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Advanced Hydraulic-Electric Power Take Off (AHPTO)

WES Power Take Off
Stage 1 Project
Public Report

Nova Innovation

This project has been supported by Wave Energy Scotland

Abbreviations

AHPTO – Advanced Hydraulic Power Take Off

LCOE – Levelised Cost of Electricity

OWC – Oscillating Water Column

PMG – Permanent Magnet Generator

PTO – Power Take Off

WEC – Wave Energy Converter

WP – Work Package

1 Project Report

1.1 Project Introduction

The objective of the Advanced Hydraulic-electric PTO (AHPTO) has been to utilise a novel combination of proven, 'best-in-class' hydraulic and power electronic subsystems to significantly increase the power capture, reliability, controllability and grid compatibility of WEC prime-movers.

1.2 Description of Project Technology

Simple 'off the shelf' industrial hydraulics have been employed alongside supercapacitors and full-scale rated converter power electronics to more efficiently convert the WEC power fluctuations into grid-compliant power.

An overall schematic diagram of the AHPTO system is shown in Figure 1

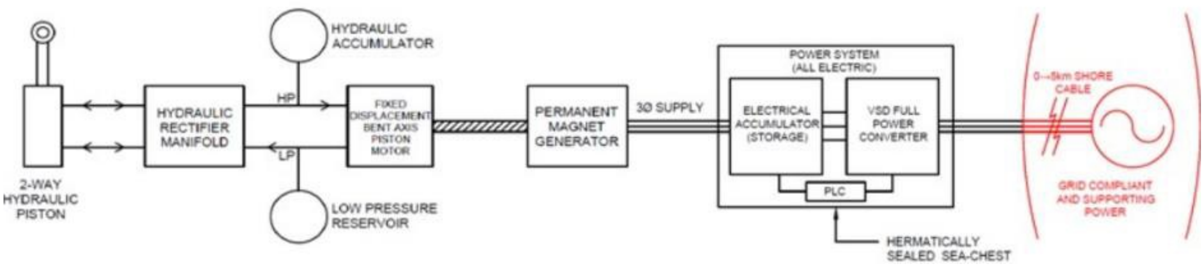

Figure 1 - AHPTO Schematic, Copyright © Nova Innovation 2016

1.3 Scope of Work

The project has been divided into 4 primary work packages:

WP1 – Concept Investigation and Simulation. A wave to wire model of the AHPTO system and its interaction with two different WEC types has been simulated in Mathworks' Simulink/Simscape. A reliability assessment has been conducted and compared to the 'best in class' system.

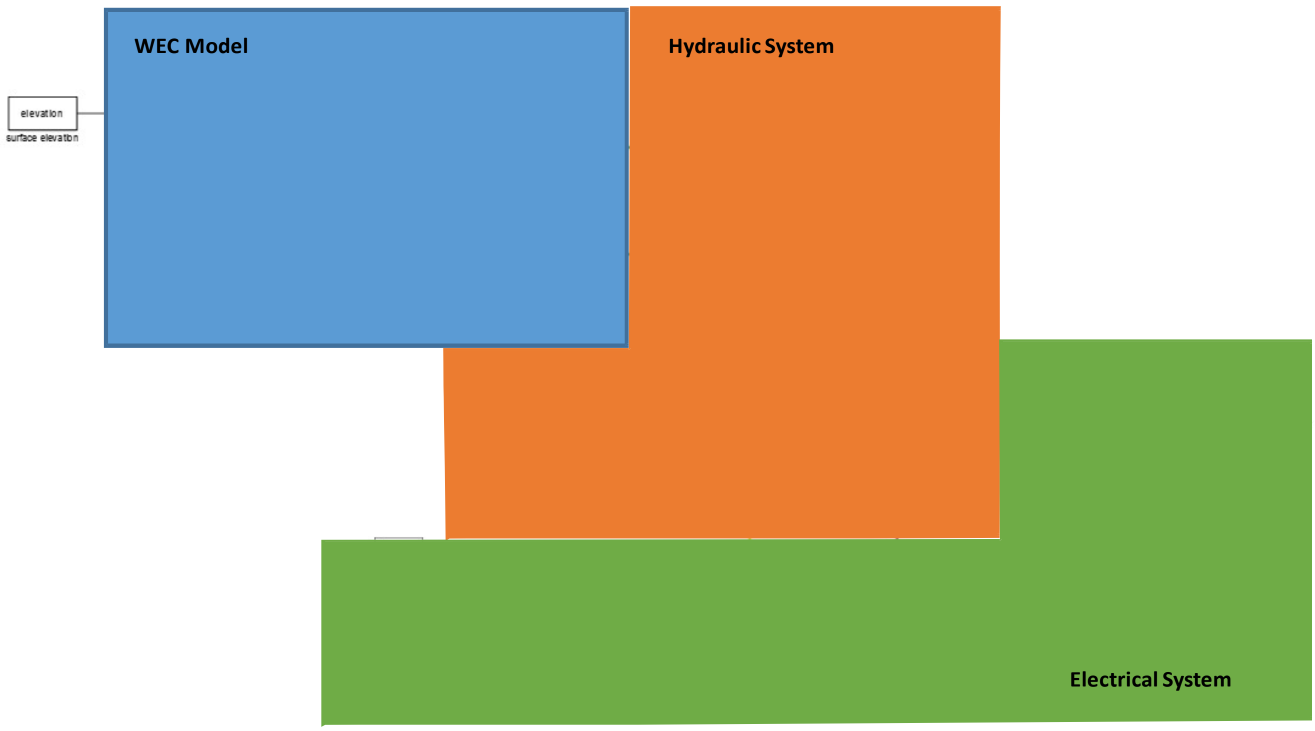

Figure 2 - 'Wave to Wire' Simulink / Simhydraulics model, Copyright © Nova Innovation 2016

WP2 – Concept Optimisation. The simulation from WP1 has been further enhanced with a refined model of the power electronics and control system. This model has been used to assess the performance of the system and its sensitivity to a number of parameters.

WP3- Scaled System Testing. A scaled system (1kW) has been constructed incorporating both physical and simulated elements of the system. Simulations running on a real-time computer have provided the inputs to, and receive feedback from the physical elements of the system. This 'hardware-in-the-loop' approach offers a cost-effective method of testing elements of the system under conditions that would otherwise be impracticable, such as the system response to irregular 'real world' waves.

Figure 3 - Scaled System Test Setup, Copyright © Nova Innovation 2016

WP4- LCOE Analysis. A model was developed to assess the improvement in levelised cost of energy (LCOE) of the AHPTO system over the current 'Best in Class' wave energy PTO system.

1.4 Project Achievements

1 Using Permanent Magnet Generators (PMGs) and Variable Frequency Drives (VFDs) it is feasible to construct a hydraulic PTO based on fixed rather than variable displacement hydraulic motors. This architecture can operate at high efficiencies in the vastly varying power levels associated with irregular wave conditions.

2 Matlab, Simulink and the Simscape toolboxes are effective software tools for modelling WEC PTO systems. Models of the response of two types of WEC have been created and coupled to the hydraulic system, PMG, power electronics and control system. The two WEC types are an Oscillating Wave Surge Converter and a Heaving Surging Buoy.

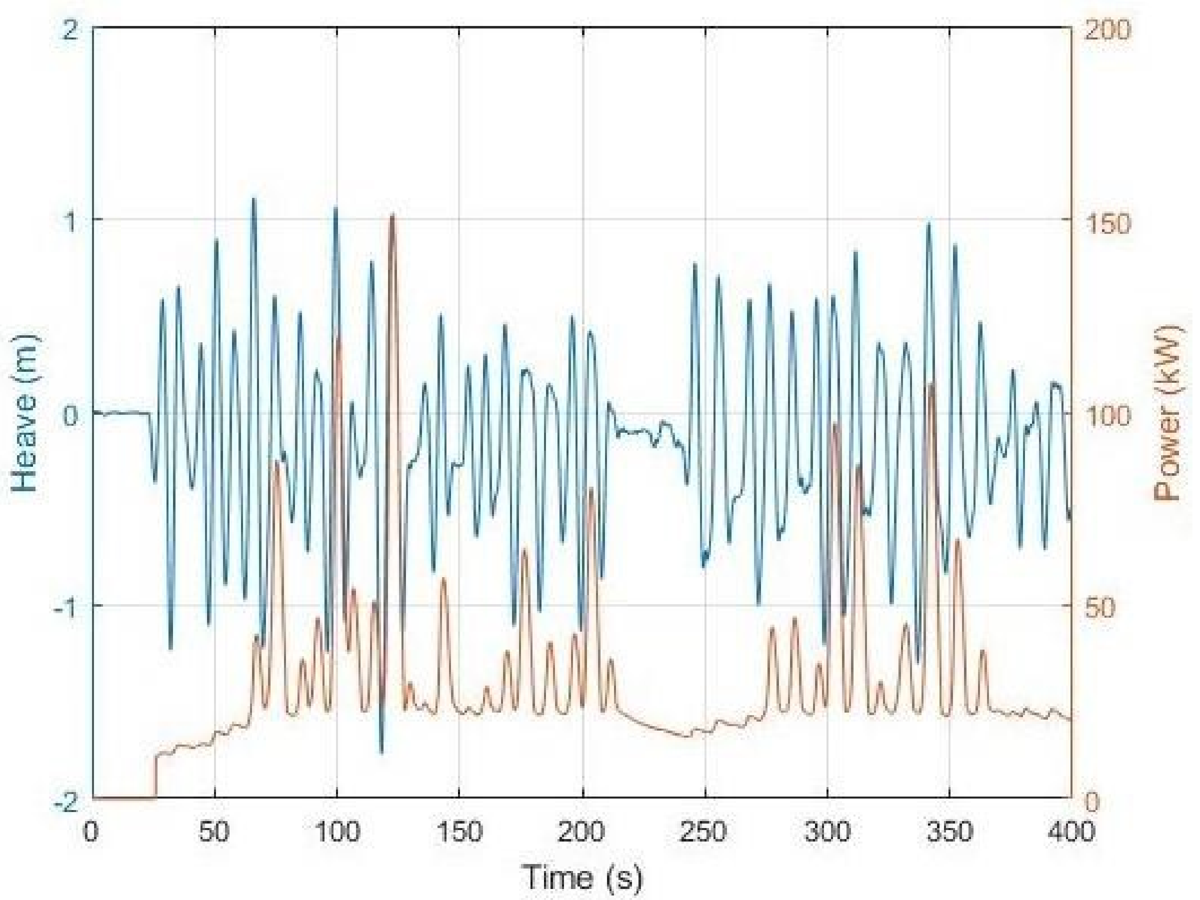

Figure 4 - Example Simulation Output of the Motion of a Buoy type WEC in Irregular Seas and the Power at the Hydraulic Motor, Copyright © Nova Innovation 2016

3 The ratio of the peak power absorbed at the hydraulic cylinders to the average power exported to the grid in commonly occurring irregular seas was found to be around 10:1. This is consistent with findings reported by Pelamis.[1]

4 Simulations have concentrated on the system response to irregular waves. Whilst the use of regular wave simulations can be useful in the early development and understanding of the behaviour of concepts, the irregular waves that are experienced in practice are the only true test that a system is fit for purpose.

[1] SEC-D-004_D2-3_PTO System Performance and Reliabiity_C3 – confidential report

5 Incorporating an element of electrical energy storage allows control over the quality of power delivered to the grid. The delivery of smoothed power to the grid has been demonstrated in a scaled test.

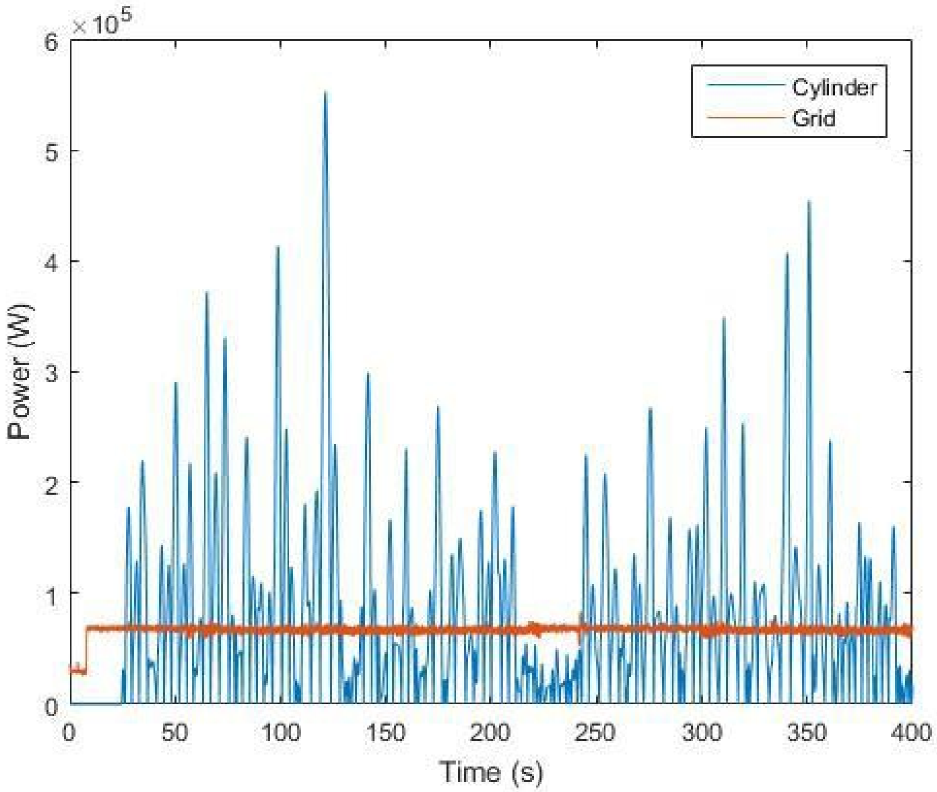

Figure 5 - Results from a scaled test showing hydraulic power at the cylinder (simulated) and smoothed power (measured) being delivered to the grid, Copyright © Nova Innovation 2016

6 The reliability of hydraulic and electrical / electronic systems is highly sensitive to the operating environment and duty of the component. Generic reliability data from industry can be misleading unless it is possible to identify and isolate results that represent truly comparable operating scenarios. This is rarely the case for wave power applications.

7 The use of dual redundant drive trains has a number of advantages:

i. In low power sea conditions where fixed losses are significant, operating on a single, smaller system is more efficient.

ii. In the highest annual energy seas one half of a dual redundant drive train can still produce a high percentage of the power that could be captured by the full system. This is because the system needs to be over rated to cope with large seas and transient peaks. This translates into an availability improvement.

8 The charge/discharge rates and the number of charge cycles of current battery technology is not suitable for smoothing the high frequency power flows associated with wave-by-wave smoothing. Supercapacitors are however suited to rapid charging and discharging and to millions of charge discharge cycles.

9 A small scale test has been constructed that utilises a real-time computer running a simulation of the WEC and hydraulic system. This is coupled to a physical test of the PMG, power electronics and energy storage system. This method of incorporating simulations into a physical test using modern computing hardware and software systems represents a cost effective and rapid means of testing components and sub-systems.

Expensive, large or otherwise impracticable aspects of the system can be simulated but still provide representative outputs (and receive feedback from) the physical system. Whilst it has been used here to test the AHPTO system the method is generically applicable to many dynamic systems. It is particularly relevant to the Marine Energy sector where testing a prime mover in real or representative conditions can be prohibitively expensive.

10 It has been possible to generate directly comparable results between the small-scale Hardware-in-the-Loop test and the entirely simulated system. This gives confidence in the methodology that has been adopted.

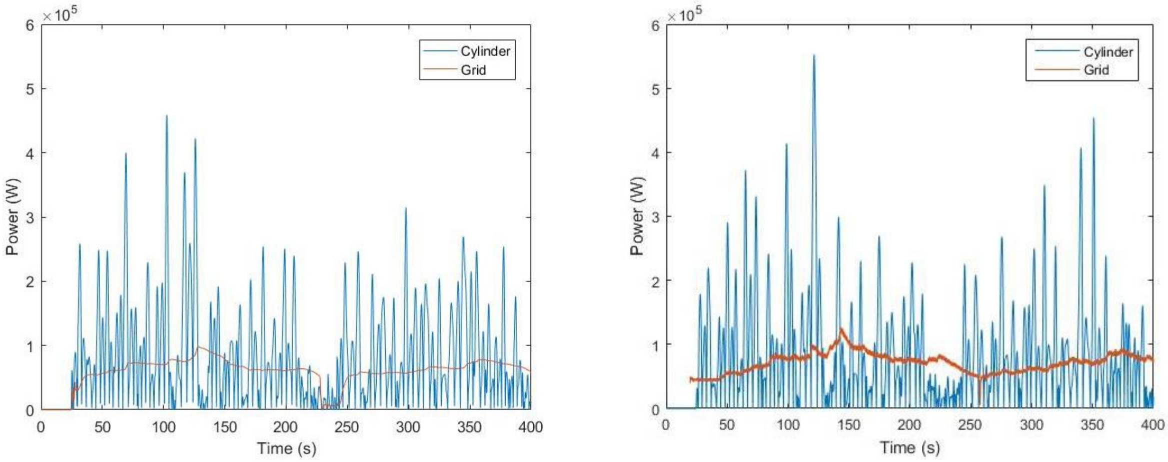

Figure 6 - Power at the cylinder and delivered to the grid for the full scale and the scaled test systems, Copyright © Nova Innovation 2016

1.5 Applicability to WEC Device Types

This technology is suitable for any WEC type that extracts power by the application of force between two (or more) rigid bodies, or between a body and the seabed. i.e. it is applicable to all WEC types other than those which are defined by their PTO type such as overtopping devices and Oscillating Water Columns (OWCs)

1.6 Summary of Performance against Target Outcome Metrics

This stage 1 study has shown that the AHPTO concept is technically feasible and that it has certain advantages:

- The energy conversion efficiency of the PMG/VFD is very good over a wide range of torque and speed. Our simulations indicate that the overall AHPTO system efficiency should be as good as, or slightly better than the 'best in class' system.
- The quality of power delivered from the energy storage system is superior to that which can be extracted from a system with accumulator storage only.
- There are advantages to the use of dual redundant drive trains. Firstly, in low power sea conditions where fixed losses are significant, operating on a single smaller system is more efficient. Secondly, in the highest annual energy seas one half of a dual redundant drive train can still produce a high percentage of the power that could be captured by the full system. This is because the system needs to be over rated to cope with large seas and transient peaks.

However, it is anticipated that the improvement in LCOE of the AHPTO system compared to the 'best in class' hydraulic system is likely to be modest (in the order of a few percent). It would also require a very significant investment of both time and money to develop the AHPTO system to a comparable stage as the 'best in class' hydraulic system. For these reasons the decision has been taken not to progress to a Stage 2 application.

1.7 Communications and Publicity Activity

There are no communications or publicity activity planned in regards to this project.

1.8 Recommendations for Further Work

Due to the outcomes in this project showing only marginal benefit it is felt that this project should not be taken forward.