Renewable Energy 69 (2014) 375–385

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Wave farm impact: The role of farm-to-coast distance

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ARTICLE INFO

Article history:
Received 29 May 2013
Accepted 28 March 2014
Available online

Keywords:
Wave energy
Wave energy converter
WEC array
Marine energy
Environmental impact
Numerical model

ABSTRACT

The objective of this work is to investigate how the impact of a wave farm on the nearshore wave conditions depends on its location and, more specifically, its distance to the coast. For this purpose eight case studies in an area with a very substantial wave resource are considered; they encompass three values of the farm-to-coast distance (2 km, 4 km and 6 km) plus a baseline situation (with no farm), in combination with two wave conditions representative of winter and summer scenarios. A coastal wave model is implemented on a high-resolution nested grid. The interaction between the individual Wave Energy Converters (WECs) of the array and the waves is simulated by the model on the basis of experimental data, i.e., the wave transmission coefficients are obtained from laboratory tests. To characterise the nearshore impact of the wave farm we define a series of impact indicators, including the Nearshore Impact (*NI*), the Maximum absolute Nearshore Impact (NI_{max}) and the Relative Nearshore Impact (*RNI*). We find that increasing the farm-to-coast distance does not guarantee a reduction of the Maximum absolute Nearshore Impact, and that the distance influences the location of the point of occurrence of the maximum impact along the coast.

1. Introduction

Marine energy is arguably one of the renewable energies with the greatest potential for development [1,2], and this translates into a series of very active research lines: (i) the characterisation of the resource [3–19]; (ii) the selection of optimum sites for marine energy farms [20–23]; (iii) the application of marine energy to island communities [24–29]; (iv) the development of efficient, reliable technologies and the assessment of their performance [30–34, 36–41]. This scientific and technological progress will result, in all likelihood, in the installation of new marine energy farms in the coming years, and therefore it is essential to understand the potential environmental impacts.

The impact of tidal stream and tidal barrage energy was the subject of a number of recent works [42–48]. As for wave energy, with which this article is concerned, Millar, Smith and Reeve [49] analysed the impact of a wave farm on the nearshore wave conditions assuming notional values of the wave energy absorption coefficient. Smith, Pearce and Millar [50] included a wave energy absorption coefficient that is frequency-dependent. Venugopal and Smith [51] employed a nonlinear Boussinesq wave model to determine how the variations in the wave absorption coefficient influence wave reflection and transmission. Palha, Mendes, Fortes, Brito-Melo and Sarmento [52] applied a parabolic mid-slope wave model to perform a sensitivity analysis with different configurations of a wave farm consisting of Pelamis WECs. The influence of a Pelamis wave farm on the coastline was also considered by Rusu and Guedes Soares [53], and is similar to the effect of islands in ocean models, which was studied by Refs. [54,55].

Monk, Zou and Conley [56] applied the classical equation of wave diffraction past an impermeable, rigid, semi-infinite breakwater over a uniform water depth to analyse wave propagation in the lee of a wave farm. Beels, Troch, De Visch, Kofoed and De Backer [57] carried out laboratory experiments and numerical modelling to study the wake effects of a single Wave Dragon WEC and a farm of five of them. Zanuttigh and Angelelli [58] used numerical modelling to determine wave propagation past a wave farm. Zacharioudaki and Reeve [59] investigated the influence of the layout of the wave farm on its nearshore impact by means of numerical modelling and laboratory tests. Abanades, Greaves and Iglesias [60] studied the impact of a wave farm on the beach profile and its implications for coastal protection.

The present paper is concerned with an important aspect that was not specifically addressed in previous works, namely how the impact of a wave farm on the nearshore wave conditions varies

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http://dx.doi.org/10.1016/j.renene.2014.03.059
0960-1481/

when the distance between the wave farm and the coastline is modified. This question is relevant from the standpoint of both the project developers and the regulators, as one of the key decisions to be taken in any project is the location of the wave farm. A number of aspects must be taken into account in that decision, ranging from the resource itself through the cost of the submarine cable to the impact on the nearshore. The latter is arguably one of the least understood – and that is the motivation for the present work.

The investigation was conducted through eight case studies in one of the regions with the largest wave resource in Europe, with an average wave power of the order of 50 kW m^{-1} – not in vain is it called the Death Coast (*Costa da Morte*) [61]. Located in Galicia, NW Spain, the Death Coast extends from Cape Finisterre to the Sisargas Isles; the area chosen for the present investigation is the section from Cape Vilan to Cape do Trece (Fig. 1). The eight case studies were defined by combining three locations of the wave farm at different distances plus one baseline scenario (no wave farm) with two wave cases representative of typical winter and summer conditions. In order to characterise the impact on the nearshore wave conditions, we defined a series of impact indicators and auxiliary concepts: the Nearshore Impact (*NI*) value, the Maximum absolute Nearshore Impact (NI_{max}) value, the Maximum Nearshore Impact (*MNI*) point, the Relative Nearshore Impact (*RNI*) value and the Direct nearshore Array Projection (DAP).

An important aspect of this work is that the interaction between the waves and the individual WECs of the wave farm was modelled on the basis of *ad hoc* laboratory tests. In other words, the values of the wave transmission coefficient were determined through physical model tests. The WEC chosen for the study was WaveCat, a floating, overtopping WEC designed for robustness and reliability [62]. The layout of the wave farm consists of two rows of WECs, each with 10 units.

This article is structured as follows. Section 2 (Material and methods) covers the wave propagation model and the case studies. The results are presented and discussed in Section 3. Finally, conclusions are drawn in Section 4.

2. Material and methods

2.1. Wave propagation model

In each of the study cases the deep water wave field was propagated by means of SWAN, a third generation spectral wave model [63] that was calibrated and validated for the Death Coast using data from offshore and coastal wave buoys in a previous work [61]. SWAN is based on the equation of conservation of wave action [64]. Wave power is computed from its *x*- and *y*-components, denoted by J_x and J_y respectively, which are given by:

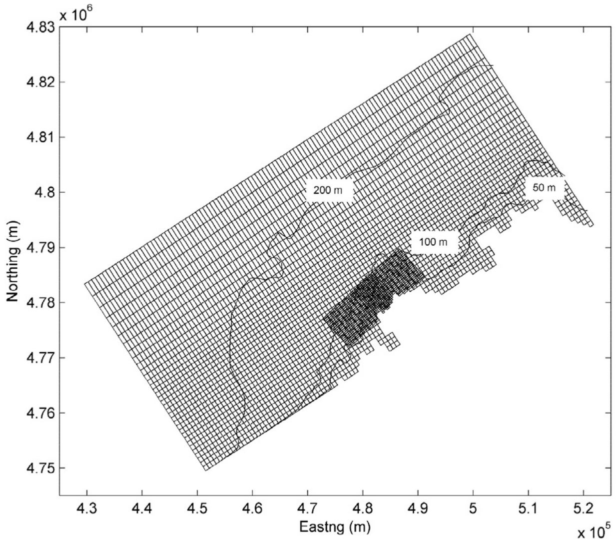

Fig. 2. Computational grids of the coastal wave model.

$$J_x = \rho g \int_0^{2\pi} \int_0^{\infty} S(f,\theta) c_g(f,h) \cos\theta \, df \, d\theta, \tag{1}$$

$$J_y = \rho g \int_0^{2\pi} \int_0^{\infty} S(f,\theta) c_g(f,h) \sin\theta \, df \, d\theta, \tag{2}$$

where *x*, *y* represent the coordinates of the computational grid, ρ is the water density, *g* is the acceleration of gravity, c_g is the group velocity, and $S(f, \theta)$ is the directional spectral density, which specifies how the energy is distributed over frequencies (*f*) and directions (θ) [64]. The wave power magnitude is then given by

$$J = \left(J_x^2 + J_y^2\right)^{1/2}, \tag{3}$$

and has units of W m^{-1} in the SI (wave power, or wave energy flux, per unit length of wave front).

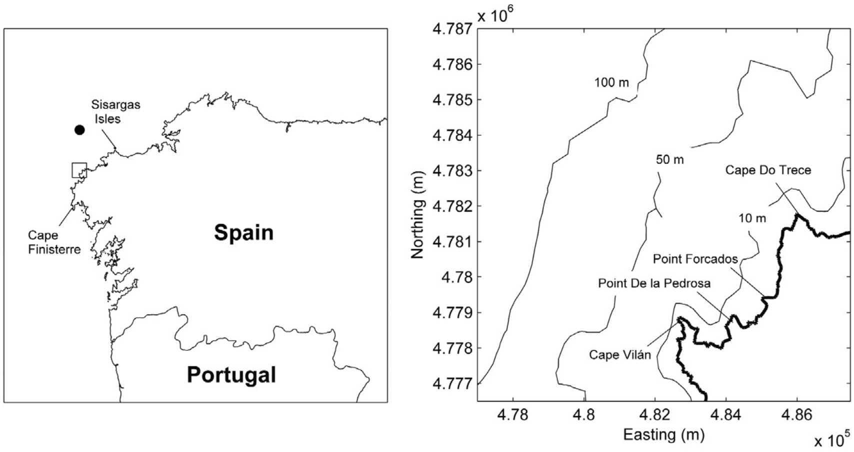

Fig. 1. Study area: the Death Coast, NW Spain. The black circle marks the position of the wave buoy.