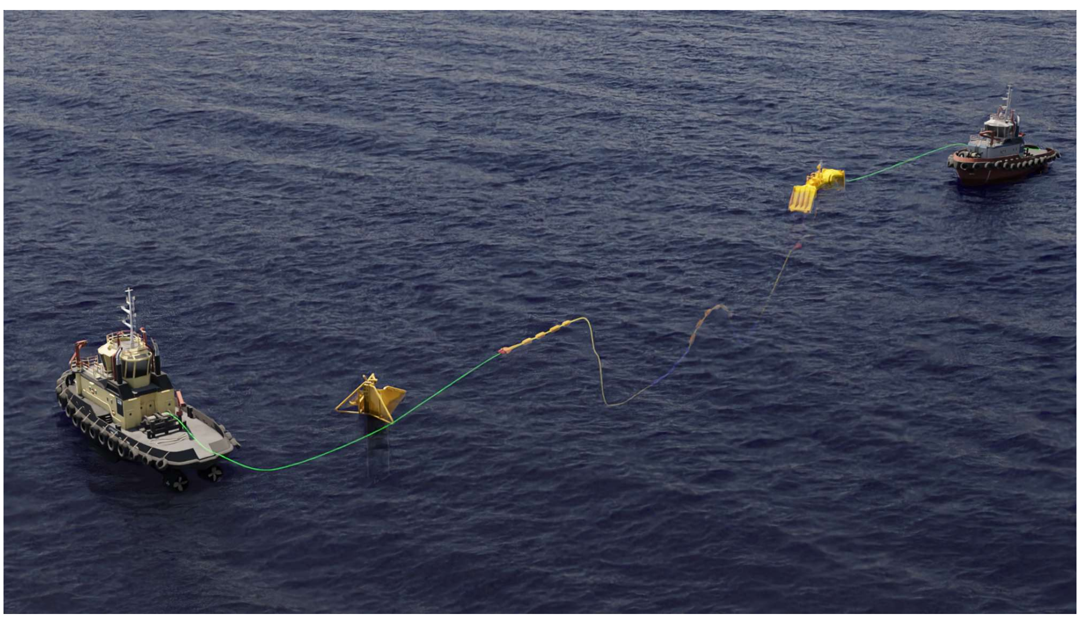
C-DART

WES Quick Connection Systems Stage 3 Public Report

Blackfish Engineering Design Ltd



This project has been supported by Wave Energy Scotland

1 Project Introduction

The Wave Energy Scotland Quick Connection System programme was explicitly created to enable the development of technology to support wave developers to reduce cost and risk of marine operations associated with installation and recovery of devices. The key drivers of the required solution are to maximise weather conditions for operations, reduce personnel risk and reduce the duration of the operation, whilst minimising the impact of power generation and infrastructure integration on the wave device.

Blackfish Engineering Design Ltd have created a novel concept as part of this programme. The concept was developed from scratch, creating a solution that specifically addresses these issues, as opposed to taking an existing solution or technology and developing it further for wave devices.

The project was led by Blackfish Engineering Design Ltd, an engineering consultancy based in Bristol specialising in mechanical system design and structural engineering for the offshore renewable and marine markets. Other companies in volved in the project were:

- **Skua Marine Ltd**, who are experts in marine operational planning, logistics and project management. Skua were instrumental in developing the marine operational aspects of the solution.
- **Morek Ltd**, who completed all of the Orcaflex analysis and naval architecture work
- **Flowave**, who managed and tested the 1/20th scale model to provide data for Orcaflex validation
- **Underwater Trials Centre**, Fort William, who provided vessels, personnel and a facility to demonstrate and prove the marine operations of the system. This was independently witnessed by **The Waves Group**, who provided valuable feedback in relation to the viability of the concept.
- **National Decommissioning Centre**, who provided the 3D simulation centre in order to demonstrate the concept virtually in large weather conditions. The model was created by the Offshore Simulation Centre in Norway.
- **Bureau Veritas**, who undertook an assessment of the concept from a certification point of view and provided a route map to guide the certification process.
- **Queen Mary University,** who undertook an assessment of the benefits of non-causal control and how it can be applied to the C-DART concept.

The stage 3 project required physical demonstration of the concept. Instead of a single test of the entire system at sea it was decided that several independent tests would be completed as part of this project, which included:

- A marine operations test, to demonstrate and prove that the vessel manoeuvres required as part of the solution were achievable and viable. This was completed using basic geometry to replicate the function of the connection device
- A full scale wooden mock-up to demonstrate the connection system technology on dry land, without the complication of using real vessels, to test and demonstrate the geometry of the system, tolerances, clearances and to more easily enable optimisation and modification.

- A 1/20th scale tank test to derive loads and motions of the connection system to provide validation data for the Orcaflex modelling.
- Virtual Simulation of the full device, based upon the validated Orcaflex model, to demonstrate viability of the technology in larger sea states that were impractical to test as part of the marine operations tests.

After these tests had been completed there was then a final phase of the project to capture all of the learning and create an updated design of the concept, based around a FEED study for connecting a Mocean Blue X1.1 device in a North Sea location.

The concept has been made to be as simple and reliable as possible, based on the exploiting the core principles of gravity, buoyancy, geometry and rope tension. As a result, there are no complex mechanisms, actuators, stored energy systems to provide a connection, or complex control systems required and the mated connection is entirely passive. In this way reliability is improved significantly.

The main requirements of the concept are that:

- It shall enable a mechanical and electrical connection and disconnection in sea states up to 2m Hs and 30kts wind in order to enable operations in worse weather to improve availability of devices.
- The concept shall not require major changes to the Wave Energy Converter (WEC) structure, mooring attachment, electrical attachment or control system, to simplify the integration with different devices.
- The system shall eliminate personnel HSE risks by ensuring no deck operations, divers, Remotely Operated Vehicles (ROVs), personnel transfers or close proximity vessel operations.
- The concept shall use standard available workboats, multicats or tug vessels with no modifications, that are available on spot market day rate, to improve availability and reduce downtime.

The original project scope was to develop two test cases for the technology. These were planned to be a solution for connecting and disconnecting WECs as well as an offshore charging system for electric Crew Transfer Vessels (eCTVs) to support offshore wind turbine farm maintenance. During the project, a derivation of the C-DART concept was created for a mooring only connector (no electrical connector) that is suited to temporary moorings. The scope of the project was therefore changed so that this concept could be developed and tested instead of the eCTV solution. This mooring connector became the second test case and assessed alongside the Mocean Blue X1.1 FEED study.

2 Description of Project Technology

2.1 C-DART floating WEC connection system

The C-DART concept is a system that enables a floating WEC, TEC or other floating structure to be mechanically and electrically connected to the seabed or other local infrastructure. The concept is based around a pre-installed sparbuoy with very specific geometry at the top. The WEC is towed to site and by using unique vessel manoeuvres the tow rope is caught by the sparbuoy and located such that an installation dart attached to the tow line is then pulled into the sparbuoy, located and locked in position. Once this has been achieved and electrical continuity tested, the tow line is released, leaving the WEC attached to the sparbuoy by a load bearing umbilical cable.

The release process uses a similar approach, by catching a tow line and engaging a second dart into the sparbuoy to release the installation dart.

In this way, the entire process is entirely hands free, requires no ROVs or divers, no deck operations, no personnel or vessel transfers, no close proximity vessel operations to transfer or tie off ropes. There are no complex mechanisms, energy storage (hydraulics, batteries, springs), no load bearing actuators or control system. As such, the reliability is increased compared to actuated systems that require control of mechanisms, and HSE risks are minimised. The sparbuoy is accessible for minor maintenance in calm wether and as all key infrastructure is above water the risks of leakage are minimised.

The operation is feasible in seastates up to Hs 2m and 30kts of wind from a variety of different headings and is viable using standard workboats, mulitcat vessels or tug vessels with no deck modifications.

The key advantages of the C-DART system are that it can:

- Provide a single sparbuoy that allows 360deg free yawing capability for the WEC
- Increase the operational weather window to allow operations in ~2m wave height (Hs), 1m/s tidal flow and hours of darkness to improve availability. This improves LCOE of a WEC by improving availability.
- Significantly reduce HSE risk: No ROVs, divers, high risk deck operations, personnel transfers or close-proximity vessel operations
- Achieve a connection in less than 10 minutes from arriving at the spar bouy
- Improve reliability with a passive connection: No actuators, stored energy systems, complex mechanisms or control systems
- Be easily integrated with WEC devices: Only existing padeyes and electrical cable interface, little performance impact, upstream flow measurement to provide yield improvement
- Use available small vessels on a spot market rates with no permanent deck modifications.
- Enable remote maintenance and connector capping

Detailed technical information is not available in this report as the technology is currently in the process of being protected by patent.

2.2 Mooring connector

During the course of development of the electrical and mechanical connector for a WEC device, a further concept was innovated to better exploit the potential available markets. The concept of using gravity, buoyancy, geometry and marine operations can also be applied to a much simpler connector without an electrical connection, to provide temporary mooring to vessels, platforms, barges or similar that require to be moored repeatably in the same location. This could be applicable to dive support, salvage, offshore construction, or in-harbour operations.

The principle of operation is similar to the C-DART concept, whereby a vessel is self-powered or towed to location, where a number of mooring buoys have been pre-laid using single catenary mooring chain. A tender vessel the pulls a mooring line with an in-line dart towards the mooring buoy, catches the rope on the buoy and the vessel the pulls the mooring line in. This catches the dart in the buoy and locks it in place using a simple gravity latch. It is now a secure mooring connection, and no personnel have been required to handle ropes, shackles or hydraulic locking pins.

To release the dart, a messenger line is attached to the rear of the dart and then either pulled from the tender vessel or pulled from the moored vessel. This releases the line and the moored vessel is free to steam or be towed away.

The main advantages of this system are that it:

- Reduces HSE risk, as no personnel are required to handle high tension or heavy lines, manage shackles, or connect using hydraulic hooks.
- Enables a much quicker connection and disconnection process than the incumbent manual from the buoys and more than one mooring can be disconnected simultaneously
- Eliminate the need to climb aboard a mooring buoy to make a connection, particularly in heavy seas
- It permits a safe remote release, even under load, so that the moored vessel can release itself easily if required without a tender boat to support

This system has been designed for smaller (<10m) vessels so that the release hand be achieved by hand, or larger (20m-30m) vessels that would require a winch to provide enough force to release the mechanism.

Detailed technical information is not available in this report as the technology is currently in the process of being protected by patent.

3 Scope of Work

3.1 C-DART concept

The scope of work for the stage 3 project for the C-DART concept included:

- Specification, design, manufacture, assembly, transport and two weeks of testing for the marine operations test at the UTC in Fort William. This test was completed to specifically demonstrate and prove viability of the marine operations and vessel manoeuvres required.

Figure 1 - Installation equipment (showing Loch Shiel and Ben Chrom vessels)

- Specification, design, Orcaflex assessment, manufacture, assembly and one week of testing at Flowave Tank facility in Edinburgh. The work included processing of the results, Orcaflex validation activity and creating a new Orcaflex model of the system based on the validation data.

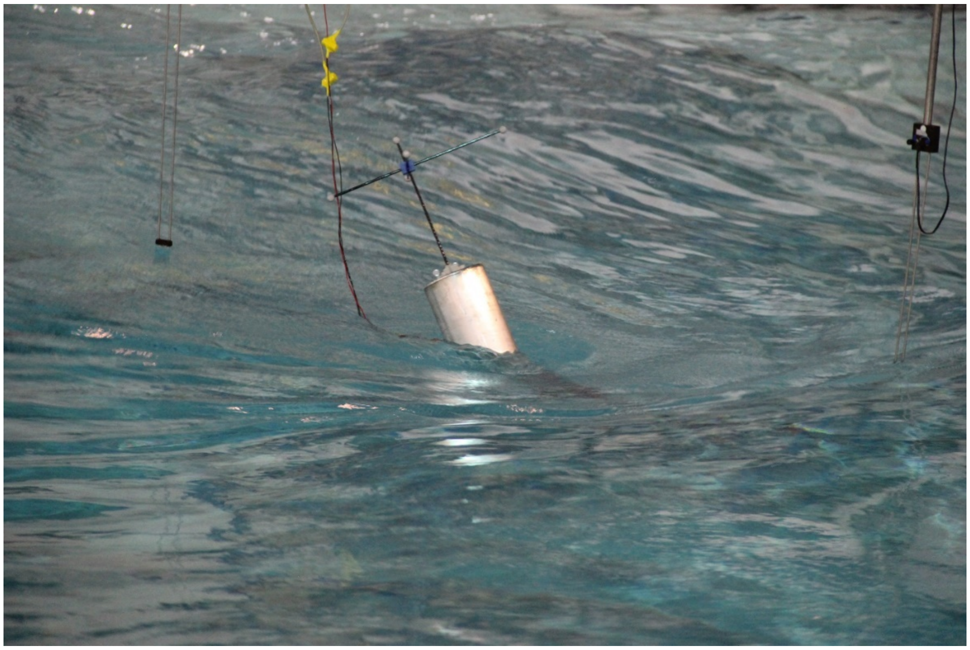


Figure 2 - Tank Test set up, showing spar buoy

- Specification, design, manufacture, assembly of a full scale wooden mock-up, followed by four weeks of testing, replicating all aspects of the detailed connection system and geometry optimisation.

Figure 3 - Assembled rig

- Specification, Orcaflex model creation, scene creation for the virtual prototyping simulation at NDC, with 3 days of simulator testing. Subsequently, some errors were found in the simulation and a further two days of testing were completed to successfully demonstrate that the concept is viable in high seastates.

Figure 4 - Vessel being controlled during C-Dart installation simulation

- A review of the current certification guidelines with Bureau Veritas, and subsequent HAZID assessment of the operational procedures. This enabled a gap analysis to identify what further work is required to achieve certification in the future.

- A qualitative assessment of the benefits of using non-causal control techniques to improve WEC yield. The sparbuoy offers the unique ability to measure the oncoming waves directly using an on-board IMU. This information is relayed to the WEC controller so that the WEC can react to the known oncoming waves to improve yield or manage loads. The assessment indicated that in some wave regimes, enormous yield improvements can be achieved (>200%), and overall, a 50% increase in yield could be expected. Further work is being undertaken by Queen Mary University as part of the WES Control Systems programme.

- A FEED study with Mocean Energy, based on the learning and results of the previous tests. This specific study was completed to provide an outline design for a Blue X1.1 WEC installed in a central North Sea location, with the aim to provide electrical storage to offshore infrastructure, for example subsea or surface batteries for charging AUVs or ASVs, or powering well heads. This detailed study has addressed all aspects of the solution and resulted in updated detailed CAD models of all geometry, the umbilical and updated marine operational planning.

3.2 Mooring connector concept

The mooring connector innovation was made 8 months into the 12 month project. The scope of the overall programme was changed to develop this, rather than an eCTV charging solution. The scope of work achieved in this time has included:

- Creation of a basic plywood mock-up of the concept, and testing to demonstrate feasibility. This mock-up enabled the testing of different dart shapes, chute angles and allowed load testing to demonstrate that the dart could be released under load using a line with significantly less load than the mooring line.
- CAD design of a concept to discuss with potential customers. This was used to create an animation of concept with a barge.
- 3D print of this concept to display at the All-Energy Conference in May 2022.
- Further detailed design calculations and iterative design to improve the concept. This was used to update the animation, demonstrating the use of this solution with barges, vessels, floating solar farms and floating dry dock solutions. Two design points have been assessed in detail: a small 10m vessel (3.6te MBL rope) that can be released by hand, and a larger 20m vessel that cannot be released by hand (13.7te MBL rope). A further design point for a floating dry dock solution to store offshore wind floating foundations is underway, demonstrating the solution is scalable.
- Two further 3D printed models of the design, that demonstrates the principle of operation. One model replicated the entire buoy, dart and catcher mechanism, and the other replicated only the catcher and dart.

4 Project Achievements

There are a number of project highlights and achievements that are worth mentioning:

- The concept to catch a rope and pull in a dart to make an electrical and mechanical connection is still as valid now as it was when it was first conceived. None of the tests have identified any showstoppers or serious issues, and any identified issues have generally been easily overcome.
- The marine operations test provided excellent validation of the marine operations requirements. These were witnessed independently by The Waves Group, and they provided some very positive feedback about the concept and its potential.
- The tank test provided data to validate the Orcaflex modelling. The data comparison was superb, with almost no error between measured data and predicted data. This provided great confidence that the Orcaflex modelling was correct and can be used for further modelling.
- The wooden rig was excellent value for money to demonstrate full scale geometry and allow modifications and optimisation of geometry quickly and easily. The profile cut plywood was very quick to cut and assemble, and provided a strong and robust test rig.
- The virtual prototyping simulation offered amazing reality of the solution, and provided huge confidence that the operations are feasible in 2m HS and 30kt wind. Installation and recovery operations were attempted with varying starting positions, weather, vessel skippers, and single and twin vessel installation. Whilst recognising that it was a simulation and not reality, this facility offers amazing value for money to demonstrate early stage technology in real world conditions before committing to more expensive offshore testing.
- Breaking down the testing into discrete tests to address specific risks in different areas proved to be a very appropriate and successful approach resulting in specific de-risking of the technology. Confidence in increasing TRL was achieved in this way. This would not have been so successful or achievable had a single test programme been conducted.
- The third party reviews have not identified any show stoppers and in fact are very complimentary of the concept. Both the Waves Group and Bureau Veritas have reviewed the concept in detail and whilst they have identified risks and issues, all can be overcome with correct engineering.
- Further opportunities have been identified to provide improved benefits to the concept. These include the upstream flow measurement to improve yield by 50%, integration of battery storage, and integration of spar buoy docking with ASVs and AUVs. Although these are long term benefits and the engineering solutions are not defined, these all offer benefits to further improve the business case for the sparbuoy solution.
- The innovation of the mooring connector has created a solution that uses the same proven principles of gravity, buoyancy, geometry and vessel manoeuvres to create a connection, but this solution is significantly simpler than the C-DART concept. This provides an opportunity to exploit this concept commercially, and then feed the results and improvements back into the C-DART concept to improve it further.

5 Recommendations for Further Work

For the C-DART concept, there is significant further work to bring this to market. The next phases of work would include:

- Further detailed engineering and analysis, in particular stress analysis of the sparbuoy and darts, loads and fatigue assessment of the umbilical, design for manufacture for the sparbuoy and dart.
- Create a full-scale installation using a dummy WEC device, using a marine test centre and full scale vessels. This would need to demonstrate the electrical connection as well as the mechanical connection. This should also be done in conditions representative to those at sea. This would bring the technology to TRL6 and demonstrate to developers the benefits of the entire system.
- Create a live project with a developer to help fund the development. This could be with Mocean or another WEC / TEC developer. The most effective route to market is to undertake a real project with a developer.

For the mooring connector the development is more straightforward and testing to achieve TRL6/7 can be achieved in a relatively short time period. The next steps in order to achieve this are:

- Further 3D printing to demonstrate the solution and optimise geometry
- Install a prototype in a marine environment for demonstration using vessels or barges. Two potential sites have been identified, namely UTC at Loch Linnhe and another offshore contractor at Montrose Harbour. Both these locations could be used to practice and demonstrate the installation using real vessels, and provide footage of the process to enable clear communication to potential customers of how the system works. An Orkney based vessel operator has also offered their services to demonstrate the performance of the mooring connector.
- A workshop test, to demonstrate the system under load and that the mooring buoy and dart can resist the design loads with suitable safety factor applied. This will aid the certification of the device and provide confidence to customers that the buoy is strong enough for a given size of vessel.
- Once this testing is complete, further detailed engagement with potential customers with the results from the testing. These would include floating solar farms, floating dry dock solutions, barge or vessel mooring and harbour authorities.

6 Communications and Publicity Activity

Communication activity throughout the project has been mainly focussed around engagement with specific customers and WEC / TEC developers, as these are the main target for the C-DART product. Blackfish has engaged with developers with floating devices that either yaw or are fixed, and many conversations are ongoing. The choice to radically change a mooring or attachment design for a given device is a significant decision and one that requires much discussion, analysis and assessment.

For the mooring connector, this has again been constrained to direct conversations with potential customers, whilst the concept is in development. Detailed discussions with many potential customers are ongoing, including marine operators, mooring buoy manufacturers and distributors, solar farm developers, a floating dry dock developer, test centres and harbours.

Public presentations have included the WES conference in Edinburgh in May 2022, All Energy conference in Glasgow in May 2022, discussions with potential customers at the Electric and Hybrid Marine conference in Amsterdam in June 2022, discussions with potential customers at the Seaworks conference in Southampton in June 2022 and an update to Marine Energy Wales quarterly review in April 2022. Various social posts have also been used to publicise some of the testing that has been completed throughout the course of the project.

For more information about either C-DART WEC connection system or the mooring connector, please contact Tim Warren at Blackfish Engineering. (tim.warren@blackfishengeering.com)

7 Useful References and Additional Data

Blackfish Engineering Design Ltd: www.blackfishengineering.com

Skua Marine Ltd: www.skuamarine.com

Flowave: www.flowavett.co.uk

UTC: www.uwtrialsltd.co.uk

National Decommissioning Centre: www.ukndc.com

Wave Energy Scotland: www.waveenergyscotland.co.uk

Publicity Material

Filename	Media Type	Description