International Journal of Marine Energy 10 (2015) 113–126

Contents lists available at ScienceDirect

International Journal of Marine Energy

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

Optimizing wave energy parks with over 1000 interacting point-absorbers using an approximate analytical method

Malin Göteman [a,*], Jens Engström [a], Mikael Eriksson [a,b], Jan Isberg [a]

[a] Department of Engineering Sciences, Uppsala University, Sweden
[b] Seabased Industry AB, Uppsala, Sweden

A R T I C L E I N F O

Article history:
Received 9 September 2014
Revised 23 January 2015
Accepted 19 February 2015
Available online 26 February 2015

Keywords:
Wave energy parks
Hydrodynamics
Power fluctuations

A B S T R A C T

Large arrays of wave energy converters of point-absorber type are studied using an approximate analytical model. The model is validated against a numerical method that takes into account full hydrodynamic interactions based on linear potential flow theory. The low computational cost of the analytical model enables parameter studies of parks in the MW range and includes up to over 1000 interacting devices. The model is actuated by irregular wave data obtained at the Swedish west coast. In particular, focus is on comparing park geometries and improving park configurations to minimize the power fluctuations.

1. Introduction

Since the initial works on wave energy [1], research has lead to many different approaches to convert energy in ocean waves to electricity, which has resulted in numerous different techniques. This paper concerns point-absorber wave energy converters (WECs), where a cylindrical buoy at the sea surface is connected to a bottom-mounted linear generator through a line.

To produce power of more than a few MW and enable an even power distribution, future designs will necessarily include arrays of many absorbing units. As the individual units in these wave power

* Corresponding author.
E-mail addresses: malin.goteman@angstrom.uu.se (M. Göteman), jens.engstrom@angstrom.uu.se (J. Engström), mikael.eriksson@seabased.com (M. Eriksson), jan.isberg@angstrom.uu.se (J. Isberg).

http://dx.doi.org/10.1016/j.ijome.2015.02.001
2214-1669/

parks interact by scattered and radiated waves, the numerical simulations get very heavy when the number of interacting bodies grow. In certain situations, assumptions can simplify the calculations and enable simulations of a large number of structures.

The electricity produced by a point-absorber WEC with linear generator will fluctuate with the incoming waves. In order to connect wave energy parks to the electric grid, means must be taken to reduce the power fluctuations inherent in the wave source. Luckily, the hydrodynamical interactions between WECs in a wave energy park can be used to smoothen out the power fluctuations, a fact that was discussed already in early works on wave energy [2,3]. With the recent commercialization and full-scale implementation of wave energy, the area has received new attention [4–8]. Although a lot of papers have studied arrays of a few WECs or larger arrays in regular waves, so far, there are few publications on full-scale experiments of WEC arrays, and/or large-scale arrays in irregular waves. In [9], experiments with up to three full-scale point-absorber devices were conducted off-shore at the Swedish west coast. It was shown that the standard deviation of power delivered to the electrical substation reduces with 30% and 80% with two and three WECs, respectively, as a mean for an arbitrary array member. In a recent paper [10], scale experiments performed in a wave basin with 25 heaving WECs were presented. For long-crested waves, around 17% reduction in significant wave height was observed downwave the WEC array.

The aim of this paper is to study wave energy parks in the MW regime and with over 1000 WECs, with the particular focus on maximizing power absorption while lowering the power fluctuations. In three earlier papers [11–13], properties of wave energy parks were studied as functions of various parameters. In the first two papers, the hydrodynamical interaction between devices was calculated using the boundary element potential flow solver WAMIT. The method is robust and reliable, but the computational cost for large parks is high and each array configuration must be studied separately by trial and error. As an alternative, here an approximate semi-analytical method is used. Instead of studying each park configuration separately, the parameters can be varied continuously and give hints of optimal configurations. To lower the computational cost and enable simulations of a larger number of interacting structures, here the hydrodynamical interaction due to scattered waves has been neglected, but interactions due to radiated waves is included between all the WECs. Despite this approximation, the model shows good agreement with the standard numerical model for the parks where both methods have been applied.

2. Theory

2.1. Linear potential flow theory

Consider a volume of fluid with finite depth h and define a global coordinate system (x, y, z) such that $z = -h$ at the seabed and $z = 0$ at the undisturbed free sea surface, and N floating cylinders with radius R and draft d, labeled by indices $j \in [1, N]$, and constrained to move in heave only. Divide the fluid domain into interior and exterior domains underneath and outside each buoy. Under the assumption of incompressible, homogeneous fluid density and negligible viscosity and vorticity, the governing equation reduces to the Laplace equation $\Delta\Phi = 0$, where Φ is the fluid velocity potential. Under the assumption of non-steep waves, the non-linear boundary condition at the free sea surface can be linearized and the first order approximation taken. In addition, the fluid is not penetrating the seabed or the floating bodies, and the full linear boundary conditions are

$$\frac{\partial\Phi}{\partial t} + gz\bigg|_{z\approx 0} = 0, \qquad \frac{\partial\Phi}{\partial z}\bigg|_{z=-h} = 0, \qquad \frac{\partial\Phi}{\partial n}\bigg|_{S_B} = V_n, \tag{1}$$

where n is the normal direction of the body surface. For bodies that are not oscillating, the last boundary constraint in (1) is the condition that the fluid should not penetrate the body surface, $\partial_n\Phi| = 0$. Under the assumption that the time-dependence is sinusoidal, it can be factored out as $\Phi(x, y, z, t) = \mathrm{Re}(\phi(x, y, z)e^{-i\omega t})$, where the angular frequency ω is related to the wave number k through the dispersion relation $\omega^2 = gk\tanh(kh)$. In the frequency domain, the first of the boundary conditions in (1), the linearized Bernoulli equation, simplifies to $-\omega^2\phi + g\frac{\partial\phi}{\partial z} = 0$ at the sea surface.