The Albany M4 project: Demonstrating WA's wave energy potential

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Abstract—**The paper presents elements of the design, manufacturing and deployment of a wave energy converter demonstrator in Albany, on the south coast of Western Australia (WA). The project, funded by WA Department of Primary Industries and Regional Development, the Blue Economy Cooperative Research Centre and The University of Western Australia (UWA) aims at advancing the development of the technology and at testing and validating the infrastructure and supply chain necessary for emerging ocean energy markets, including the aquaculture industry in the region.The demonstrator is a wave attenuator called M4 for 'Moored MultiMode Multibody', developed by M4 Wave Power Ltd at the University of Manchester, UK. It has undergone extensive optimisation, with published results demonstrating high energy capture and excellent survivability. Design was undertaken by BE-CRC partners at BMT in collaboration with UWA. Upon operation, data associated with mooring line loads, hydrodynamic response and power generation will be made available live on a dedicated website for the benefit of the whole community. Aspects associated with structural design, mooring design, local procurement, environmental permitting, and deployment operations are presented.**

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I. INTRODUCTION

Wave energy in Australia is still underdeveloped compared to Europe and the US despite world class resources [1], very dynamic SMEs, and significant research capabilities. The development of the Garden Island Project by Carnegie Clean Energy in 2015 [2] and the King Island Project by Wave Swell Energy [3] in 2022 were critical milestones in demonstrating Australia's capabilities and know-how. Yet, wave energy is not considered in any of the federal or state decarbonisation strategies.

The M4 (for Moored MultiMode Multibody) wave energy converter (WEC) will be deployed in Albany, 450km south of Perth, Western Australia (WA), in the summer 2024-25, for a duration of about 6 months. It is a wave attenuator developed by Prof. Peter Stansby from the University of Manchester and M4 Wave Power Ltd. To the authors' knowledge, this is the first and only fully open-source deployment where all data and information associated with the project are made available in the public domain.

The project, led by Marine Energy Research Australia (MERA) at the University of Western Australia (UWA), is funded by the Blue Economy Cooperative Research Centre (BE-CRC), the Department of Primary Industries and Regional Development (DPIRD) of Western Australia and UWA. It involves multiple partners, including the Australian Maritime College who undertook wave tank testing (presented in a companion paper at ICOE2024), the University of Queensland who undertook hydrodynamic optimisation, BMT who undertook the design of the mooring system and the M4 structure and the environmental impact assessment, the University of Manchester who designed the Power take-off (PTO), and RMIT University who assisted with PTO development.

II. MOTIVATION AND OBJECTIVES

Considering the Australian context and the limited number of domestic WEC deployments, the objectives of the M4 demonstrator project are to:

- Raise awareness within governments, investors, and communities of the potential of wave energy in Australia. This is achieved by a strong engagement with a large group of relevant stakeholders, including potential end-users.
- Advance the Technology Readiness Level (TRL) of the M4 technology.
- Demonstrate the capabilities of the local supply chain by designing, manufacturing, and procuring the M4 Wave Energy Converter (WEC) domestically, and as much as possible locally in Albany.
- Develop the PTO and its control system to optimise energy capture.
- Demonstrate the potential of wave energy to decarbonise the local industry by collaborating with aquaculture through the Shellfish Hatchery as a potential end-user.
- Share the lessons learnt during the process to benefit the whole wave energy industry and improve confidence within potential investors and end-users. This will be achieved by specific communication and engagement after decommissioning of the M4 WEC.

III. THE M4 DEVICE

A. *Concept*

The M4 WEC is a hinged attenuator line-absorber type WEC (Fig. 1). In developing the M4 the objectives were to (i) target a Levelised Cost of Energy (LCOE) similar to that in offshore wind with high energy capture, and a potential capacity of 1-10MW, (ii) exhibit a high survivability in extremes waves, and (iii) enable easy access of the critical parts of the device to reduce maintenance cost. To achieve this, the following features were considered:

1. Include multi-bodies for high wave energy capture across a broad range of real wave conditions, through streamlined floats with multi-mode hydrodynamic interactions.
2. Being a moored floating device for easy deployment and towing to port for long-term maintenance.
3. The float size/volume increases downwave to minimise shadowing from upwave floats and to facilitate alignment with the wave direction due to drift forces. The mooring is attached to the small bow float and drift forces increase downwave.
4. Being scalable to several power take-offs (PTOs).
5. The PTO is accessible above deck for dry access and maintenance.

These considerations resulted in the following technical criteria:

1. The bow-mid and mid-stern spacing are approximately half a wavelength spacing to be predominantly in anti-phase. Power is generated from the relative angular rotation around the hinge.
2. The pitch resonance for bow-mid and mid-stern floats, and heave for each float are of different periods to be within the range of a particular wave climate.
3. The anti-phase surge forcing, as well as heave, causes power generation due to the anti-phase moments about the hinge above mid float. This was shown by mathematical modelling [4].
4. The floats have a rounded base to minimise drag losses.
5. Motion in extreme waves is limited due to dunking, such that no end-stop on PTO is needed.

The M4 device has undergone extensive optimisation through modelling and tank testing, with published results [5] demonstrating high energy capture and excellent survivability. The M4 Albany project is the first open-sea deployment aiming at progressing TRL from 6 to 7.

B. *History of development*

Development started a decade ago, as described in [5]. Initially a 3-float system was tested and modelled with overall length about a wavelength. Froude scaling was demonstrated experimentally probably for first time for a WEC. Streamlined floats were introduced and float spacings modified. The 3-float was extended up to 8 floats and multi-PTOs with linear diffraction/radiation modelling, the relevant pitch response having been shown to be remarkably linear. The 6-float version with two PTOs (one bow, 3 mid and 2 stern floats or 132) was tested experimentally to confirm performance. Modelling indicated that a 121 system was cost effective, and this system with two identical PTOs at the hinges was chosen for Albany, see Fig. 1. Recent development has concentrated on the design of an electric PTO suitable for high torque, low frequency excitation.

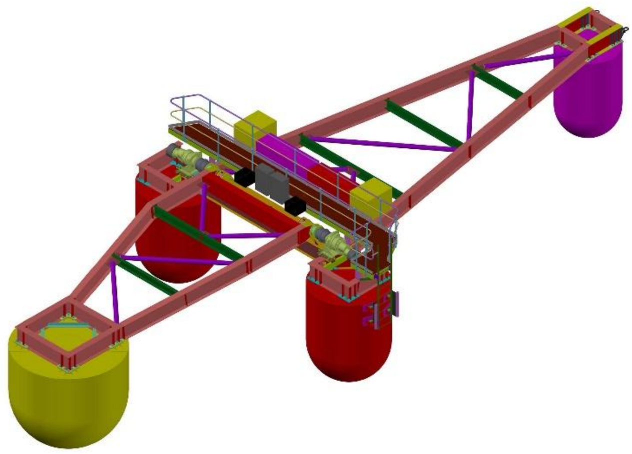

Fig. 1. The M4 configuration used for deployment in Albany. Drawing established by BMT.

IV. ALBANY AND SITE CHARACTERISTICS

The deployment site is located in King George Sound, the outer harbour of Albany, WA, about 2 km North-East of Albany's Historic Whaling Station at Discovery Bay. It is under the custodianship of the Southern Ports Authority, a WA Government Trading Enterprise., that also operates the Albany port.

C. *Environmental & Social Context*

The Albany Harbours – King George Sound, Princess Royal Harbour, Oyster Harbour – were formed around 6,000 years ago. The Noongar people are the region's traditional Aboriginal custodians, with a rich cultural history of at least 50,000 years. They have a strong relationship to islands and coastline, for spiritual reasons and place for seasonal camping, hunting, and fishing. Albany was the first European colonialisation and port in Western Australia (1826), which quickly developed industries that impacted the populations of native oysters, sea lions, and whales. The last Australian whaling station to close in 1978, Albany flourished as a 'renewable energy capital' for many decades. Clearing of land for farming and discharge of fertilisers led to excessive algal growth and significant seagrass loss until stricter legislation was introduced in the 1990s. Improvements in water quality have since restored seagrass and oyster populations and encouraged shellfish aquaculture.

Two benthic habitat surveys were conducted at the M4 deployment site (~0.25 km2, 12-15m depth), near Seal Island (May/June 2022; January 2023). The survey vessel was equipped to collect acoustic reflection intensity, or backscatter data (at 1m resolution) and side scan sonar data (0.2m/pixel), and 5.1km of towed video over nine transects (high-definition GoPro camera at 90° angle to seabed, ~2m band, vessel speed 1-2 knots). A local marine environmental consultant with expertise in seagrass restoration identified six seagrass species, with dense but patchy cover up to 50% but decreasing to <5% in the north-eastern area of the site. This sparse area experiences seasonal loss of seagrass and was therefore determined the best location for the M4 anchor installation. Photos from the anchor installation in July 2024 confirmed these seabed conditions.

In addition to resident sensitive species of sharks, rays, turtles, penguins, sea lions, and dolphins, King George Sound is recognised as a nursery, resting, breeding, and feeding site during the annual migration of Southern Right, Humpback, and Blue Whales (April to October). The M4 is considered low impact on marine fauna as the majority deployment period (summer months) does not overlap with migration, the device has no moving parts below the surface and does not emit sound, and mooring lines were designed to minimise entanglement risk.

D. *Wave climate*

Wave data collected from a Sofar Ocean 'Spotter' wave buoy (operated by UWA) moored at the intended deployment location of the M4 and an acoustic wave and current profiler (AWAC) at Beacon 4 (operated by Southern Ports), about 8 km northwest of the Spotter buoy, have been the two main sources of wave data at the location. The two datasets were studied extensively and showed good correlation across various parameters, including significant wave height, mean and peak periods, as well as the individual spectral shape of each sea state. The joint distribution of wave height and period at the site, derived over a period of 5 years, is shown in Fig. 2.

The wave climate at the site is characterised by a mix of locally-generated wind sea and swell arriving from distant storms. Wind sea is more dominant in the summer, while swell is stronger in the winter. The swells generally have smaller wave heights but are present year-round. Larger wave heights are observed in the summer months. The average mean wave period across the year is around 5 seconds. The predominant wave direction is from the East.

Higher wave-power levels are observed in the summer months, with an average of 3.5 kW/m for December-March. The summer months also have less spreading, with the average peak spreading from January to March being 31.7°. Further details, including wind and current data at the site, are presented in [6]. The wind is mostly aligned with the current, with the wind direction being predominantly easterly from November to March. Thus, sea states with significant wind sea components, which occur during the summer months, are associated with currents nearly collinear with wind and waves, all coming from the east. This makes the summer months an ideal period for the demonstration.

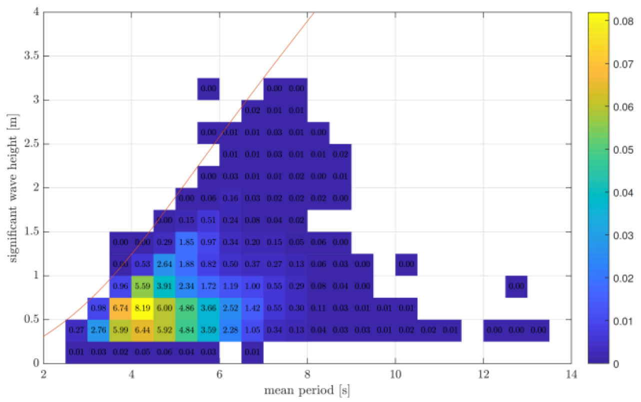

Fig. 2. Joint probability distribution (scatter diagram) of significant wave height and mean period at the site, for the summer months (Oct–Mar). Data collected over 5 years period (2017–2021).

E. Seabed

No geotechnical information about the seabed was obtained at the deployment site. However, a geophysical survey, undertaken offshore Torbay on the south coast, about 10 km west of Albany, coupled with an extrapolation of the local geological terrestrial characteristics provide insights about the likely conditions to be encountered. The seabed is expected to be constituted of a layer of 1 to 2 m of loose to medium dense calcareous sand, above a stronger layer of weathered Tamala limestone of highly variable strength. These assumptions are confirmed by observations from installation of short helical anchors by the local aquaculture industry.

V. Structural Design and Manufacturing

F. Design

The structural design was undertaken by BMT following a Basis of Design report that defined the codes, standards and analysis software to be used, the site specific design data, including wave climate and environmental conditions, the M4 device design data, and the analysis methodology. It proceeded in several steps. First, a structural dynamic analysis simulation was conducted in Orcaflex to obtain the structural loads, which were subsequently used to perform a static structural analysis in Spacegass to size the primary steelwork sections. Manual computations for various structural details and appropriate selection of the mechanical elements (such as couplings) were also undertaken. The floats were there designed using Strand7 and ANSYS for the structural parts, and Maxsurf for the buoyancy and stability.

Once all calculations were completed, and after a couple of iterations through collaboration with UWA, a 3D CAD model of the WEC parts and assembly were prepared, as well as the 2D engineering drawings suitable for fabrication. BMT also prepared the tender documentations, including specification, scope and returnable schedule, and continued to be involved in the project by providing support during the fabrication, assembly, deployment, operation and retrieval of the device, responding to technical queries from the contractor, and providing engineering design for tasks such as lifting of the M4 parts and assembly to deployment and retrieval.

An example of the 3D CAD model is presented in Fig.3, with some of the key engineering data below:

- Length overall: 24,050 mm
- Width overall: 9,500 mm
- Ballasted mass: 38,640 kg

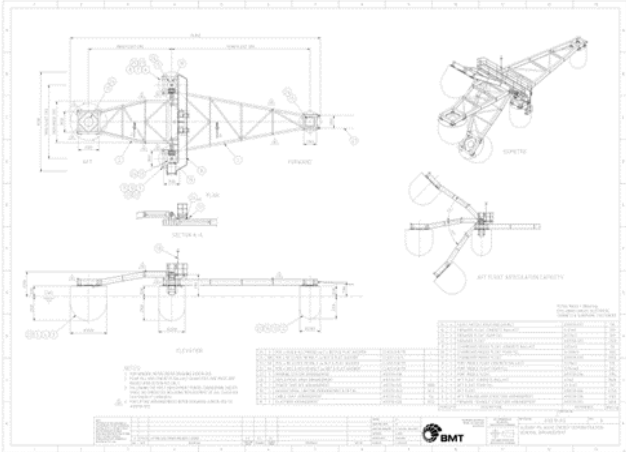

Fig. 3. The general arrangement drawing as prepared by BMT.

G. Manufacturing and assembly

SMC Marine was appointed as Head Contractor through a tendering process. The manufacturing of the M4 WEC was subcontracted to MCB, a local mechanical workshop about 5 km from Albany township. The choice of a local manufacturer was motivated by (i) the aim of demonstrating the capability of the local supply chain and (ii) the proximity to the deployment site which simplified transport operations.

The WEC was manufactured in several parts from the 2D engineering drawings developed by BMT. The floats were completed first. A decision was made early in the design process to change the round cross-section of the floats into an octagonal (front float) and dodecagonal (mid and back floats) cross-section. Calculations showed that this has negligeable effect on the hydrodynamic behaviour of the WEC, while significantly simplifying manufacturing.

The bow and stern arms of the M4 were manufactured in parallel. Some further simplifications were achieved, in agreement with BMT, about the assembly of the different H and I sections constituting the arms, resulting in cost savings.

All parts were then whipblasted and covered with one coat of paint. Here again, the decision of a single coat of paint, without any biofouling protection measure, was made, considering the short duration of deployment (6 months) as a cost saving measure.

Once coated, the two arms were connected and the hinge assembled, the most technically challenging part of the assembling process. The two gear boxes and generators were assembled at the hinge on each float (as per Fig. 1), while all the control cabinets (see PTO section) were assembled on a dedicated platform above the hinge (Fig. 4).

Fig 4. M4 WED during assembly. Bow and stern arms connected to floaters with PTO and control cabinet installed.

The final assembly of the arms with the floats was undertaken at the Albany town marina, as the parts needed to be transported separately. Once fully assembled, and the PTO fully commissioned, the M4 WEC was lifted to water by a 350t crane, the floats were then ballasted with sand, until the targeted draft was achieved.

Lastly, the M4 WEC got towed to site and hooked by hawser to the mooring buoy (see mooring and anchoring section).

VI. Power Take-Off

H. Design

Since the aim of the Albany M4 project is to provide open access performance data from sea trials, the power take-off was designed to operate for a single season, under a range of sea states, rather than for lowest cost of energy over the design life. This allowed the use of off-the shelf generators and gearboxes, together with a RTU box power electronic development system and integrated controller, using auto-code generation from Simulink. The generator has integrated encoder position sensing for commutation. Components are summarised in [7].

The reciprocating rotation at the platform hinge is high torque, low speed, 2.3 rpm, an order of magnitude slower than wind turbines of similar power. However, most electrical machines are designed for high speed, low torque so a 711:1 speed step-up Boneng gearbox with three epi-cyclic stages was used. The M4 platform performs optimally in terms of power generation with a T_P of 3.5 s, and most probable Hs of 0.5 m, which gives an average power of about 500 W per PTO. Allowing for a 10:1 peak to average power ratio, a 6 kW, 2,000 rpm Siemens 1FK7103-2AC74-1AA1 generator was selected.

The drivetrain also needs to withstand extreme sea states. Although the M4 self-limits due to dunking, the worst-case load on the gearboxes is the accelerating load from the generator inertia in extreme seas, with the electrical power offtake disabled, estimated at 42 kNm on the low-speed side of the gearbox. There is still a finite likelihood of a high sea states so torque-limiting has been implemented, to allow continued operation, within the rating of the PTO [7]. However, the limit on torque results in higher platform speeds, and in extreme sea states the generator is disconnected to protect the rest of the PTO from over-voltage.

I. Control

Passive damping control is used for power extraction, setting the desired torque at the hinge proportional to the hinge rotational speed. Hinge speed is estimated from the measured generator speed and referred across the gearbox. The reference torque is then scaled by the efficiency and divided by the gear ratio, to convert to torque at the generator. During dry testing, the reference was modified to account for backlash. Future work could address alternative power extraction methods such as model predictive control.

Individual powertrain components use local low-level control, with high level monitoring for power flow control and protection, all implemented on a central RTU control box, based on a TI DSP platform, as shown in Fig. 5. The generator inverter is controlled with field-oriented control. The torque magnitude is limited by the 3-phase Si IGBT AC/DC inverter, to protect the generator from overcurrent and the gearbox from overload. Temperature monitoring is fitted to protect the generator; this could also be used to adjust the torque limit to allow short-term overloads when the machine is cool, up to the higher current limit of the inverter. Field weakening is implemented, allowing speed range extension above the generator rated speed, but with reduced torque capability [8]. The electrical machine will be shut down to protect the inverter from over-voltage at its maximum field-weakening speed (approx. 6000 rpm at rated current) since no power can be generated above this speed [7].

The bidirectional SiC DC/DC converter is used to regulate the DC voltage to 600 V, exchanging power with the super-capacitor, which provides power smoothing. The converter control includes duty-cycle and current limits. In stand-alone mode, the IGBT chopper circuit dissipates the power generated into a resistor load, balancing average power extracted from the platform, based on DC system current measurements. The chopper circuit will also limit the DC voltage if the super-capacitor control is inactive, for example because it is fully charged. Power can also be extracted from the super-capacitor to recharge the platform battery.

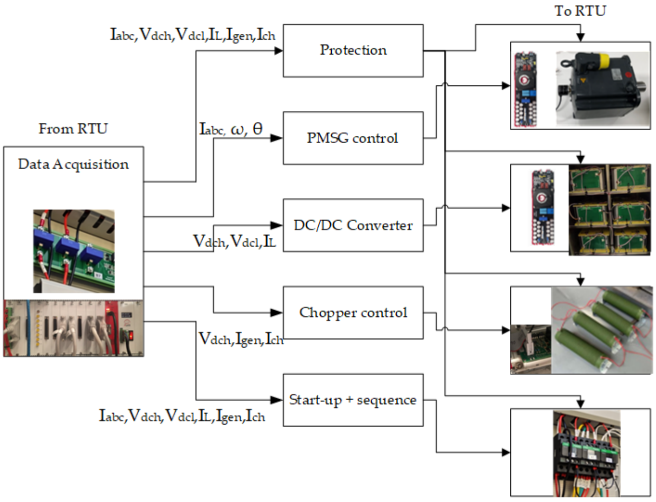

Fig 5. PTO Control overview
RTU=Real time unit, Iabc=PMSG phase currents, Igen=PMSG dc current, Vdch, Vdcl are the high and low side dc voltages, IL= converter inductor current, Ich=chopper current, ω = PMSG speed, θ=PMSG orientation.

J. *Dry testing*

An experimental setup consisting of the drivetrain generator and gear box, back-to-back mechanically coupled with an identical generator and gear box is used to test and validate the power-offtake system operation and undertake "dry tests". Fig 6 shows a photograph of the dry testing setup. One generator is driven in motoring mode and emulates the M4 dynamics by executing the model developed in fig. 5. The model runs within the RTU control box and outputs the speed reference to the motor speed controller. The torque exerted by the generator is fed back to the M4 model which dynamically modifies the speed to replicate the behaviour of the actual M4 platform.

Fig 6. PTO assembled for dry testing.

The dry testing was used to evaluate and improve the power off-take algorithm, tune the control system and investigate the impact of gearbox backlash. Due to the dynamic variation of speed in the neighbourhood of 0.25 Hz to 0.35 Hz, the current control tuning of the generator required consideration of this frequency to avoid significant controller lag. The impact of backlash imposed a reduction of power and the overall power was increased up to 10% by modifying the generator current controller to switch between two states when the gearbox transitions the direction of speed.

K. *Assembly and marinisation*

For assembly on the WEC, the two PTO units were disconnected from the dry testing rig and separately connected to the shafts above the port and starboard mid-floats using 2 couplings. Two marinised housings per PTO, enclosing the gearbox and generator, and generator and coupling, respectively, were then fabricated and installed. The marinised enclosures were each fabricated in two pieces to enable access to the PTO.

VII. Mooring and Anchoring

The design of the mooring and anchoring system was undertaken by BMT [9] following a mooring dynamics analysis simulation in Orcaflex to obtain mooring loads. Wherever possible, the mooring system design was performed in compliance with the DNVGL Offshore Standards-Position Mooring (DNVGL 2018) and DNVGL Marine Operations and Marine Warranty (DNVGL 2016), as relevant Australian Codes and Standards do not exist to serve the purpose of this project. The American Bureau of Shipping (ABS 2018) Guide for Position Mooring Systems (ABS 2018) was also employed as a complementary to the DNV design codes, wherever it is required. For the mooring line properties and anchor selection, the Vryhof Manual-The Guidance to Anchoring (Vryhof 2018) was employed as the product brochure. The mooring buoy selection was also implemented based on Trelleborg Marine and Infrastructure product brochure for Surface Buoyancy (Trelleborg 2017).

The installation of the anchors and mooring lines was subcontracted to JEYCO, a WA based supplier, and iterated to account for the local availability of anchors and chains and the capability of the local vessels. The final solution is presented in Fig. 7. It includes:

- A 10t mooring buoy (Trelleborg Marine and Infrastructure) to which the M4 WEC is connected by 2x 64mm Akwaflex Hawsers.
- 2x2.5 t concrete clump weights laid on the seabed.
- 3x750 kg Stingray anchors.
- 2x120m 32mm U3 Studlink Chain.
- 3x40m 32mm U3 Studlink Chain.

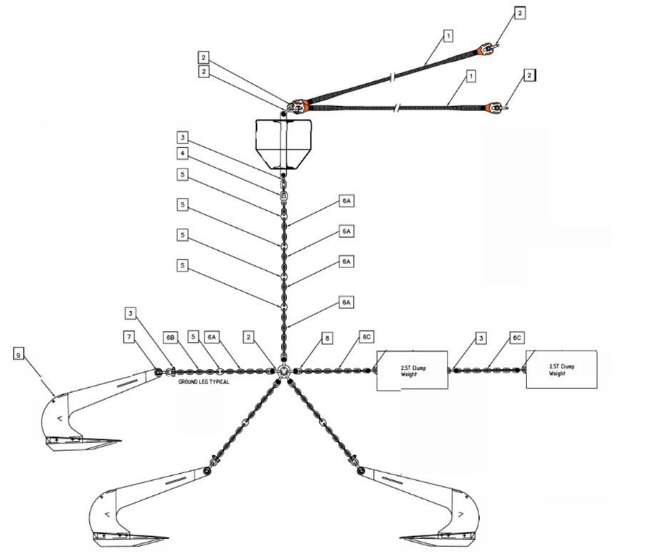

Fig 7. M4 WEC anchoring solution in King George Sound, Albany, WA (courtesy of JEYCO).

The anchors and mooring lines were installed in July 2024 using vessels from Albany Tug Services and professional WA divers. To mitigate entanglement risk between the anchor flukes and the mooring chains, the anchors were slightly buried using jetting techniques.

VIII. Instrumentation

A number of instruments will be mounted on the WEC to measure responses of interest: two 25-tonne load shackles, two inertial motion sensors (IMS; one with differential GPS), and two rotary encoders. The load shackles are attached to the bow and hooked to the hawsers to measure the mooring load, specifically the mooring force component along the symmetry plane of the M4. One inertial motion sensor will be mounted on the front arm, and the other on the back arm. Together, they will provide the motion of the M4 in seven rigid-body degrees of freedom. The rotary encoders will measure the relative angular displacement between the front and back assemblies on the low-speed end of the shaft, providing redundancy for one of the inertial motion sensors.

The instruments can take power from the PTO but for redundancy, power is also generated by 8 solar panels and 2 wind turbines onboard. This ensures that remote contact with the WEC can be maintained even in calm weather.

Data from the PTO and from the instruments constitute key research outcomes of the M4 project to validate previous modelling of the WEC's performance and behaviour.

IX. Deployment

L. *Environmental approval and permitting*

Compiled from the seabed surveys and benthic habitat analysis, an Environmental Impact Assessment and Management Plan was prepared by BMT in collaboration with UWA [10] and submitted to the WA Department of Water and Environmental Regulation. Due diligence in determining the best site and anchoring system was found satisfactory, and the M4 Project does not require additional work into seagrass offsetting or remediation after device retrieval. In recognition of the M4 being a short-term research project, the Department's approval is in lieu of a formal permit where longer term commercial projects will need to demonstrate ongoing monitoring and mitigation measures for their benthic footprint.

The landlord of the Albany Harbours seabed is the Southern Ports Authority. The local harbourmaster and port staff were involved in the initial identification of potential M4 deployment sites. In December 2021, the 'Spotter' buoy was installed at the designated wave energy site near Seal Island, with real-time data transmission for metocean analyses. In July 2024, this existing seabed licence got extended to include the M4 anchoring system.

M. *Marine safety and operational management*

In collaboration with the Albany harbourmaster and the M4 Head Contractor, a Marine Safety and Operational Management Plan was developed that specifies the procedures to protect vessel traffic and anchorages, monitor the device, limit human interaction, and respond to emergencies [11]. The M4 is fitted with flashing light beacons and an Automatic Identification System (AIS), registered with the Australian Maritime Safety Authority, and reported to mariners via the WA Department of Transport. Signage and video cameras are installed to deter trespassers. The AIS positioning information is used to track the position of the device 24/7 and alert project managers and authorities if it was to drift outside its circle of operation, triggering an emergency response. An additional GPS is installed on the mooring buoy.

Wave energy converters are not considered within the Australian marine regulations. Consideration of WEC classification can have significant implications on compliance requirements, notably access and personnel safety measures, such as handrails, Personal Protective Equipment etc, as seen on domestic vessels, and therefore additional weight. In collaboration with the Albany Harbourmaster, it was agreed that the M4 WEC neither classified as a vessel, nor a barge, as (i) not used for navigational purposes, (ii) not equipped with means of propulsion, and (iii) not routinely accessed by personnel, except briefly in urgent cases of maintenance inspection.

All M4 WEC safety measures are consistent with other moored structures such as buoys.

N. Data reporting

Analogue data from the PTO, as well as encoder and load shackle data will be logged to a Schneider data acquisition system. Data from the IMUs will be saved direct to the PC. Ultimately all data will be exported to the on-board PC and then synchronised to a cloud-based repository over the 4G network (with satellite connection for redundancy).

From the cloud, processed data will be publicly displayed (in close to real-time) on a website hosted on the wawaves.org webpage.

X. Conclusions

The Albany M4 wave energy project is aiming at designing, manufacturing, deploying, operating and decommissioning a 11kW, 24 m long, ~38t wave energy demonstrator in King George Sound, Albany, Western Australia. The project funded by the Blue Economy Cooperative Research Centre, the Department of Primary Industries and Regional Development (DPIRD) of Western Australia and the University of Western Australia for a total of $4.8M is the first fully open-source project, streaming live all data recorded, including energy production, as well as providing a detailed record of the learnings from the project. Upon decommissioning in March 2025 reports and academic publications will be issued to (i) demonstrate the potential on wave energy to contribute to the Australian Net Zero by 20250 plan, (ii) demonstrate the capability of the Australian research expertise and supply chain and (iii) advance the development of wave energy technology for the benefits of the whole industry.

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