Effectively performing marine operations in strong current areas

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***Abstract*— SABELLA's D10 marine current turbine was immersed in the Fromveur Passage in June 2015, becoming the first, and at present only, full scale marine current turbine to inject electricity into the grid in France. The initial installation was performed by lowering the whole tidal turbine at once, including the gravity-based foundation and its ballasts. This operation was carried out using a standard heavy lift vessel, without dynamic positioning, kept in position by her two anchors and three tugs. The installation was partially successful with the need for a new operation two months later for the connection of the turbine to her export cable. For the retrieval operation, only the turbine was retrieved, while the foundation remained on the seabed. This operation was carried out by MOJO MARITIME using an OCV vessel, with dynamic positioning (DP). This kind of vessel proved to be much more reliable and safer than the first installation vessel, and perfectly adapted to this kind of operation. Specific procedures and tools had to be developed for this operation, including an offshore berth and a "Launch And Recovery System". Another operation was performed by SABELLA and MOJO MARITIME in order to install a new connector at the end of the export cable, for which the vessel had to leep perfectly her position during more than 48 hours with the cable hanging on her side. This was made possible thanks to a good choice of vessel, a perfect planning and a good management onboard. These innovative methods bring cost reduction opportunities by enabling the use of smaller vessels with lower lifting capacities and result in shorter operating times through adapted tools and well-prepared procedures.**

***Keywords*— Marine Current Turbines, Tidal Turbines, Tidal Energy, Marine Operations, Management of operations at sea, DP vessel, Maintenance, O&M, France, Fromveur Passage**

I. Introduction

The future of marine current turbines industrial projects lies in reducing the levelized cost of electricity (LCOE). However, offshore operations in strong marine currents areas are complex and expensive and so represent a key area for cost reduction. Defining effective offshore operations presents the challenge of finding a good compromise between the complexity, the feasibility, the safety and the cost of offshore operations.

D10 marine current turbine was immersed in the Fromveur Passage in June 2015 and became the first and, at present, sole, grid-connected full-scale tidal turbine that injected electricity into the French grid. After one year of demonstration and at the end of the initial one-year authorized period, SABELLA decided to retrieve the turbine in order to get feedback and benefit from experience, before putting her back in water for three more years, until a pilot farm is deployed on the same site.

Another operation was carried out during summer 2017 in order to install a new connector at the end of the export cable.

With these different operations at sea, SABELLA gained a big return on experience on the realization of effective offshore operations in strong current areas and now has a clear view of offshore means and management needed for the installation and maintenance of its future tidal turbines.

II. SABELLA D10 MARINE CURRENT TURBINE

A. *SABELLA's Technology*

The technology developed by SABELLA is a horizontal axis tidal turbine composed of two modular sub-assemblies:

- A Gravity Based Structure (GBS): 3-feet triangular iron structure with cast iron ballasts, enabling to maintain the device on the seabed thanks to its own weight;
- A Turbine: fixed nacelle with a 10-meter diameter rotor made of 6-blades, hosting a direct drive permanent magnet generator, a conversion line and an electrical transformer.

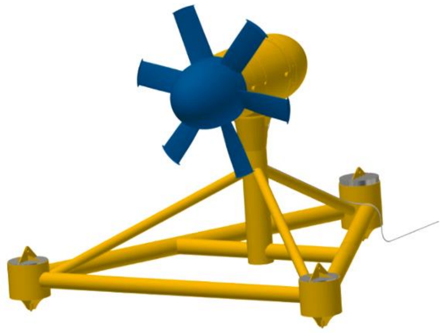

Fig. 1 Sabella D10 Marine Current Turbine

The turbine is guided onto the GBS thanks to a male – female cone interface, as shown in Fig. 2 below.

Fig. 2 Interface between the GBS and the turbine

The turbine is connected to the submarine electricity export cable via a cable jumper attached to the nacelle, which is approximately 150 m long.

B. Dimensions and weights

The dimensions of the different parts of D10 are shown in Fig. 3.

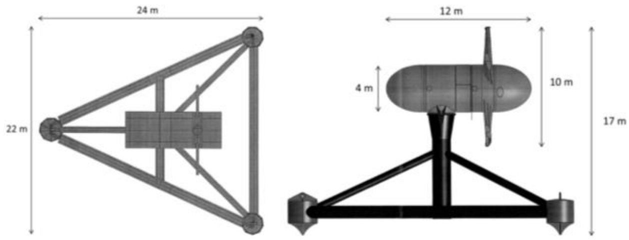

Fig. 3 D10 Marine Current Turbine's dimensions

The total weight of the device (GBS and its counterweights and turbine) is around 400 tons in air and 300 tons in water. The weight of the turbine alone is about 100 tons in air and 40 tons in water.

Three lifting points are placed on the GBS, above each leg, and four trunnions are located on the nacelle as lifting points.

C. Connection to shore

The cable jumper is connected to the main export cable through a dry-mate connector, originally installed on a metallic used to guide both connector halves. When the connector was replaced during September 2017, a bigger diameter connector was chosen, that is purely cylindrical. In order to ease the connection between the cable jumper and the export cable, a specific guiding tool will be used on the vessel's deck.

Fig. 4 D10's initial dry mate connector on its guiding plate

In order to respect the bending radius of the cable during the lowering or recovery of the cable on deck, an arch is placed at the end of the abandonment loop. On each side of the arch, nine cast iron shells are positioned around the cable in order to protect it by mechanically limiting the bend radius. Their minimum bending radius is 1.3 m.

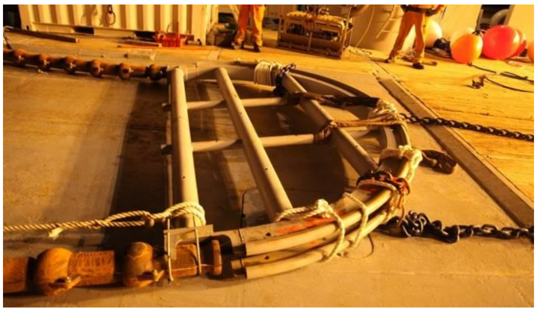

Fig. 5 Arch and cast-iron shells to respect the cable's bending radius

III. FROMVEUR STE'S CHARACTERISTICS

Geographical characteristics, distance to port and meteo-ocean conditions determine vessel selection and define the operational windows for installation and maintenance of the turbine.

A. Site location

The Fromveur Passage is located off the western coast of Brittany, France, between Molene archipelago and Ushant Island, as shown in Fig. 6.

Fig. 6 Location of the Fromveur Passage

The closest commercial port is located in Brest and the navigation route to Fromveur Passage is about 30 NM. A part of this navigating route is exposed to strong marine currents in the "Goulet de Brest", the channel to enter the roadstead of Brest (point 1 in Fig. 7), and in the "Chenal Du Four" (points 2 to point 3 in Fig. 7).

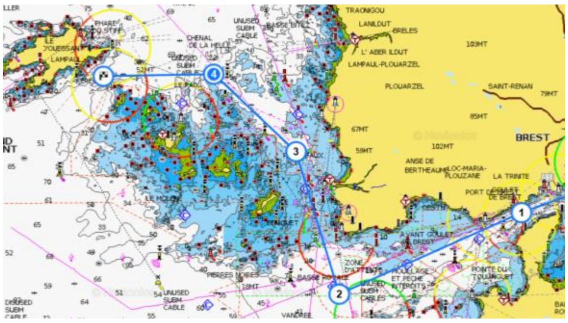

Fig. 7 Navigation route from Brest to the Fromveur Passage

B. Seabed and Bathymetry

Depth at the installation point is approximately 53 m (LAT) and the seabed in the vicinity of the marine current turbine is made of rock (granite).

C. Tidal Currents

In the area, the tide is semi-diurnal with a tidal range varying from 2.75 m at mean neap tide to 5.85 m at mean spring tide. Due to the Fromveur Passage's topography, the limited water depth and the large tidal range, marine currents can reach a velocity of 4 m.s-1 during spring tides and are nearly bidirectional at the tidal turbine location, allowing energy production with currents from both directions without loss of efficiency with a downstream current.

Since tidal currents are predictable, operational windows can be determined in advance and neap tides are preferred. An interesting neap tide lasts between 3 and 7 days and there are 24 neap tide periods per year.

The operations on site are constrained by current velocities and performance of the vessel used. The slack water can last between 1 hour and 2 hours. Thus, depending on the position keeping capabilities of the vessel, the operations on site must be limited to slack water periods or restricted to those which are possible during the whole tidal cycle.

D. Metocean conditions

Although operational windows are first determined by tidal currents, the sea state and wind conditions need to be assessed for the on-site operations but also for the transit between Brest and the Fromveur Passage. Mermaid software, developed by MOJO MARITIME, was used to schedule and optimize maintenance operations and assess weather windows for the D10 turbine retrieval operation and for the connector installation operation. [1], [2]

Offshore operations in strong currents areas are complex and restricted by many parameters, such as current velocity, sea state, wind, seabed conditions, water depth, etc. Reliable documentation of a vessel's position and heading keeping capabilities is vital for planning and execution of safe and reliable operations with dynamic positioning (DP) vessels [3]. Depending on the vessel's sea-keeping capabilities, operational windows can be very limited; therefore the choice of the vessel is critical for an effective offshore operation. Vessels capable of operating in extreme environment and thus presenting wide operational windows are to be favoured for effective operations.

IV. Marine Current Turbine Installation

D10's initial installation operation was performed in June 2015 by lowering the whole marine current turbine "all in one", including the GBS. This method was selected in order to minimize the duration of the operation. Given that the combined GBS and turbine weigh around 400 tons in air, the lifting capacity of the installation vessel was the main selection criteria. A standard heavy lift vessel, without dynamic positioning, equipped with two 450-ton cranes, was mobilised and kept in position by her two anchors and three tugs.

Fig. 8 Heavy Lift Vessel used for the initial installation

At this stage of the project, the position precision had some flexibility in latitude and longitude. The main constraint for the turbine installation was the precision with regards to the direction of the turbine and the attitude of the structure. The tolerance required by SABELLA for the orientation angle was 5°. In order to monitor the installation precision, a gyrocompass and an inertial sensor were placed on the device, on the GBS.

The marine current turbine was placed on the seabed in June 2015, with a good orientation and attitude but with the need for a second operation to carry out the connection between the jumper and export cables. The positioning of the vessel with two anchors and three tugs proved to be too difficult to maintain when the current increased from astern. The initial installation was deemed partially successful. The connection to the export cable was performed two months later by the Argonaute, a DP1 class AHTS (Anchor Handling Tugs Supply) dynamic positioning vessel, which had previously been used to lay the export cable.

Fig. 9 Argonaute vessel used for the cable laying and connection operations

These difficulties would not have arisen with a DP vessel with good sea keeping capabilities, but very few of those types of vessels have the necessary lifting capacity for an all in-one installation strategy. In order to remove the lifting capacity constraint and therefore enable the use of modern multi-purpose OCV vessels as used by the Oil&Gas sector, a modular approach will be chosen for the installation of future projects, with an initial installation in several packages: GBS without counterweights, counterweights and finally the turbine.

V. MAINTENANCE OPERATIONS

After one year of demonstration at sea and at the end of the initial authorized period, SABELLA decided to retrieve the turbine for check-up and upgrade in July 2016. Thanks to its modular technology, only the turbine was retrieved during this operation, the foundation and the export cable remaining on the seabed. This retrieval operation, illustrated in Fig. 10, was carried out by MOJO MARITIME.

The weight of the package being reduced by retrieving only the turbine, an IMR (Inspection, Maintenance and Repair) vessel, with DP class III and a 400 t AHC (Active Heave Compensation) crane was used. IMR vessels are multi-function vessels made for underwater offshore operations and are used by the Oil & Gas industry. Thanks to their powerful azimuth thrusters, this kind of vessel presents very good position keeping capabilities in currents of more than 5 knots.

Fig. 10 Sabella D10’s turbine retrieval in July 2016

For this operation, specific procedures and tools had to be developed. MOJO MARITIME set up the marine operation procedures based on their own experience and expertise in marine energy offshore operations. Regarding sea-fastening design, lifting plan and structure dimensioning, DNVGL-ST-N001 standard was used [4].

A. *Turbine’s offshore berth*

An offshore berth, allowing the turbine to be securely installed on the vessel’s deck for transportation, was designed and constructed. The berth was seafastened to the deck by welding.

Fig. 11 D10’s turbine on ifs offshore berth after retrieval

B. *Launch And Recovery System*

A remotely actuated hydraulic lifting tool had to be designed and constructed to lift the turbine from the structure. This “LARS” (Launch And Recovery System), shown in Fig. 12, is made of a frame fitting the nacelle shape and four grommets, moved by hydraulic actuators and closing around the four lifting trunnions located on the nacelle. Four video cameras are positioned on the frame, monitoring the four grommets to verify their proper closing around the trunnions.

The difficulty in this tool’s development laid in the fact that it was designed while the turbine was already immersed. Consequently, it was impossible to check any dimension and no guiding system was placed in advance on the turbine. Everything was perfectly managed by MOJO MARITIME and SABELLA and this tool enabled the safe recovery of the turbine in July 2016. During the same operation, the opportunity was taken to carry out a reinstallation test of the turbine on its foundation, thereby validating and strengthening SABELLA's modular technology.

Fig. 12 Launch And Recovery System during turbine's retrieval

An acoustic transponder is located on the LARS to monitor the bearing and distance of the device to the vessel. Monitoring instruments are connected to the vessel via a data cable attached to the hydraulic cables. A work class ROV was also used to observe and control the operation.

Fig. 13 ROV video of two grommets around the lifting trunnions

C. Connector installation operation

Another maintenance operation was performed by SABELLA and MOJO MARITIME in end of August 2017, in order to install a new connector at the end of the export cable. This operation was once again carried out using a DP vessel, with lower lifting capacities as no heavy lift had to be performed. The specificity of this operation is that the vessel had to be kept perfectly in position during more than 48 hours with the cable hanging on the vessel's side, while the connector was being installed. The choice of the vessel and the management of the position keeping were thus crucial for this operation.

Fig. 14 Export cable on deck after the connector's replacement, just before final laying

D. Procedures

For these two maintenance operations, method statements and procedures were prepared and compiled into Project Execution Plan documents which defined detailed task plans and timings of each operation. In strong current areas, tasks which need to be done during slack water periods are to be precisely programmed so that they do not end up outside of the slack period. Potential problems and delays have to be assessed in advance and scenarios for each of them have to be clearly defined, in order to reduce the reflexion times when they arise. Tool-Box Talks Meetings (task-specific risk assessments and personnel briefings) were held onboard before each task and were essential for the operation to be well coordinated and for all operators to perfectly know and understand their roles and tasks. QHSE and Risk management plans were established to ensure operations were conducted in a safe and efficient manner.

VI. Discussion

SABELLA's tidal turbine installation and maintenance operations combined with MOJO MARITIME experience highlight that there is a lack of suitable vessels (and associated ROVs) on the market today to conduct safe operations at a reduced cost.

Tidal risk and cost reduction require increased site accessibility by widening the operational windows. As demonstrated in the above sections, the best contemporary DP vessels coming from the Oil & Gas sector can keep station at currents slightly above 5 knots. This limitation means that subsea interventions occur only during neap tides. A similar issue lies within subsea operations assisted by ROVs that can only hold station in currents up to 2 knots, which constrains the accessible working windows to slack tides only.

Estimating marine operations costs in a tidal energy project is not limited to the day rate and mobilization fee of a vessel but also by her ability of achieving the operation in a safe manner and in a wide range of operational windows due to the reduced site accessibility in strong current areas. Thus, site accessibility needs to be carefully assessed based on vessel capabilities when calculating the LCOE of a project as this can significantly increase or lower marine current turbines availability. Indeed, installing turbines with a slightly more expensive asset but with good station-keeping capabilities could end up being a more cost-effective solution compared to a cheaper vessel struggling to hold station in tidal races.

For example, anchored heavy lift vessels have lower day rates but also present much higher risks due to poor station-keeping capabilities and therefore limited operational windows. Conversely, DP vessels present a lower risk and wider operational windows although their interventions are still limited to neap tides. DP OCV vessels, currently used in the Oil & Gas industry, have similar operational prices as anchored heavy lift vessels but with stronger station-keeping limits. They sometimes have higher day rates but allow the installation operations to be completed in a shorter timeframe and with less risk which is beneficial

In order to target commercial development of the tidal energy sector, specific and new offshore and subsea assets will need to emerge. MOJO MARITIME has therefore designed an asset taking the advantages of both OCV and heavy lift platforms: sufficient crane capacities, large deck area, high DP performance, etc. The HF4 vessel is one example of state-of-the-art, high performance, dynamic positioning vessel capable of operating in extreme environments (Fig. 15). This vessel will be able to effectively hold station in tidal currents up to 10 knots procuring her 100% accessibility of sites such as the Fromveur Passage.

Fig. 15 MOJO MARITIME HF4 vessel lifting Sabella D10 turbine

MOJO MARITIME is also currently developing a new concept of work-class ROV designed to operate at tidal sites. This HF-ROV would be able to fly in current environments of up to 5 knots, thus extensively enlarging their operational windows and the amount of time where subsea operations could be carried out.

VII. Conclusions

Due to the package weight and the original installation philosophy, D10 tidal turbine's initial installation operation was performed using a standard heavy lift vessel, without dynamic positioning, kept in position by her two anchors and three tugs. The installation was partially successful because of the position keeping difficulties in strong current. In order to remove the lifting capacity constraint and to be able to mobilize multi-purpose commonly used in Oil & Gas vessels, a modular approach is considered for the installation of the future projects.

For the retrieval operation, only the turbine, a much lighter package, was retrieved, the foundation remaining on the seabed. An IMR vessel, with dynamic positioning class III and very good position keeping capabilities, was used. This kind of vessel proved to be much more reliable, safer and perfectly adapted for this kind of operations in strong current areas. A similar vessel, with lower crane capacities, was also used for another operation consisting in replacing the connector at the end of the export cable.

The modular approach and the innovative tools and methods developed for installation and maintenance of the marine current turbine bring costs reduction opportunities thanks to the use of smaller vessels, with lower lifting capacities and high performance dynamic positioning capabilities. The use of the appropriate vessel with adapted tools and well-prepared procedures enable to shorter operating time and wider operational windows and thus to reduce risks for critical operations.

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