown to be at its peak at a wave height of 2 meters and a peak period of 11 seconds. Higher significant wave heights and shorter peak periods lead to higher power output from the PAWEC. The power output is at its highest when it resonates, this happens at a point in PP and SH (4m & 15s). As power output rises, the PAWEC efficiency decreases. At PP & S.H. (2m & 7s), the PAWEC performs most efficiently of all the target parameter considered, it can also be deduced from the study that at extreme cases the device show no abnormal behavior. Over all, it can be concluded that the PAWEC is suitable for the region, further research is needed on the mooring line design to optimize the Power output and efficiency. A study on the cost effectiveness of the PAWEC in the region is also needed. published in journals; data was not gathered from a single source, and failure is highly dependent on how the boat is launched. The operator's skill, so the data will be better if it comes from a single source. When more information becomes available, the results may be updated.

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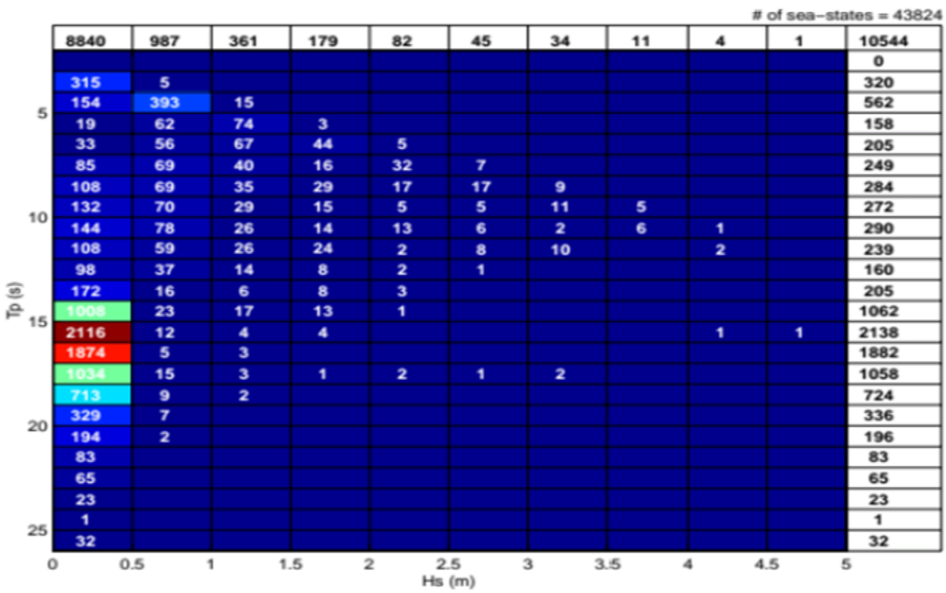
APPENDIX A; Histogram of Directional Significant Wave Height and Period from 270 to 360 degrees [10]



APPENDIX B: Histogram of Significant Wave Height and Period [10]