Heterogeneous versus homogeneous arrays of wave energy converters

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I. INTRODUCTION

OVER the years, numerous work has been published on the best wave energy harvesting technologies [1-4]. The devices must, however, be deployed in arrays to generate enough power to contribute to the grid [5]. Other reasons to deploy multiple WECs in a common area include minimizing the overall design and running costs. For many years, researchers have studied multiple aspects of the WEC array.

The most popular WEC array problem in literature is optimizing the layout that maximizes the positive hydrodynamic interaction resulting from the proximity of the devices in the array. More often than not, these optimization solutions result in a layout that is not regular shaped like a square, triangular, or even circular layout. However, from experience in optimizing wind farms, it can be understood that other factors like the cost of moorings, power cables, and even ease of access during maintenance can constrain devices' practical layout design.

Typical configurations of Wave Energy Converters (WECs) are usually arrays of identical devices. To further increase harvested power and/or improve quality of generated power, this work presents study on the design of heterogeneous arrays of WECs. WEC devices can have different sizes (dimensions), allowing for possible more constructive interference between the devices in the array. This is achieved via the optimization of the individual sizes of the devices in order to maximize the performance index of the overall array. The heterogeneity of cylindrical devices can be achieved by varying the radius and draught of the cylindrical buoys.

In this work, our focus is not on optimizing the layout of the devices but on finding the optimal dimensions of devices that can maximize the positive interaction or minimize the negative interaction between devices in an easy, practical, and implementable layout. To achieve this, we investigate two types of arrays; the first is a traditional array of identical devices, which is here referred to as the homogeneous array; secondly, we investigate an array where the devices have varying dimensions. Devices in the heterogeneous array will be optimized to have different radii and drafts. An illustration of the homogeneous and heterogeneous array is presented in Fig. 1.

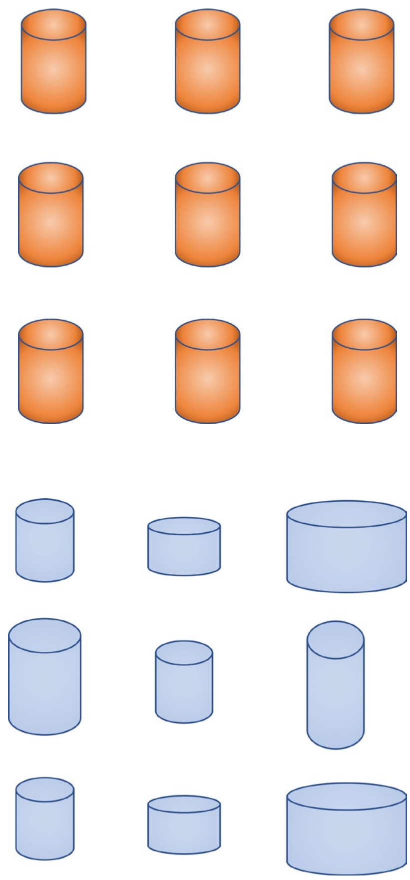

Fig. 1. Homogeneous and heterogeneous array.

To highlight the significance of the optimized heterogenous array, the performance of the array is compared to that of a homogeneous array that has the same number of devices in an identical layout and has a total volume for all the devices to be similar to the total volume of all the heterogeneous array devices. The optimization is carried out using a genetic algorithm. A case study is presented. The homogeneous and heterogeneous optimization problem are formulated in the following section.

II.PROBLEM FORMULATION

Whether having a heterogeneous array is better than a homogeneous array is not intuitive; this has to be investigated scientifically. Finding the optimal dimension of the devices in the arrays is an optimization problem. For the homogeneous array, we want to find the dimension of a WEC (radius and draught) that maximizes the positive inter-device interaction in the given layout. The optimization objective for this problem is the popular q-factor:

$$q = \frac{P_{array}}{N.P_{isolated}} \tag{1}$$

$$s.t\ R \in [R_{min}, R_{max}]$$
$$D \in [D_{min}, D_{max}]$$

q is the ratio of the power from the interaction array (P_{array}) to the power from the same number of devices N in isolation ($NP_{isolated}$). Productive interaction between the devices is indicated by a q > 1; else, it is destructive. The optimal radius and draft for a homogeneous array device are obtained from this optimization.

For the same array layout and location as the homogenous array, we investigate whether having a heterogeneous array can lead to better power from the array or even other benefits. An optimization problem is formulated to find the combination of device dimensions with better power output relative to the optimized homogeneous array. The search is, however, constrained such that the total volume of the devices in the heterogeneous array has to be approximately equal to or less than the total volume of the homogeneous array being compared. A novel performance measure, the p-factor, is formulated as:

$$p = \frac{P_{heterogenous}}{P_{homogenous}} \tag{2}$$

$$s.t\ R_i \in [R_{min}, R_{max}]$$
$$D_i \in [D_{min}, D_{max}]$$
$$\forall\ i = 1{:}N$$
$$T.V\ of\ Het. \leq 1.05\ \times T.V\ of\ Hom.$$

Like the q-factor, when p > 1, this means a better performance by the heterogeneous array; otherwise, p < 1 means the heterogeneous array does not result in better performance. Theoretically, we expect p should not be less than 1; if there is no better performing heterogeneous solution, the size of the devices in the heterogeneous optimization should converge to the dimensions of the homogeneous array, thereby, p = 1. T.V. is an acronym for total volume. A flowchart of the heterogeneous array optimization is presented in Fig. 2:

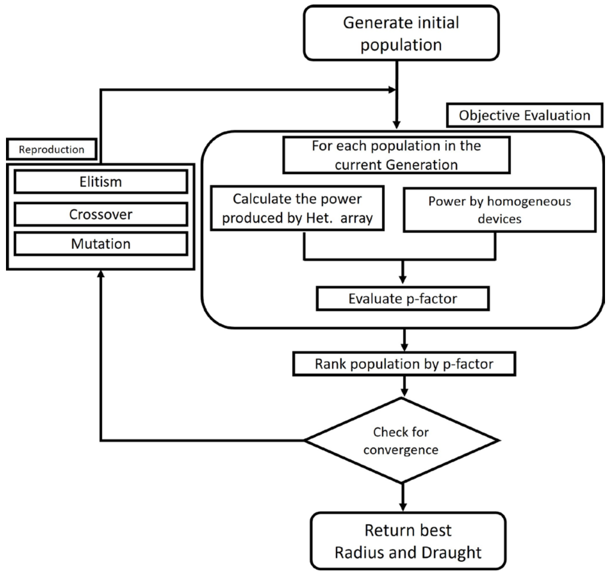

Fig. 2. Flowchart for heterogeneous array optimization.

The Genetic algorithm is a non-deterministic optimisation algorithm. In the first step, initial populations are generated randomly. For each of these population members, the power is computed and compared to an already stored power from a homogenous array. The power ratio are then the best ones are selected and cross them to create a new generation, which is potentially better than the first one. Over many iterations, this process returns the best dimensions for the devices in the heterogenous array.

III. RESULTS

Results for homogeneous and heterogeneous array optimization for an array containing 7 devices in this section. The 7-device layout adopted is described in [6]. The regular wave condition in the deployment site is T = 6.00 s, wave height H = 0.8222 m. Hydrodynamic coefficients are computed using the semi-analytic model developed in this project. The optimized radius and draught are R = 6.85 m, and D = 6.18 m, respectively. The optimal dimensions do not violate the constraints on maximum radius and draught set as $R\_\max = 10m$, and $D\_\max = 10\ m$. A constructive q = 2.8698 is achieved for the layout.

The optimized 7-device homogeneous (black) and heterogeneous (red) arrays are plotted in Fig. 3. The devices are symmetric about the positive x-axis, corresponding to the incident wave direction. As

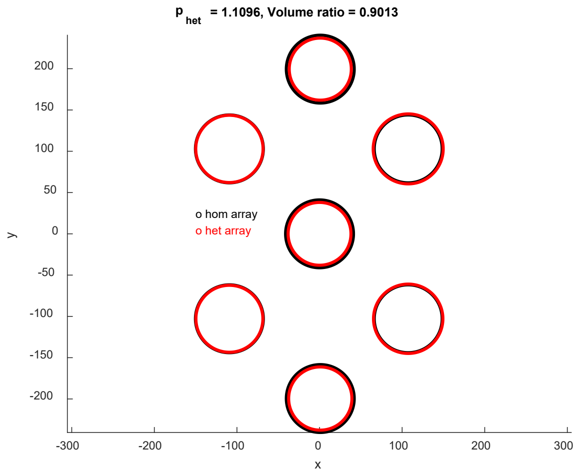

Fig. 3. Optimized heterogeneous array of 7 devices.

observed, the optimal radii of leading devices are almost the same radius as the homogeneous array. The diameters of devices in the middle column are smaller, while the diameters of trailing devices are bigger than the homogeneous dimensions. Overall, the heterogeneous achieved a total power increase of about 9.71% with a total volume of about 10% less than that of the homogeneous array.

IV. DISCUSSION & CONCLUSION

Heterogeneous arrays were found to have significant advantages over traditional arrays of identical devices. Apart from the increase in total power extraction from the waves, a significant reduction in the volume of material needed and, consequently, the cost.

V. ACKNOWLEDGEMENT

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