13th EWTEC 2019
Proceedings of the 13th European Wave and Tidal Energy Conference 1-6 Sept 2019, Naples, Italy

Effective offshore operations in strong tidal currents locations

Diane Dhomé, Aude Cessou, Jean-Christophe Allo

Abstract— **Sabella D10 tidal turbine was immersed in the Fromveur Passage in June 2015, becoming the first, and at present only, full scale tidal turbine to inject electricity into the French grid. The initial installation was carried out by lowering the whole tidal turbine at once, including the gravity-based foundation and its ballasts. This 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 with the need for another operation two months later for the connection of the turbine to the subsea cable. For the retrieval operation, only the turbine was recovered, the foundation and export cable remaining on the seabed. This operation was carried out using an OCV vessel, with dynamic positioning (DP). This proved to be much more reliable and safer than the first installation, and perfectly adapted to this kind of operation. A smaller DP vessel, with lower lifting capacity, was used for the turbine's reinstallation operation in 2018. Specific procedures and tools had to be developed for these operations, including an offshore berth and a "Launch And Recovery System". Another operation was carried out in order to install a new connector at the end of the export cable, for which the vessel had to keep perfectly in position during more than 48 hours with the cable hanging on the side. This was made possible thanks to a good vessel selection, a careful planning and a good management onboard. These innovative methods bring cost reduction opportunities by allowing the use of smaller vessels with lower lifting capacities and result in shorter operating times through adapted tools and well-prepared procedures.**

Keywords—**Marine operations, DP vessel, OCV, maintenance, tidal turbines**

I. Introduction

THE future of tidal energy projects lies in reducing the levelized cost of electricity (LCOE). However, marine operations in strong tidal currents locations 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 tidal turbine was immersed in the Fromveur Passage in June 2015 and became the first and, at present, only, grid-connected full-scale marine current 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 return on 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 in summer 2017 in order to install a new connector at the end of the export cable. The turbine was then reinstalled on her foundation and reconnected to her export cable in October 2018.

With these different offshore operations, 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 Tidal Turbine

A. The technology

The technology developed by SABELLA is a horizontal axis tidal turbine composed of two modular sub-assemblies (see Fig. 1):

- 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.

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

Paper ID number: 1774- Conference track: Operations, maintenance and decommissioning.

D. Dhomé is at SABELLA, 7 rue Félix Le Dantec, 29000 Quimper, France (e-mail: d.dhome@sabella.bzh).

A. Cessou is at SABELLA, 7 rue Félix Le Dantec, 29000 Quimper, France (e-mail: a.cessou@sabella.bzh).

J.-C. Allo is at SABELLA, 7 rue Félix Le Dantec, 29000 Quimper, France (e-mail: jc.allo@sabella.bzh).

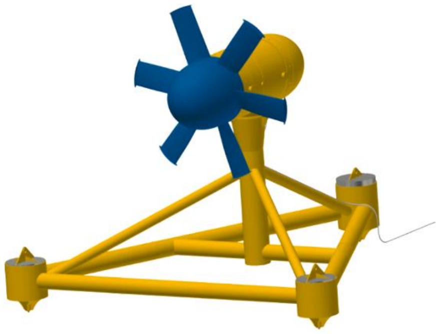

Fig. 1. D10 Marine Current Turbine.

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

Fig. 2. Interface between the Gravity Based Foundation and the turbine.

B. *Tidal turbine characteristics*

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

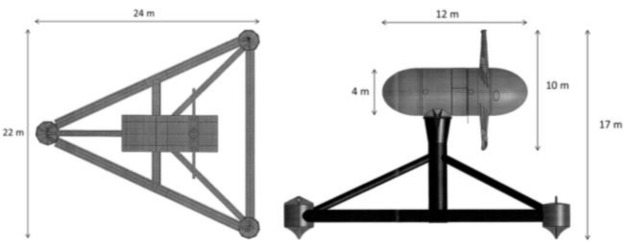

Fig.3. D10 tidal turbine's dimensions.

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 approximately 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 the shore*

The cable jumper is connected to the main subsea cable through a dry-mate connector, originally installed on a metallic plate used to guide both half connectors. When the connector was replaced in 2017, a bigger diameter connector was chosen, purely cylindrical. In order to ease the connection between the cable jumper and the export cable, a specific guiding tool has been built and is used on the vessel's deck.

Fig. 4. D10 second dry mate connector on its guiding berth.

In order to respect the cable's minimum bending radius during its lowering or recovery on deck, a quadrant is placed at the end of the abandonment loop. On each side of this 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. Quadrant and cast-iron shells allowing to respect the cable's minimum bending radius.

III. SITE 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.

D. *Site location*

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

Fig. 6. Fromveur Passage location.

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

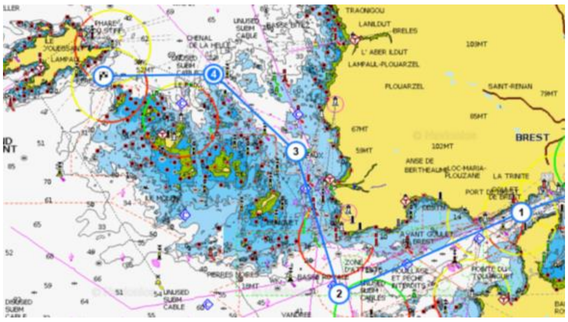

Fig. 7. Navigation route between Brest and Fromveur Passage.

E. *Seabed characteristics*

The depth at the turbine location is approximately 53 m (LAT) and the seabed around the tidal turbine is made of rock (granite).

F. *Marine currents*

In this location, the tide is semi-diurnal with a tidal range varying between 2.75 m at mean neap tide and 5.85 m at mean spring tide. Due to the topography of the Fromveur Passage, 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.

As tidal currents are perfectly predictable, operational windows can be determined in advance and neap tides are preferred for marine operations. 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 position keeping performance of the vessel used. The slack water can last between 1 hour and 2 hours. Thus, depending on the vessel’s station keeping capabilities, the operations on site must be limited to slack water periods or restricted to those which are possible during the whole tidal cycle.

G. *Metocean considerations*

Although operational windows are first determined by marine currents, sea state and wind conditions need to be assessed for the operation itself 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 D10 turbine retrieval operation and for the connector replacement operation.

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 vessels [3]. Depending on the vessel’s station-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. TIDAL TURBINE INITIAL INSTALLATION

D10 tidal turbine’s initial installation was performed in June 2015 by lowering the tidal turbine “all in one”, including the GBS and the ballasts. This method was selected in order to minimize the duration of the operation. Given that the total weight is around 400 tonnes 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. Standard heavy lift vessel used for D10 initial installation.

At this stage of the project, there was some flexibility on the positioning precision in latitude and longitude. The main constraint was the precision on 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 GBS.

The tidal turbine was laid on the seabed in June 2015, with a good orientation and attitude but with the need for a second operation to perform the connection between the jumper and export cables. The positioning keeping of the vessel with two anchors and three tugs proved to be too difficult with the current increasing 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) vessel, which had previously been used to lay the subsea cable (Fig. 9).

Fig. 9. Vessel used for D10 export cable laying and connection operation.

These difficulties would not have arisen with a DP vessel with good positioning capabilities, but very few of these 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 allow the use of modern multi-purpose OCV vessels as used by the Oil&Gas sector, a modular approach will be preferred 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 initially 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, while the foundation and the export cable remained on the seabed. This retrieval operation is illustrated in Fig. 10.

As the weight of the lifts is 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. D10 turbine retrieval in July 2016.

For this operation, specific procedures and tools had to be developed. Regarding sea-fastening design, lifting plan and structure dimensioning, DNVGL-ST-N001 standard was used [4].

H. *Offshore berth for the turbine*

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

Fig. 11. D10 turbine on its offshore berth on the vessel's deck after retrieval.

I. *Launch And Recovery System*

A remotely actuated hydraulic lifting tool was designed and built in order to lift the turbine from the foundation. 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 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 design laid in the fact that it was designed while the turbine was already immersed. Therefore, it was impossible to check any dimension and no guiding system was placed in advance on the turbine. Everything was perfectly managed and this tool enabled the safe retrieval 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. D10 turbine lifting using the LARS in July 2016.

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

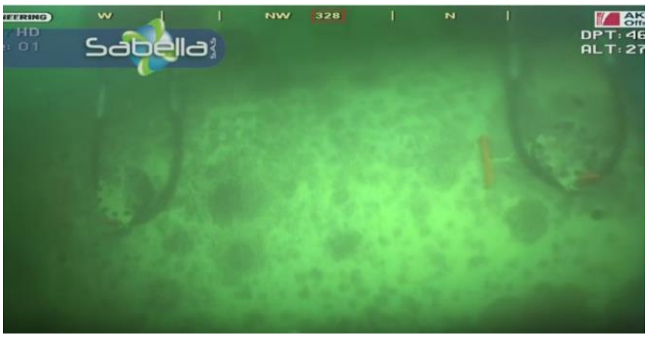

Fig. 13. Grommets around the turbine's lifting trunnions, as seen by the ROV.

J. Connector installation operation

Another maintenance operation was carried out in end of August 2017, in order to install a new connector at the end of the subsea 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 mounted. The vessel choice and the management of the position keeping were thus crucial for this operation.

Fig. 14. Subsea cable on deck ready to be lowered back to the seabed after connector's replacement.

K. Turbine reinstallation

The turbine was then reinstalled onto her foundation and reconnected to the subsea cable in October 2018. For this operation, another DP class II IMR, shown in Fig. 15, was used. Compared to the vessel used for the turbine retrieval, this vessel had much smaller lifting capacities, with a 150 t AHC crane.

This brought other challenges as everything was on the limits, this requiring even more careful preparation and management, but also allowed cost reduction thanks to the use of a smaller vessel.

Fig. 15. D10 turbine reinstallation in October 2015.

Moreover, this vessel was already equipped with all survey and ROV equipment, thus reducing the mobilisation and preparation time and participating in the cost optimisation.

L. Procedures

For these three marine operations, method statements and procedures were prepared and compiled into Project Execution Plan documents which defined detailed task plans and timings for each operation. In strong marine current areas, tasks which need to be done during slack water periods are to be precisely programmed so that they do not end up out 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 thinking times when they arise. Tool-Box Talks Meetings (task-specific risk assessments and personnel briefings) are held onboard before each task and are 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 are established to ensure that operations are conducted in a safe and efficient manner.

VI. DISCUSSION

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

Marine currents 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 position with 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 to her ability to achieve 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 tidal turbines availability. Indeed, installing turbines with a slightly more expensive asset but with good station-keeping capabilities could prove to be a more cost-effective solution compared to a cheaper vessel struggling to hold station in tidal areas.

For example, anchored heavy lift vessels have lower day rates but also present much higher risks due to poor position-keeping capabilities and therefore limited operational windows. On the opposite, 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 for example 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. 16). 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. However, some uncertainties remain regarding the timeframe of production of such vessels, as the tidal energy market is not large enough for such investments today.

Fig. 16. Drawing of the HF4 vessel lifting D10 turbine.

MOJO MARITIME is also currently developing a new concept of work-class ROV designed to operate at tidal energy 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 performed.

VII. Conclusion

Due to the total 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 two anchors and three tugs. The installation was partially successful because of the station 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 and has been validated by several maintenance operations.

For the retrieval operation, only the turbine, a much lighter package, was retrieved, the foundation and subsea cable remaining on the seabed. An IMR vessel, with dynamic positioning class III and very good station-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. A similar vessel was finally used for the turbine reinstallation, but this ship had much lower lifting capacities, making the operation cheaper but also more complex to manage.

This modular approach and the innovative tools and methods developed for installation and maintenance of the tidal 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 shorten operating time and widen operational windows and thus to reduce risks for critical operations.

REFERENCES

[1] Mermaid website [Online]. Available: http://mojomermaid.com
[2] R. Walker, B. Sewell, M. Morandeau, A. Boswell. Quantifying and Reducing Installation Risks for Offshore Wind Turbine Generators. Offshore 2013. Nov. 21, 2013.
[3] Standard — DNVGL-ST-0111. Assessment of station keeping capability of dynamic positioning vessels. Edition July 2016.
[4] Standard — DNVGL-ST-N001. Marine operations and marine warrant. Edition June 2016.