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Lessons learned using electrical research test infrastructures to address the electrical challenges faced by ocean energy developers

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ABSTRACT

The design and control of power take-off systems (PTO) of wave energy converters (WECs) require in-depth analysis in order to ascertain their energy capabilities and operation boundaries. However, many of the properties of the PTO system can be difficult to replicate in numerical simulations. The use of electrical research test infrastructures incorporating hardware-in-the-loop (HIL) simulation can be used instead to investigate the operation of the device using real electrical equipment and measured signals, in combination with the simulated numerical model. This paper will demonstrate the methodology of integrating a WEC into an electrical test infrastructure incorporating HIL, and adapting the WEC to fit to the physical limitations of the infrastructure. Four case studies of oscillating water column devices, at various stages of development progress, are used to illustrate the procedures. The results show the benefits and limitations of using the electrical test infrastructure, and the lessons learned that must be taken into account for future tests. Finally, recommendations are made on how electrical test infrastructures may be advanced in order to accelerate the development of WECs.

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1. Introduction

The European Blue Growth initiative is seeking a 'future innovative offshore economy' with marine renewable energy highlighted as a key contributor [1]. Initiatives of this type have resulted in increased focus on research and development activities in grid connection of ocean energy devices, particularity in the area of control and performance of the generators, power electronics and the grid interface equipment. The consensus from literature and communications with the ocean energy industry is that the most promising cost-reduction pathways for WECs, in relation to electrical components, are in the area of advanced controls, and improved power conversion for increased energy yield, [2–8]. Sub-systems including control systems, power take off (PTO), and power electronics are also identified as an area of high importance in research prioritisation in [5]. Moreover, it has been identified that optimised control strategies allow a reduction in capital expenditure by providing a significant increase in yield with a marginal increase in capital costs (sensors and software), without the need for structural modifications to be made to the device [7,8].

Presently, wave energy converters (WECs) have very high levelised costs of electricity. The high risk and high costs associated with testing at sea do not allow for iterative at-sea design, therefore laboratory scale electrical test infrastructures are used in the interim for prototype development in a controlled and repeatable test environment. These infrastructures provide a cost effective method of investigating different configurations of electrical components and control, and obtaining bench test measured data. They allow the WEC developer to address the many electrical challenges that exist in developing and deploying the device at sea. The testing of devices on electrical test infrastructures is essential before prototype testing to reduce complexity, and thus cost, during the development of the project. PTO and control design for WECs can be facilitated using onshore hardware-in-the-loop test-rigs. There are numerous advantages of such systems. The electrical test infrastructures can be used to compare and validate numerical models, and to verify that the designs operate as theoretically predicted. They enable various generator and power electronics configurations to be tested under both normal and extreme sea states in an onshore, controlled environment. The infrastructures can also be used in the design and optimisation of control algorithms to maximise the efficiency of the WEC while maintaining proper power quality in the grid connection. Careful analysis of the PTO control strategy enables optimal sizing of the electrical equipment during the design phase [9]. Small-scale electrical test infrastructures are available at University College Cork (UCC) [10], Tecnalia [11] and SINTEF [12], while larger scale electrical test facilities are available in NAREC [13] and DTU [14]. Further details of these facilities are given as part of the FP7 MaRINET project [15].

There are many different types of WEC PTO systems; a summary of the main types is given in [16]. While oscillating water column (OWC), overtopping devices and hydraulic motors coupled to generators may be emulated by a rotary test rig, concepts using hydraulic circuits or linear generators required different test infrastructures. A heaving buoy was emulated using a linear test rig in [17] in order to optimise its control law. The system consists of two 350 kVA power electronics converters with a common DC link, and a DC/DC converter with brake resistor to dump the energy of the linear electric generator in the case of issues with the grid side converter. The electric linear generator is a switched reluctance machine that is divided into two sub-machines where one is used as a motor actuator and the other is operated as a generator. Both are driven by the power electronic converters. A quarter scale linear electromechanical test rig is available in [10], which replicates the linear motion of the structure that would be induced by waves. Scaled WEC prototypes can be directly attached to this system for characterisation and analysis, or alternatively, this test rig can also be used to test moorings [18]. A two-body heaving buoy with a hydraulic PTO was tested using hardware-in-the-loop (HIL) in [19] where the main objective of these tests was to validate the state space models by measuring the displacement of the hydraulic piston. A representative PTO was used which consisted of a hydraulic cylinder connected to a motorised proportional valve which was used to vary the PTO damping coefficient. Stroke lengths were limited using buffer end stops. A WEC device based on the gyroscopic effect was tested in a HIL test rig which was able to emulate the wave induced motion of a floating structure in [20]. The test rig replicated pitching angle by either using a time history file which is then directly reproduced by the test rig or by HIL simulation, where the pitching was