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The Wave Energy Converter CECO: Current Status and Future Perspectives †

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Abstract: This work reviews the advances in the development of CECO, a wave energy converter (WEC) of the floating oscillating bodies subgroup that has its motions and power take-off system (PTO) restricted to an inclined direction. For this purpose, the review is conducted on the basis of the Technology Readiness Levels (TRLs), the most frequently used metric to assess the maturity of a technology. The main conclusions and milestones of each stage are also presented along with an introduction to the ongoing works and a general picture of future research lines.

Keywords: renewable energy; marine energy; ocean energy; wave energy; technology readiness level; proof of concept; physical modelling; numerical modelling; ocean engineering; marine structures

1. Introduction

With about 32,000 TW·h/year available worldwide, the ocean's waves are a source of renewable energy that is still unexploited [1]. For this reason, many different wave energy converters (WECs) have been proposed over the past decades and more than 100 concepts are under development [2]. Although each one is based on a different working principle, a convergence on a single design is unlikely, in contrast with wind turbine generators [3].

One of the WECs that is currently under development is CECO, which belongs to the floating oscillating bodies subgroup (Figure 1). The main particularity of this WEC is the sloped direction of its motions and power take-off system (PTO). An oscillating body with sloped motions uses both the vertical and the horizontal components of the wave-induced force, in contraposition to a heaving buoy, which essentially uses the vertical component. Thanks to this feature, CECO can absorb larger amounts of wave energy than heaving buoys.

This work reviews the current Technology Readiness Level (TRL) of CECO and the requirements to move it into the next level. After summarizing the works carried out since the concept was conceived, the most recent advances and ongoing works are presented. Furthermore, future works and priority research objectives are listed and discussed.

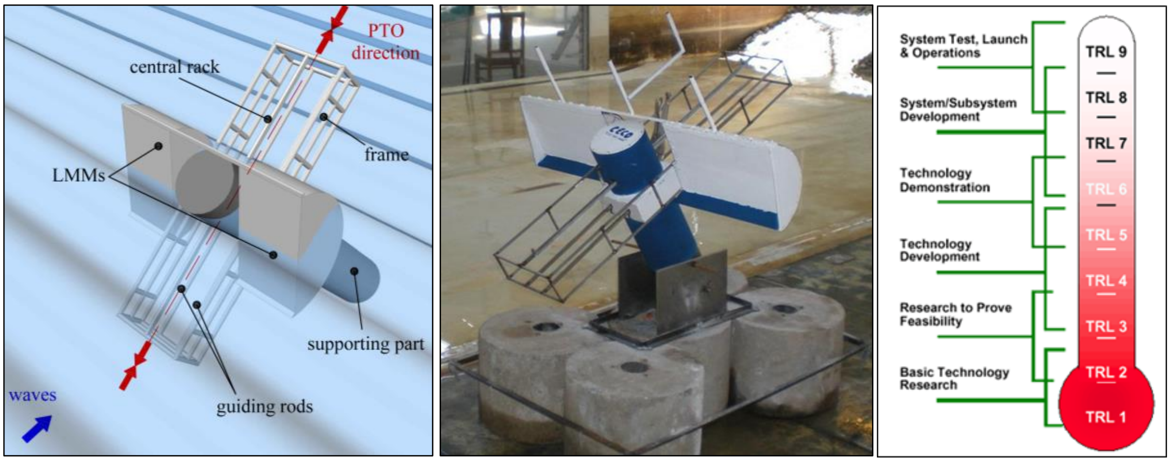

Figure 1. A sketch concept of the latest CECO version (**left**), the physical model of CECO during the experimental proof of concept (**middle**) and the Technology Readiness Level (TRL) scale (**right**).

2. The TRL Scale

The TRL scale was originally proposed by the National Aeronautics and Space Administration (NASA) in the late 1990s with the aim of allowing more effective assessment and also a better communication on the maturity of new Space technologies (Figure 1). Today, this metric is the most used tool for the maturity assessment of any type of technology worldwide.

In the particular case of wave energy, given the variety of WEC types, understanding the design limitations and constraints of each particular type is of major interest. According to Ruehl and Bull [4], the design topics to consider during the development of any WEC include deployment depth, floating or submerged design, Power Take-Off (PTO) options, anchor/mooring requirements, as well as issues related to the full-scale design such as: performance harvesting wave power, survivability, environmental concerns, and operations and maintenance requirements.

3. Progress in the Development of CECO

3.1. TRL 1-2

The CECO concept was originally proposed by Eng. Pinho Ribeiro in 2011. The development works started with the focus on understanding its main design limitations and constraints. For this purpose, an experimental proof of concept study was carried out in a wave tank at the Hydraulics Laboratory of the Hydraulics, Water Resources and Environment Division (SHRHA) of the Faculty of Engineering of the University of Porto (FEUP), Portugal [5]. Thanks to the insight obtained with this simplified reproduction of CECO (Figure 1), the ability of this WEC to harness wave energy was confirmed and the potential issues with the chosen solution could be identified.

3.2. TRL-3

The development of CECO concept at TRL-3 started five years ago, in 2013. On the basis of the results and conclusions obtained during the initial proof of concept, an improved design was tested once again at the FEUP's experimental facility [6]. Several improvements were introduced in the physical model, such as: the floaters (also known as Lateral Mobile Modules or LMMs) geometry, the guiding system of the main rods, the structural bars and the cross-section of the central body. After the experiments, the capture efficiency of the device was set to a range between 10% and 30% of the incident wave power.

At this TRL, numerical modelling techniques are crucial to understand the basic physics of any WEC, since the cost of experimental testing of a large number of cases, with different configurations and for several wave conditions, is significantly reduced. Therefore, the first step was to implement a panel model of the last CECO version. Then, hydrodynamic coefficients from potential flow solvers along with the instantaneous hydrostatic, Froude-Krylov and PTO forces were used to simulate and calibrate the behavior of the device in the time-domain [7]. Subsequently, the influence of several design parameters on the performance of the device was investigated, namely: the PTO damping, *b* [8], the PTO inclination, *a* [9], the wave climate seasonality [10] and the water depth, *d* [11], among others.

The amount of wave power that CECO can absorb could also be obtained for a broad range of wave conditions and configurations thanks to the application of numerical modelling techniques. All these information was summarized in the WEC power matrices (an example of power matrix is shown in Figure 2), which give the amount of absorbed wave power for different sea states, as a function of the wave parameters (commonly the significant wave height and the peak period). These matrices are a very useful tool, as they can be directly combined with site-specific wave matrices to estimate the total amount of absorbed wave energy. The major conclusions reached during this stage are summarized in the following:

- the mechanical friction losses in the rack-pinion system have to be reduced in order to maximize the WEC's efficiency;
- the current CECO geometry performs better at sites with milder wave conditions;
- the PTO inclination plays a relevant role in the performance of the WEC, being the configurations with 30 and 45º of inclination those with a better performance; and
- the performance of CECO slightly decreases with the operating water depth.

However, bearing in mind the large list of parameters that influence the performance of CECO, along with the multiple possible CECO configurations, a detailed evaluation of the performance of this WEC results very time- and cost-consuming, even with numerical techniques. For this reason, artificial intelligence methods and, particularly, artificial neural networks (ANNs), are being applied. This machine learning technique has been already used with success in other fields of marine engineering (e.g., [12]) and also in the development of other WECs such as the OWC [13]. The application of artificial intelligence algorithms to optimize the design and the tuning of the device to site-specific wave conditions will faster the transition of CECO from TRL 3 to TRL 4.

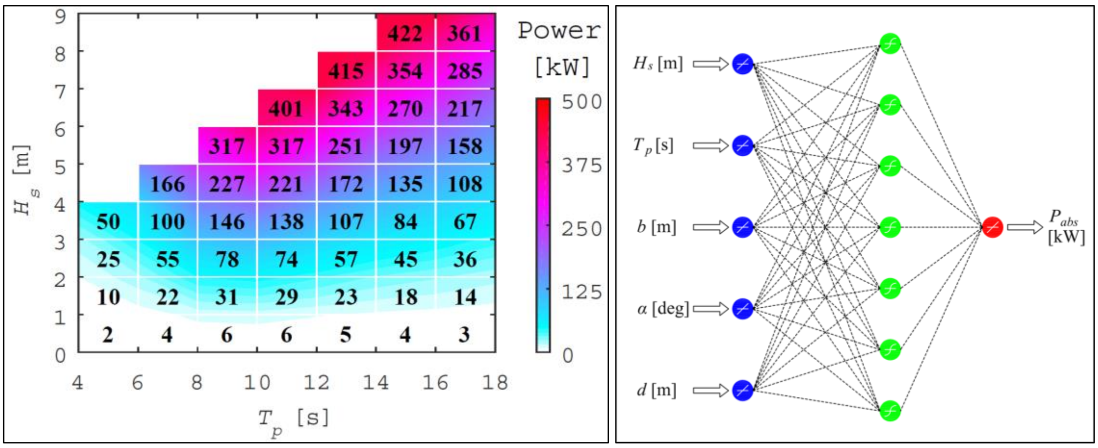

Figure 2. Absorbed power matrix of CECO for a power take-off (PTO) inclination of *a* = 45° and an operating water depth of *d* = 30 m (**left**) and an example of the artificial neural network (ANN) that is being trained to estimate CECO's performance under site-specific wave conditions (**right**).

4. Conclusions and Future Work

In the upcoming TRL, the development of component models is required to formulate an advanced concept design [4]. To achieve this, advanced numerical methods and medium scale experimental tests in a wave tank are needed, along with the aforementioned machine learning methods. Some of the aspects that will focus research in the forthcoming works are:

- the mechanical conversion machinery (rack-pinion and gear system);
- the structural configuration and materials, including the foundation and the survival mode; and
- the electric and electronic components, including an *ad-hoc* control strategy.

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