COST REDUCTIONS THROUGH SMART TRANSPORTATION AND INSTALLATION ENGINEERING - *experience of the MeyGen Tidal Array.*

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ABSTRACT

In 2010, as part of the Pentland Firth and Orkney Waters leasing round, The Crown Estate awarded an agreement for lease to MeyGen Limited, granting the option to develop a tidal stream project of up to 398MW at an offshore site between Scotland's northernmost coast and the island of Stroma. Today, the MeyGen project is the largest operating tidal stream project in the world and has exported more than 20GWh to grid.

In the first phase of the project, 4 No. 1.5MW turbines were installed on gravity-based turbine support structures as part of MeyGen's "deploy and monitor strategy". Two different turbine technologies were installed in this first phase (Atlantis Resources AR1500 and Andritz Hydro Hammerfest AH1000 MK1), each with their own transportation and installation characteristics. A feature of this first phase has been the facility to recover and redeploy turbines, working during neap tides within exceptionally narrow installation windows that exist between the strong tidal flows that characterise the location. Bespoke engineering solutions have been required to achieve on-bottom stability of cables and foundations on rocky seabeds and rapid mechanical and electrical mating of major components. The project has also developed strategies for streamlining mobilisations and operational planning, so reducing vessel time on hire.

In this paper the authors discuss ways in which the project has engaged innovative engineering and operational strategies to overcome key temporary phase challenges, while progressively building quantifiable cost efficiencies into transportation and installation operations.

INTRODUCTION

The MeyGen tidal development project covers some of the fastest flowing waters in the UK, in a 3.5km wide area just 2km from Scotland's north-east tip. To the north of the site is the uninhabited island of Stroma, which creates a natural channel with the Scottish mainland, accelerating millions of tonnes of water that flow between the North Sea and the Atlantic Ocean every day. This site was originally identified by Atlantis in 2007, following a global review of tidal resource which concluded that the high flows, medium water depths and proximity to the mainland rendered it a prime location for development.

As part of the Pentland Firth and Orkney Waters leasing round, The Crown Estate awarded an agreement for lease to MeyGen Limited in 2010, granting the option to develop a tidal stream project of up to 398MW.

The MeyGen project is currently the largest operating tidal stream project in the world. MeyGen has now exported 20GWh of electricity to the national grid, eclipsing the previous record of approximately 11GWh. In the first half of 2019 alone, MeyGen has exported over 7GWh of predictable renewable energy to the grid, equivalent to the average annual electricity consumption of over 2,200 typical UK homes.

MEYGEN PHASE 1A

In the first phase of the MeyGen project (Phase 1A) 4 No. 1.5MW turbines were installed on gravity turbine support structures, as a precursor to the development of the remaining consented 86MW project. Phase 1A is demonstrating that the development of tidal array projects is both commercially viable and technically feasible. Invaluable lessons are being drawn from the construction, installation, operation and maintenance of this phase of the project, and fed into subsequent phases.

Two different turbine technologies were deployed during Phase 1A: 3 No. Andriz Hydro Hammerfest AH1000 Mk 1 turbines and one Atlantis Resources AR1500 turbine, all of which were limited to be within a pre-consented envelope, Figure 1.

The three AH1000 MkI turbines, Figure 1a, are a development of the 1.0MW AH1000 unit deployed by Andriz Hydro Hammerfest at the European Marine Energy Centre, where AHH demonstrated the commercial viability of their latest prototype. This successful demonstration was a pre-requisite to the decision to place an order for 3 units to be installed within Phase1A.

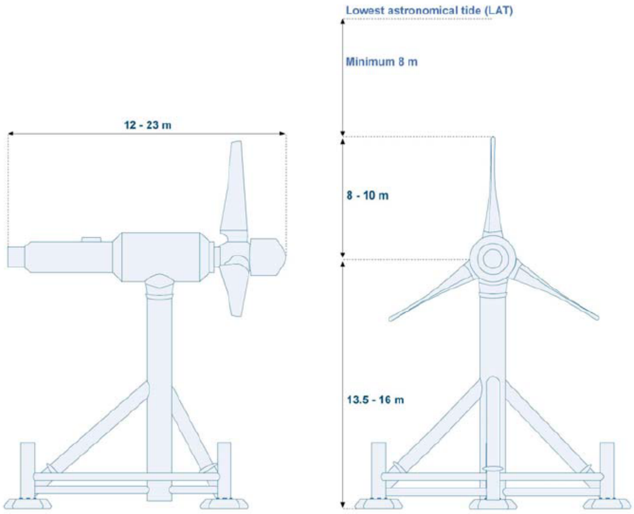

Figure 1 – Turbine design envelope

The AR1500 turbine, Figure 1b, is also an extension of a 1.0MW prototype that was deployed at the European Marine Energy Centre to demonstrate its commercial viability. The AR1500 is designed for simplicity, reliability and to achieve extended intervals operating underwater without intervention. It is a SIMEC Atlantis design, which incorporates several innovations designed to further reduce cost of electricity generation.

Figure 2 - (a) AHH1000 MkI and (b) ARL1500 turbines

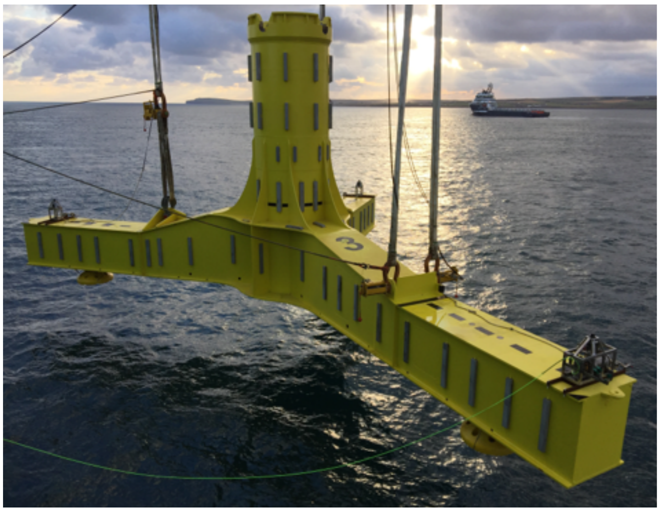

Figure 3 – Turbine Support Structure installation 2016

Each turbine is located on an individual foundation weighing between 240 and 285 tonnes, coupled with 6 ballast blocks weighing 205 tonnes each, which provide horizontal stability over the lifetime of the turbine, Figure 3.

The project construction program required that the turbine foundations were installed to the seabed after the installation of the export cables and before the turbines themselves were lowered into position. Each turbine has a dedicated subsea array cable laid directly on the seabed and brought ashore via a horizontal, directionally drilled borehole within the foreshore bedrock, Figure 4.

The turbines were lowered onto the foundation and engaged the passive stab arrangements and electrical connectors. With exceptionally strong tidal flows at the site, a key challenge has been to achieve mechanical and electrical connection in narrow slack windows, typically 40 to 80 minutes in duration.

Figure 4 – Export cable installation 2015

COMMERCIAL DRIVERS

Phase 1A of MeyGen operates with 5 ROCs and has generated £1.85m of revenue to in the 1st half of 2019. Total system availability, a key performance metric, is approaching 90% for 2019 to date and during Q2 2019 was recorded at almost 98%, see Figure 5. 2019 performance represents the longest period of uninterrupted generation from a multi-megawatt tidal turbine array ever achieved.

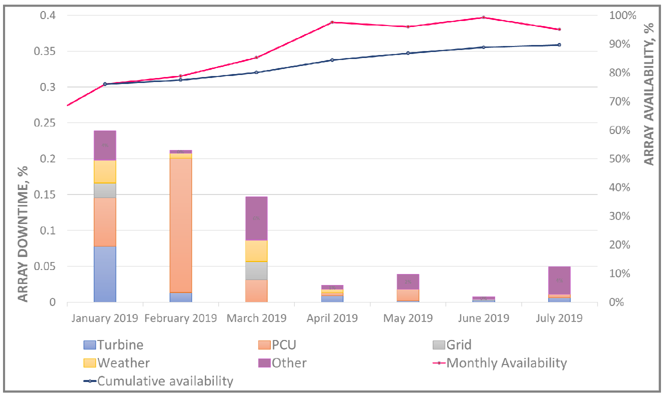

Figure 5 – Array availability and downtime

Driving this performance has been improvement of turbine operation focused on improvements to system control, fine-tuning of power converter units and reduction of time to return the generating plant to production after outages on the local 33kV electricity network.

The main commercial drivers for the project are:

- Net export power driven by turbine capacity factor and system availability;
- The duration between preventative maintenance cycles, and;
- Costs associated with the installation and recovery of the tidal turbines.

System capacity factor is an intrinsic aspect of the turbine design, as are the site characteristics which are largely fixed at project inception. Optimum system availability can be achieved with the correct operating strategy which has been a focus of MeyGen O&M team for the initial phase of operation.

MeyGen are working closely with the turbine suppliers to implement system wide condition monitoring, to enhance their ability to predict system failures or drift away from operational norms. This data is used to assess component condition and to identify operating strategies that are likely to maximise the array yield while alternative operating strategies may be implemented, or reactive maintenance can be conducted.

Costs associated with the installation and recovery of the turbines are also largely intrinsic to the turbines design and this is an area where both turbine suppliers are likely to take lessons learnt from MeyGen into future system designs.

The operating costs associated with the handling of these large assets are driven by the level of equipment and personnel needed to install and recover the turbines. The greater the deck spread the higher the rental cost, time needed to mobilise & de-mobilise a vessel and number of crew needed to operate the equipment.

There can be no doubt that lessons drawn from the MeyGen project will lead to significant cost reductions in both CAPEX and OPEX as tidal industry builds upon learnings from the operational experience gained from the MeyGen project.

Figure 6 – AR1500 installation with minimal deck spread

Figure 7 – AH1000 MkI with cable handling equipment

TRANSPORTATION AND INSTALLATION

During the development of Phase 1A and into operations, Simec Atlantis (then Atlantis Resources Ltd.) engaged Apollo Offshore Engineering Ltd. for specific engineering scopes of work, mainly associated with the transportation and installation operations.

Key to cost reduction is the avoidance of unnecessary installation vessel time. Generally, a 250 or 400 tonne construction support vessel (CSV) has been chartered to provide sufficient lift capability and back deck capacity. With CSV day rates in the range £20k to £50k, the impact of a saved half day is an appreciable amount of the mobilisation budget. Hence there has been a drive throughout the phase of development to minimise time spent in mobilisation and offshore works.

To this end, improvements have been sought in areas such as:

- Rapid connection and disconnection of the turbine and gravity base;
- Minimal seafastening and load distribution arrangements on the back deck of each CSV;
- Definition of departure criteria and weather routing.

Having identified areas of potential efficiency, the Meygen team repeatedly challenged Apollo to devise and/or engineer technical solutions. Some of the strategies developed by the Project are now discussed.

STAB & CONNECTION MANAGEMENT SYSTEM (CMS)

Both the AH1000 MkI and AR1500 turbine designs have all the power conditioning equipment (inverters, converters and frequency controllers) located in the onshore substation building. This affords the opportunity to streamline the process of subsea connection of the turbine to the gravity base, both mechanically and electrically, enabling quick and easy access in the event of unscheduled faults.

The two designs employ a two-part gravity stab mechanism, with the male on the turbine and the female on the support structure tower. The turbine is lowered onto the structure by a CSV operating on DP, without any need for divers or ROV intervention.

The AH1000 MkI turbine has a mechanical spindle arrangement that docks into the lower part while a cable tail is dry-mated to the subsea export cable. The dry-mating requires an increased deck spread, Figure 7, and multiple slack tides to undertake the cable and turbine handling works. The requirement to retain the export cable on deck between slack tides restricts these works to neap tides. limiting operations to about 50 days a year.

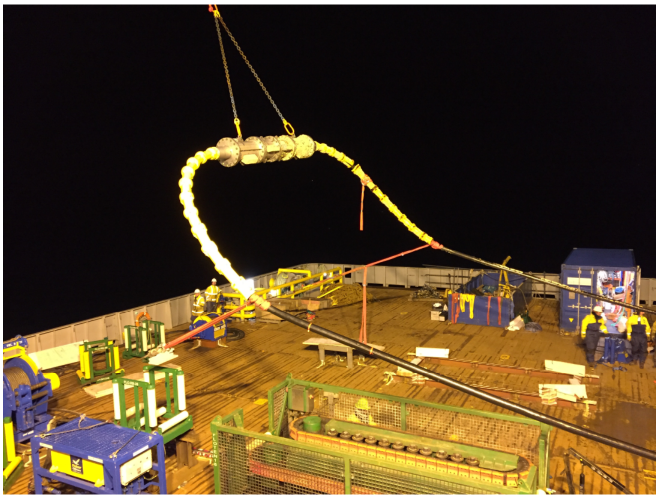

Figure 8 - handling for cable connection operations for the AHH100 turbine. Note the uncluttered deck layout which is the result of learning from several previous operations.

The AR1500 uses a passive wet-mate connection system that docks and undocks as part of the turbine installation and recovery. This negates the need for any cable handling equipment or the operation to connect or break a dry-mate connector. This significantly reduces the asset and operational risk to the marine crew, Figure 6, allowing the AR1500 to be installed or recovered in slack tides which are present on about 300 days a year.

The AR1500 stab is designed to progressively align the turbine with the support structure as the two parts are brought together, using mechanical key components which are integrated into the mechanism. See Figure 9. A key engineering challenge was to overcome the tidal forces on the turbine and guide it into place, achieving a snug fit and transmitting all the loads into the base.

Figure 9 - ARL1500 mating operation (onshore trial)

As the mechanical connection is completed on the AR1500 unit, so the electrical Connection Management System (CMS) also engages, thus simplifying the operation to a single tidal window without any external intervention. The CMS uses wet-mate connectors, a technology proven in the oil and gas industry, to join the turbine's electrical and control systems to the subsea cable back to shore.

With the stab controlling the alignment and rate of descent of the turbine, a smooth, repeatable connection is achieved. The connectivity from the shore to the turbine can be tested before the CSV releases the turbine from the installation tool, thus ensuring everything is ready for operation without delay.

Once a foundation has been established on the seabed floor, the AR1500 turbine can be installed in a very short amount of time. By compressing the operation to a single relatively short slack tide window, substantial vessel cost is saved over a two-stage connection, while greater flexibility is afforded to the operations team to undertake the works.

Engineering verification of the complex mating surfaces was performed using a 3D linear-elastic finite elements method in ANSYS™. As a novel structure there were several engineering questions:

- To what code should the design be assessed?
- How should the very high cycle, non-linear marine loads be characterised?
- How can the fatigue life be assessed?
- What are realistic operational parameters?
- What material offers best life of field performance?
- How to make the component?

A limit state design approach was adopted. Reference was made to DNV-OSS-312 [1], in conjunction with other recognised industry standards, as necessary to address all appropriate technical aspects.

Demonstration of fatigue capacity proved to be complicated as the loading is non-linear, with a high number of cycles (10^9) due to the tide and blade rotations. The initial assessment of the first stab was undertaken assuming a fully non-linear basis, however insights from this analysis resulted in a simplified approach, which will be applicable in future stab systems.

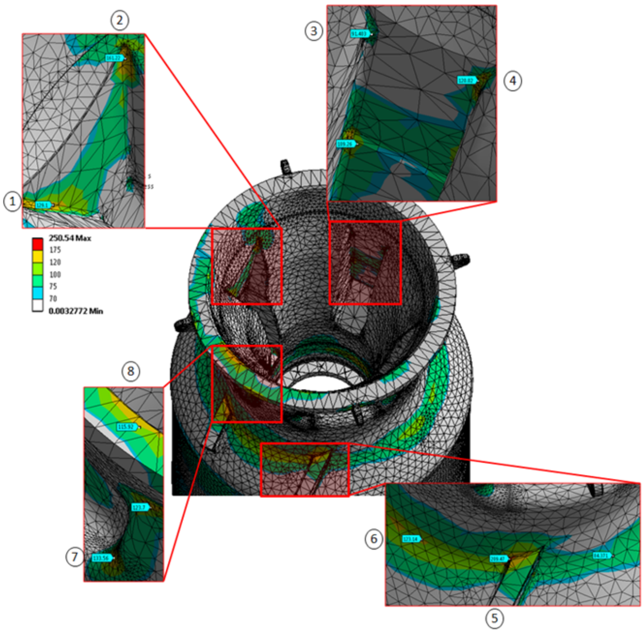

Figure 10 - ANSYS model of female connector on ARL1500 showing complex areas of stress concentration

Cast steel was selected for the main stab parts, considering overall performance with respect to Norsok M-001 and DNVGL-OS-B101 [2]. Orkot material was selected for the bearing pads on account of its low swell rate and resistance to sea water.

EFFICIENT MOBILISATION

Through a series of recovery and redeployment operations, the project has taken advantage of opportunities to build efficiencies into the marine operations. None of these are particularly advanced or unique to the Project, however they have successfully contributed to the financial performance of operations.

Driving the selection of vessels are factors such as the vessels DP capability in high flow environments, crane capacity, outreach, lift height, back deck area and capacity.

Typical vessels have had 250 to 400 tonne cranes and deck areas upwards of 1350 m^2. Each has its own motion characteristics which determine installation limits. Over a series of installation operations, SIMEC Atlantis and Apollo have developed a lean approach to setting installation limits. The aim here has been to make best use of existing analyses and to avoid repeat working. Known allowable accelerations at the crane hook are correlated with the results of motion calculations using Orcina's Orcaflex software, to produce go/no-go criteria for a spread of sea states. These are worked into operational procedures and vessel routing.

The project has, wherever practicable, re-used transportation frames and grillages. These are characterised by a set of allowable forces applied at turbine mount, which are effectively pre-approved for each deployment. The grillages are also sized such that the footprint is less than 10 t/m^2, which is the typical capacity of an offshore work vessel.

Thus, the engineering for each mobilisation is reduced to:

- Orcaflex simulations using vessel RAO's to determine the accelerations and hence forces induced on the grillage,
- Based on this produce go/ no-go criteria;
- Check the deck is rated sufficiently;
- Review the locations of the frame cleats, to ensure that sufficient capacity is provided.

The Marine Warranty Surveyor can simply and efficiently check calculations, leading to fewer delays and avoiding last minute working i.e. avoiding late and costly surprises.

Figure 11 – AR1500 and AH1000 MkI aboard the Seabed Stingray

As the Project has acquired experience of mobilisations and recovery operations, the back-deck layout has progressively simplified and standardised to avoid clutter, reducing handling operations and welding time. See for instance Figure 8. This experience has also provided sufficient confidence in the engineering process to enable SIMEC Atlantis to achieve an arrange two turbines to be carried on a 250 tonne CVS, Figure 11.

[1] DNV-OSS-312, Certification of Tidal and Wave Energy Converters specification.
[2] DNVGL-OS-B101, Metallic materials, July 2015.

WELD ARRANGEMENTS

Welding time can add up and Apollo were challenged in a recent operation to devise restraints that minimise the time spent securing the spread. Wherever possible, the welds were to be 6mm leg lengths which can be installed in a single pass of the welding gun. In contrast an 8mm fillet weld may require less length but needs three or more passes to build up the required thickness. A 6mm weld base weld on a stopper can take less than half the welding time of an 8mm weld of comparable strength. All this has an appreciable impact on the time the vessel is in port during mobilisation. 12mm welds may be common in other applications but introduce unnecessary cost in short mobilisations, Figure 12.

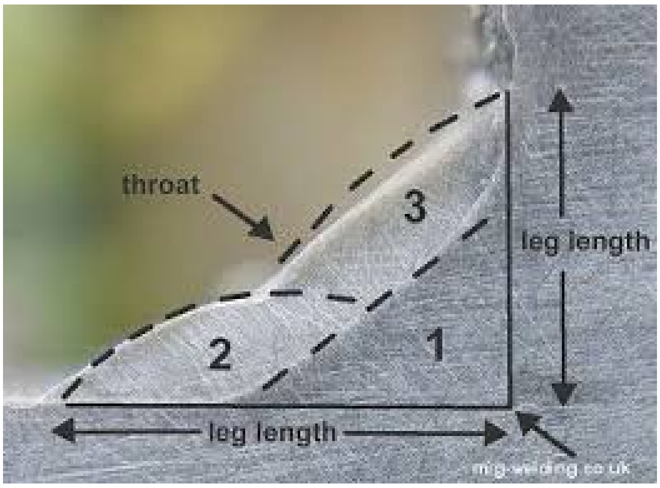

Figure 12 - Typical weld construction for greater than 6mm welds.

Another subtle design change was to reduce the welding requirements connecting the sea fastening plates to the main grillages. Typically, these are welded on the three sides where the plate is fitted into the UC on the bottom frame. Of these, the top weld is an overhand weld, with limited access, which requires extra time and specific welder qualifications. By removing the top weld connection from the spread, a significant saving was made.

SHORT TRANSIT

Some of these techniques depend on short transit routes to field. The MeyGen project has been supported from onshore bases in the Cromarty Firth, which is just a few miles from the site. Hence departure can be based on forecastable weather windows.

A recent development has been the use of directional operability envelopes to support the departure decision. Again, use is made of known properties of the spread from previous operations. The support frame strength tends to govern, so reference is made to allowable accelerations of the turbines through their centres of gravity. Using time domain simulations of the vessel motions in the relevant load condition, appropriate directional transit criteria are obtained. These are considered with reference to the forecast conditions on the proposed route, to determine if there is sufficient window to reach the relatively sheltered MeyGen site.

An example was on 13th December 2018, when strong south-easterly winds were forecast for the Moray Firth. While a direct transit up the east coast of Caithness was outside criteria, an alternative route was feasible, bearing east to Fraserburgh before transiting towards Wick in a north-westerly direction and rounding Duncansby Head to arrive at the location. Figure 13 shows the strongly directional swell prediction for the route.

By using directional data, SIMEC Atlantis proposed a route that allowed the Master to take the decision to depart port safely in relatively harsh conditions; a significant project achievement which avoided several costly days of waiting on weather midwinter.

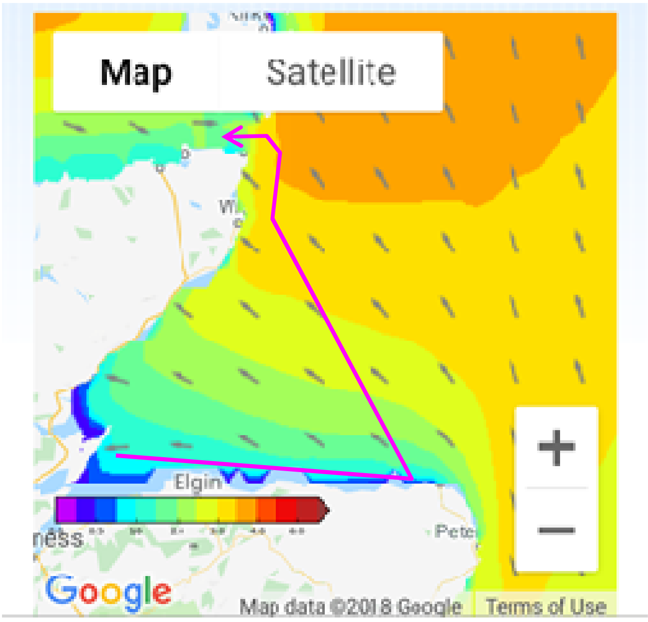

Figure 13 – Vessel routing December 2018

FUTURE CHALLENGES

The next phase of the Meygen development, Phase 1B is under way with preparations to increase power conversion with the deployment of two additional AR2000 turbines. In this phase a subsea hub will be deployed so that multiple turbines can be connected to a single power export cable.

This development will significantly reduce the costs associated with grid connection. The length of power export cable as well as the amount of onshore conversion equipment required for grid connection will be reduced, as will the amount of horizontal directional drilling and the vessel time required for cable installation. Installation of the hub and the requirement to intervene to access subsea power transformers will introduce additional transportation and installation challenges that will no doubt be embraced and resolved by the Project in its practical, innovative way.