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Estimation of the wave energy conversion efficiency in the Atlantic Ocean close to the European islands

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ABSTRACT

This paper presents an evaluation of the efficiency of twelve state of the art wave energy converters in the Atlantic Ocean, in the vicinity of the most important European islands and archipelagos (Iceland, Archipelago of Azores, Madeira Archipelago and Canary Islands). An analysis of the wave conditions in the target areas was first performed by considering a 10-year interval (2004–2013) of wave data provided by the European Centre for Medium-Range Weather Forecasts. For this reason, twenty reference points, all located in water depths of about 50 m, were defined. In order to provide a general picture of the wave potential and also to highlight the presence of some hot spots, several wave parameters, such as significant wave height, mean wave direction and wave power, were evaluated. Then, for every nearshore area, based on the bivariate distributions of the sea states occurrences and also on the power matrix of each device, the performances of each wave energy converter were estimated in terms of the expected electrical power. The results of the present work provide valuable information for the future wave farm projects, which could become in the near future a reliable and effective way to produce energy in island environments.

1. Introduction

In order to provide a sustainable energy future, in 2007 the European Union (EU) adopted the renewable energy sources directive 2009/28/EC, which secures the legislative framework until 2020. This stipulates that almost 20% of the final energy consumption needs to be obtained from renewable resources, while at the same time the greenhouse gas emission will be reduced by almost 30% [1]. These objectives can be achieved since Europe is characterized by a large portfolio of renewable resources, which vary from solar to hydro-power, being already estimated that most of the EU member states will reach or exceed these targets [2].

Usually, the natural resources from the marine areas are more significant than onshore, and even some enclosed sea basins, such as the Black or the Caspian seas can provide in certain places appropriate conditions to develop viable marine energy projects [3–8].

As regards the island areas, they can be considered a particular case, since they have limited or no access to the European energy network grid, the main source of power being provided by various Autonomous Power Stations (APSs). One of the main disadvantages of these systems is that they produce energy at a high price (0.25 €/kWh), the expenses being related to the acquisition and transport by sea of the fossil fuels. Beside this, the burning of petroleum products is usually associated with a negative impact on the environment, some islands being characterized by unique ecological systems such as the Dia Island from the Cretan Sea [9].

As an alternative, the renewable energy systems can be successfully used in these remote areas, intensive research being now focused on the implementation of wind turbines or photovoltaic panels, eventually in hybrid systems, which can provide the energy demand for a specific island need. From this perspective, the Canary Islands can be considered a representative area, since from the total installed electrical capacity (3163 MW in 2012) almost 11% was covered from renewable resources. Compared to this capacity, it is estimated that in the near future the onshore wind sector will increase from 145 MW to 1025 MW, while the photovoltaic market will extend from 129 MW to 160 MW, being also expected to be added another 50 MW capacity from the wave farm projects [10].

Regarding the global wave energy, it is estimated that this potential is close to 2.1 TW, the European nearshore areas presenting an annual wave power that exceeds 20 kW/m, especially in the

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north-west, where the coastal areas are exposed to the strong North Atlantic waves [11,12]. This energy can be extracted by using wave energy converters (WECs), which are designed to work for different wave climates, their performances being directly related to the sea-state characteristics [13,14]. Similarly to the wind industry, in order to identify the seasonal distribution of the wave energy, at least 5 years of historical data need to be considered, although a 10-year period is usually recommended since this will allow to avoid better the inter-annual wave fluctuations in the wave climate [15]. In this way, it is possible to select the areas where the wave energy is more significant and also to highlight the technical and economical viability of a specific wave farm configuration which could operate in these regions.

Most of the islands and archipelagos are located in the offshore areas, so that they can be considered to be hot spots, since the wave energy is naturally concentrated in these environments. In general, the coastal environments of the islands are characterized by a good ratio between the water depth and the shoreline distance, which may lead to achieve better performances of the WEC systems than in the case of the continental coastal areas [16–18].

Moreover, beside the energy generation, the wave farm projects can be also used for the coastal protection [19], in order to limit the effects of the erosion processes. Previous studies highlighted that the WEC systems (aligned parallel to the coastline) can reduce considerably the wave heights, especially during the storm conditions, while for the nearshore currents, significant variations might be also induced [20,21].

In this context, the present work aims to evaluate the wave energy potential of the main European islands and archipelagos located in the Atlantic Ocean and also to determine the performances of various types of wave generators, which could operate in these coastal environments.

2. Methods and materials

2.1. Target areas

Fig. 1 presents the geographical locations of twenty reference points (denoted from P1 to P20), which are used to define the wave conditions in the four different target areas (Iceland, Archipelago of Azores, Madeira Archipelago and Canary Islands). The first region considered for the analysis is Iceland, where most of the points (P2–P5) were selected in the southwestern part of the island, since the waves coming from the main basin of the North Atlantic Ocean are more relevant compared to those coming from the Norwegian Sea, which are expected however to be also identified throughout the point P1. Going further in the south (below 40° latitude north), the Azores Islands, located in the middle of the Atlantic Ocean, were also considered in the present analysis. In this case, all the reference points were chosen close to the northern coasts, with the mention that since the island São Miguel (in the east) is bigger, in this particular case two reference points (P9 and P10) were considered for evaluation. Madeira Archipelago (that belongs to Portugal together with the Azores) was also considered and in this case a special attention was payed to the Porto Santo Island (P14 and P15) which appears to have more concentrated wave energy resources. The last target area taken into account for evaluation in the present work is represented by the Canary Islands, which are a Spanish region located in the northwestern part of the African coast, the local wave conditions being identified in this case throughout the group of points P16–P20.

More details regarding the reference points P1–P20 are provided in Table 1, where the corresponding water depths and the geographical coordinates are indicated for each point. In order to provide a realistic evaluation of the WECs performances, the locations of the points were selected such as the corresponding depth to be around 50 m.

It can be noticed that, for the reference points above defined, the maximum distances from the coastline occur in the case of the points from Iceland, with a maximum of 11.7 km for P5 and a minimum of 3.9 km for P3. For the rest of the points, a maximum of 3.6 km is noticed at the point P15 (Madeira), which is followed by P19 (Canary) with 3.3 km and P11 (Madeira) with 3 km, respectively.

2.2. Reanalysis dataset

The present work is based on the ERA-Interim global

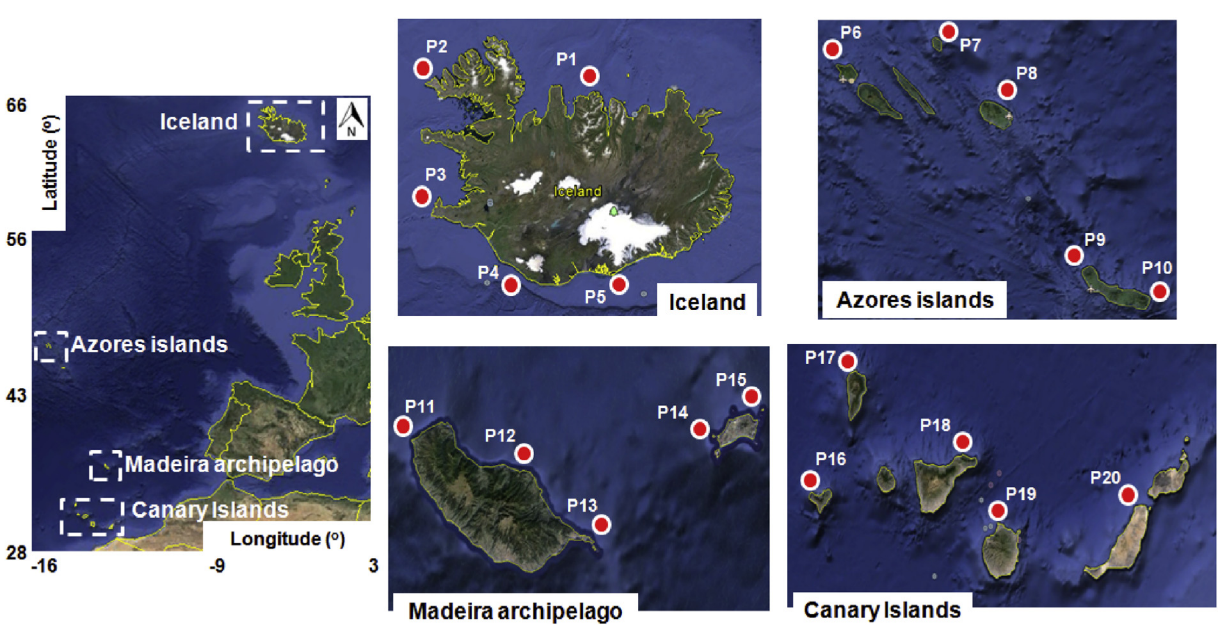

Fig. 1. The positions of the reference points (P1–P20) that were defined in the coastal environments of the European islands of the Atlantic Ocean. The wave conditions in four different coastal areas were evaluated: Iceland, Azores Islands, Madeira Archipelago and Canary Islands. Figures processed from Google Earth (2014).