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Selection of design power of wave energy converters based on wave basin experiments

Luca Martinelli [a,b,*], Barbara Zanuttigh [b], Jens Peter Kofoed [c]

[a] University of Padova, IMAGE, Via Ognissanti 39, 35129 Padova, Italy
[b] University of Bologna, DICAM, Viale Risorgimento 2, 40136 Bologna, Italy
[c] Wave Energy Research Group, Department of Civil Engineering, Aalborg University, Sohngaardsholmsvej 57, 9000 Aalborg, Denmark

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ABSTRACT

Aim of this paper is to develop a method for selecting the optimal power generation capacity for which a wave energy converter (WEC) should be rated. This method is suitable for the earliest stages of development, when several studies are missing, including design of the Power Take Off (PTO) system, and the first economic considerations become essential for investment opportunities. It relies on the availability of an experimental description of the maximum possible produced power under realistic conditions, typically obtained by dummy PTOs. It consists of three steps: statistical characterisation of the measured efficiency; description of the energy production by means of a function of the design capacity; application of a simple formula for cost benefit analysis. The analyses here proposed are based on the experimental results of 3D tests on two floating wave energy devices, named LEANCON and DEXA.

Limitations of this method essentially consist in the presence of scale effects related to the laboratory investigations, where mechanical, aerodynamic, electrical losses are not accurately represented.

1. Introduction

Recently, many concepts for wave energy converters (WECs) have been developed or significantly optimised (for instance PICO [1], Pelamis [2]; WaveGen [3]; Ocean Power Technologies [4]; Wave Dragon [5]; SeaBeavI [6]). This proliferation of new devices to be tested (together with the main interest focused on the demonstration of improved efficiency) is urging for the definition of an efficient and common testing procedure.

Laboratory tests carried out at the initial stage of the design usually provide a deterministic efficiency or expected energy production of the device, even if the irregular and random nature of the wave attack is correctly simulated. Results may be based on a more realistic power production expectation. The purpose of this note is to show the importance of a stochastic description of the experimental device efficiency, in order to define a more accurate assessment of the power production.

It is well known that, after an initial experimental investigation, the steps of the design process include many expensive and specific studies, involving numerical simulations and large scale testing.

These studies aim at the development of the i) Power Take Off (PTO) system, ii) the device geometry and –if appropriate- iii) the mooring system:

i. The PTO, that converts an irregular oscillatory energy flux into electricity, is obviously a key element in the device economic performance ([7,8]), resulting in significant barrier to commercialising. Falcão [9] first provided a statistical representation of the power production suited to a shore fixed Oscillating Water Column (OWC) device. He proposed a method for random waves, by essentially deriving the variance and the probability distribution of the PICO plant through the transfer function by Evans [10], and by assuming a linear relation between turbine flow rate and pressure head.
ii. the device geometry may be improved to benefit from the possible presence of the natural resonance which has been theoretically and experimentally proved to be a very efficient mechanism ([11,12]);
iii. the mooring design, and in particular the weathervaning scheme under oblique waves, largely affects the floating body movements ([13,14]) and presumably the energy production.

Economics of the wave energy sources are discussed by several authors, among others by [15–18]. Optimisation is generally based on availability of advanced studies of the device. In practice, an

* Corresponding author. University of Padova, IMAGE, Via Ognissanti 39, 35129 Padova, Italy.
E-mail addresses: luca.martinelli@unipd.it (L. Martinelli), barbara.zanuttigh@unibo.it (B. Zanuttigh), jpk@civil.aau.dk (J.P. Kofoed).

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accurate selection of power capacity is needed at earlier stages, i.e. just after proof of concept experiments.

In these experiments, i) the PTO response is only schematically represented; ii) the device geometry is generally defined by the inventor on the basis of intuitions and iii) the mooring system is seldom realistic. Nevertheless in most cases the statistic nature of the waves is respected, since its importance is considered essential.

This paper examines the stochastic nature of the power performance based on existing 3D tests of two floating WECs, specifically LEANCON – an OWC device – and DEXA – a Wave Activated Body (WAB) device.

Specific objectives of the paper are:

- to identify the power generation capacity for which the device should be designed. Such design value is necessarily greater than the average power and lower than the highest possible peak, certainly infrequent and therefore contributing very little to the overall yearly power production;
- to provide a preliminary tool to analyse different strategies as regards the exploitation of extreme waves. On the basis of the amount of energy harvested in these conditions, it can be decided if it is worthwhile to keep the device running or to switch it off, putting it in safe mode.

The paper is organized as follows. Section 2 describes the tests, the WECs and their hydrodynamic functioning concept. The results of power production and device efficiency are summarised in Section 3. Section 4 presents the statistical approach. A cost benefit analysis is then performed in Section 5 to provide basic criteria for selecting the capacity factor. Finally conclusions are drawn in Section 6.

2. The experimental dataset

2.1 The facility and tested wave attacks

3D hydrodynamic tests were performed in the directional wave basin of the Hydraulics and Costal Engineering Laboratory at Aalborg University, DK. The basin is 15.7 m long, 8.5 m wide and 1.5 m deep. The wave generator is a piston type paddle system composed of 10 actuators with stroke length of 0.5 m, enabling generation of short-crested waves. The software used for controlling the paddle system to generate waves is AwaSys developed by the same laboratory (Aalborg University). Regular and irregular short-crested waves with peak periods up to approximately 3 s, oblique 2D and 3D waves can be generated with good results.

The active absorption on the wave paddles was not used, but passive absorption was placed at the rear end of the basin and at both sides. The absorbing sidewalls were made of crates (1.21 × 1.21 m, 0.70 m deep). The 1:4 sloping beach placed opposite to the wave maker was made of concrete and gravel with $D_{50} = 5$ cm.

Tested wave attacks are reported at prototype scale in Table 1 and reproduce the typical annual wave climate of the North Sea ([19]). For each wave attack a 3D Jonswap spectrum was adopted with directional spreading equal to 22.7°.

Measurements were carried out with logging frequency of 25 Hz and test duration was approximately of 30 min (corresponding to more than 1000 waves in most cases) for each irregular wave state.

Table 1
Wave states representative of the North Sea climate, prototype scale (1:1).

Wave state	H_s [m]	T_z [s]	T_p [s]	Energy flux [kW/m]	Prob. occur. [%]
1	1.0	4.0	5.6	2.1	46.8
2	2.0	5.0	7.0	11.6	22.6
3	3.0	6.0	8.4	32.0	10.8
4	4.0	7.0	9.8	65.6	5.1
5	5.0	8.0	11.2	114.0	2.4

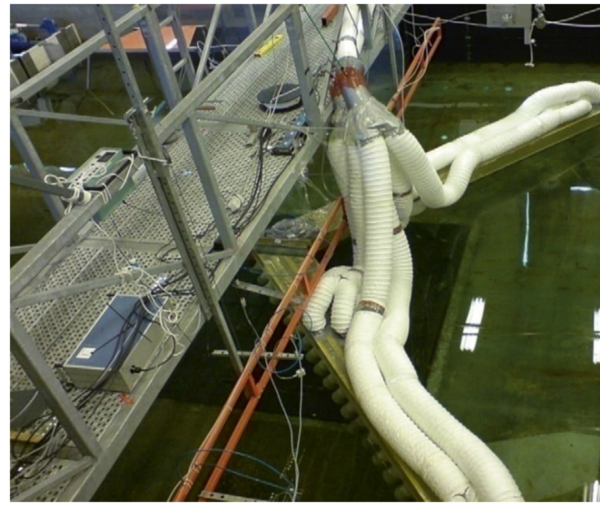

Fig. 1. Picture showing the OWC device.

2.2. The OWC device: characteristics and measurements

The tested OWC is the LEANCON WEC [20], a multi-chamber floating device working in near-shore and off-shore conditions (details in [19]).

The model is formed by a floating V-shaped slender structure, with two arms oblique 40° with respect to the incident wave front (Fig. 1). The reference full scale device is 240 m wide, intended for deployment in the Danish part of the North Sea. The model of the device is realised in fiberglass, and it is 6 m wide (scale 1:40). In all tests, water depth was kept constant at 0.73 m.

The floating beams are equipped, in the bottom submerged half, with two rows of cylindrical chambers (each may be considered to be an OWC). Fig. 2 shows a side view. In the model each chamber is channelled via flexible hoses toward two larger ducts, lying parallel to the arm. One duct is kept at high pressure, the other one at low pressure, separated by a dummy turbine (an artificial pressure drop). In full scale these ducts and hoses are integrated into the structure. As the wave travels across the structure, the air present in the chambers over the crest is pressurized and it opens the relative non-return valves. The air is therefore forced to enter into the high pressure duct and from here to the turbine. After the generator, the air, at a pressure below the atmospheric one, is gathered at the second duct and from here it is sucked out of the system by the pipes placed at the wave troughs, again flowing past non-return valves. The structure beam is therefore divided into high pressure zones, connected to chambers that redirect the air toward the main inlet duct and from here toward the dummy turbine, and low

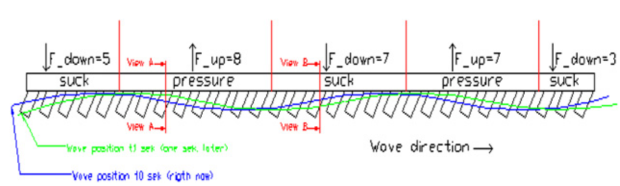

Fig. 2. Side view of the arm of the OWC device.