THE DEPLOYMENT OF THE OE35 DEVICE AT THE US NAVY TEST SITE (WETS)

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INTRODUCTION

Ocean Energy will be installing a full scale floating oscillating water column (OWC) at the US Navy Wave Energy Test Site (WETS) located at Kaneohe Marine Corps Base Hawaii (MCBH) on the northeast coast of the island of Oahu in the second half of this year (2018).

This paper will provide some history of the company, background to the technology and its development path and present an update on the commercialization of the OE35 device. The deployment at WETS will be at Technology Readiness Level (TRL) 7 and will have the Dresser Rand HydroAir™ Turbine installed, rated at 500kW.

Ocean Energy have been developing the OE Buoy for the last 15 years. Each of the TRLs up to and including TRL6 have been achieved through a number of successful testing and development stages. TRL1-4 consisted of both 1/50 and 1/15 scale laboratory testing which was followed by over three years total deployment at the Galway Bay ¼ Scale Wave Energy Test Site in Ireland.
A follow-on project in 2019 will take the OE35 hull to Scotland for deployment at the European Marine Energy Centre (EMEC) and repower it with a 1MW rated HydroAir™ Turbine.

A project of this size involves many project partners and various topics such as permits and consents, equipment design and procurement, fabrication, installation, operation, and decommissioning, all of which will be presented and discussed.

THE OE35 DEVICE

The OE35 uses the technologically mature OWC concept that utilizes the air flow through a turbine to generate electricity. This air flow is created by the water column encapsulated by the hull which acts like a piston to drive the air flow through the turbine. The distinction of this type of wave energy conversion is that the air flow is reciprocating. This requires an efficient turbine that can operate across a wide range of operating conditions. This concept is shown in Figure 1.

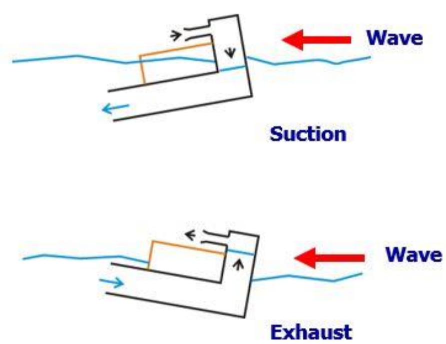

FIGURE 1. OE BUOY - OWC PRINCIPLE.

The structure is a steel barge-type structure with a subsea duct (the 'sea duct'), facing away from the incoming wave direction. The construction of the barge type hull is similar to typical ship construction configurations and manufacturing methodologies. The total length of the hull is 37.5m and total beam is 18.5m.

The OE35 Structure has two buoyancy modules. The primary one is located at the bend in the sea duct which protrudes above the still water level and acts as a housing for the electrical equipment and a platform to mount the Turbine, and the second at the bow of the structure. The stern of the sea duct has a structure which protrudes above the still water level and acts as a support for an access walkway between the primary buoyancy module deck and the stern of the

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structure. The stern structure also provides a location to connect the stern mooring lines.

Technology Development

Ocean Energy have always been advocates of the controlled development process for wave energy technologies. The development from conceptual idea to commercial stage is envisaged to grow through five defined stages, each followed by a stage-gate to determine what coms next. In the wave energy protocol each stage includes defined TRLs [1]

Ocean Energy have completed three of the five stages, and the WETS and EMEC projects will allow Stage 4 to be completed. The advantages of conducting Stage 4 across two different real sea conditions, is that the ocean environment at WETS is less severe that that at EMEC, which will allow for a "shake-down" of the device and reduce the risks associated with the deployment before installation at EMEC.

The various stages of the technology development so far are described below.

Tank Testing

Stage 1 and Stage 2 were completed using the small scale physical models of the OE Buoy shown in Figure 2. These models represent 50th and 15th scale of the Ocean Energy device. 50th scale testing was carried out at the University College Cork Hydraulics and Maritime Research Centre, Ireland while the 15th scale model was tested at the wave basin facilities of Ecole Central Nantes in France.

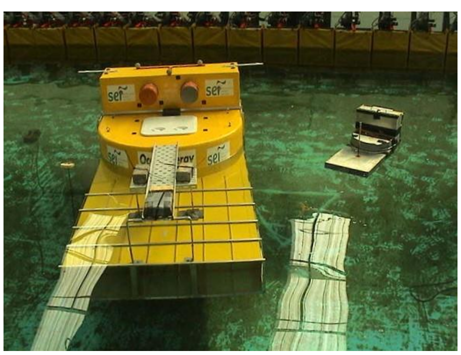

FIGURE 2. SMALL AND MEDIUM SCALE OE BUOY MODELS (TRL1-4)

Quarter Scale In-Ocean Testing

Following on from Stage 2, a medium scale device was build and installed at the ¼ scale demonstration site in Galway Bay, Ireland. This device is shown on site in Figure 3. It was first deployed with an orifice plate for comparison with the previous tank testing, but then fitted with a Wells Turbine. By the time it was decommissioned, it had accumulated over 24,000 hours (c. 3 years) of in-ocean testing, thus validating the previous stages of the development program. Further details of the testing regime and comparisons across the stages will be presented

FIGURE 3. OE BUOY DEPLOYED AT ¼ SCALE GALWAY BAY TEST SITE. (TRL 5-6)

Full Scale Structural Design and Fabrication

This section will discuss the catalogue of events in the structural design process, from converting the experience gained in Stages 1 to 3, to developing a full-size sea going structure that will confirm to the chosen standard and designed for deployment in extreme ocean environments, along with the experiences gained from the fabrication process. A graphic of the OE35 with the HydroAir Turbine is shown in Figure **Error! Reference source not found.**

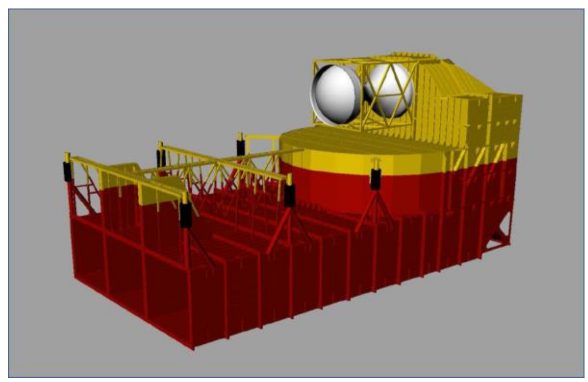

FIGURE 4 OE35 WITH HYDROAIR TURBINE.

SIEMENS POWER TAKE OFF (PTO) SYSTEM

The Power Take Off (PTO) system onboard the OE35 is being provided by Dresser Rand (A Siemens Business). The deployment at WETS will have a 500kW rated PTO onboard the device, which will be connected to the local electrical grid via a 11kV subsea cable. The PTO is comprised of the air turbine and the electrical system.

HydroAir Turbine

The challenge of OWC technology, as a whole, is to achieve satisfactory efficiency over a wide operating range. The pressure and airflow not only vary between zero and 100 percent, but also change direction. At the same time, the shaft rotation must be maintained in one direction (i.e. clockwise rotation).

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Siemens patented a variable radius turbine (VRT) called the HydroAir™ turbine. It uses a combination of corrosion-resistant stainless steel, aluminum and reinforced composites and offers the following benefits when compared to other turbines being used for wave energy capture such as superior efficiency, one moving part (the rotor), lower rotational speeds than competing turbines (reduces friction losses), wide operating range, self-starting, and reduced noise.

The HydroAir turbine takes advantage of the impulse turbine design principles. The impulse turbine design has a broad operating range, uses the VRT principle to increase efficiency and has minimal moving parts. All of this translates into increased reliability and reduced maintenance. In comparison with both Wells turbines and conventional impulse turbines, the HydroAir turbine offers a step-change in efficiency and operating range. It achieves its remarkable performance with fixed guide vanes and rotor blades .

HydroAir Technology Development

Similar to OE buoy, HydroAir turbine has been through various development stages and TRL levels. The first prototype of HydroAir was successfully tested in a novel land-based test facility. This facility allowed testing of bi-directional turbines under transient conditions, validation of computational fluid dynamics simulations and testing of turbine control strategies under realistic sea states. The test facility employed a pneumatic wave generator (of unique design) to simulate the air flow of an oscillating water column.

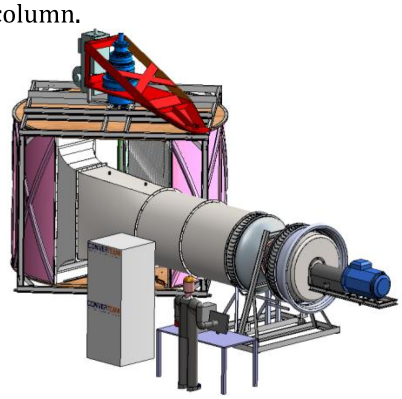

FIGURE 5 HYDROAIR TEST FACILITY.

A second prototype of HydroAir turbine was manufactured and deployed in Australia in 2010. (Figure **Error! Reference source not found.**)

FIGURE 6 PROTOTYPE HYDROAIR.

The deployment at WETS will be a large scale 500kW turbine at Technology Readiness Level (TRL) 7 shown below.

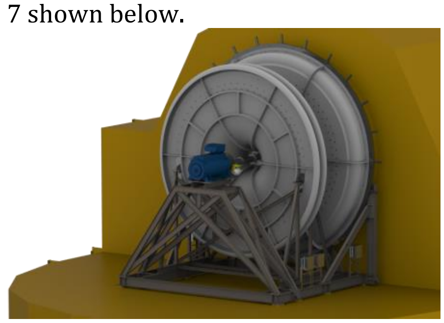

FIGURE 7 HYDROAIR ONBOARD OE35.

Electro-Mechanical Integration

The turbine will be connected to the generator by means of a direct drive shaft. This results in a simple mechanical assembly, with ease of access to turbine rotor during planned maintenance and repairs.

Electrical Sub-system

The electrical subsystem consists of the generator, variable frequency drive (VFD) and provides interface to connect with the primary transformer and switchgear, which subsequently transmits power to the on-shore grid. The one-line diagram of the system is shown in Figure **Error! Reference source not found.**

Permanent Magnet Generator

Based on the functional requirements of the HydroAir PTO, a list of key technical requirements for the generator was created: 1. Variable speed harnessing; the generator should be able to capture power from the full range of rotor speeds ranging from 350-650 rpm. 2. Efficiency greater than 97% for the operating rotor speed range. 3. Low auxiliary power consumption. These resulted in choosing the PMG as the generator choice of design.

VFD

To leverage the variable rotor speed and to produce grid compliant electricity, a back-to-back Inverter-DC-Bus-Converter system is connected to the generator.

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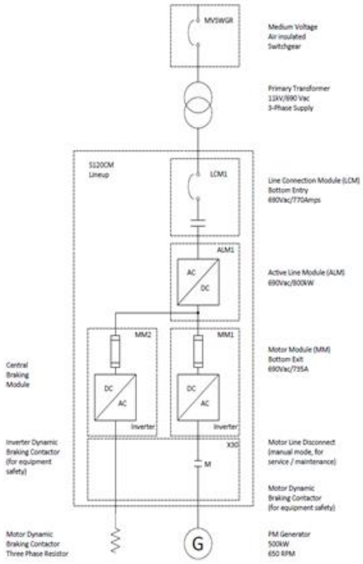

Figure 8 Electrical Schematic

Siemens SINAMICS S120 is a modular system to configure enclosed drive line-ups with a central line infeed (rectifier) and common DC bus supplying power to multiple motor modules (inverters). The S120 cabinet will be housed within the machine room of the Ocean Energy buoy.

WETS DEPLOYMENT

The OE35 will be installed at berth A at the WETS site. This deployment location has a water depth of approximately 60m and has a compatible three-point catenary mooring pre-installed. A six-month fabrication and fit-out schedule at the Vigor shipyard Portland, Oregon will be followed by commissioning and testing before the hull is transported by wet tow to Hawaii.

Once on site, the umbilical cable will be connected on board the device and cold spliced to the subsea cable anchor as a dry mate action. Both the trunk cable and umbilical have an embedded fiber optic cable for data transfer and control, which will also be connected at the cable anchor.

The 12-month deployment at the WETS site will allow for a systematic operation and test schedule to be carried out, with the objective to understand as much as possible about the interaction of the hull and PTO across the various sea states experienced on site.

The site at WETS has an average wave climate of approximately 12kW/m [2] , therefore the site is benign in terms of the North Atlantic. In comparison, the site at EMEC has an average wave climate of 22kW/m [3]. Figure 6 shows the Joint Probability Distribution (JPD) wave climate This clearly shows the limitation of the exposure the OE35 will have to high sea states at WETS.

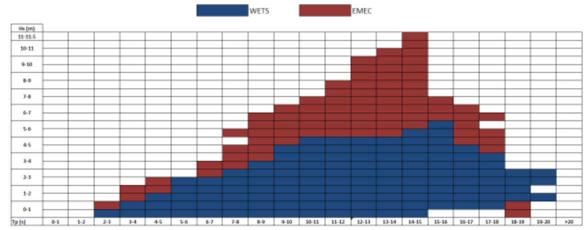

FIGURE 9 WETS & EMEC JPD COMPARISON

EMEC PROJECT

A follow-on project to the WETS deployment will be a 12-month installation of the OE35 at EMEC. However, the PTO will be ungraded to a 1MW rated machine.

Further details of the background to this project, its implementation and schedule will be presented.

CONCLUSIONS

Ocean Energy have followed each stage of the development process that has been adopted as best practice for the wave energy industry, and are actively involved in two projects to complete Stage 4 of the development process.

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