Renewable Energy 36 (2011) 3402–3416

Contents lists available at ScienceDirect

Renewable Energy

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

A methodology for production and cost assessment of a farm of wave energy converters

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ARTICLE INFO

Article history:
Received 23 October 2009
Accepted 10 May 2011
Available online 23 June 2011

Keywords:
Power production
Cost
Farm
Wave energy
Wave Dragon

ABSTRACT

To generate a substantial amount of power, Wave Energy Converters (WECs) are arranged in several rows or in a 'farm'. Both the power production and cost of a farm are lay-out dependent.

In this paper, the wave power redistribution in and around three farm lay-outs in a near shore North Sea wave climate, is assessed numerically using a time-dependent mild-slope equation model. The modelling of the wave power redistribution is an efficient tool to assess the power production of a farm. Further, for each lay-out an optimal (low cost) submarine cable network is designed. The methodology to assess the power production and cost of a farm of WECs is applied to the Wave Dragon Wave Energy Converter (WD–WEC). The WD–WEC is a floating offshore converter of the overtopping type, which captures the water volume of overtopped waves in a basin above mean sea level and produces power when the water drains back to the sea through hydro turbines.

It is observed that the cable cost is relatively small compared to the cost of the WD–WECs. As a result, WD–WECs should be installed in a lay-out to increase power production rather than decrease cable cost, taking spatial and safety considerations into account. WD–WECs arranged in a single line produce the highest amount of power, but require an available sea area with a large width (51 km). Installing a single line of WD–WECs in front of a farm of wind turbines increases the time window for accessing the wind farm (applied to Horns Rev II – significant wave height smaller than 1–2 m during 8 h at minimum) by 9–14%.

1. Introduction

Several Wave Energy Converters (WECs) need to be installed in a geometric configuration or in a 'farm', as the rated power of a single device is relatively small. WECs in a farm are partly absorbing and partly redistributing the incident wave power. Consequently a wake behind each WEC is created. The power absorbed by each individual WEC in a farm is affected by the wakes of its neighbouring WECs. The wake effects in a farm and consequently the power produced by the farm, depend on the wave climate and on the lay-out of the farm. The farm lay-out does not only affect the amount of produced power but also modifies the cost of the farm.

In this paper a methodology to assess the power production and cost of a farm of WECs is presented. The methodology is applied to a floating offshore WEC of the overtopping type; the Wave Dragon Wave Energy Converter (WD–WEC) [1].

The WD–WEC consists of two main structural elements (Fig. 1):

- two wave reflectors to focus the incident waves towards a ramp;
- a main body where the focussed waves run up the curved ramp, overtop in a water reservoir above mean sea level and consequently have an increased potential energy compared to the surrounding sea. The obtained potential energy is converted into electricity when the stored water drains back to the sea through hydro turbines.

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0960-1481/$ – see front matter © 2011 Published by Elsevier Ltd.
doi:10.1016/j.renene.2011.05.019

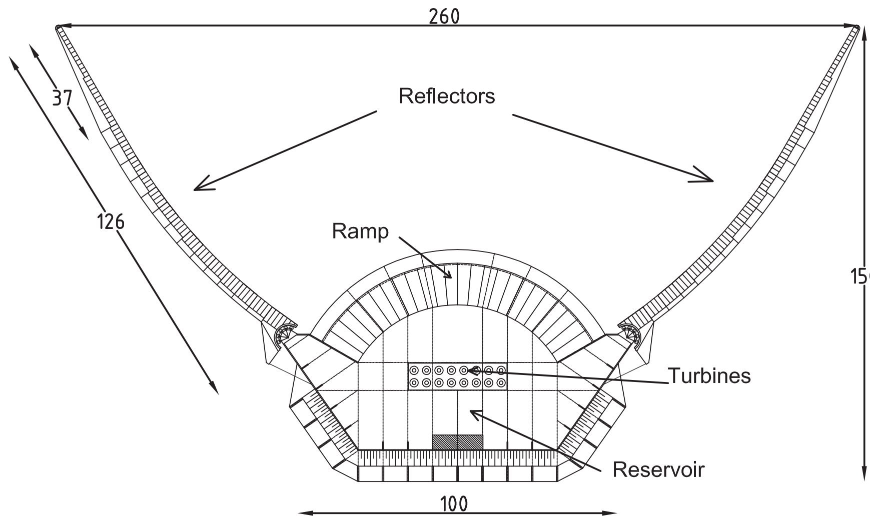

Fig. 1. Main structural elements of a WD–WEC in plan view (copyright Wave Dragon) – dimensions in m.

The WD–WEC is chosen as an example for application of the proposed methodology as sufficient technical characteristics and cost estimates of this WEC are publicly available in literature. The power production and cost of three farm lay-outs of WD–WECs with a rated power of 198 MW (same order of magnitude as offshore farms of wind turbines) in a near shore North Sea wave climate are studied; 99 WD–WECs arranged (i) in a single line, (ii) in a staggered grid and (iii) behind each other. First, the wake in the lee of a single WD–WEC and multiple WD–WECs is studied in a phase-resolving time domain model based on the depth-integrated mild-slope equations of Radder and Dingemans [2], MILDwave, developed at Ghent University [3]. Therefore, the wave reflectors and the main body (ramp and reservoir) of the WD–WEC are simulated in MILDwave as porous structures, with similar reflection, respectively absorption, characteristics, as obtained for the prototype WD–WEC by using the sponge layer technique [3]. From the simulated wakes the power production of the considered lay-outs is assessed. Further, an optimal cable network is designed for each farm lay-out by minimizing the cable cost and capitalized cost of expected constrained energy from cable losses. The methodology to estimate the production and cost of a farm of WECs can easily be applied to other WECs of the overtopping type. When considering WECs with a body or water column that is oscillating, radiated waves should be considered as well when calculating the wave power redistribution in and around the farm.

In the next section the near shore North Sea wave climate is presented. The implementation of a WD–WEC in MILDwave through the sponge layer technique is briefly discussed in Section 3. Furthermore, the wake behind a single WD–WEC is studied in detail. Section 4 deals with the power absorbed by the 3 farm lay-outs of WD–WECs. An optimal submarine cable network for each farm lay-out is determined in Section 5 using an iterative approach. In Section 6, the effect of installing a farm of WD–WECs in front of a wind farm on the time window for accessing this wind farm, is discussed.

2. Near shore North Sea wave climate

n this paper a WD–WEC, in a typical near shore North Sea wave climate (Location point 2 on the Danish Continental Shelf [4]), is studied. The mean annual available wave power in this wave climate (water depth $h = 31$ m) equals 12 kW/m [4]. Wave situations on this location and their related wave power p and frequency of occurrence (FO) are given in Table 1. Note that the significant wave height H_s in Table 1 represents a H_s -interval. For example 48% of the time, waves with H_s between 0.5 m and 1.5 m occur ($H_s = 1$ m). Also the contribution ($= p.FO$) of each wave situation to the yearly average available wave power is given in Table 1. Only 5 wave situations are considered. During the rest of the year (frequency of occurrence = 16%), wave heights are mainly smaller than 0.5 m and sometimes larger than 5.5 m. These situations are neglected in the following, as they contribute only marginally to the total power production over a year.

Not all waves are coming from the same wave direction as shown in the wave rose in Fig. 2(a). A segment of a wave rose shows the relative frequency of occurrence of mean wave directions in that sector. Each segment is divided into the considered H_s-intervals (Table 1) to indicate the contribution of high and low energetic waves. Most waves (more than 20%) are coming from the north-west. The contribution of the different wave sectors to the average annual available wave power (in %) is shown in Fig. 2(b).

Table 1
Wave situations in a near shore North Sea wave climate (Location point 2 on the Danish Continental Shelf [4]).

Wave situation [–]	H_s [m]	T_p [s]	Wave power p [kW/m]	Frequency of occurrence (FO) [%]	Contribution to the yearly average available wave power (p FO) [kW/m]
1	1	5.6	2.5	48	1.2
2	2	7.0	12.4	21	2.6
3	3	8.4	33.5	10	3.4
4	4	9.8	69.6	4	2.8
5	5	11.2	124.2	1	1.2