PALM prototype design and test

WES Quick Connection Systems
Stage 3
Public Report

Apollo

This project has been supported by Wave Energy Scotland

1 Project Introduction

Apollo have developed the PALM (Pull and Lock Marine) QCS (Quick Connection System) for WES (Wave Energy Scotland) as part of WES' Scottish Government funded programme to accelerate technology innovation for wave energy.

Stage 3 of the programme has seen the design, manufacture, and testing of a demonstrator-scale PALM prototype.

This document presents a public record of the advances made in the Stage 3 WES project and identifies residual risks and opportunities for further development in the progression towards commercialisation of the PALM system.

2 Description of Project Technology

The PALM QCS comprises a plug and receptacle. The receptacle is permanently mounted to the floating structure, i.e. the WEC (Wave Energy Converter), and the plug is permanently connected to the moorings and/or electrical export/inter-array cable. The action of pulling the plug into the receptacle connects the WEC to its mooring and electrical connections.

The plug is pulled into the receptacle by a winch or crane line on the installation vessel. There is no additional locking mechanism required, meaning there are no divers, ROVs, or electrical/hydraulic control lines running down to the connection. The cam slot mechanism is at the core of the PALM's innovation, and it is this design feature that allows the connection to be made with minimal moving parts. Mechanical simplicity is a core driving principle of the design, in order to minimize CAPEX and maximise reliability.

The functionality of the prototype design, constructed in the Stage 3 project, is mechanical and electrical. The mooring load is transferred through the tapered load shoulders, and the electrical connection is made through 3 wetmate stab connectors.

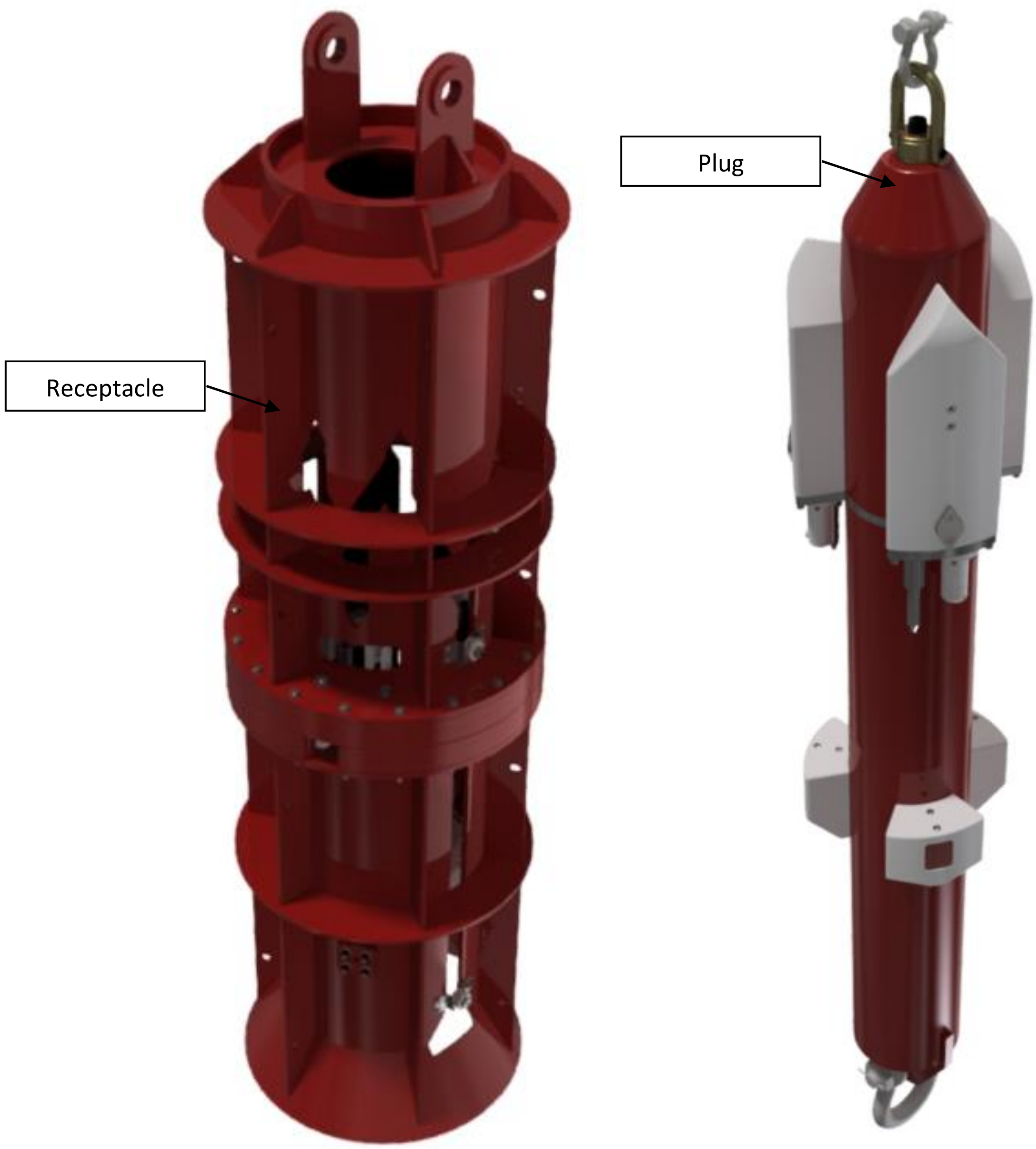

Figure 1 : PALM QCS Prototype

3 Scope of Work

3.1 Overview

Stage 3 saw the physical demonstration of the PALM QCS for a notional WEC in the format of detailed design, prototype manufacturing, onshore function testing, and open-water trials.

Target outcomes for the stage were as follows:

- Generate evidence that the duration, cost, and risk of offshore operations for prototype wave energy converters will be improved by use of this QCS.
- Mitigate technical and implementation risks for use of the QCS, through demonstration of the QCS systems under relevant operational environment conditions.
- Provide WEC developers with sufficient confidence to allow the QCS technology to be incorporated into the design of their early stage WEC prototypes.
- Optimise the design of a refined QCS system that complies with regulatory and classification requirements for development of the proposed connection system.
- Propose and adopt a credible strategy for commercial development of the QCS technology.
- Engage with developers, offering credible short term opportunities to apply the QCS to prototype device demonstrations.

The Stage 3 project began with further conceptual design and the primary geometrical definition of the workshop/site testing prototype. It was important to develop the full-scale prototype's key features and geometry first, to ensure that the laboratory 1/8th-scale prototype design was representative.

The design team developed the concept in CAD, with engineering verification largely conducted by FEA. The wider project team and WES representatives were invited to interrogate the design through review sessions. Through this iterative process the design was developed and ultimately frozen, allowing the 1/8th-scale prototype to be designed, printed, assembled, and tested.

Laboratory test outcomes were compiled and reviewed by the project team. Critical learnings were identified, with design changes actioned by the team to optimise the full-scale prototype for the workshop test.

In tandem with the detailed design of the full-scale prototype, the engineering team developed the workshop and site testing programme requirements and procedures. This involved additional design effort in creating storyboards, rigging drawings, and manufacturing drawings for the required testing support frames.

The Apollo team worked closely with the fabrication team at GEG (Global Energy Group) South Fabrication division to manage the procurement, fabrication, machining, and assembly phases of the prototype build.

The workshop test phase began with the integration of the telemetry systems (developed by WWW Engineering) that would be used to monitor the PALM QCS's function during the onshore and in-water trials. The kit was then moved to and assembled at the test site at GEG South Fabrication. The PALM QCS was successfully trialled through several functionality tests, a misalignment test and a 20-tonne static load test.

The project team reviewed the outcomes from the onshore test and agreed the necessary actions to be completed prior to the in-water testing.

Apollo worked with Briggs Marine (who provided the vessel and crew for in-water testing) to finalise the test procedure and – along with GEG – to make final logistical arrangements for the harbour and site testing.

Harbour and site testing saw the successful function testing of the PALM in water, including multiple trials of the marine operations procedure, representing a full deployment and recovery sequence for a marine energy device.

3.2 Laboratory scale testing

A test rig was built from aluminium extrusions to support the receptacle and a small electric motor winch drive. A PLC program was written to control the motor to run the plug up and down repeatedly, completing hundreds of trial connections and disconnections. This setup went on to be used as a demonstration and marketing tool at several marine energy conferences and events.

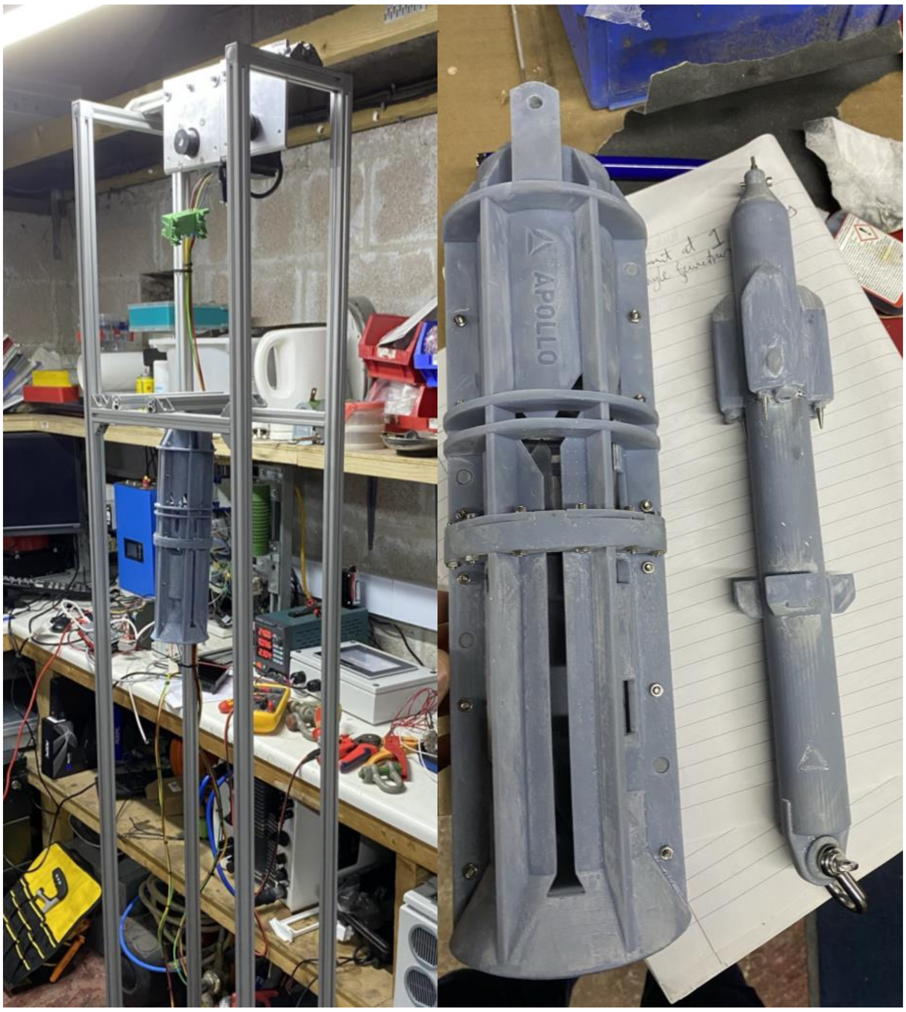

Figure 2 : Laboratory scale test rig and 3D printed model

3.3 Workshop testing

Essentially this was a scaled-up version of the laboratory test, with a manufactured PALM QCS sized to meet the requirements of the primary test case WEC that was studied in Stage 2, the Mocean Energy Blue X device.

A steel frame supported the receptacle, and a mobile crane was used to raise and lower the plug. The testing scope included function testing, misalignment testing and proof testing with a 20-tonne static load.

Figure 3 : Workshop test rig and prototype PALM QCS

3.4 Quayside and site testing

The same test frame was flipped into a horizontal configuration and welded to the deck of the testing vessel, allowing for in-water function testing and full marine operations trials. The function testing confirmed that the PALM QCS could be connected and disconnected underwater, using a winch installed on the back deck of the testing vessel (the Forth Constructor). Full marine operations trials comprised the pull in and connection/ disconnection of a simple mooring in a semi-open water location using the vessel's winch and craneage.

Figure 4 : PALM QCS mounted onto the Forth Constructor for quayside and site testing

4 Project Achievements

A full PALM connection cycle was completed in 18 minutes during in-water testing, timed from approaching the buoy to successful mechanical and electrical connection. This was with a crew and vessel performing the procedure for the first time, and with significant room left for optimisation of the steps. It is not unreasonable to now target a 10-minute connection time for the PALM at this scale. Disconnection timescales are similar.

The risk of offshore operations was explored thoroughly through trialling of the marine procedure. A number of key learnings were obtained through this practical experience that will be fed back into future deployments such as optimal mooring length, buoy retrieval methods and plug recovery/restraint methodology.

Stage 3 saw the PALM tested in increasingly relevant operational environment conditions, from the lab-scale through to site testing. This incremental progression was very effective in early identification and mitigation of design issues, in particular at the 1/8th-scale 3D-printed prototyping stage which highlighted some geometrical changes that had to be made to the design.

The site testing arrangement and programme offered an environment that was representative of the true conditions that a real-world PALM deployment for wave energy would see. The project team's understanding of the system's behaviour in this environment was greatly enhanced, with a number of valuable opportunities for improvement identified, including material choice and marine operations best practice.

At the conclusion of Stage 3, the Technology Readiness Level of the PALM QCS was self-assessed as being TRL5. The project documentation was reviewed independently by the European Marine Energy Centre (EMEC) against standard IEC TS 62600-10 "Marine Energy – Wave, tidal and other current converters – Part 10: Assessment of mooring system for marine energy converters (MECs)". UK and European patent applications have been submitted and published.

5 Recommendations for Further Work

The complexity of controlling 2 floating bodies (WEC and pull-in vessel) during deployment and recovery remains untested. This should be specified as a feature of the next stage of PALM development through additional physical demonstration. Also, while the geometric action of the electrical connector was simulated during Stage 3, a true electrical function test needs to be undertaken.

Key residual risks have been identified with regards to optimal marine operational procedures, as well as long-term integrity of the mechanism for failure modes such as mechanical wear, fatigue, corrosion, and marine growth. An extended prototype deployment of at least 6 months is in preparation, to address these risks, close out the above untested features, and raise the technology readiness level to TRL6.

Thereafter, the objective is to integrate the PALM QCS with a working WEC and complete a pilot deployment.

6 Communications and Publicity Activity

The PALM has been the subject of several webinars, presentations, and papers delivered by the Apollo project team, as follows:

- Institution of Mechanical Engineers (webinar, December 2021): A case study on the PALM technology and testing programme
- Marine Energy Wales (webinar, January 2022): A case study on the PALM technology and testing programme
- Society for Underwater technology (Aberdeen, April 2022): Gadgets and Widgets meeting; the PALM QCS
- Wave Energy Scotland Annual conference (Edinburgh, May 2022): update on the development of the PALM technology and testing programme
- Renewables UK Global Offshore Wind conference (Manchester, June 2022): FOW quick connection systems, featuring the PALM QCS.
- Institute of Marine Engineering, Science and Technology (webinar, October 2022): Physical testing of the PALM QCS
- Renewable UK Floating Offshore Wind conference (Aberdeen, October 2022): presentation and panel discussion regarding the PALM and floating wind O&M in general
- The Offshore Wind Growth Partnership Supply Chain Engagement Event (London, December 2022): pitch to investors on the commercialisation of the PALM QCS
- Subsea Expo (Aberdeen, January 2023): presentation on innovation technologies for floating wind O&M
- Marine Energy Wales 2023 conference (Swansea, March 2022): overview of the PALM QCS and future commercialisation

The PALM QCS was demonstrated in the following exhibitions:

- All Energy (Glasgow, 2022) – courtesy of Wave Energy Scotland
- Floating Offshore Wind (Aberdeen, 2022)

In addition, the PALM QCS has featured in various social media posts on the Apollo Linkedin and Facebook sites.

7 Useful References and Additional Data

Additional information on the system specification, functionality, and commercial modelling is available upon request (email: info@apollo.engineer).

Publicity Material

Filename	Media Type	Description
PALM WES render	.png	CAD model 3D render marketing image
PALM WES testing team	.jpg	Photo of the Apollo team and WES reps at the yard testing site
FOW PALM v2	.mp4	Video / slideshow of the Stage 3 activities