CPower Alba
power from the next wave

Wave Energy Advanced Control System (WEACS)

WES Control Systems Stage 1 Public Report

CPower Alba Ltd

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1 Project Introduction

The Wave Energy Scotland (WES) Control Systems competition seeks to help novel wave energy conversion systems characterize and adapt to prevailing wave conditions through increasingly sophisticated control systems, while demonstrating feasible and practical means of advancing the state of the art. A competitive stage-gated process allows evaluation at the feasibility-, numerical-simulation and physical-demonstration phases, to help ensure value for money during the R&D progression.

The Wave Energy Advanced Control System (WEACS) project is intended to research, design and develop a holistic control system, that includes high-level supervisory and diagnostic functions, along with low-level, real-time dynamic-control processes. WEACS will play a critical role in wave energy conversion device (WEC) control in that it is responsible for operational control of all subsystems under normal, extreme, fault or other conditions.

The ultimate figures of merit for WECs are the ability to survive in the open-ocean and the ability to produce electricity that is cost competitive. Among the most important high-level functions of WEACS are the ability to ensure safe and effective WEC operation and to extract the maximum possible energy from the wave environment. Ultimately, WEACS will handle wave-to-wave generator control by commanding the most appropriate generator driveshaft torque. The coded and compiled algorithm that accomplishes this task (Optimisation Module), will both optimize wave power extraction by the WEC, while not violating other system constraints, e.g., temperature, torque and speed.

During Stage 1, a comprehensive literature review was conducted that assessed the current state of the art in control methods. A ranking system was utilized to select the most-appropriate methods for Stage 2 controller development, with a focus on suitability, maturity, practicality, and potential benefit. Broad examination and evaluation of the most-relevant control strategies for this project yielded two methodologies for Stage 2 development: Approximate Complex Conjugate Control / Optimal Velocity Tracking (ACCC/OVT); and, Model Predictive Control (MPC).

Selecting both allows for clear advancement over the baseline linear damping scenario with an aspirational target approaching the theoretical optimum for energy extraction in most sea states, while balancing risk and reward in later project Stages. ACCC/OVT offers a level of computational simplicity that indicates a more-practical opportunity for real-time operation, and a level of robustness with respect to handling of uncertainties from real-seas that can help to improve long-term survivability of the WEC as well. MPC can, in turn, be seen as a natural extension, benefiting from the work to be conducted for the ACCC/OVT implementation, carrying the potential for further benefits across a range of key metrics.

The Stage 1 team included CPower Alba Ltd, its internal project lead Cruz Atcheson, and project team members Wood Group and Wave-Venture.

CPower Alba Ltd and its parent Columbia Power Technologies, Inc., collectively (CPower), are developing a utility-scale WEC system, the StingRAY. CPower's Product Development and Delivery team have extensive theoretical and applied experience in wave energy applications. They possess engineering, theoretical, and academic backgrounds directly applicable to wave energy, including: electrical; mechanical and nuclear engineering; maintenance supervision; quality assurance; electric plant operations; electric transmission design; industrial controls and design; control theory; electromagnetic motor design; magnetic circuit design; and a breadth and depth of knowledge gained from an extensive series of scaled physical wave energy experiments. The engineering team has over 50 man-years of numerical modelling and experimental validation history and over 30 man-years of experience with direct-drive investigation. The company has a successful track record managing complex multi-year projects and employing multiple project partners.

Cruz Atcheson is an independent engineering consultancy, having no equity stake on any project or technology and specialising in wave, tidal and floating offshore wind energy applications.

Three key areas of work focus are: concept design, due diligence support and project development support. Team members have unique expertise in the development of design tools for wave, tidal and floating offshore wind applications, and over 50 person-years of direct experience.

Wood Group is a leading clean energy, multi-disciplinary engineering consultancy specialising in renewable energy. Wood Group has the capability to deliver at every phase of a project, from the early stages of site selection, feasibility and design right through to project management of the construction phase and operation and maintenance. The highly-qualified team of over 320 consultants have extensive UK and international experience providing consultancy services in over 90 countries across six continents. To date, Wood Group has assessed over 160 GW of renewable energy development internationally.

Within the controls field, Wood Group is world-class in its breadth and depth of expertise and experience, with expertise acquired from over 25 years into all areas related to control design, from modelling, to system identification, signal processing, load calculations, control certification, implementation, retrofitting, commissioning and service.

Wave-Venture is a specialist wave energy consultancy and software provider. Over the past 15 years, Wave Venture staff members have developed unique capabilities and understanding in wave energy technology research and development. From a base of strong engineering competence, we are focused on merging engineering and economic analysis methods and on applying these to deliver wave energy technology related services with a commercial focus.

They provide advisory and analysis services to companies that are: investing in wave energy technology; conducting research and development on wave energy conversion systems; and planning deployments of wave energy farms.

2 Description of Project Technology

WEACS serves as the central nervous system of a WEC. It provides many critical functions during calibration, commissioning, tow operations, deployment, recovery, and normal operation of the WEC. WEACS utilizes a modular input/output (I/O) design and should be adaptably connectable to all WEC systems, including the electric plant, station power (WEC's internal power distribution), cooling system, climate control, ballast control, bilge, safety and emergency, surveillance, and other auxiliary systems. These links may include digital and analog I/O, as well as standard communications protocols allowing the WEACS to issue commands and collect data from these WEC subsystems. It allows remote operators to access real-time data, capture WEC operational and performance data, and implement power take-off (PTO) control strategies. By utilizing an easily configurable hardware software interface, the system is adaptable to various WEC designs.

WEACS operates under the assumption that all WECs will be designed with their own independent safety and emergency systems that act independently of, but still communicate with, the WEACS system. This assumption is intended to assure that critical safety and regulatory requirements of the WEC are in the control of the WEC developer.

The WEACS programmable logic controller (PLC) provides primary control functionality of the WEC. The PLC has access to real-time and historic data, as well as external (internet) data.

Software and logic facilitates all control actions required during WEC operation. The control hardware will be programmed to perform the desired algorithms for the PTO and cooling systems. The control logic must also provide alarm functionality to alert operators when parameters are outside of operational set points including controlled shutdown. Algorithm programming may be accomplished in several different languages, allowing for greater efficiency.

The complexity of the control algorithm will necessitate that each WEC have its own Optimisation Module, however, with varying degrees of similarities among various WECs, it is likely that aspects of these will be transferrable.

During real-time operation, WEACS will compute and send a commanded value for generator current to accomplish near-instantaneous generator control that provides the required generator reaction torque to achieve the optimised commanded and actual driveshaft torque. This will optimize wave power extraction by the WEC, while not violating other system constraints, e.g., temperature, torque and speed. When safe limits (max/min caps on a parameter of interest) are imposed, it is done to prevent exceedance of that parameter to prevent component damage, but power will continue to be produced and the WEC is not shut down.

3 *Scope of Work*

Stage 1 comprised five work packages.

1) Project Management. Deliverables include: Risk Register - a comprehensive programme and technical risk register; Feasibility Study - a confidential report of the Stage 1 activities, findings, and achievements against Target Outcomes; and this Public Summary Report.
2) WEACS Methodology. The objectives were: definition of WEACS intended control command actions and measurement/sensing/modelling/prediction requirements; confirmation of WEACS ability to deliver the required control system functionality; confirmation of the project-targeted StingRAY WEC's controllability and ability to be integrated with WEACS; and assessment of WEACS applicability to other WEC and PTO types.
3) WEACS Impact. The objectives were assessment and reporting of the expected benefits of WEACS in the WES Target Outcome Metric areas.
4) WEACS Implementation Feasibility Assessment. The objectives were: confirmation of suitable software and hardware for both project development and commercial production; selection of the appropriate control development methodology; and confirmation of WEACS overall feasibility and readiness to enter the design and development phase.
5) Stage 2 Application & Stage 3 Preliminary Plan. This task focused on the completion and submission of the Stage 2 application, including simulation plan, and the Stage 3 Preliminary Plan.

4 *Project Achievements*

Stage 1 achievements:

- The WEACS system, its status, functionality, design and applicability to various WECs were described in detail, yielding a positive assessment of the feasibility of its development, simulation and implementation in subsequent stages.
- The available WEC simulation and controller development environments were surveyed with the specific objective of selecting a practical and robust platform for Stage 2 Optimisation Module development. The choice of the Simulink/WEC-Sim/AQWA combination, along with deep experience within the team, provides a platform for both rapid development and thorough verification and de-risking of the

Optimisation Module. This also sets the stage for a successful physical demonstration in Stage 3, leading to eventual commercialisation.

- The comprehensive literature review assembled, explained and assessed the current state of the art in control methods. A ranking system was created to select the most appropriate methods for Stage 2 controller development, with a focus on suitability, maturity, practicality, and potential benefit. This broad examination and evaluation of the most-relevant control strategies for this project yielded two methodologies, ACCC/AVT and MPC, that will be taken forward to stage 2.
- The benefits of the most-relevant methodologies were assessed with respect to their impact on WES Target Metrics, further supporting the dual choice of MPC and ACCC/AVT.
- Demonstration that WEACS' design, development, simulation and testing within Stages 2 and 3 is both feasible and desirable, with the potential to have industry-wide benefits and a direct impact in near-term future StingRAY WEC developments in Scotland.

5 Recommendations for Further Work

Recommended scope for Stage 2 includes:

Design and development of the proposed control system

1) Development of the Optimisation Module algorithm for WEACS implementation
2) Software-in-the-loop (SIL) simulation of the integrated WEACS controller and StingRAY hydrodynamics numerical model
3) Demonstration of the improvement in the WES Target Outcome Metrics
4) Assessment of the impact of e.g., delay, failures, hardware degradation and other potential input errors

Front End Engineering Design (FEED) of Stage 3 control hardware, including

1) Definition of the hardware-in-the-loop (HIL) demonstration of the integrated WEACS controller
2) Control system hardware
3) Practical measurement/sensing
4) Actuation/control action mechanism capability
5) Demonstration and testing of any key hardware components or systems

Front End Engineering Design (FEED) of Stage 3 physical demonstration hardware

1) Definition of requirements and FEED of test rigs and associated hardware for physical demonstration in Stage 3
2) Definition of the improvement in the WES Target Outcome Metrics from the physical demonstration

6 Communications and Publicity Activity

The WEACS team attended the WES Annual Meeting and presented a poster describing the project.

7 Useful References and Additional Data

WEACS Stage 1 Feasibility Assessment.docx (Confidential)

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