Preliminary design of the OWEL wave energy converter commercial demonstrator

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Abstract: The consortium responsible for the next stage of development of the OWEL wave energy converter will construct and test a large scale, pre-commercial demonstrator. It is expected that this will be installed at Wave Hub during 2013 and grid connected for a testing period lasting around 12 months. This paper reports on the preliminary design work being undertaken in the development of the marine demonstration device. This concentrates primarily on producing a fully costed design by detailing the hydraulic design and aspects of stability as well as providing insight into various design features such as the power take-off, naval architecture, moorings and control. The design is being largely informed by the results of a 12 month research project funded by the South West Regional Development Agency (SWRDA) in which a detailed techno-economic model for a large scale OWEL device was generated.

Keywords: *Wave Energy, Pre-commercial Demonstrator Design, Wave Hub*

1. Introduction

The OWEL (Offshore Wave Energy Limited) wave energy converter is a floating, moored device that uses incident, deep water waves to compress air and drive an air turbine. It is designed to be deployed offshore in energetic deep water locations.

The device concept has been in development for a number of years and has successfully undergone a number of phases of research. The first proved the concept at small scale for a number of different arrangements. A much larger scale device was tested in the second phase in order to demonstrate the ability of the concept to be scaled up. The latest phase of development was funded by the South West Regional Development Agency (SWRDA) and has recently been completed. This incorporated a number of experimental and computational studies to optimise the design and inform the design of the large scale, marine demonstrator. The results from these three phases of testing are reported in detail in [1-4]. A level of confidence has been achieved through the wide variety of results and studies conducted. This has led to the progression of the device and its potential to be developed for commercial deployment.

A pre-commercial, marine demonstration unit is being currently designed for ocean deployment at the Wave Hub facility in the south west of England. This phase of development is intended to demonstrate the performance of a large scale OWEL unit and its ability to be deployed at sea and grid connected, with the overall goal of generating a costed, DNV accredited, full scale, commercial design. This work will represent a critical stage in the commercial route to market. The 3 year £5M project is being funded through a £2.5m award by the UK's Technology Strategy Board (TSB). Private investment will fulfil the remaining half of the required project funds.

This paper presents the initial design of the demonstrator based on the findings from the SWRDA research programme. The design process that will be used to generate the final design is discussed with the associated challenges for such a project and the plans for the future development of OWEL.

2. Principle of Operation

The OWEL converter is a floating duct which is open at one end to capture incident waves. The sides and floor are angled inward to induce a rise in wave height within the duct. As a wave enters the device, it creates a seal with the roof creating a trapped pocket of air ahead of the wave front. As the wave progresses, the air is compressed and passes through an exit pipe to the power take-off system. A schematic of this process is shown in Fig. 1. This proposed method will generate uni-directional air flow meaning standard air turbines can be used instead of the less efficient bi-directional turbines used in oscillating water columns.

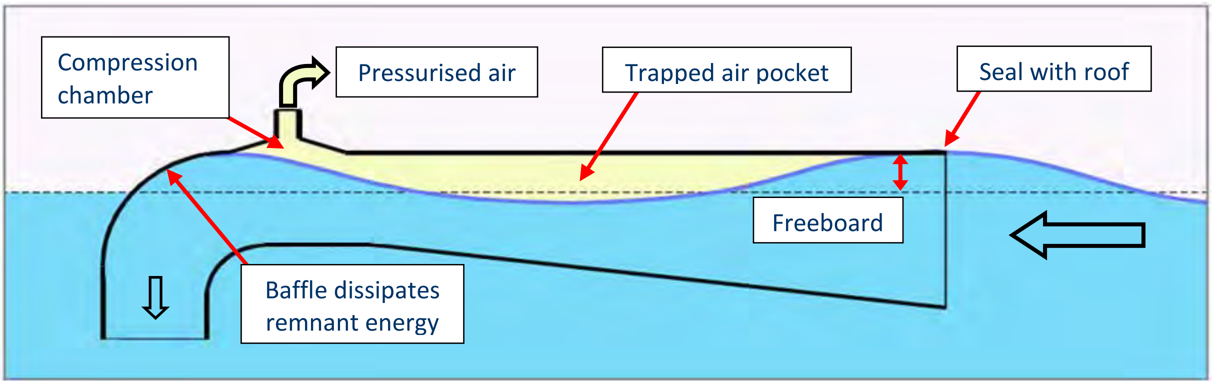


Fig. 1, Schematic of the device operation.

3. Project Overview

The design presented in this paper is considered the initial, baseline design that has been based purely on the results from the previous phases of testing. It is expected that the design will evolve and transform through the course of the project as the various demands from each subsystem are met and compromises made. A significant portion of this project will be spent generating a d etailed, engineering design for the demonstration and commercial devices. £2.5m is available to the project through the TSB funding grant with a further £2.5m of co-financing being sought in order to complete the 3 year project from design to decommissioning.

A further aim of the project is to demonstrate the ability of the device to meet the criteria of the successor to the Marine Renewables Development Fund (MRDF). It is therefore intended to keep the device on s tation for about a year as part of this project in order to verify the consistency of power output, sea-keeping properties and demonstrate reliability and survivability. In addition to the at-sea testing activity, techno-economic modelling will be used to optimise the design so as to minimise the cost of delivered energy.

Effort has been made to progress the OWEL development programme in systematic and methodical order, in line with EMEC standards [5]. By following a logical progression through ever increasing scales, more knowledge has been assimilated and the risk of failure or mistakes, reduced. The results from the previous development phases have provided enough confidence in the device design to progress to a much larger scale. It is anticipated that many lessons will be learnt from testing in an oceanic environment as there are limitations to what can be realised in a laboratory. That being said, the testing to date has identified many key design variables, device characteristics and results that have been fundamental in creating an initial design for the demonstrator.

4. Design Implications from Experimental Results

4.1. 2D Wave Flume Experiments

The 2D testing of a ~1:80 scale model of an OWEL duct, at the University of Southampton showed two regions of peak performance, as shown in Fig 2a. All of the tests were run for a fixed model with mono-chromatic waves. Although these were idealised conditions, a large amount of knowledge was gained from the results of these tests. By running over 200 wave cases for each design configuration it became straight forward to build a detailed picture of the performance and how design changes altered this.

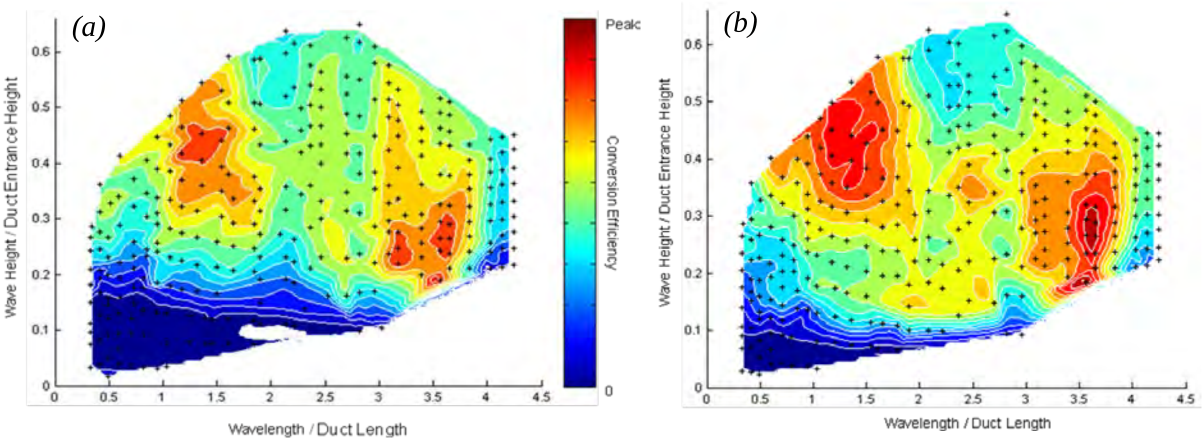


Fig. 2, Non-dimensional performance contour plots for a 2D scale model, in baseline configuration (a) and improved configuration (b).

The experiments resulted in an improved design that featured a re-designed rear duct and also demonstrated that the orientation of the duct is critical to increase performance over a wider range of wave heights. Fig. 2 compares the performance, contour plots as functions of non-dimensionalised wavelength and height, for the original design (a) and the improved design configuration (b). The improved configuration had better performance and wider bandwidths of peak efficiency and was used as the design for the model in the subsequent testing phase.

4.2. 3D Wave Basin Experiments

A series of testing at the wave basin in HMRC, Cork during 2009 generated many results and insights into previously un-investigated aspects of the device. A multi-duct, small scale model (fig. 7) was tested over a range of idealised and realistic conditions with both floating and fixed configurations. A fundamental and detailed understanding of OWEL was gained, including performance, motion and loading characteristics. The non-dimensional, performance contour plot for a floating model, tested in short crested, Bretschneider sea states is shown in Fig. 3. This compares well to the performance shown in Fig. 2, and peak performance was similar. It was found that the bandwidth performance peak widened for a floating model in comparison to a fixed model with mono-chromatic waves.

These results gave confidence in the ability of OWEL to be designed for a particular wave climate, as the peak performance can be shifted to different wavelengths by altering the duct length. Fig. 4 shows the average wave power available at Wave Hub [6], where the peak energy is at T_z=7.5s, H_s=4m, which corresponds to a wavelength/Duct length (λ/DL) ratio of just less than 2. The length of the demonstrator has been dictated by the results of the small scale testing in order to position the peak performance in Fig. 3 at the conditions of maximum energy in Fig. 4.

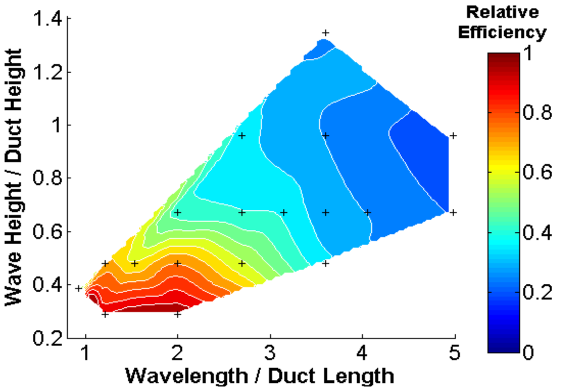


Fig. 3, Performance contour plot, with efficiencies relative to maximum, for a floating 3D model in directional sea states.

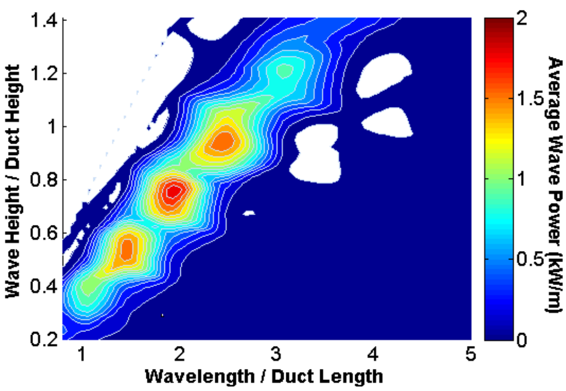


Fig. 4, Average wave power available at Wave Hub

The motions of the small scale, multi-duct OWEL model were measured in realistic, scaled sea states and their effect on performance was investigated. The tests showed that the motions of the duct helped to improve performance for certain sea states. This broadened bandwidth and led to better performance for most sea states and in particular at λ/DL ratios of 2-3. This was because the phase relationship between the incident wave and pitch and surge was such that the model pitched bow down and surged forward into the incident wave. The pulse of power occurred at around a 90° phase lag to the pitch which is thought to be optimum. At the design wave, the motions resulted in a 20% increase in performance over the fixed configuration. This ideal response improves the capture performance of each duct through better wave sealing and air compression within it. This relationship can be seen in the time series motions and power plot in Fig. 5. The RAO (Response Amplitude Operator) plot in Fig. 6 clearly shows the increased pitch and surge motions occurring between 2-3 λ/DL and these are the motions that are beneficial to the power capture. It is therefore important to consider these motions when specifying the naval architecture of the demonstrator. Motions of the design will be assessed using a w ave diffraction code such as ANSYS AQWA to ensure that similar behaviour is exhibited in order to benefit performance.

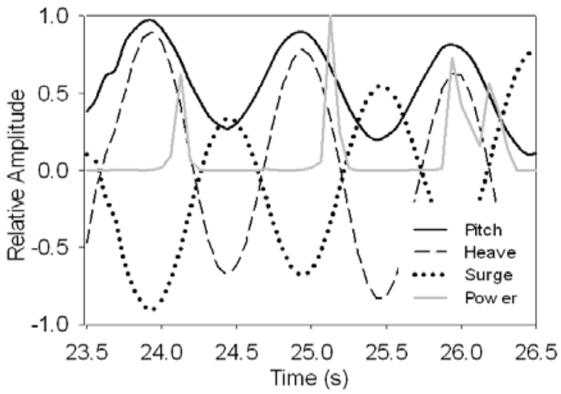


Fig. 5, Time series of motions and power output for a small scale, multi duct model.

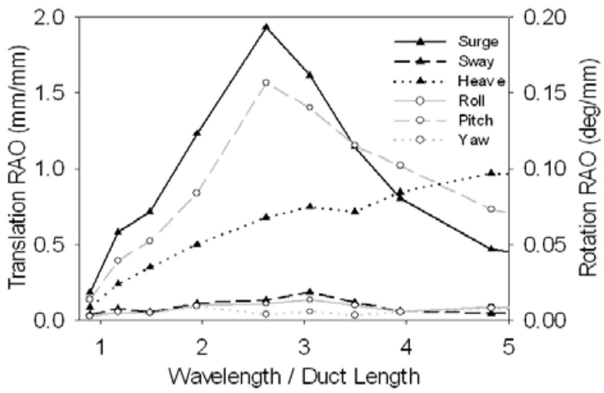


Fig. 6, RAOs for a small scale, multi duct, model of OWEL.

An orifice was used to provide damping to the exiting airflow and the pressure differential across it was measured to determine flowrate and power in order to calculate the conversion efficiency. Fig. 8 shows a typical, time-series pressure trace measuring the pressure drop across the orifice. The dashed line shows the average pressure of the time span which demonstrates that the peak pressures are significantly greater than the average. This type of flow regime is similar to that of an OWC however, unlike an OWC the airflow exhibits very little return flow. Therefore, air flow rectification or self rectifying turbines are not required and so a more conventional air turbine is well suited. A number of orifice sizes were tested in the previous experimental studies to find the optimum applied damping. It is expected that the damping of the air turbine will be variable and so can be controlled to best suit the incident wave climate. This along with the flow rates and pressure data will help to specify the requirements of the turbine characteristics.

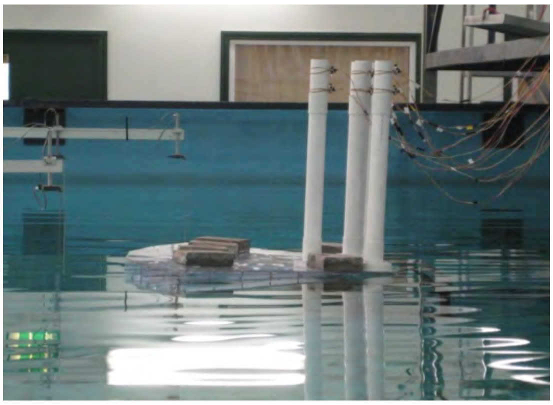


Fig. 7, Experimental testing of a multi- duct, 3D model at HMRC, Cork.

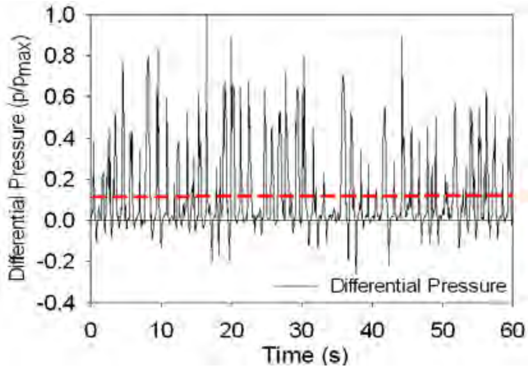


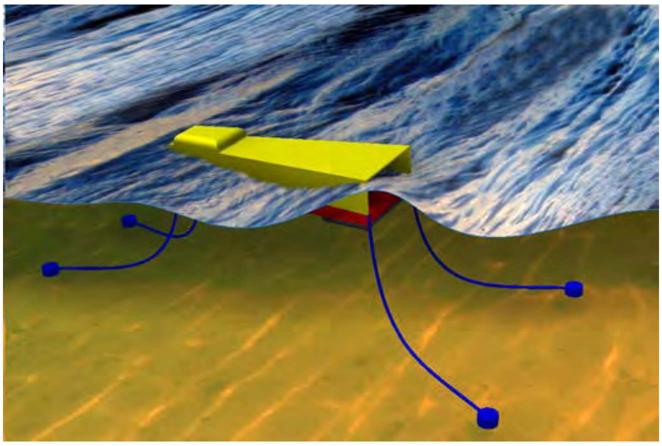
Fig. 8, Plot of normalised, orifice pressure drop for a typical sea state.

Various mooring configurations were also trialled during the wave basin testing and it was seen that different designs have clear effect on the motions of the device as well as the peak and average loads. These small scale moorings, were intended as simple models of a full scale mooring system to provide initial data on the order of the loads that can be expected. As the waves at Wave Hub have low directionality [6], the full scale mooring system will be designed to keep the device on station and orientated towards the predominant wave direction. Computational analysis of the motions and moorings, using a commercial diffraction code, will be undertaken to assess loading and support the final design.

5. Initial Design

5.1. Overview

The Wave Hub, marine demonstrator has been designated the D500 as it is expected to be rated at 500kW. The unit will be a scaled down version of the full scale, commercial design and comprise a single floating duct rather than a large, multi-duct, floating platform as has been previously suggested. This means that a smaller duct can be tested and used as a development platform before a full scale commercial device is designed. An artist's impression and a selection of key figures are given in Fig. 9, whilst the drawings of the initial design are shown in Fig. 10 with the key dimensions and components labelled.



D500 Key Figures	
LOA ca.	42m
Beam ca.	18m
Draft ca.	8m
Lightship ca.	650t
Ballast ca.	300t
Total ca.	900t

Fig. 9, An artist's impression and key figures of the D500 demonstrator.

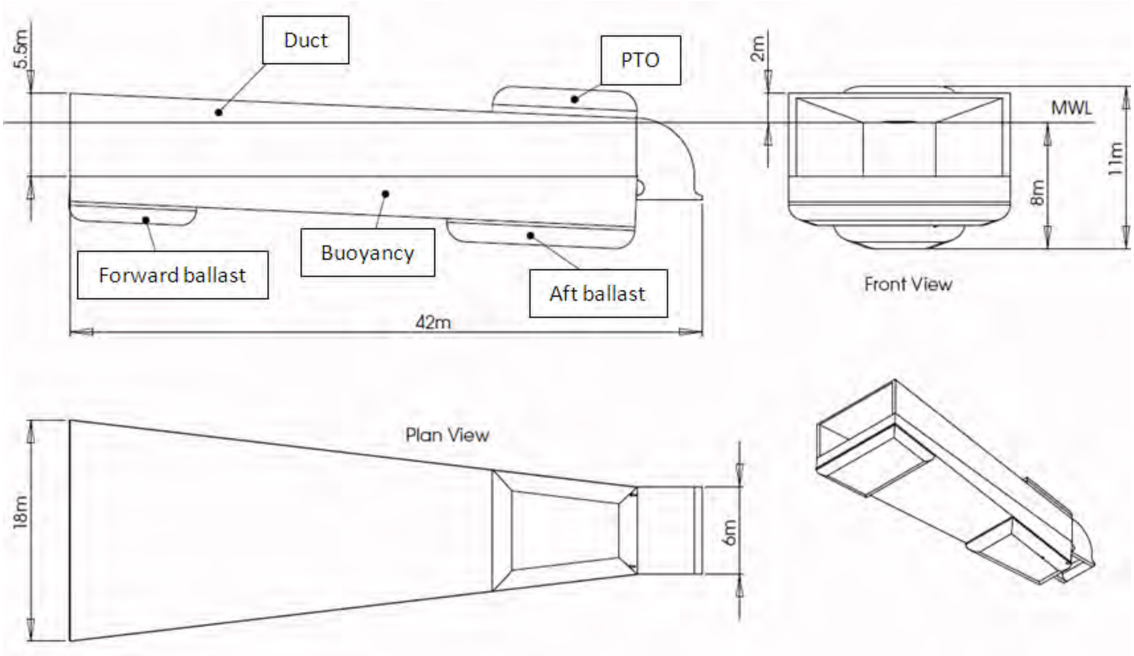


Fig. 10, The general assembly drawings of the initial design of the OWEL demonstrator.

The main duct is likely to be made of steel however concrete is being considered as an alternative material depending on structural loading requirements and costs. The power take-off unit, a turbine and generator set, will be located in a watertight housing at the rear of the duct, above the waterline. Below the main duct will be the main volumes of ballast and buoyancy required to correctly trim the device and determine the motion responses.

A control system to alter the freeboard and natural pitch frequency is being considered. This will involve controlling the volume of air or water in tanks below the duct. By altering the buoyancy, the freeboard can be varied to match the incident wave climate. This also forms a part of the survival strategy in that during storm conditions the freeboard can be reduced to lessen the impact of incident waves on the device. Controlling the position of the ballast about the centre of buoyancy will allow the natural pitch period to be tuned to the optimum value. This will ensure that the phase difference between pitch and wave front is beneficial to the performance as described by the results discussed in the previous section.

5.2. Project Organisation

The demonstrator will be developed by a consortium of organisations that, between them, bring together the wealth of experience needed to successfully deliver a project of this nature. IT Power and OWEL will lead the project whilst the DNV will monitor the design process in order to provide confidence and certify it to DNV standards [7]. In order to best demonstrate the responsibilities of each consortium member, the device can be broken down into its main constituent parts and subsystems, as shown in Fig. 11.

Involving a number of organisations is beneficial to a large and complex project such as the development of a wave energy converter. It brings a wide variety of knowledge into the design process and also clearly demonstrates that third-parties have confidence in the project. Ensuring that the design progresses as planned will be challenging, given the level of communication required between the various consortium partners. A robust design method will be used to facilitate the process, meaning that the design requirements and expectations will be clear.

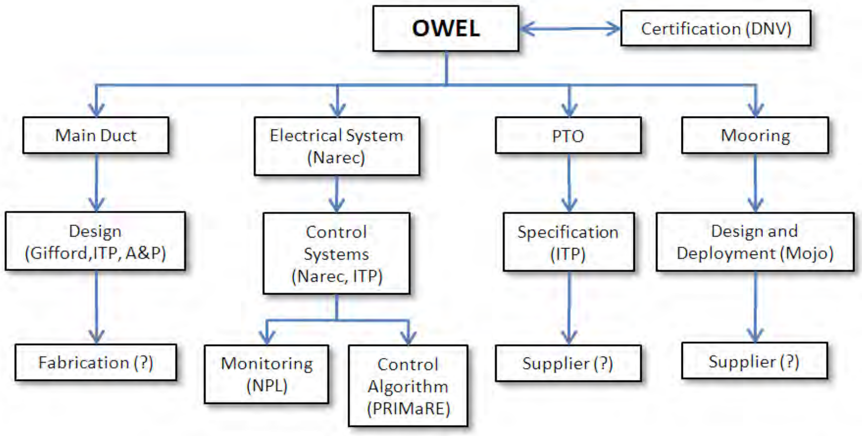


Fig. 11, A chart showing the breakdown of the main subsystems of the OWEL demonstrator and the consortium members responsible.

5.3. *Design Framework*

The design framework that will be used in the process, works by formulating a "Problem Definition" and "Design Solution" for each major subsection or component in the system. The problem definition is a document created to identify the requirements and constraints on the design, which includes stakeholder expectations, design constraints and assumptions, problem boundaries and interfaces. This also includes functional analysis to determine what the design needs to achieve and a validation to check that the problem that has been defined is actually that which requires a solution. A design solution is then generated to meet the requirements of the problem definition. This begins by assessing and recording all possible ideas and alternative designs. A final design is chosen through modelling, life-cycle cost analysis and risk analysis. The solution is then validated against the problem definition to ensure that the design solution fulfils the problem definition, stakeholder expectations and functional requirements.

Consortium members will likely resort to their own design methods to devise design solutions, however, the problem definitions will be created for all necessary design points. This will unify the group as it will be clear what the problem is and the requirements of the solution. It is then the responsibility of the organisation involved with each design point to generate a suitable design solution. This process mitigates any potential confusion over the design requirements and also clearly sets out responsibilities.

6. Future Development

The forthcoming decade is likely to bring about large advances in wave energy device development. In order for a device to have commercial promise, it has to be successfully demonstrated in a marine environment. The industry is therefore gearing itself towards providing proving and development sites for device teams. Once a machine has been proven at an ocean site at large scale, it will most likely be deployed in small arrays of 3-5MW. In order to attract interest from utilities, device deployment of this magnitude will be required, along with demonstrated reliability. OWEL is therefore aiming to develop its converter to meet these capability requirements.

6.1. *Single Duct Commercial unit*

Following on from the Wave Hub demonstrator, a first generation commercial OWEL D1000 will be developed as a refinement of the single duct design. It will incorporate advances made following the lessons learned through the D500, meaning that the output for a single duct should rise. It is envisaged that the first commercial scale deployment of OWEL will feature a number of these single ducts in small array. Deployed in a higher energy wave climate, such as that at the Portuguese Pilot Zone, the improved design will likely be rated at about 1MW per device.

6.2. Multi Duct Commercial unit

A second generation commercial OWEL device could comprise a number of ducts combined to form a large floating platform with a multi-megawatt output. This concept is shown in the artist's impression in Fig. 12. By combining a number of ducts the device could benefit from shared costs of subsystems such as mooring, grid connection, control systems and power take-off. Multiple ducts could also help to smooth power output if the compressed air pulses from each duct were designed to arrive at the turbine of out of phase at staggered times.

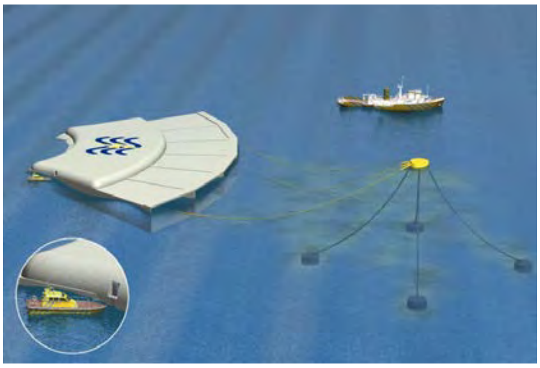


Fig. 12, An artist's impression of a second generation OWEL MD3000 3MW unit

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