TIGER PAIMPOL TEST – T1.2.5 : Paimpol-Bréhat testing, power curve accreditation and data sharing / reporting

V2

July 2023

Document History

Revision	Date	Description	Originated by	Reviewed by	Approved by
1	May 2023	Initial version	R.Coquet	M. Tournabien	R.Coquet
2	July 2023	Small corrections	R.Coquet	M. Tournabien	R.Coquet

Disclaimer

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1 Context

The 1MW tidal turbine Oceanquest was installed and grid connected, operated and recovered between April 2019 and October 2021 off the coast of Paimpol-Brehat, Brittany.

The tidal turbine is designed with several vertical axis turbines mounted in a mechanical structure made of plates and fairings. There are two counter rotating columns. Each column is equipped with two rotors of 8m diameter and 3.8 m height. A permanent magnet generator is installed on the top of each shaft. A parking brake is placed at the bottom of each shaft.

The electrical elements are installed in a watertight enclosure, located inside the upper central fairings. The turbine is connected to shore with power and fiber optic links.

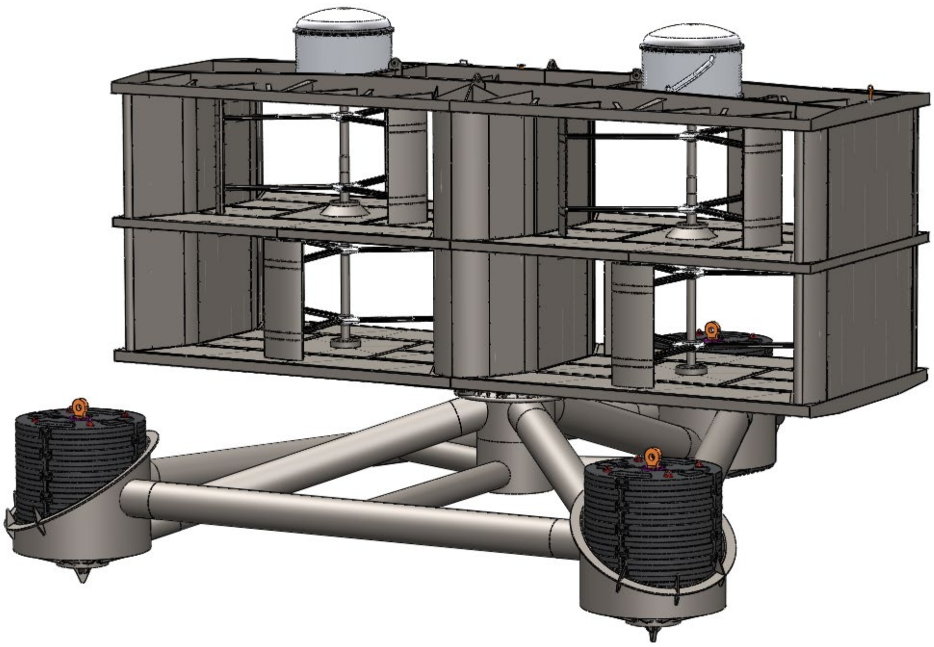

Figure 1 – Overview of the turbine and the foundation

The turbine and the foundation were retrieved and transported to Cherbourg in October 2021 (Figure 2).

Figure 2 | Retrieval of the Oceanquest tidal turbine, Oct 2021

During the turbine operational phase (Apr 2019 – Sep 2021), many results were achieved:

- Operation of the turbine for more than 2 years;
- Survey dives were executed to visually inspect the turbine, to perform various operations and/or to perform various measurements;
- A power curve test was undertaken, for power curve accreditation;
- Anode and coating performance was assessed.

2 Operation and maintenance performance and lessons

1.1 Operation performances

The turbine has been successfully operated for c. 2 years without a major defect.

During the duration of the operation, monthly operation reports were created (confidential).

These monthly reports contain the following data:

- Time series presenting the electrical power generation (kW) of the turbine (10-minute averages);
- Time series showing the rotational speed of rotor 1 and 2;
- Daily average of the tidal coefficient and daily maximum significant wave height (30-minute average);
- Availability: Number of daily hours where the turbine is available / unavailable / stopped due to weather conditions / stopped due to tests in progress / stopped due to unavailability of the network.

1.2 Maintenance performances

For the Oceanquest turbines, any maintenance needed means lifting the turbine out of the water and bringing it back to quay side for intervention.

Some ROV or diving inspection can be performed without retrieving the turbine, but these correspond only to check and visual inspections.

During the c. 2 years of operation, no maintenance operation was performed.

The retrieval and decommissioning operation provided a key learning opportunity for planning of maintenance operations for the next turbine generation. A description of these operations and the lesson learnt are available in deliverable T1.2.7.

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3 Test procedure for power curve accreditation process and lessons

The power curve assessment assessment was performed following the IEC TS 62600-200 technical specification. This technical specification is widely recognized in the tidal industry.

The European Marine Energy Centre (EMEC), as a third party, performed an accredited inspection of the metocean and electrical data collection process and reporting.

The Oceanquest turbine was deployed at the Paimpol Bréhat test site with the purpose of demonstrating its hydrodynamic performance and robustness.

The existing electrical infrastructure at the test site was reused and the power take off system of the turbine was optimized around it. This approach was designed to allow the best turbine availability and control of the operation point, at the cost of a non-conventional power export and injection system.

As such, it is understood that the performance curve assessed in this power curve accreditation process is not intended to be used directly for energy production projections for potential commercial developments, but rather to consolidate HydroQuest's knowledge of the hydrodynamic performance of its Oceanquest turbine in real conditions.

1.3 Tidal energy converter

3.1.1 Equivalent diameter

As defined in IEC TS 62600-200, the turbine is defined to be a rectangular capture area. The equivalent diameter is calculated from following formulas:

$$A = A_1 = hw$$
$$D_{E,1} = (4hw/\pi)^{1/2}$$
$$D_E = D_{E,1}$$

According to § 3.19 of IEC TS 62600-200, the projected capture area is the frontal area of the tidal energy converter (TEC) including the duct or other structures which contribute to the power extracted by the device perpendicular to the principal axis of energy capture.
The equivalent diameter is 17.56 m.

3.1.1.1 Power take-off system

The power take-off system including the generators and converters is presented in the following diagram.

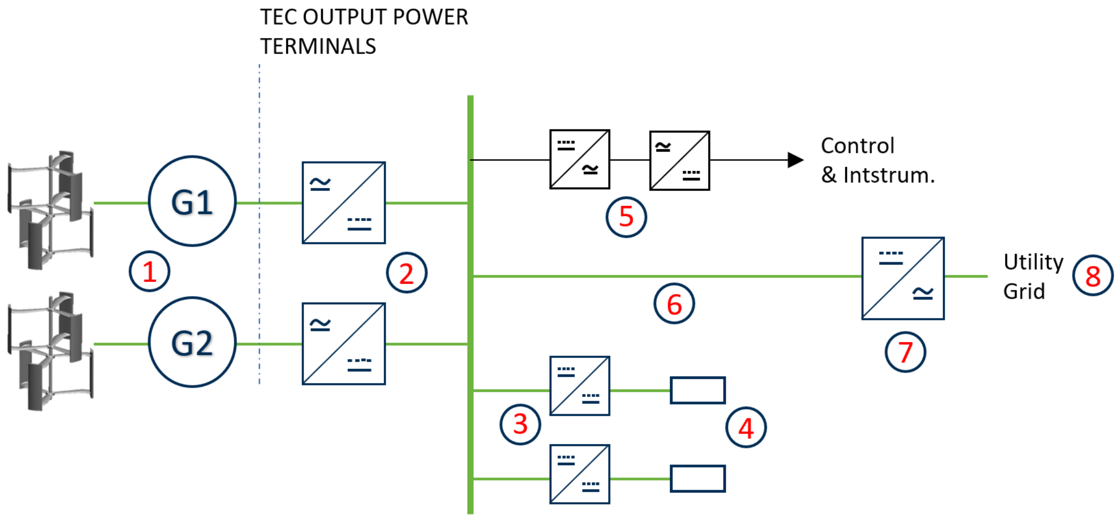

Figure 3 – Power Take-off system

1.4 Tidal energy converter test site

The following section describes the test site.

3.1.1.2 Bathymetry

Three bathymetric surveys were performed on the test site. These surveys fulfil the criteria of IHO 2008. The area studied in these surveys covers a surface observing the following dimensions: 10 equivalent diameters of HydroQuest turbine upstream and downstream and 5 equivalent diameters of HydroQuest turbine on either side.

The seabed is not flat. It is uneven, rocky with outcrops. High-resolution bathymetry shows that the size of the TEC relative to the cross-sectional area of the TEC test site prevents flow from diverting into the device and does not create a local increase in the incident resource.

3.1.1.3 Devices

The following figure shows the location of the turbine, the location of the allowable ADCP deployment boxes and the actual location of the ADCPs.

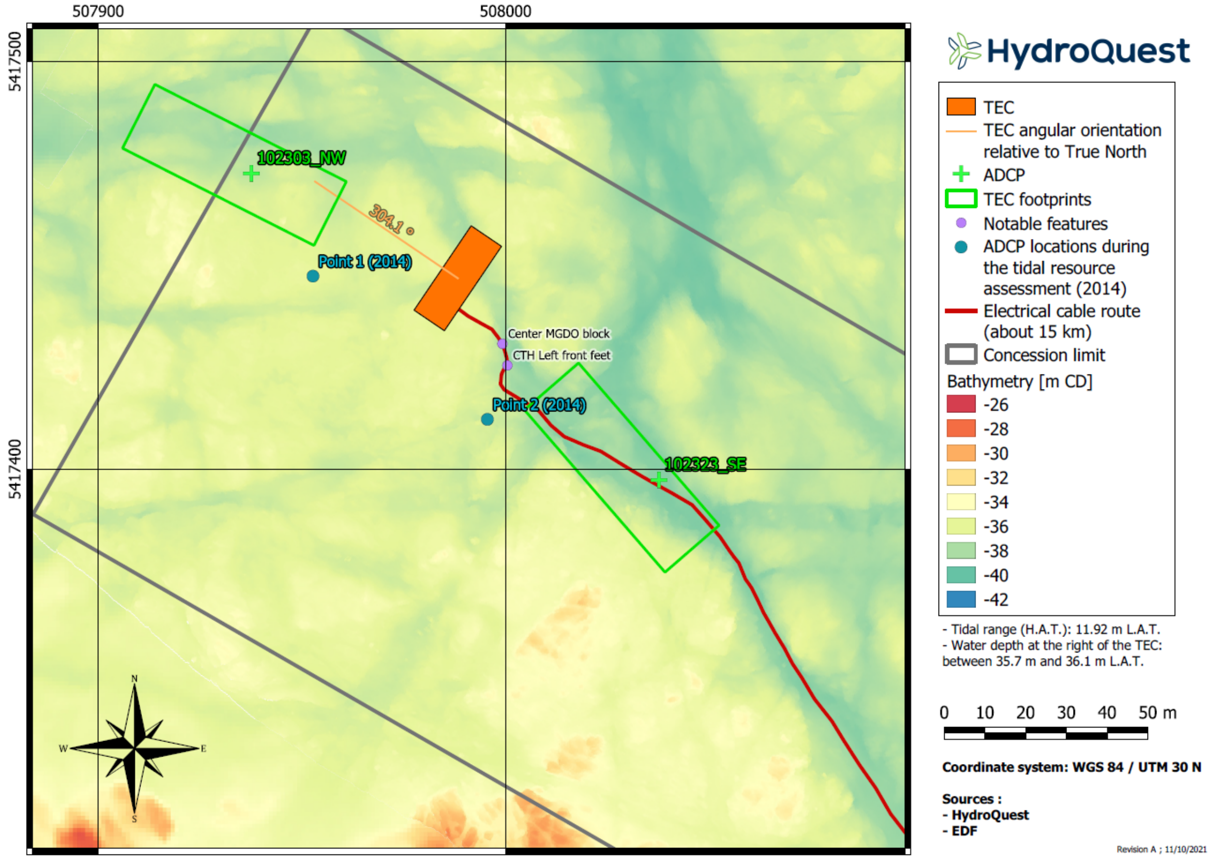

Figure 4 : Hydrographical chart of the test area

3.1.2 Current velocity and wave

Two bottom mounted current profilers were deployed at the TEC site during spring 2014, prior to the deployment of the TEC (see Figure 4). The following table provides the principal flow directions at the hub height.

Table 1: Main flow directions at the hub height during the tidal resource assessment during spring 2014.

Year	Point	Principal Flood direction [°]	Principal Ebb direction [°]
2014	Point 1	119	319
2014	Point 2	116	318

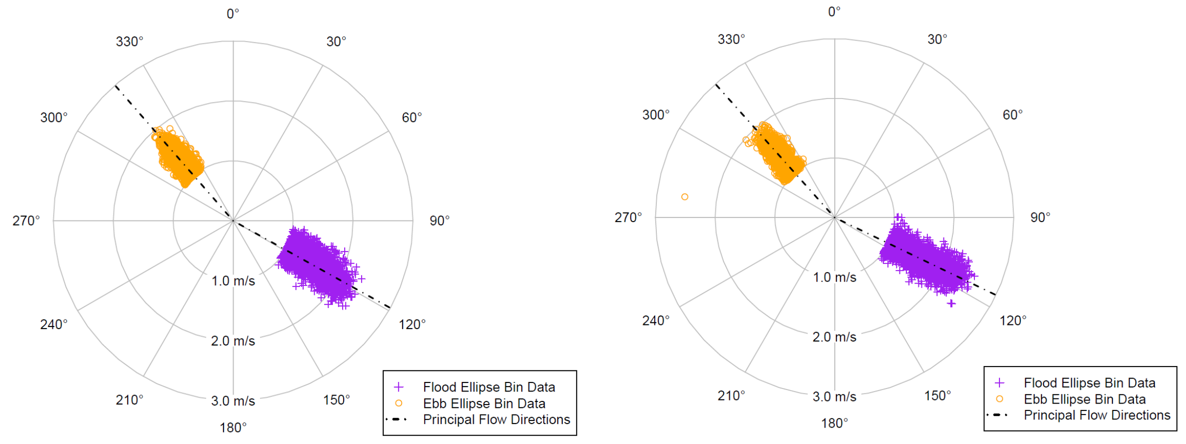

Figure 5: Tidal ellipse at the hub height for the Point 1 (left) and the Point 2 (right) of the ADCP campaign during spring 2014.

Figure 6 illustrates the tidal ellipse and principal flow directions relative to the TEC. The principal flood direction is equal to 119°, the principal ebb direction is equal to 318°. Consequently, the misalignment between the TEC direction and the principal flood direction is equal to 5.5° and the misalignment between the TEC direction and the principal ebb direction is equal to 14°. The TEC design basis defines a normal functioning for a tidal current misalignment from -20° to 20° relative to the TEC orientation. Thus, the observed misalignment values are included in the domain defined by the design basis.

The principal flow directions measured during the power curve assessment campaign are very consistent with those of the tidal assessment campaign. The difference of measured angle during the flood could be explained by a significant spatial heterogeneity of the flow direction in this energetic site.

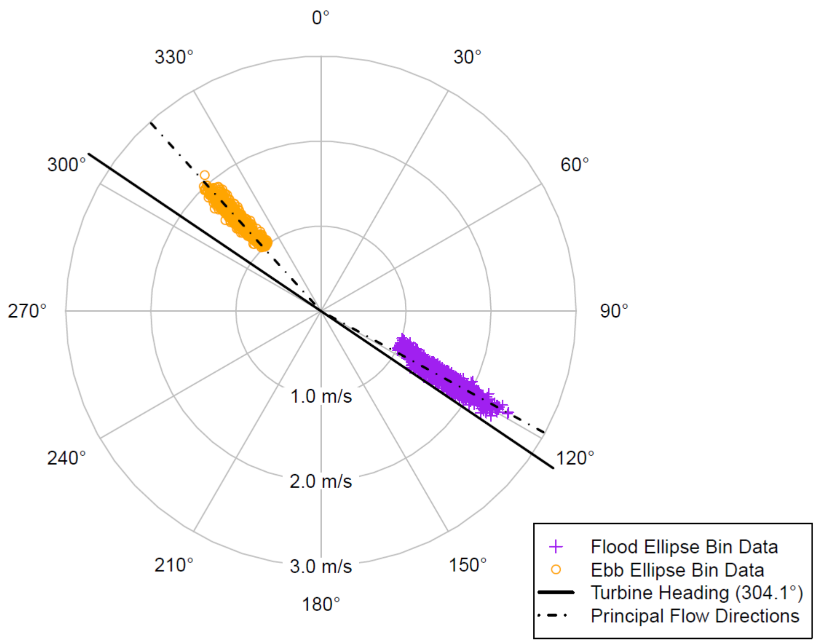

Figure 6 : Tidal ellipse plot identifying principal ebb and flood directions.

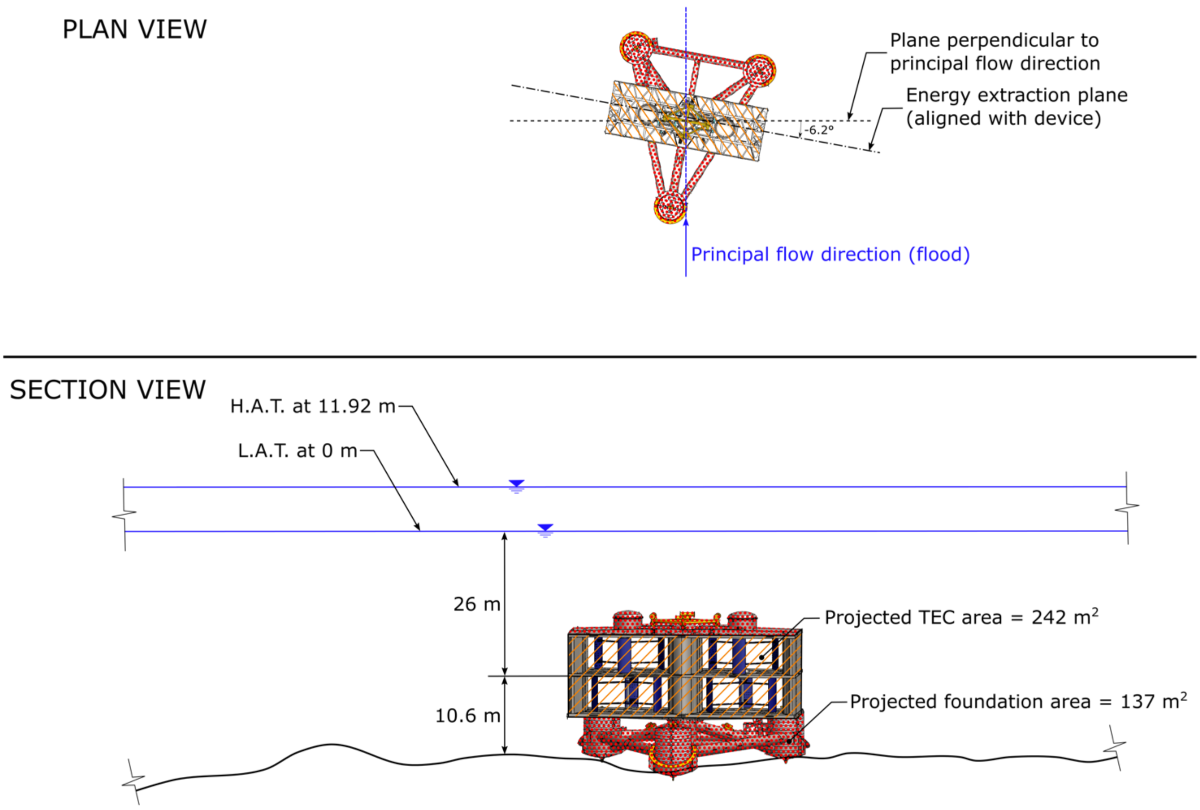

Figure 7 : Plot of the cross-sectional area consumed by TEC on plane perpendicular to principal flow direction (flood)

1.5 Test equipment

3.1.3 TEC Active power measurement

The net electrical power of the TEC is measured by the gen-side converters.

The measurement of the net active power is achieved by the gen-side converters by the means of:

- Generator side current measurement (Hall Effect current transducer – Datasheet not communicated by ABB)
- DC bus voltage measurement (Voltage Transformer – Datasheet not communicated by ABB) and computation of the generator side voltage based on PWM modulation index.

The measure uncertainty for this parameter is defined by the product manufacturer (ABB) at 2% of the converter nominal power.

3.1.4 TEC Active power acquisition

The acquisition is then achieved by the turbine control PLC through profinet communication with the converters. The 1Hz data logging of the values is achieved by the Supervision server (windows-based *Ignition* software) through TCP IP communication with the turbine control PLC.

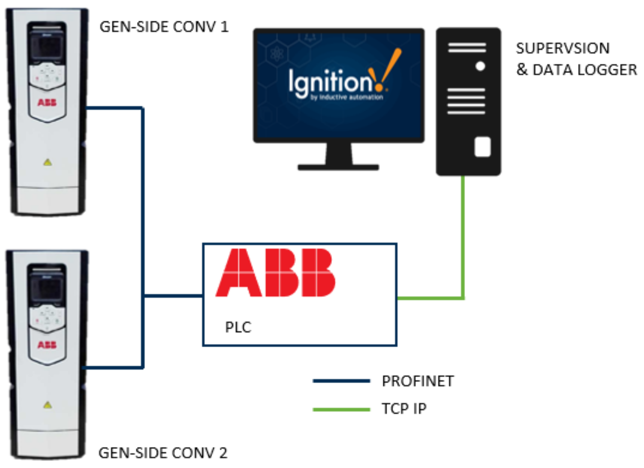

Figure 8 : power measurement and acquisition

3.1.5 TEC Auxiliary Power Consumption

Due to the grid configuration presented in section 3.1.1.1, the totality of the auxiliary power need of the TEC has been supplied from the mainland public distribution grid.

The main auxiliary power continuous consumers are listed below:

- Liquid cooling system pumps
- Electrical shelter cooling fans
- Power drive cooling fans
- Turbine control system (PLCs)
- Electrical control circuitry
- Environmental instrumentation system (including current profiler)
- Supervision system

These consumers are fed through the two auxiliary power supplies. The power flowing through these power supplies is acquired and logged by the same system used for the acquisition and logging of the TEC Active power. From this acquisition, power consumption during the high-power production periods and during the neap tide periods was measured. The variation between production and stand-by period is due to the higher cooling needs during high-power production periods.

3.1.6 Current profilers

The current profilers were Nortek Signature 500 ADCPs (Acoustic Doppler Current Profiler).

Figure 9 : Nortek Signature 500 ADCP

The Signature 500 ADCP measures current profiles at up to 8 Hz sampling frequency. It can also measure direct vertical velocity profiles, wave height and direction. The datasheet, the Nortek certification and the certificates of calibration of the ADCP are available.

The ADCPs were configured with Nortek's MIDAS software.

Compass calibration of the two ADCPs was carried out using Nortek Signature Deployment software just before boarding. ADCP are installed in their non-ferrous deployment frames. This calibration is carried out using the lifting crane of the boat, above the dock.

The ADCP head is 0.90 m above the seabed.

The following figures illustrated the capture bins of the current profilers across the projected capture area of the TEC.

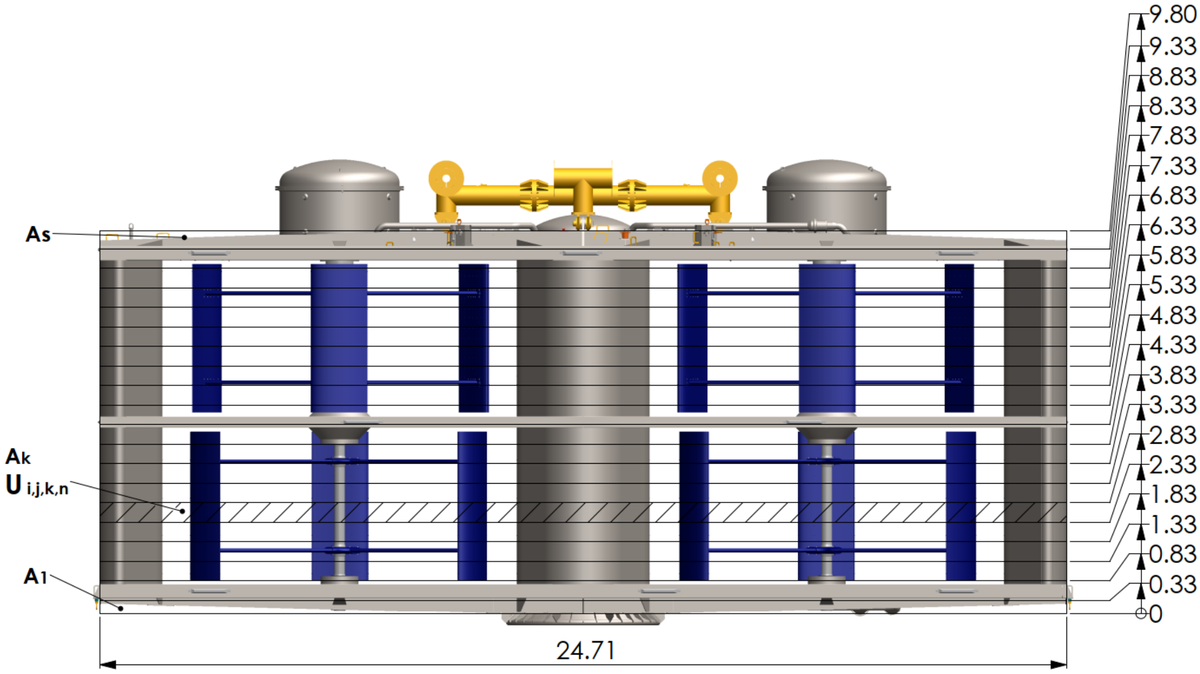

Figure 10: Capture bins of the current profilers across the projected capture area for flood datasets

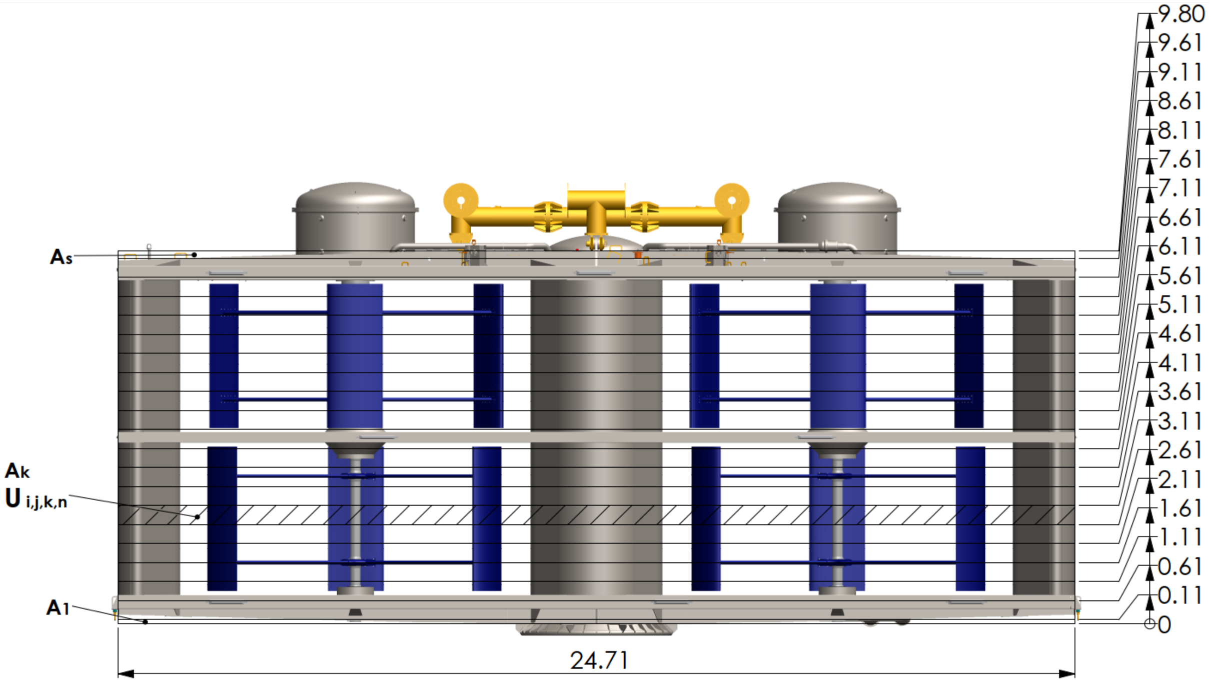

Figure 11: Capture bins of the current profilers across the projected capture area for ebb datasets

1.6 Measured data

The measured data used to populate the velocity bins are provided in a scatter plot for each of the flood and ebb datasets. Figure 12 provides the scatter plot of performance data for the flood datasets. Figure 13 provides the scatter plot of performance data for the ebb datasets.

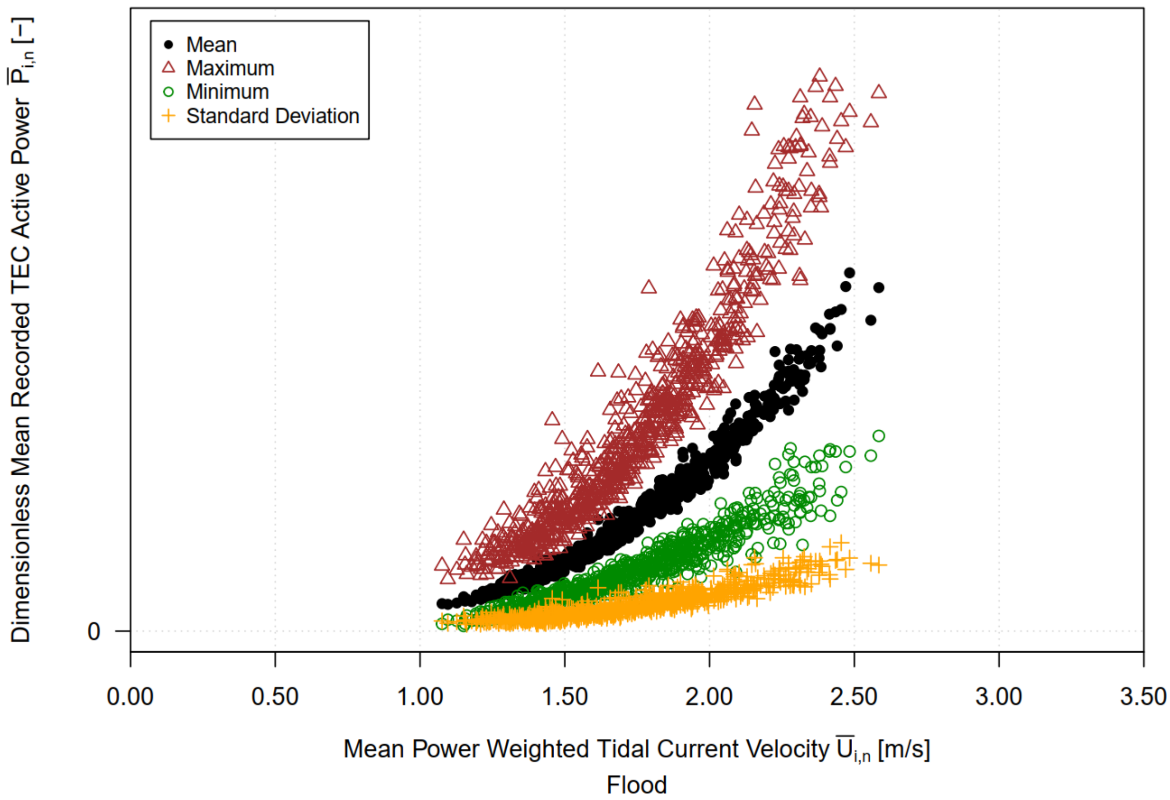

Figure 12 : Scatter plot of performance data for flood dataset

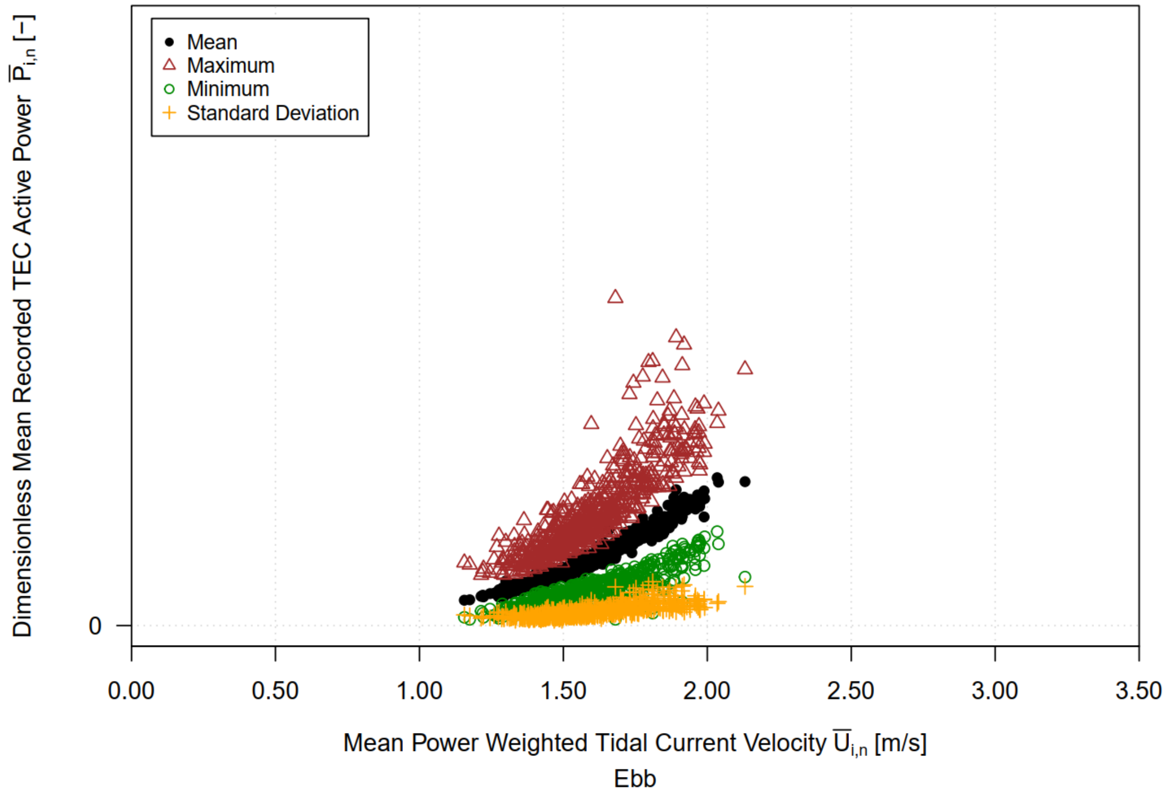

Figure 13 : Scatter plot of performance data for ebb dataset

1.7 Accreditation

The accreditation report is confidential but the accreditation certificate is available in the Appendix.

1.8 Lessons learnt

The inspection process aligned with the requirements of the ISO/IEC 17020:2012 standard to which EMEC is accredited as an 'Inspection Body'. These additional requirements, which are not required by IEC TS 62600-200, explain some deviations presented in the accreditation certificate in the Appendix.

Moreover, some deviations have been identified during the process, especially regarding calibration procedures and data uncertainties. Thanks to this accreditation process, these deviations will be avoided for later test procedures.

4 Anode and coatings performance and lessons

The following section highlights the analysis of anode and coating performance. This analysis was performed once the turbine was retrieved and landed at the quayside.

1.9 Coating

The general anti-fouling coating condition after c. 2 years of operation was very good. The difference between the areas treated with anti-fouling coating and the areas without was very clear.

The top and bottom of the structure, which were coated only with an anti-corrosion system, were covered with fouling while the rest of the structure was clean.

No corroded area was observed, but some localized barnacles were observed, often on local damage or screw heads, these having allowed their fixation.

1.10 Anodes

As the Oceanquest turbine is a prototype, anodes were designed for a 2 year lifetime.

After c. 2.5 years of immersion, the following observations were made:

- On coated areas, anodes consumption is much less than predicted (less than 50%)
- On non-coated areas, anodes consumption is much less than predicted (about 60%)

The following pictures show some anodes after turbine retrieval:

Figure 14 – Cathodic protection on the foundation after 2.5 years of immersion (Non coated areas)

Figure 15– Cathodic protection on the turbine after 2.5 years of immersion (Coated areas)

As a general conclusion, cathodic protection performed perfectly over the immersion life of the structure.

Anodes in coated areas are consumed less than those in non-coated areas. It can be assumed that the degradation of the coating is actually lower than degradation rates taken into account in the design: the cathodic protection current consumption is therefore lower than estimated.

5 Next generation control strategy

The Oceanquest tidal turbine operation point was controlled using a power signal feedback algorithm allowing constant TSR operation.

Different sets of parameters of the control algorithm have been tried, leading to a performance optimization of the tidal device.

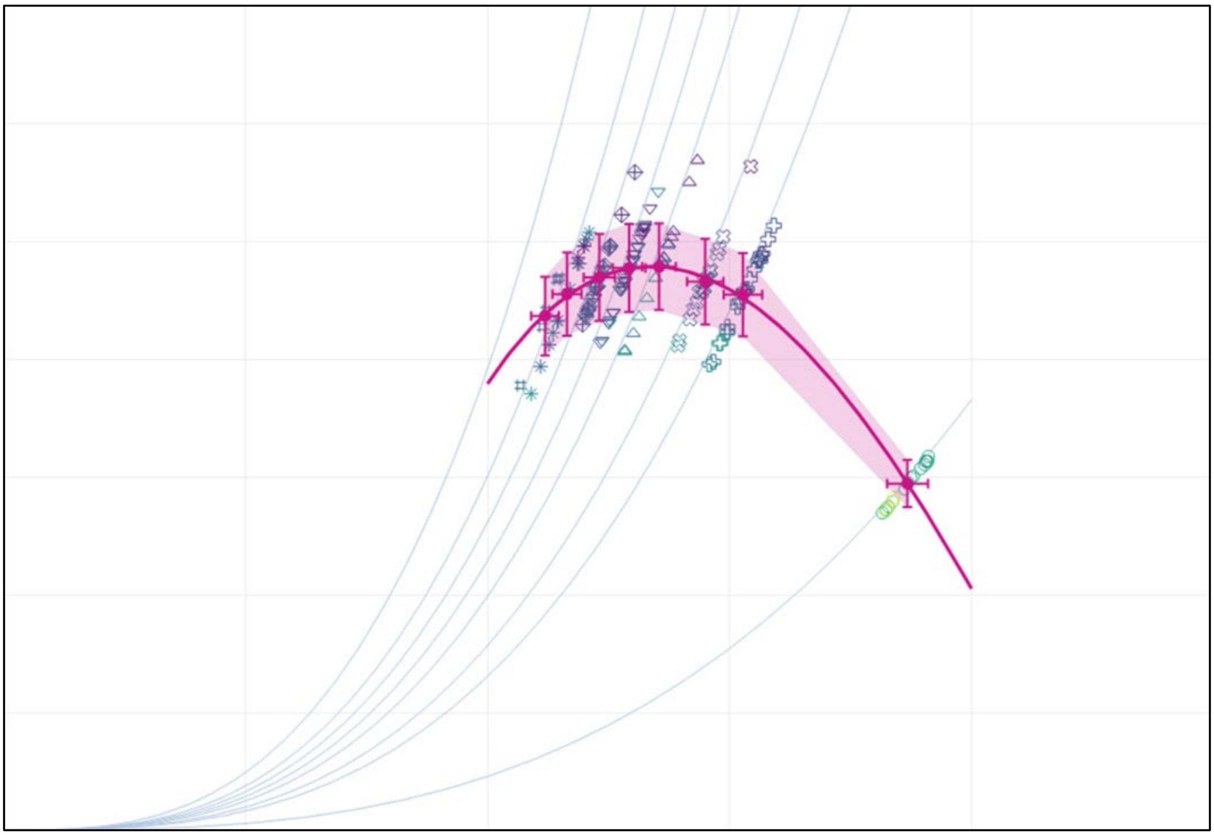

Figure 16 : Tidal turbine performance for different settings of the control algorithm

During the operation period, the performance and limitations of the control algorithm have been assessed, and the turbine performance in several operation zones have been measured.

Building on this experience, a more robust control algorithm has been developed for the new generation of turbine. While the power signal feedback strategy has been conserved, a dynamic parameter adjustment has been defined in order to maximize the power output.

Appendix – Accreditation certificate

Inspection Certificate

Proposer: ***HydroQuest***
Inovallia–Bâtement B, 16 Chemin de Malacher, 38240 Meylan, France
Name of Technology: ***Paimpol Prototype***

The *Paimpol Prototype* was tested at *Paimpol-Bréhat*, between *16 August to 19 September 2020*. EMEC verify that the *Paimpol Prototype* met the following performance claims:

- *Compliance with IEC technical specification: 62600-200:2013 Part 200: Electricity producing tidal energy converters – Power Performance assessment*

Documentation used for showing compliance with the requirements:

Reference	Title	Issued by	Version	Date
REP921	*Inspection of HydroQuest's Paimpol Prototype Power Performance Assessment at Paimpol Bréhat.*	Craig Dibb	1	08/12/2022

NOTE: This Inspection Certificate is part of the full inspection report identified above and should be read in conjunction with it.

Authorised by:

Name: *Caroline Lourie*
Title: *Technical Manager*
Date: *08/12/2022*
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