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Adaptability of a generic wave energy converter to different climate conditions

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ABSTRACT

This study evaluates the influence of wave climate tunability on the performance of a generic Wave Energy Converter (WEC) for different climate scenarios. The generic WEC is assumed to be composed of an array of heaving, floating cylinders. In this study, two natural periods for the cylinders of 4 s and 8 s (typical of enclosed seas and the mean Atlantic swell, respectively) and a location-tunable cylinder are considered to evaluate the influence of tuning on the power performance of the cylinder. The WEC power matrix is computed using a frequency domain model, and the performance of the WEC is evaluated along the global coasts; the met-ocean data originated from the global reanalysis database (GOW) from Reguero et al. (2012). The performance of the WEC is evaluated using two parameters: the capture width ratio (CWR), which evaluates the efficiency of the converter at each location, and the kW/Ton (KWT) parameter, which evaluates the efficiency of the converter using "economic" terms. Tuning a converter for each location displayed a positive CWR; however, the KWT was low after WEC tuning because of the weight of the structures required to tune the converter that experiences high peak periods.

1. Introduction

By contrast to wind energy, an abundance of technologies exist in the wave energy sector, and a dominant technology has not emerged. Many developers are testing inventions and simultaneously optimizing the power absorption characteristics to achieve commercial prototypes. Nevertheless, uncertainty remains for this topic, and solutions could be either global or site specific.

In the optimization process, a key parameter is the wave power absorbed by the device. To maximize the Wave Energy Converter (WEC) power absorption, the local wave climate must be considered. The main assumption for the optimization scheme is that the maximum annual power absorption is obtained when the WEC natural period matches the most probable sea-state period at the point of interest.

Extensive research investigating the optimization and tuning of wave energy converters has been performed in recent years. For instance, two main methods for tuning a device were previously studied: geometry tuning (which affects the natural period of the device) and the Power Take Off (PTO) control (which has the ability to alter the absorption characteristics over time) [1]. Additionally, a previous study investigated the geometry tuning procedure; that study tuned a bottom hinged flap to the prevailing wave frequency by experimenting with modifying the inertia [2]. The sensitivity of the resonant frequency to slight changes in the geometry was analyzed using a new numerical model [3]. Finally, a procedure for optimizing the geometries of a generic heaving wave energy converter was presented [4]. These investigations demonstrated that optimizing the geometry of the tuning process is a key step in maximizing the power absorption of any WEC. In [5] an geometry optimization tool was developed in order to match the geometry of the device to the predominant wave spectrum on the area of study.

The annual power production of a WEC depends on the local wave climate and the power matrix of the WEC. As indicated above, the ideal case to maximize power production is to match the most probable sea states with higher production in the power matrix. This matching is achieved by tuning the resonant frequency of the WEC with the most probable sea state frequency.

Apart from tuning the resonant frequency of the WEC with the most probable frequency, the shape and characteristics of the power matrix also greatly influences the performance of a WEC at a given location. Different types of WECs were studied [6], and the displayed differences on power matrices resulting from the WEC type depended on the absorption principle and the geometry of the converter.

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Therefore, in the design and optimization of a WEC, the met-ocean conditions of the potential deployment sites must be considered. To maximize the potential economic revenue, WECs should be able to be deployed in as many locations as possible. Each site has different met-ocean conditions; therefore, maximizing the number of potential deployment sites may be attained through geometrically tuning WECs.

Globally, wave climate conditions are highly variable, and wave parameters (i.e., significant wave height, H_s, and peak period, T_p) have different values depending on the location. To date, no study has investigated the best adaptability strategy of WECs to different ocean climate scenarios. Whether a unique solution for all locations or a customizable design (variable depending on the location) is appropriate has not been addressed. Currently, no analysis is available investigating which of the following methods is economically favorable: 1) developing WECs tuned for each location, 2) deploying unique broadband WEC that are valid for a high number of locations or 3) implementing site-tunable WECs.

This paper presents a study investigating the geometric adaptation of a generic WEC to different global climate scenarios. Two non-adaptive solutions and a customizable solution (variable resonant characteristics) are globally tested to analyze the improvements in power production resulting from the tuning mechanism. Performance is assessed based on two parameters: the capture width ratio (CWR) and the kW/Ton indicator. CWR represents the efficiency of the conversion in percentage with respect the incident wave resource and the Kw/Ton indicator represents the average power with respect the ballast weight of the converter.

This paper is structured as follows: first, a brief description of the climate database and the main global distribution of the tuning parameters is presented; second, the numerical model used to compute the performance of the converter is introduced, and the characteristics of the WEC are presented; finally, the results of the different options are analyzed in terms of the CWR and the KWT for each of the proposed options.

2. Climate data

A global climate database is required to analyze WEC global power production. In this study, a global wave reanalysis database is used (GOW1.0) [7,8]. GOW 1.0 is based on an NCEP/NCAR atmospheric forcing reanalysis [9], which constitutes one of the longest and most up-to-date global re-analyses. This database provides spectral sea-state parameters (significant wave height (H_S), mean period (T_m), peak period (T_p) and mean direction (θ_m)) and directional spectra components, $S(f,\ \theta)$, along the coast. GOW 1.0 covers the period 1948–2008 at a 1 × 1.5 global resolution. For the present analysis, 1188 GOW 1.1 nodes along the world shorelines have been selected with an average spacing of 200 km. This database has been calibrated with satellite data and globally validated with buoy data.

In this study, the following three sea state parameters are used:

- Wave height (H_s). H_s is notable because the wave energy is related to the square of the wave height. H_s is also important in terms of WEC survivability because WECs must be designed to survive extreme conditions.
- Wave incident direction (θ). The performance of several WECs depends on the wave direction, and the performance of wave energy farms also depends on the spatial distribution of WECs relative to wave direction.
- Peak period (T_p). The performance of the floating WECs depends on the matching the wave period of the incoming waves with the natural period of the floating device.

Although all of these variables are important and necessary in the study of wave energy converters, the direction and wave height are not key variables regarding the tunability of a wave energy converter. The peak period will be the key parameter investigated in this study.

The GOW database offers global information. WEC farms will be first deployed on continental shelves away from the breaking zone. For this study, 1188 GOW 1.0 nodes located between 50 and 100 m of water depth around global coastlines have been selected. In this analysis, the prospective wave energy farm is assumed to be deployed in deep water (>50 m), consequently the GOW database can be used without further propagation modeling.

Fig. 1 shows several statistical parameters used to characterize the T_p of the selected nodes. The upper left panel shows the average peak period, μ_{Tp}. Globally, the variability of μ_{Tp} is high. The lowest values of μ_{Tp} (less than 5 s) are found in enclosed seas (i.e., the Mediterranean) that are dominated by low fetch SEA waves; whereas the highest values (higher than 12 s) are found along coasts that are dominated mainly by SWELL waves (Indian Sea Indonesia; Pacific Central America) or by highly developed SEAS (Southwest Australia). Intermediate to low values (between 6 and 9 s) are found in the east-oriented oceanic coasts that are attacked primarily by long fetch SEA waves (Atlantic North and South America; Pacific Japan, New Guinea and Australia). Finally, medium to high periods (between 9 and 12 s) are encountered on west-oriented oceanic coasts attacked by SEA and SWELL waves (Atlantic Europe and Africa; Pacific North America and Southern Chile).

The upper right and the lower left panels of Fig. 1 show the standard deviation, σ_{Tp}, and the coefficient of variation, $C_{VTp} = \sigma_{Tp}/\mu_{Tp}$, of the peak periods, respectively. Both parameters are relevant in the understanding of the variability in the peak period parameter and the shape of the distribution. The lowest values, $C_{VTp} \leq 0.2$, correspond to those south- and west-oriented coastlines that are governed by constant SEAs or SWELLs and are exposed to the southern Pacific waves generated by the roaring forties or in those eastern-oriented Atlantic, Indian and Pacific coasts submitted to the developed SEAs generated by the trade winds. Intermediate C_{VTp} values between 0.2 and 0.4 correspond to of the majority of the remaining coastline. These values indicate that the variability of the peak period is higher in these areas, and although tuning of a WEC is possible, the influence of the wave period on WEC design is higher and should be considered. The highest values, $C_{VTp} > 0.4$, are found in enclosed seas (i.e., the Timor Sea coast in northwest Australia), along which the SEAs display a higher rate of variability.

Finally, the bottom right panel of Fig. 1 shows the modal value of the peak period. Comparing this panel with the μ_{Tp}, the modal value of T_p is higher than the mean globally, indicating a negative skewness of the T_p distribution (a longer upper tail than the lower tail).

Spectral parameters in the database can be used to compute the global energy resource in deep waters (assuming seas have a Pierson-Moskowitz spectrum with $T_p \approx 1.4T_{-1,0}$) by using the International Energy Agency's formula for the sea state mean energy flux:

$$F_e(W/m) \cong 577\ H_s^2\ T_z \cong 412\ H_s^2 T_p$$

Fig. 2 shows the average, μ_{Fe}, the standard deviation, σ_{Fe}, and the coefficient of variation, C_{VFe}, of the wave energy flux, F_e (kW/m). The variability in the wave energy resource is high around the globe. The areas with the highest energy resource (60–80 kW/m) correspond to the high latitudes (Northwest Europe, Northwest America and the Southwest portion of America, Africa and Australia). The tropical and subtropical areas have lower power resources and the