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Control of rapid phase oscillations in the modelling of large wave energy arrays

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ABSTRACT

Several recently developed concepts for economically viable conversion of ocean wave energy are based on large arrays of point absorbers. Simulations of the hydrodynamic interactions between devices in wave energy parks provide guidelines for optimal configurations with regard to maximizing produced electricity while minimizing fluctuations and costs. Parameters that influence the performance include the geometrical lay-out of the park, the number of wave energy converters and their dimensions and separating distance, as well as the wave climate and the incoming wave spectral characteristics. However, the complexity of the simulations increases rapidly with growing number of interacting units, and simulations become a severe challenge that calls for new methods. Here we address the problem of rapid phase oscillations appearing in the simulation of large arrays of point absorbers using potential theory for the structure–fluid interaction. We do this by analytically integrating out the factors that are causing the oscillations. Our group has successfully utilized this method to model parks with up to 1000 point absorbers.

1. Introduction

For large-scale utilization of wave power from the oceans it is required that a large number of wave energy converters (WECs) operate in unison. In particular this is the case for parks of point absorber

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WECs, which consist of large arrays of wave-absorbing units with a spatial extent smaller than the wavelength of the incoming ocean waves. Interconnecting wave energy converters in large wave power parks can also reduce the fluctuations in power generation, which is a necessity for grid integration.

Many point absorber array concepts are currently under active investigation, and some of these including, e.g., Fred Olsen's Bolt [1], Seabased Industry AB [2], Wave Star A/S [3], are moving towards commercialization. Device developers moving into the commercial phase will require robust and reliable tools not only to estimate power production but also to show utilities how their power plant can be integrated in the grid and how crucial components can be dimensioned and optimized. While the modelling of single devices still needs improvement to be able to reliably optimize the energy absorption of each device, the shift from prototype scale to commercial scale will also take the modelling from single devices to several hundred aggregated devices, coupled hydrodynamically as well as electrically. Recently, several papers have presented works on numerical and physical modelling of wave energy parks [4–9]

The interaction of devices in an array is an important problem in wave hydrodynamics as well as in electric engineering: it can lead to a substantial increase or reduction in produced electricity for the array, depending on park geometry, interspacing between the devices, the wave spectrum and the orientation relative to the wave direction [4,7,8,10–13]. On the other hand, the size of the array should be minimized to save cost on e.g. electrical cable and to minimize conflict with other interests in the coastal area.

Different approaches have been developed to simplify the calculations and enable simulations of a large number of interacting structures. The first theoretical results on arrays were based on the point absorber assumption [14–17], where the absorbers are assumed so small that the influence of the scattered waves on remaining absorbers can be neglected. Likewise, with the plane-wave method using the wide-spacing assumption the structures are assumed to be too far apart to influence each other by scattered waves [18–20]. The multiple-scattering method, imported from acoustics, is based on single-body hydrodynamic characteristics and describes the interaction through a cascade of scatterings [21,22]; the drawback is that the number of interacting wave components to be accounted for increases rapidly with the number of devices and modes of oscillation. A comparison of methods for computing hydrodynamic characteristics of finite arrays of wave power devices was performed as a sub-task of the Offshore Wave Energy Converter Project (JOULE Program) and is summarized in [23].

In this paper we propose a new method for performing efficient computations of the hydrodynamic interaction for WEC arrays covering a large area. With this method we solve the problem with rapidly oscillating phases associated with large parks by shifting coordinates and analytically integrating out the troublesome factors that are causing the oscillations. Our group has successfully utilized this method to model parks with up to 1000 point absorbers [7,10,24]. This is highly relevant to future projects. In fact, during the first half of 2015 a wave power park of 1 MW is being installed at the Swedish west coast by Seabased Industry AB. This is the first stage of a larger park with altogether 360 wave power converters that corresponding to a total installed power of 10 MW. In the last section we illustrate the use of the method with small examples including three point absorbers.

2. Theory

For waves useful for power conversion, the wave/absorber interaction can be modelled using potential theory. This assumes an ideal fluid, i.e. incompressible, irrotational and non-viscous fluid, which implies that the velocity potential ϕ satisfies the Laplace equation $\nabla^2\phi = 0$.. A device array consists of N wave power devices each in M modes of oscillation. To simplify notation a combined oscillator index may be defined by:

$$j = M(n-1) + m,\ \ n = 1, 2, \ldots, N,\ \ m = 1, 2, \ldots, M$$

where n is the device index and m is the oscillation mode index. The oscillator index is referred to as an array mode of oscillation; there are MN such modes. Under the assumption that the waves have small amplitude compared to wave length, the dynamic free surface boundary condition can be