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Thesis Overview: Oscillating wave surge converters – Large eddy simulation modelling of wave farms hydrodynamics and its related energy potential

Thesis Overview: Oscillating wave surge converters – Modelagem da hidrodinâmica e do potencial energético em parques de geração por simulação numérica de grandes escalas

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Resumo

O Oscillating Wave Surge Converter (OWSC) é um dos principais sistemas de geração de energia a partir das ondas do mar, promovendo energia a partir da captação da componente horizontal do movimento das ondas. Esta tecnologia, que encontra-se em escala pré-comercial de desenvolvimento, detém um dos maiores potenciais para geração de eletricidade, tendo em vista seu princípio de funcionamento e o grande aperfeiçoamento no design experimentado ao longo dos últimos anos. A modelagem numérica computacional representa hoje uma das principais ferramentas para o estudo e projeto deste e de diversos outros sistemas de conversão a partir das ondas do mar. Nesse contexto, surge a necessidade de um estudo detalhado acerca de um parque de geração composto por diversos conversores deste tipo, o que representa uma situação mais próxima da realidade, uma vez que a grande maioria dos sistemas renováveis contemplam diversos módulos de um mesmo conversor. Tendo em vista a complexidade da hidrodinâmica associada a estes casos, é empregada a metodologia de modelagem numérica baseada em grandes escalas (Large Eddy Simulation – LES) para representar corretamente, com suficiente riqueza de detalhes, o movimento da estrutura e os campos de escoamento envolvidos. Para tal, utiliza-se o código computacional OpenFOAM v.4.1 e sua extensão OlaFlow, em conjunto do modelo de LES conhecido por Wall Adapting Local Eddy Viscosity (WALE), possibilitando uma representação do sistema bastante próxima dos casos reais de aplicação. O modelo proposto demonstrou bastante aderência dos resultados quando comparado a estudos experimentais presentes na literatura. Da mesma forma, se observou que mudanças na altura e no período de onda, na declividade do fundo, na reflexão das ondas, no espaçamento entre conversores e no layout dos parques, podem ocasionar variações importantes na geração de energia do sistema, aumentando ou reduzindo consideravelmente sua eficiência, ressaltando, portanto, a importância destes parâmetros no projeto e desenvolvimento desta tecnologia.

Palavras-chave: Energias renováveis do oceano. Energia das ondas do mar. Oscillating Wave Surge Converter. Parques de geração. OpenFOAM. Computational Fluid Dynamics. Large Eddy Simulation.

Abstract
The Oscillating Wave Surge Converter (OWSC) is one of the most relevant systems for harnessing energy from ocean waves, generating energy by capturing the horizontal component of wave motion. This technology, which is on a pre-commercial development scale, presents one of the greatest potentials for electricity generation, due to its operating principle and the great improvement in design experienced over the last few years. Today, Computational numerical modelling is one of the main tools for the study and design of this and several other power generation systems from sea waves. In this context, a detailed study of a wave farm composed of several OWSCs is necessary, which represents a case closer to reality, since most renewable systems include several modules of the same converter. Considering the complexity of the existing hydrodynamics in these cases, a numerical modeling methodology based on the Large Eddy Simulation (LES) methodology is applied to correctly represent the oscillation of the structure and the observed flow fields. In order to achieve the objectives, the OpenFOAM v.4.1 computational code and the OlaFlow extension are used, together with the Wall Adapting Local Eddy Viscosity (WALE) LES model, which allows a representation of the system very close to real application cases. The proposed model demonstrated a good adherence of the results when compared to experimental studies present in the literature. Likewise, it was observed that changes in wave height and period, bottom slope, wave reflection, spacing between converters, and the wave farm layout can cause important variations in the energy generated by the system, increasing or reducing considerably its efficiency, emphasizing the importance of these parameters in the design and development of this technology.
Keywords: Ocean renewable energy. Ocean wave energy. Oscillating Wave Surge Converter. Wave farms. OpenFOAM. Computational Fluid Dynamics. Large Eddy Simulation.

1. Introduction

The Oscillating Wave Surge Converter (OWSC) represents, among the foremost wave energy conversion systems, one of the most promising renewable technologies with great potential for generating electricity. This technology is at a very advanced stage of development, which includes several design improvement processes and tests carried out in laboratories and on a full scale at sea. The converter operating principle consists of the oscillation back and forth of a large structure (flap) due to the horizontal movement imposed by wave hydrodynamics, which promotes high-pressure fluid pumping inside a secondary hydraulic system, where a generator turbine is positioned. In addition, this system is very versatile, as it can be installed in different regions of the ocean, fully submerged or partially submerged, allowing its association with other renewable energy systems such as offshore wind and solar systems.

Numerical modelling is today the main tool for studying this and several other wave conversion technologies due to the great technological advance experienced in the computational area and its cost-benefit analysis. However, most case studies carried out and published in the literature rely on simplified numerical models, such as those based on potential flow theory. Furthermore, the main methodology considered to represent the complexity of the flow turbulence is based on the application of Reynolds Averaged Navier-Stokes (RANS) equations, where greater details of fluctuations in properties and eddies are lost. On the other hand, many studies about OWSCs refer to analysis on a single flap, and the influence of several structures together needs to be considered in order to correctly represent a real wave farm.

In this context, the main objective of the thesis is to study the hydrodynamics involved in an OWSC wave farm. Thus, the application of numerical modelling based on Large Eddy Simulation (LES) is proposed, which allows representing the most energetic vortices of the flow as well as providing important details of the flow fields and the fluctuation of their properties. These two aspects represent the originality of the work in the area and emphasize its important contribution to future scientific work and the development of this and other wave conversion technologies.

The open-source computational code OpenFOAM v. 4.1, along with the OlaFlow extension, were used in this work. Both are based on the discretization methodology in finite volumes and on the Volume of Fluid (VOF) method for representing the free surface, being quite adequate to mathematically model the problem and provide results closer to real-world cases.

2. Objectives

The main objective of this thesis is to apply the Large Eddy Simulation methodology to study how wave hydrodynamics modify the energy generation in a wave farm composed of several OWSCs. On the other hand, the thesis also has the following specific objectives: the numerical validation of the applied model (performed through comparisons with an experimental case of a critical system situation); the evaluation of different LES models (such as the Smagorinsky and Wall Adapting Local Eddy Viscosity – WALE); the comparison between 2D and 3D models; the analysis and understanding of the associated dynamics in the case of three equal flaps arranged in sequence; the estimation of the amount of energy captured by the converter; and study wave farm layouts that optimize the power production.

3. Conclusions

The proposed numerical model demonstrated considerable adherence compared to the experimental results available in the literature, referring to a critical case of the system (known as Slamming). In addition, this model also presented satisfactory results, both in two-dimensional and three-dimensional cases. Therefore, important hydrodynamic variables such as the angular displacement of the flap, the observed angular velocity, the experienced wave force, and the captured power are sufficiently reproduced by this model.

An analysis carried out on a system composed of three flaps in series showed that an increase in wave height is responsible for an intensification of turbulence in the region between the structures, intensifying the associated hydrodynamic phenomena. On the other hand, an increase in the wave period tends to intensify the velocity magnitude in the vicinity of the flaps, while very long periods are unfavorable to the oscillation of the converter. It was also observed that, at very great depths (where the relationship between the submergence depth and the flap height is greater than 1), the captured energy and the oscillation pattern of the structure tend to decrease significantly. This last observation suggests that the power absorbed by the system increases in cases where the converter is partially submerged.

After studying the ideal distance between flaps, it was concluded that a spacing equal to 1.5 times the height of the structure can result in an increase of up to 22% in the captured power. In the same way, it was observed that an interleaved type of layout (starting from an idealized case where several flaps are aligned side by side along the perpendicular line to the wave movement direction, the structures are interspersed, while one is installed downstream, the other is installed upstream) can represent an increase of up to 30% in the total energy captured by the system.

Finally, it is observed that bottoms with a mild slope (less than 5º) favors the oscillatory behavior of the structure, allowing the system to capture a greater amount of wave energy. On the other hand, land with slopes greater than 10° causes the generation of turbulence over the structures, which can restrict the oscillation of the flaps and, consequently, reduce the energy potential of the system. In these last cases, it is recommended that the converter be installed away from the bottom to maintain the efficiency of the system.

Comprehensively, the numerical model proposed in the thesis, combined with LES modelling, proved to be a powerful analysis tool, providing important information about the hydrodynamics of the system and being, therefore, quite relevant for the design and layout of the system. Furthermore, it is expected that this model can also be applied to several other conversion systems due to its robustness and versatility.

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Publications Related to Thesis

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