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Performance of optimally tuned arrays of heaving point absorbers

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ABSTRACT

Arrays of heaving point absorbers in various arrangements are analysed to study their performance in terms of the amount of power absorption and the power uniformity among floaters. The numerical simulations for the determination of hydrodynamic coefficients and forces are obtained using a Boundary Element Method (BEM) code. A linear external damping coefficient is applied to enable power extraction and a supplementary mass is introduced to tune the floater to the incoming wave conditions. Each floater is assumed to have its own identical power take-off system. The external damping coefficient and the supplementary mass are individually optimized for each floater to maximize the total power absorption by the array. This optimization is implemented with slamming, stroke and force restrictions imposed on the floater motion by SQP method. Attention is also paid to the performance of each floater in various arrangements. Furthermore, the effect of incoming wave headings is taken into account. To quantify the performance, q-factor and coefficient of variation are compared for each array for a range of sea states. This present study will be helpful in the understanding and design of the best possible configuration of arrays of heaving point absorber WEC systems to extract more wave power and achieve better power recovery uniformity.

1. Introduction

The energy extracted from the ocean waves is one of the promising sources of renewable energy to control the energy demands. A huge amount of energy is available in ocean waves and wave energy is one of the energy resources among the renewable energies for green power generation. The production of wave energy has attracted and created interest among various industries and governments to carry out research and development for the wave power technologies. The wave energy also faces technical and economic challenges, due to the harsh conditions of the ocean environment, which imply high maintenance and installation costs. Despite the challenges, a great variety of wave energy conversion technologies have been developed and proposed for extraction of energy from the ocean waves. The research and development of various WEC have been carried out by scientists and engineers, and among them are overtopping devices, oscillating water columns and point absorber systems [7,9,11,12,14,23].

The wave energy has a considerable amount of advantage as compared to other renewable energy source, as it is more predictable, persistent and spatially concentrated. Moreover, wave energy production has low visual and environmental impact, negligible land use and follows the seasonal variability of energy demand in different climates. These favourable aspects of ocean wave energy together with its enormous potential strongly motivate and support the scientific community in finding viable and profitable engineering solutions to capture energy from waves. The extraction of wave energy by point absorbers wave energy converter (WEC) systems consist of a floater with horizontal dimensions that are small compared to the incident wave lengths. The floater oscillates according to one or more degrees of freedom in order to absorb energy by damping the floater motion and then the energy is converted into electricity by a generator. The point absorbers have to operate in arrays to produce amounts of energy that make commercial exploitation meaningful as each device normally has limited capability. Many point absorbers have been developed to work in farms such as Dexawave and some concepts have been developed in which point absorbers are attached to a large common structure such as in Wave Star, Manchester Bobber and FO^3.

Several theoretical models were developed by researchers in order to deal with the waves and interacting bodies. Budal [2],

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Evans [6] and Falnes [8] adopted the point absorber approximation theory to derive the expressions for the maximum power for an array of point absorber to absorb wave energy. The approximation relies on the assumption that the bodies are small compared to the incident wave lengths so that the wave scattering within the array can be neglected while calculating the interactions. A theory accounting more accurately for the wave body interactions is the plane wave approximation theory which is based on the assumption that the bodies are widely spaced relative to the incident wavelengths, so that the radiated and circular scattered waves can be locally approximated by plane waves [18,20,24]. This theory is not suitable for the closely spaced bodies as the wide spacing requirement is not fulfilled except for very short wave lengths. In the majority of studies, both theories have been applied to arrays for unconstrained conditions. Contrary to the point absorber approximation, the plane wave approximation is also suitable to study the power absorption of an array in sub-optimal conditions, as scattering might be relatively important in that case.

A significant study on the arrays of point absorber has been carried out in the last few decades. The hydrodynamic forces acting on the groups of interacting vertical axis-symmetric bodies are analysed by Mavrakos [15]. The theory developed in the study is compared with the point absorber approximation theory and plane wave approximation theory. McIver [19] studied the heaving point absorbers with constraint displacements by means of the plane wave approximation. The wave absorption by heave and surge motion is developed for arrays of rigid-body device. The improvement on the performance of the device for an unequal spacing and the effects of constraining amplitude on the device motion is presented. Further, McIver et al. [21] analysed the array interactions in irregular unidirectional and directionally spread seas for a varying number of oscillators. The study suggested that the motion restrictions significantly reduce the power absorption capability of the array for longer wave lengths.

The study of the power absorption by arrays of vertical axis-symmetric wave energy device is performed by Mavrakos and Kalofonos [16]. The evaluation of the optimum wave-power absorption characteristics of arrays of interacting wave-energy devices is analysed and the method is based on single-body hydrodynamic characteristics. Mavrakos and McIver [17] presented a brief comparison of the methods for computing hydrodynamic characteristics of arrays of wave power devices. Ricci et al. [22] compared results obtained with a BEM code to the point absorber approximation and optimized the point absorber geometry and inter-body distance of two array configurations each consisting of five floaters in irregular waves. A brief comparison of the numerical and experimental results for the response of the array of heaving floaters is presented by Thomas et al. [27]. An investigation on the interaction of multi-body heaving point absorbers in a floating platform in multi directional waves using mode expansion method is performed by Taghipour et al. [26]. The performance of the device in absorbing the wave energy and its dynamic behaviour in ocean waves considering the effect of power absorption mechanism is presented using the multi-body analysis approach.

The arrays of wave energy devices are in general separated by relatively small distances which has a significant effect due to the interaction among floaters. The interaction of devices is an important area in wave hydrodynamics and a number of studies have been carried out on the optimal configuration of wave energy devices. A preliminary study on the optimal array formation was performed by Fitzgerald et al. [10]. Child et al. [3] investigated the influence of the spatial configuration of a wave energy device array upon total power output. Engstrom et al. [5] evaluated the performance of large arrays of point absorbing direct-driven wave energy converters where it was shown that interconnected devices also serve the purpose of power smoothing. Therefore, efficient arrangement of devices not only lead to higher power and but also better power quality. Moreover, variation of response of arrays of heaving point absorbers was experimentally shown in Troch et al. [28].

In the present study, the performance of the multiple point absorbers arranged in various arrays namely – circular, concentric, linear, grid and random is evaluated and the results obtained are compared to ascertain the performance of each type of array for a range of sea states and wave headings. Apart from the total amount of power absorbed by the array, attention is paid to the individual power absorption and the power quality of the array. The control parameters – external damping coefficient and supplementary mass are individually optimized to maximize the power extracted by the array. Moreover, the variation of the control parameters is presented.

2. Numerical modelling

The hydrodynamic performance of several floater shapes was investigated in a previous study [25], leading to the conclusion that the cone-cylinder floater shape was expected to be the most favourable because of the large wetted area close to the free water surface, making the floater benefit from higher wave excitation forces. Between the hemispheres and cone shapes with the same dimensions, very similar power absorption efficiencies were encountered. A slight advantage was observed for the cone shape, but the difference was only between 3 and 5%. For this reason, in the present study, a conical shape floater (Fig. 1) with an apex angle of 90°, a diameter D of 5 m extended by a cylindrical part of 0.5 m (thus making an equilibrium draft of 3 m), is used to study the performance of several array arrangements.

2.1. Arrangements of arrays of point absorbers

In order to analyse the arrangements of multiple point absorbers this study is carried out for five different arrangements of arrays. An array of 12 cone-cylinder floaters is considered, with each floater having the dimension as shown in Fig. 1 forming a part of the WEC. The various array arrangements which have been considered in this study are – linear, grid circular, concentric and a random array where 12 floaters are placed randomly in a square box.

A linear arrangement for the array of 12 floaters with 6 floaters at the top and 6 floaters at the bottom is presented in Fig. 2(a). The floaters are placed in a rectangular fixed structure with four

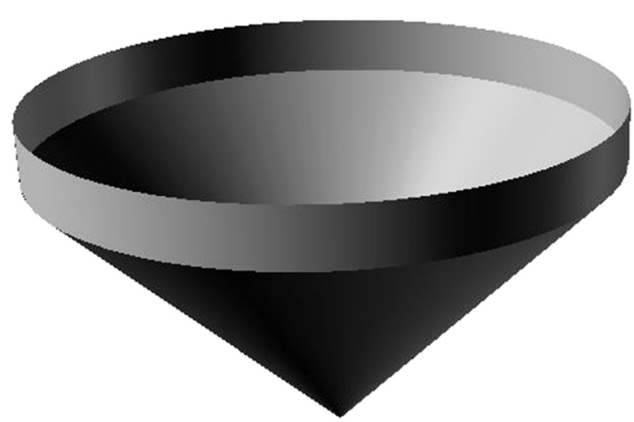

Fig. 1. Cone-cylinder floater.