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A global analysis of the operation and maintenance role on the placing of wave energy farms

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ABSTRACT

In this work an analysis of suitable locations for the development of wave energy farms is carried out based on representative operation and maintenance parameters. The analysis is applied globally on the basis of long-term global climate data set. Availability and accessibility levels are assessed first by considering different wave height thresholds. Secondly, the O&M access limits are quantified in terms of the weather windows and waiting period between them considering different windows lengths and scenarios. Finally, the O&M cost per kW h is calculated for a wave energy converter based on a point absorber concept. O&M costs has been calculated following the methodology proposed on Guanche et al. (2014). As expected, results show that locations with mild wave climate have very low O&M costs per kW h. Some areas with high wave resource, such as Scotland, Spain or Nova Scotia present reasonable O&M costs compared to the power production in these areas. However, other locations with high resource like Chile or Australia resulted in extremely high O&M costs due to the inaccessibility of these sites during long periods of time.

1. Introduction

Wave energy converters (WEC) are still at a prototype testing stage. Some countries are promoting wave energy conversion by dedicated investments or special feed in tariffs. However, there are just few regions in the world where WEC prototypes have been tested offshore.

When assessing WEC installation sites, developers usually aim for sites with the highest wave energy resource. Consequently, countries like Scotland, Ireland or Portugal have made important efforts to incorporate the high untapped potential of this energy source to their energy mix.

However, high wave energy resource is usually linked to rougher sea conditions. Therefore, the selection of a location for the deployment of a WEC is highly dependent on the deployment, operation and maintenance activities and should be accounted for in the assessment process. One of the primary causes of unsuccessful marine operations is due to poor marine conditions. According to the International Energy Agency one of the key issues related with offshore marine energy is the shortage of suitable deployment vessels for adverse weather conditions and the long time that should be waited for the maintenance operations. In the case of offshore wind energy, wind turbines could be deployed in areas with high wind resource but "mild" wave conditions. However in the case of WECs, both resource to be harvested and conditions for repair are completely correlated, so the site assessment should be carried out looking for a balance between both.

The research carried out in [10,11,9] led to the conclusion that accessibility and availability factors have a significant impact with respect the financial return of wave energy technology. They concluded that intensive and high O&M costs should be expected in locations with adverse climate. These O&M costs have an impact of about a 30% of the total cost of the WEC. A method for the assessment of weather windows in order to manage marine operations was presented in [16]. They concluded that the primary influencing factor that affects O&M costs is related with the amount of available weather windows on a particular location, so this is an important point when choosing the deployment location of a wave energy project. With respect to the geospatial analysis of wave energy deployment constraints in the analysis carried out in UK waters of [8] seven criteria were considered for choosing a suitable area for energy conversion: sea bottom geology, distance to shore, ports and power grid, average wave height, period and power. There are no studies related with the optimum location

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for wave energy development from a worldwide perspective, taking into account the O&M costs.

This paper presents a study of the suitability for wave energy development from a global perspective with emphasis on O&M costs. This paper has been structured as follows: first, the wave climate database will be described; second, the availability and accessibility indicators around the world will be shown; third, the O&M main parameters (weather windows and waiting period between weather windows) will be presented; finally, the worldwide influence of the O&M costs on the energy cost will be analyzed for a WEC composed by a set of heaving cylinders [3].

2. Methodology

For the global analysis of weather windows and their durations, a long-term global meteocean database is required. For this study, the global reanalysis database (GOW 1.0) from [14,5] is used. GOW 1.0 is based on the NCEP/NCAR reanalysis atmospheric forcing [7], which constitutes one of the longest global wind reanalysis. GOW 1.0 database provides hourly spectral sea state parameters: significant wave height (H_s), mean period (T_m), peak period (T_p) and mean direction (θ_m) as well as the directional spectra components $S(f, \theta)$ for the period 1948–2008, with $1^\circ \times 1.5^\circ$ global coverage. For this study, 1188 nodes along the world shoreline with an average spacing of 200 km have been selected [4] with water depths ranging from 50 m to 100 m.

In this work O&M is assessed by means of indicators including some representative sea state parameters. According to [9,16] the main parameters to be considered are the following:

- Significant wave height (H_s) is the most important parameter considering the fact that O&M activities are usually limited by this parameter. According to [9] there is a limiting working wave height depending on the type of vessel used for the operation and the type of offshore structure to be boarded (wind turbine, WEC, etc.). For offshore wind turbines the range of operating wave heights ranges from 1.5 m for Catamarans to 3 m using the Amplemann system. For WECs, the range of wave height limit is about 1.5 or 2 m according to [10,11].
- Peak period (T_p): according to [16] there is a range of operating periods for each type of barge. Normally, the limiting periods for usual barges for O&M activities range from 4 to 16 s depending on the relative direction between barge and wave propagation direction.
- Other parameters as wind speed or current speed are important in order to study the access limits for the different vessel types. According to [10,11] the wind speed access limits vary between 8 m/s and 15 m/s.

Finally, O&M cost can be calculated. Based Guanche et al. [6] an O&M cost long term assessment has been carried out.

3. Results

3.1. Accessibility and availability

Two indicators are crucial in understanding the relation between WEC operation and weather conditions: availability and accessibility. Availability is the percentage of time that a WEC (or turbine in the case of wind energy for instance) is ready to produce electricity. This parameter is dependent on met-ocean conditions and type of converters. Regarding the converter typology, each WEC has a wake up threshold, an operational range and a survival mode. However, due to the absence of long term deployments the information about the thresholds levels is scarce. For instance, according to [13] the Pelamis enters into survival mode at a $H_s = 8$ m whereas the C5-600 Wave Star prototype works up to $H_s = 6$ m, see [17]. According to [15] survival limits for SEAREV and AWS devices are reported to be $H_s = 8$ m and $H_s = 6.5$ m, respectively. Even less information is available about the wake up thresholds. In this work the wake up level is assumed to be $H_s = 0$ m. In this study, a conservative value of $H_s = 5$ m is set for the survival mode level.

Fig. 1 shows the percentage of time that WEC devices would be in the operational range along the world's coastlines. As can be seen in the figure there are lot of coastal regions reaching almost a 100% availability, many of them corresponding to low resource areas. Some low availability-high wave energy resource areas are also visible, such as the east coast of Ireland and the south-east part of Chile. Although these areas could be of interest for their high resources, availability rates should be taken into account if a wave energy farms are to be developed since availability is about 80% with and additional 20% of the time in survival mode. In terms of operation it can be concluded that although some locations have an extremely high resource, due to the survivability limitations of the devices power cannot be extracted out of the most energy-rich sea states.

Fig. 2 shows the global average available power obtained for different survivability H_s thresholds. As can be seen some sites with very high resource (like the east coast of Ireland) have similar available resource as other areas with lower total resource (like the west coast of Portugal) when a lower wave height threshold is considered for the availability study. For completeness, Table 1 shows the percentage of coastal nodes in the GOW reanalysis that satisfy certain levels of availability. As can be seen, the availability is quite high for all the thresholds considered.

Accessibility, defined as the percentage of the time when the device could be accessed for the maintenance operations, is the second relevant indicator. Accessibility is device specific too and depends both on the met-ocean conditions, the type of device and on the type of vessel used for the operations. As shown in [9] wave height limits may vary from 1 m to 3 m depending on the type of specialized vessel. Fig. 3 shows accessibility levels (in % of the year) assuming wave height to be the single variable defining accessibility. As can be seen, wave height thresholds play an important role in assessing the accessibility level and its spatial distribution. For instance, for a $H_s = 1$ m threshold almost all coastal areas have low accessibility levels with values close to 30%. Only enclosed seas like the Mediterranean or the Baltic show much higher (nearly 80%) accessibility levels for this low H_s. However wave resource at those sites is limited.

For a $H_s = 1.5$ m threshold, many locations show acceptable accessibility levels. For instance, in Europe, the accessibility indicator levels range from 68% in Denmark's North Sea coast, a 45% in the Spanish or Portuguese north and west Atlantic coasts or 20% in the open Atlantic coasts of Ireland or Scotland. In the Pacific coasts of America, the accessibility levels range from almost 90% in Central America to a 30–40% in Canada and the USA coasts, to a 20% in Chile. If the threshold is increased to $H_s = 2$ m the accessibility levels of some coastal areas change significantly as is the case for Europe, where the accessibility levels increase to a 60% in Spain and Portugal and to a 35% in Ireland and Scotland. Under this threshold areas like Chile and the South coast of Australia still have very low accessibility levels (20%). For the East (Atlantic) coast of America the levels of accessibility are quite high, nearly reaching a 90%. Reducing the strictness of this threshold, a 3 m threshold would imply very high accessibility levels all around the globe. Except for some areas with extremely rough conditions including Ireland, Chile and southern Australia, a 90% or higher availability is reached almost everywhere.