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Modelling of the multi-chamber oscillating water column in regular waves at model scale

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Abstract

This paper studies the reliability of numerical models used for estimating multi-chamber oscillating water column (MC-OWC) response in the time-domain. The model for the internal water surface level and instantaneous pressure inside the chamber at regular waves conditions using a hybrid system of hydrodynamic and thermodynamic rigid piston models without power take-off. Reliability is assessed using experimental data obtained from a wave tank used in the model concept validation. The results show the method could be extended to describe the hydrodynamics of the MC-OWC in regular and irregular wave conditions.

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Keywords: Oscillating water column; renewable energy; wave energy

1. Introduction

Renewable energy sources have a fundamental role in the reduction of air pollution, especially CO_2 emission. Among the renewable energy resources, ocean wave energy is still an emerging technology which is still largely untapped, and the potential for extracting energy from it is considerable. It is estimated that between 2000 and 4000 TWh per year of energy can be extracted worldwide from waves [1]. Ocean wave energy contains roughly 1000 times the kinetic energy of the wind, and should be harvested with much smaller and less conspicuous devices to

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produce the same power in the same available space. There are more than one hundred prototypes of various wave energy converter (WEC) systems [2], particularly in oceanic countries such as Ireland, Denmark, Portugal, U.K., U.S.A., and Australia. Several pre-commercial ocean devices have been deployed. The WEC design and development process extends from applying fundamental laws of physics at the initial concept proving stage to commercial demonstration. These processes have been found to be difficult, slow and expensive [3]. To circumvent these barriers several approaches and comprehensive programs have been proposed and implemented. There is no agreed approach to the development and evaluation of WECs. However, the technology readiness level (TRL) is considered to be a standard approach for engineering application and industrial development. TRL is a proposed program for advancement in the design and development of WECs [4]. The TRL approach can be divided into five main stages [5]: Concept Validation (TRL1-3), Model Validation (TRL4), System Validation (TRL5-6), Device Validation (TRL7-8), and Economics Validation (TRL9). The MC-OWC comprises of several chambers that divide the wave into sections and allow each chamber to run as an OWC as shown in Fig. 1. The pumped air flow that results from the change of the internal water surface in each chamber will drive the installed turbines between chambers. In the device studied here, there are four chambers.

Fig. 1. Scale model of MC-OWC.

In previous work, the initial verification of the model concept was performed using single-frequency regular waves of small amplitudes. This is considered as the first part of stage TRL1-3 in the TRL approach. Small amplitude linear wave theory assumptions were used to evaluate the power measurement and some basic parameters such as the effect of the water surface elevation and area ratio and its influence on device performance characteristics [6]. Then the capture width was studied, which is considered as the most common parameter used to define the performance of a WEC. After these stages, the basic operation of a device has been observed. The experimental data of the proposed model are ready to use for validation and calibration of the mathematical model which is used in this work [7]. After the initial verification of the models, the next step of the development and design process includes many expensive experimental studies involving numerical simulations and large-scale testing.

Amongst the number of numerical models used to analyze and simplify the interaction between waves and WECs (which include analytical methods, boundary integral equation methods), the Navier-Stokes equations and empirical methods are often used. Analytical methods that depend on a system of hydrodynamic and thermodynamic analysis are widely used to understand the interaction between waves and device bodies on a variety of WECs. The aim of this paper is to present such a single chamber OWC numerical simulation designed on Matlab/Simulink, describing the energy chain from the ocean waves to the pneumatic power extracted. The proposed model uses the hydrodynamic efficiency, the water surface level, the air velocity inside the chamber, and the air pressure as indices to evaluate the energy capture efficiency of the OWC. The simulation results are used to define the optimal design of the MC-OWC based on the wave tank conditions, to the evaluation of hydrodynamic characteristics.

2. Hydrodynamic modeling

Theoretical and numerical studies of the hydrodynamic process in WECs are difficult due to relative complex diffraction and radiation wave phenomena, so it must be fully understood [3]. The TRL approach shows that successful design and optimization of WECs must be based on theoretical modeling during the pre-conception stages [8, 9]. Theoretical and numerical modeling of WECs has achieved substantial progress during different stages