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Finding gaps on power production assessment on WECs: Wave definition analysis

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ABSTRACT

This paper presents a study of several factors that affect the long-term performance of Wave energy Converters (WECs) based on the methodology presented in de Andres et al. (2013). This methodology consists of a sea state selection technique (MaxDiss), then this selected sea states are introduced into a numerical model in order to calculate the power performance. Finally this data are interpolated with a non linear technique (Radial Basis functions) in order to obtain the long term performance of a WEC on a long met-ocean data series with low computational requirements. In this paper, three types of converter, a one body heaving converter (follower), a two-body resonant converter as well as a deep water flap are investigated. Also four different locations with different met-ocean conditions in terms of the scatter plots and the sea conditions (swell-wind sea) distribution were selected (North of Spain, West of Denmark, Chile and West of Ireland). The methodology worked perfectly for all the selected alternatives, although it was demonstrated to work better for non-resonant converters that are not band limited in their frequency response. Also, the classical method of power production assessment based on the power matrix was reviewed, analysing the analytical spectrum assumption. The influence of more than one peak spectrum on the power production was found to be large on a sea state by sea state basis (±200%) but also on the Annual Energy Production (±40%).

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1. Introduction

Wave energy converters are still at a prototype testing stage and only few converters have been on open sea conditions for a long period of time. Numerical modelling techniques are popular in order to estimate the performance of a converter on a particular location. Normally the average annual power is computed with the multiplication of the scatter plot (% of occurrences of a set of sea states) by the power matrix (power of the converter on a set of sea states). However, as stated by Ref. [1] this method just provides a figure with the average power production and it is partially inaccurate. Furthermore, when evaluating a particular wave energy converter development from the economic point of view, the interannual variability it is essential to estimate the profitability of a project according to [2]. Then, a methodology to estimate the long term performance of a wave energy converter in a location with low computational requirements it is very valuable tool for WEC development and optimization.

The methodology presented in Ref. [1] assumes that a long met-ocean data series is available with the most important spectral parameters. This methodology consists of a sea states selection techniques in order to separate a subset of sea states from the database that best represents all the database sea states. In this methodology, the MaxDiss algorithm from Ref. [3] is proposed because it represents very well the boundaries of the database in a multidimensional domain. It is based on a selection that computes the distance between points in a multidimensional space and selects the most distant points in order to cover the overall variability of the set.

The power production of these selected sea states is computed with a numerical model and then the whole series of power production is computed with a non-linear interpolation technique, a Radial Basis Functions (RBF) proposed by Ref. [4] used previously in the downscaling of wave climate to coastal areas, see Ref. [5].

In Ref. [1] the methodology was validated with a two-body heaving converter and a location in the North of Spain. However

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it is considered that the investigation of the sensitivity of the methodology to different parameters could be useful for future developments.

Currently there are several types of wave energy converters with different working principles and the power characteristics of several of these are extremely different. Ref. [6] studied eight different types of converters on different locations and as can be concluded from this paper the different mechanic principles of WECs provoke different power matrices. One of the factors that will be studied on this paper is how the different power matrices affect to the methodology and the long term performance of a WEC.

A further consideration, beyond sea state selection and device characterization, is the frequency spectrum of the sea states. When computing the power matrix of a device often an analytic spectra is supposed (i.e. JONSWAP or Bretschneider). However this assumption influences the performance of a WEC and sometimes the real spectra on open sea conditions does not fit with the analytical spectral representation. Some authors, e.g. Refs. [7] and [8] studied how an improved characterization of sea states influence the performance of a WEC. They stated that analytical spectrums are erroneous by 63% due to the existence of sea states with more than one peak. It was concluded that the sea state characterization with analytical could provoke a large error in the power production predictions. With respect the SEAREV device on the SEMREV site they concluded that he analytical spectrum assumption led to an under-estimation of the harvested power by the device.

Also [9] studied the sensitivity of the wave groupiness and spectral narrowness for some wave energy converters. They concluded that the sensitivity of a WEC to spectral bandwidth is more pronounce when the mean period is near the resonance period of the device and also when the response of the WEC is broad . Ref. [10] studied the distribution of the different sea states that occur at the Portuguese coast in terms of number of modes and directionality. Then it is clear that the sea state characterization influences the calculated power performance with numerical models of a converter significantly. Thus, it is clear that the sea state characterization is a key parameter that influences long term power performance of WEC and an accurate approach is needed in order to estima Annual Energy production of WEC.

Also, the met-ocean conditions are very variable and then the scatter plots are changeful. In Ref. [1] a location in the north of Spain was set to develop the methodology. However, as stated in Ref. [1] the broadness and the peakness of the scatter plot influences very much the long term performance of a wave energy converter and it is a parameter that should be studied for future uses of the methodology.

This paper focuses on the influence of the type of WEC, the scatter plot type and the different spectrum data types available in order to define the influence of each aspect on the ultimate power production. Also, the influence of the assumptions regarding the spectral shape on the power matrix will be investigated. Firstly the numerical model used will be explained, secondly the different sets of factors analysed (WEC, location and spectrum data type) will be explain, thirdly the methodology consisting on the set of simulations run will be stated and finally the results will be presented.

2. Numerical model description

The three wave energy converters used in this study were investigated using a common numerical model. The same equation set and computer program was used for each device with different inputs to represent the particulars of each device and its associated power take off equipment. This section will present the common aspects of the equation set and the computer program while the next section will present the device specific inputs and other considerations related to the numerical model and calculations.

The model is a classical frequency domain model as described by Ref. [11]. The equation solved to arrive at the motion of the floating body at each wave frequency is

$$\hat{u} = \hat{X}/Z_{mech} \tag{1}$$

where $\hat{u}$ is the vector of complex amplitude of velocity per unit wave height, $\hat{X}$ is the excitation transfer function, a vector of complex amplitude of excitation force per unit wave amplitude, and Z_{mech} is the mechanical impedance matrix of the system. Z_{mech} is calculated from

$$Z_{mech} = (m+a)i\omega + (b+b_e) + (c+c_e)(i\omega)^{-1} \tag{2}$$

where m is the inertia matrix of the rigid body, or bodies, composing the system, a is the hydrodynamic added mass matrix of the system, b is the hydrodynamic radiation damping matrix of the system, c is the hydrostatic stiffness matrix of the system, ω is the wave frequency and $i = \sqrt{-1}$. The quantities $\hat{X}$, a & b are calculated using WAMIT which is one of the commercially available Laplacian flow solvers. b_e and c_e are linear damping and stiffness matrices respectively that together are used to represent the so called “external forces” (due to the device floating in the water). External here is intended to indicate forces external to the hydrodynamic system, these forces include linearized power take off forces and may also include linearized mooring forces, joint reaction forces and fluid pressure forces associated with flow effects neglected by the Laplacian flow solver, namely forces due to viscous effects:

$$b_e = b_{pto} + b_{moor} + b_{joint} + b_{visc} \tag{3}$$

$$c_e = c_{pto} + c_{moor} + c_{joint} + c_{visc} \tag{4}$$

The result of Equation (1) is a velocity per unit wave amplitude, the actual velocity amplitude that results from any given incoming wave spectrum is $(\hat{a}\hat{u})$ where $\hat{a}$ is the wave amplitude which, for unidirectional waves, is calculated from Ref. [12]

$$\hat{a} = \sqrt{2S(\omega)\Delta\omega}\cdot e^{i\theta} \tag{5}$$

where $S(\omega)$ is the spectral density of the incoming waves at frequency ω, $\Delta\omega$ is the frequency step and θ is a random phase angle uniformly distributed in the range $-\pi \le \theta < \pi$.

The power take off force per unit wave height $\hat{F}_{pto}$ is

$$\hat{F}_{pto} = -\hat{u}b_{pto} - \hat{x}c_{pto} \tag{6}$$

And the power take off force due to any given input wave amplitude is $(\hat{a}\hat{F}_{pto})$.

The average power absorbed by the wave energy conversion device is then calculated from

$$P = \frac{1}{2}\sum_{\omega} |\hat{a}|^2 |\hat{u}| \left|\hat{F}_{pto}\right| \cos\left(\angle\hat{u} - \angle\hat{F}_{pto}\right) \tag{7}$$

The position of the system, in addition to the velocity, is also needed. The position per unit wave height, $\hat{x}$, can be calculated from Ref. [13,14].

$$\hat{x} = \hat{u}/(i\omega) \tag{8}$$

The response amplitude operator, a commonly used measure of strength magnitude in hydrodynamics, is $|\hat{x}|$, the magnitude of $\hat{x}$. The position amplitude, similarly to the velocity amplitude, is $(\hat{x}\hat{a})$.

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