Open Sea Operating Experience to Reduce Wave Energy Costs

Deliverable D1.3

Online Data Query Tool

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EXECUTIVE SUMMARY

The main objective of WP1 is to ensure state of the art instrumentation is installed and operates as planned in the harsh open-sea environment, enhancing successful development of the technical work of other Work Packages.

This is articulated in the following specific objectives:

- Assessment of data requirements from other Work Packages in relation to previous/existing research and operational infrastructure for the test to be completed in Mutriku Wave Power Plant and IDOM's WEC. (Completed in Task 1.1)
- Deployment of robust and state-of-the-art instrumentation system for the fulfilment of the above requirements. Development of a failure risk matrix and contingency plan for the systems comprising the instrumentation and monitoring system. (Completed in Task 1.2)
- Provision of a structured access for other Work package partners to the research data produced according to the Project Data Management Plan. (Completed in Task 1.4)

The present document aims to support the Online Data Query Tool Software containing the specific datasets regarding biradial turbine and Control Law testing, collected during the BiMEP testing campaign of the OPERA project. The Online Data Query Tool will provide an open access to the operating data after the project is finished. The final outcome of Task 1.4 has provided partners within the consortium structured data access for the assessment of the innovations proposed during the project lifetime. The query tool offers an easy way to download available data from BiMEP testing campaign from the open-access repository ZENODO.

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ABBREVIATIONS AND ACRONYMS

BIMEP	Biscay Marine Energy Platform
CL	Control Law
HSSV	High Speed Switching Valve
LCOE	Levelized Cost of Energy
OPERA	Open Sea Operating Experience to Reduce Wave Energy Costs
OWC	Oscillating Water Column
PLC	Programmable Logic Controller
PTO	Power Take-Off
RMS	Root Mean Square
TRL	Technology Readiness Level
VFD	Variable Frequency Drive
WEC	Wave Energy Converter

1. INTRODUCTION

In the scope of the OPERA project, the objective of Work Package 1 (WP1) is to provide seamless data collection and storage, enhancing successful development of the technical work of other Work Packages. WP1 has the final goal of reducing the time to market wave energy, by advancing in four key innovations aiming to reduce up to 50% the Levelized Cost of Energy (LCOE) projections of a floating Oscillating Water Column (OWC) technology.

The purpose of this deliverable is to provide a guidance on data access and interpretation, with the aim of having Findable, Accessible, Interoperable and Reusable data according to the guidelines stablish in Deliverable 8.7: Data Management Plan.

Chapter 2 in this document provides a general view of the testing campaign undergone and presents the operational data table to be published in ZENODO repository. Chapter 3 provides a column-wise explanation of the data contained in the table, aiming to facilitate comprehension of the data by any potential reader, with this information being further expanded in the Annexes of the document. A set of final conclusions are drawn in Chapter 4, outlining the outcomes of Task 1.4.

The Online Data Query Tool, developed in the scope of Task 1.4, has been implemented in Excel and offers an easy way to access all the open-access data available from BiMEP testing campaign. It contains the centrepiece information for PTO and Control Law assessment and allows the user to further analyse operational data by using the standard tools provided by MS Excel.

Other datasets described in Deliverable D8.7 has been discarded, as they are published in ZENODO or referenced in the corresponding deliverables as shown in **¡Error! No se encuentra el origen de la referencia.**.

TABLE 1-1: DATASET DEFINED IN DATA MANAGEMENT PLAN, SUPPORTING DELIVERABLES AND PUBLISHED DATASETS.

D8.7 Dataset	Supporting Deliverable(s)	Link to ZENODO dataset (If Applicable)
DS_Wave_Mutriku		https://doi.org/10.5281/zenodo.1478564
DS_Wave_BiMEP		https://doi.org/10.5281/zenodo.1311593
DS_Tethers_Lab	D2.3	
DS_Mooring_BiMEP	D2.2	
DS_Biradial_Turbine_Lab	D3.2	
DS_Power_Output_Lab	D4.1	
DS_Biradial_Turbine_Mutriku	D3.3, D4.2	https://doi.org/10.5281/zenodo.3228108
DS_Power_Output_Mutriku		

DS_Biradial_Turbine_BiMEP	D3.4, D4.3, D1.3	https://doi.org/10.5281/zenodo.3349538
DS_Power_Output_BiMEP		
DS_Power_Quality_Lab	D5.2, D5.4	https://doi.org/10.5281/zenodo.3250832
DS_Power_Quality_Mutriku		
DS_Offshore_Operations	D6.3	

2. PTO TESTING CAMPAIGN

2.1 INTRODUCTION

IDOM's MARMOK-A-5 device is a spar type OWC wave energy converter buoy. It has a diameter of 5 m and is 42 m long. MARMOK-A-5 has been deployed during almost three years continuously in BiMEP. It was first deployed at BiMEP prior to the OPERA project, mounting two Wells turbines of 15 kW rated power each (baseline configuration).

FIGURE 2-1 MARMOK-A-5 DEVICE DEPLOYED IN BIMEP

The buoy can be divided into three parts: the floater which adds floatability and holds all the electrical equipment and sensors including umbilical cable entry for grid connection; the central cylinder which holds the inner water column; and the water ballast tank which can be partially or fully emptied for buoy installation/decommissioning.

Two major innovations undertaken during the OPERA project are the design, construction and testing of a novel biradial turbine, and the development and testing of innovative Control Laws to enhance power production. Following an extensive testing campaign in the Mutriku OWC plant, the biradial turbine was installed on top of the MARMOK-A-5 buoy (refitted prototype) in summer 2018 and served as Control Law testing platform during 2019.

BiMEP is an infrastructure which purpose is to test prototypes of marine energy collectors and auxiliary equipment in the open sea. It is located off the coast at Armintza in Spain, and consist of 5.2 km^2, restricted to shipping with perimeter beacons. The depth in the site goes from 50 to 90 meters and the seabed is mostly sandy with rocky areas. Figure 2-2 shows the BiMEP site with the location of the MARMOK-A-5 mooring perimeter, with the WEC in the center.

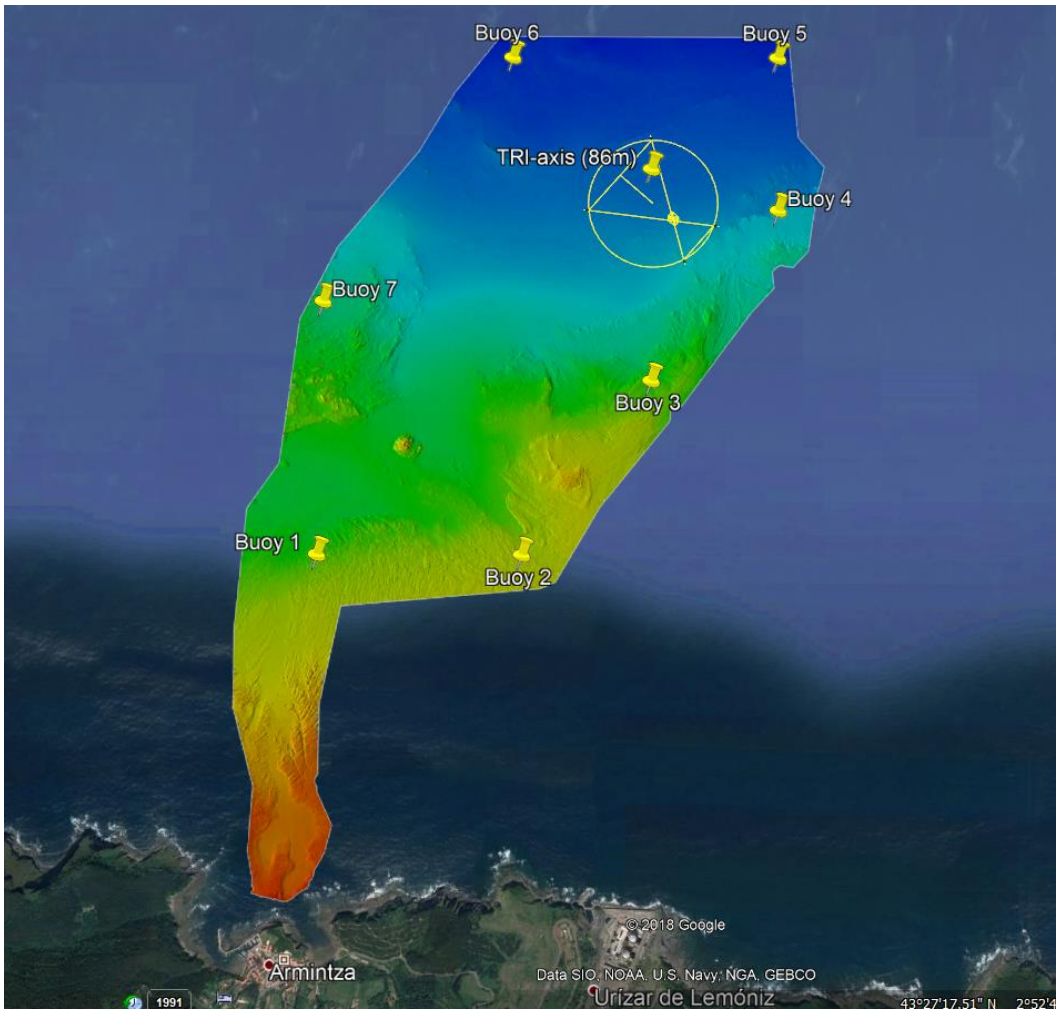

FIGURE 2-2 BIMEP TEST SITE BATHYMETRY AND WEC LOCATION

2.2 PTO TESTING CAMPAIGN

The acquired data in the open-sea tests has granted valuable information for the OPERA project. Recorded data of power production, power quality, efficiency, mooring force data, and other aspects such as electrical grid integration certainly play a significant role in ocean energy technology development.

The assessment of the biradial turbine performance has been analysed in-depth in Deliverable D3.4. A set of analysis and post processing criteria were proposed to facilitate performance assessment, down-selecting some representative tests cases from the whole set of tests produced during the project.

On the other hand, D4.3 uses the same criteria and analyses their impact in Control Law performance evaluation. It leaves open the modification of the criteria to have a more even distribution of test cases across several Control Laws and to assess their strong and weak points.

From the 2,239 tests, 358 were selected by the post processing methodology proposed in D3.4 and D4.3. In the scope of this deliverable, the complete set of tests and their operational results are presented, with the objective of providing a broader view of the tests campaign results, and in line with the commitment of publishing open-access operational data according to the latest version of the Data Management Plan (Deliverable D8.7).

2.3 OPERATIONAL DATA TABLE

FIGURE 2-3 and FIGURE 2-4 show a screenshot of the MS Excel spreadsheet, where a general and detailed view of the data obtained from the offshore testing campaign is held. Each individual test is identified by a unique ID number, whereas consecutive IDs do not have any particular time-order.

With the objective of clarifying any possible post processing of the Control Law results, the parameters used for the testing campaign are presented, allowing to identify the different versions of each Control Law tested (i.e. CL1.1, CL1.2.etc). Further details about the subsets of parameters used in each Control Law are given in D4.3.

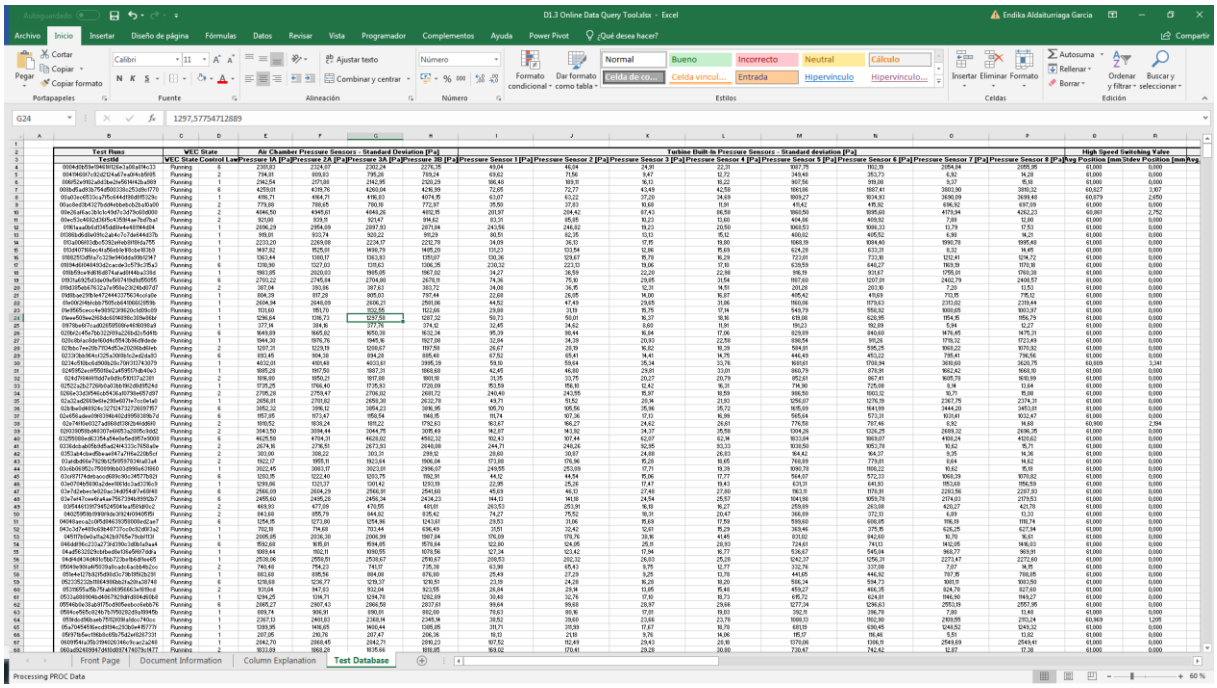

FIGURE 2-3. GENERAL VIEW OF THE ONLINE DATA QUERY TOOL

Test Runs	WEC State		Air Chamber Pressure Sensors - Standard Deviation [Pa]			
TestId	WEC State	Control Law	Pressure 1A [Pa]	Pressure 2A [Pa]	Pressure 3A [Pa]	Pressure 3B [Pa]
0004d0b59e19461ff126e3a08a814c33	Running	6	2301,83	2324,07	2302,24	2276,35
00411460f7c92d2124a67ea0f4cb5f85	Running	2	794,81	809,83	795,26	789,24
006f52e9102a8d3be2fe5614f42ba989	Running	1	2142,54	2171,88	2142,95	2120,29
008bd5ad93b754d500338c253d9c1770	Running	6	4259,01	4319,76	4260,04	4216,99
00a03ec6533ca7f5c644d198d815329c	Running	1	4116,71	4164,71	4116,83	4074,15
00ac8ed3b4327bdd4ebbebcb2ba10a00	Running	2	779,88	788,65	780,18	772,97
00e26af6ac3b1c1c49d7c3d79c60d000	Running	2	4846,50	4945,61	4848,26	4812,15
00ec53c4682d36f5c4359f4ae7bd7ba1	Running	2	921,00	939,11	921,47	914,62
01161aaa0b6d1345dd8fe4e481144d84	Running	1	2896,29	2954,09	2897,93	2871,84
01386bd6d8e091c2ab4c7c7de644d37b	Running	1	919,01	933,74	920,22	911,29
013a006f03dbc5392effeb8f18fda755	Running	1	2233,20	2269,08	2234,17	2212,78
013d407166ec4fa56eb1e1f8cbe183b9	Running	1	1497,82	1525,01	1498,79	1485,20
01882513d5fa7c329e340dda93b12147	Running	1	1363,44	1380,17	1363,93	1351,07
01894d6f048493d2cacde3c573c315a3	Running	6	1310,90	1327,03	1311,63	1306,35
018b53ce1fd616d874afad0f44ba338d	Running	1	1983,85	2020,03	1985,05	1967,02
01931a6925d3de09e5f87419d9d55055	Running	6	2703,22	2745,84	2704,80	2678,11
019d385eb67632a7e958e23f24bd07d7	Running	2	387,04	393,86	387,63	383,72
01d8bae231b1e4724443375634ccfa0e	Running	1	804,39	817,28	805,03	797,44
01e00f2f4bfcbb7505cb641066f2859b	Running	1	2604,94	2648,09	2606,21	2581,06
01e9565cecc4e389123f9620c1d09c09	Running	1	1131,60	1151,70	1132,55	1122,66
01eee509ee2f68dc6014898c309e86bf	Running	1	1296,64	1316,73	1297,58	1287,32
01f78be6f7cad02658508fe4616098a9	Running	1	377,14	384,16	377,76	374,12
020bf2c45e7bb322f89a226bd2c5d41b	Running	6	1649,89	1665,82	1650,38	1632,34
020c8bfac8de160d4c5543b96d1fdede	Running	1	1944,30	1976,76	1945,16	1927,08
021bbc7ee20b71134d53e20206bd6feb	Running	2	1207,31	1229,19	1208,67	1197,58
0233f3bb964cf325a30f8b1c2ed2da93	Running	6	893,45	904,38	894,28	885,48
0234c510bc6d908b28c70ff313743079	Running	1	4032,01	4101,48	4033,61	3995,39
0245952ecff55018e2a459517fdb40e3	Running	1	1885,28	1917,50	1887,31	1868,68
024d7f84fff11dd7e8d3c510137a2381	Running	2	1816,80	1850,21	1817,88	1801,18

FIGURE 2-4. DETAILED VIEW OF ONLINE DATA QUERY TOOL

2.3.1 DATA QUALITY

Data Quality markers were introduced during the data acquisition process. The timeseries values include a numerical quality indicator, ranging from 0 to 192. This indicator is automatically created by the acquisition system.

TABLE 2-1: DATA QUALITY INDICATOR SIGNALS

Decimal value	Quality Indicator
0	Bad
8	Bad - Not Connected
12	Bad - Device Failure
16	Bad - Sensor Failure
20	Bad - Last Know Value Passed
24	Bad - Comm Failure
64	Uncertain
68	Uncertain - Last Usable Value - timeout of some kind
80	Uncertain - Sensor not Accurate - outside of limits
192	Good

With the objective of proving the highest quality data possible, all the tests contained in the published dataset are strictly required to have a Good quality indicator, ensuring all sensor and systems provide accurate readings.

3. PROCESS INSTRUMENTATION/SIGNAL LIST

TABLE 3-1 enumerates the list of available instruments and signals as built for the tests in the MARMOK-A-5 device for the testing campaign carried out in the OPERA Project.

TABLE 3-1: DATABASE COLUMN MATCHING TO SIGNAL LIST

BiMEP PTO and Control Law Testing Data		
COMMENT	**Signal in Table**	**Comments**
Test Id		Test Number Identifier. Helps identifying test bins
WEC State	**S.08.01**	Current State of PLC State Machine: 1: Booting 2: Standby 3: Spin-up 4: Running 5: Spin-down 6: Safe Standby
Chamber pressure 1A	**P.02.01P.02.01**	RMS value of chamber pressure sensor, position 1
Chamber pressure 2A	**P.02.02**	RMS value of chamber pressure sensor, position 1
Chamber pressure 3A	**P.02.03**	RMS value of chamber pressure sensor, position 2
Chamber pressure 3B	**P.02.04**	RMS value of chamber pressure sensor, position 3
PTO Built-in Pressure Sensor P1	**P.04.02**	RMS value of pressure sensor p1. See turbine diagram in Annex
PTO Built-in Pressure Sensor P2	**P.04.03**	RMS value of pressure sensor p2. See turbine diagram in Annex
PTO Built-in Pressure Sensor P3	**P.04.04**	RMS value of pressure sensor p3. See turbine diagram in Annex
PTO Built-in Pressure Sensor P4	**P.04.05**	RMS value of pressure sensor p4. See turbine diagram in Annex
PTO Built-in Pressure Sensor P5	**P.04.06**	RMS value of pressure sensor p5. See turbine diagram in Annex
PTO Built-in Pressure Sensor P6	**P.04.07**	RMS value of pressure sensor p6. See turbine diagram in Annex
PTO Built-in Pressure Sensor P7	**P.04.08**	RMS value of pressure sensor p7. See turbine diagram in Annex
PTO Built-in Pressure Sensor P8	**P.04.09**	RMS value of pressure sensor p8. See turbine diagram in Annex
HSSV Position	**C.04.01**	HSSV valve position as the average of the position of the 4 actuators of that control the valve, in mm. 61 is fully open
HSSV Position	**C.04.01**	Standard deviation of valve aperture
Drive 1 Speed Feedback	**S.03.01**	Average Generator Speed measurement through the generator encoder.
Drive 1 Speed Feedback	**S.03.01**	Standard deviation of Generator Speed measurement through the generator encoder.
Generator Temp 1	**T.03.01**	Average Generator stator temperature value measured in winding 1
Generator Temp 2	**T.03.02**	Average Generator stator temperature value measured in winding 2
Generator Temp 3	**T.03.03**	Average Generator stator temperature value measured in winding 3

BiMEP PTO and Control Law Testing Data		
COMMENT	**Signal in Table**	**Comments**
Drive 1 Active Current	**S.06.01**	Average active current flowing to/from the generator.
Drive 1 Active Current	**S.06.01**	Standard deviation of active current flowing to/from the generator.
Drive 1 Torque Ref	**S.06.01**	Average Torque reference as % of nominal demanded by the PLC to the VFD
Drive 1 Torque Ref	**S.06.01**	Standard deviation of Torque reference as % of nominal demanded by the PLC to the VFD
Drive 1 Out Power	**S.06.01**	Average estimated VFD electrical power as measured in the Drive terminals.
Drive 1 Out Power	**S.06.01**	Standard deviation of VFD electrical power as measured in the Drive terminals.
Average Torque Slope for CL1	**S.08.01**	Torque Law Slope coefficient for CL1
Average Torque Exponent for CL1	**S.08.01**	Torque Law Exponent coefficient for CL1
Average Torque/pressure coefficient for CL2	**S.08.01**	Torque Law Torque/Pressure coefficient for CL2
Average FeedForward term for CL1	**S.08.01**	Torque Law Feedforward coefficient for CL2
Average Torque Slope for CL6	**S.08.01**	Torque Law Slope coefficient for CL6
Average Torque Exponent for CL6	**S.08.01**	Torque Law Exponent coefficient for CL6

4. CONCLUSIONS

The ambitious instrumentation and SCADA systems planned and deployed for field testing within the OPERA project have provided satisfactory results. This entailed:

- Building an homogeneous data acquisition system to incorporate all the operational data produced in the project and provide seamless access tools for every partner to access the data.
- Adequately instrumenting the innovations tested under the scope of the projects (elastomeric tethers, shared mooring configuration, biradial turbine and Control Laws) to ensure sufficient data was gathered for the technical assessment of their potentialities.
- Providing high-quality environmental information data, including real-time wave elevation information both for Mutriku and BiMEP to feed predictive Control Laws;

The testing campaign in Mutriku offered a good opportunity to validate the data acquisition system and the tool for data access and sharing between the project partners. It also allowed the publication of various datasets as stablished in D8.7, Data Management Plan.

Lessons learnt and feedback from partners were incorporated into the design of the SCADA system deployed in BiMEP, allowing to build on existing equipment and systems used during the deployment phase prior to the OPERA project.

5. REFERENCES

[1] Technical Note: “WP1-62600-30 Data Needs”. OPERA Project.
[2] Technical Note: “CORES sensor Recommendations”. OPERA Project.
[3] Technical Note: “PTO Instrumentation”. OPERA Project.
[4] Deliverable D3.4: “Open-sea performance and reliability of the OWC turbine and electrical equipment”
[5] Deliverable D4.3: “Floating OWC control algorithms”
[6] Deliverable D8.7: “Data Management Plan”

6. ANNEX I: TURBINE INSTRUMENTATION

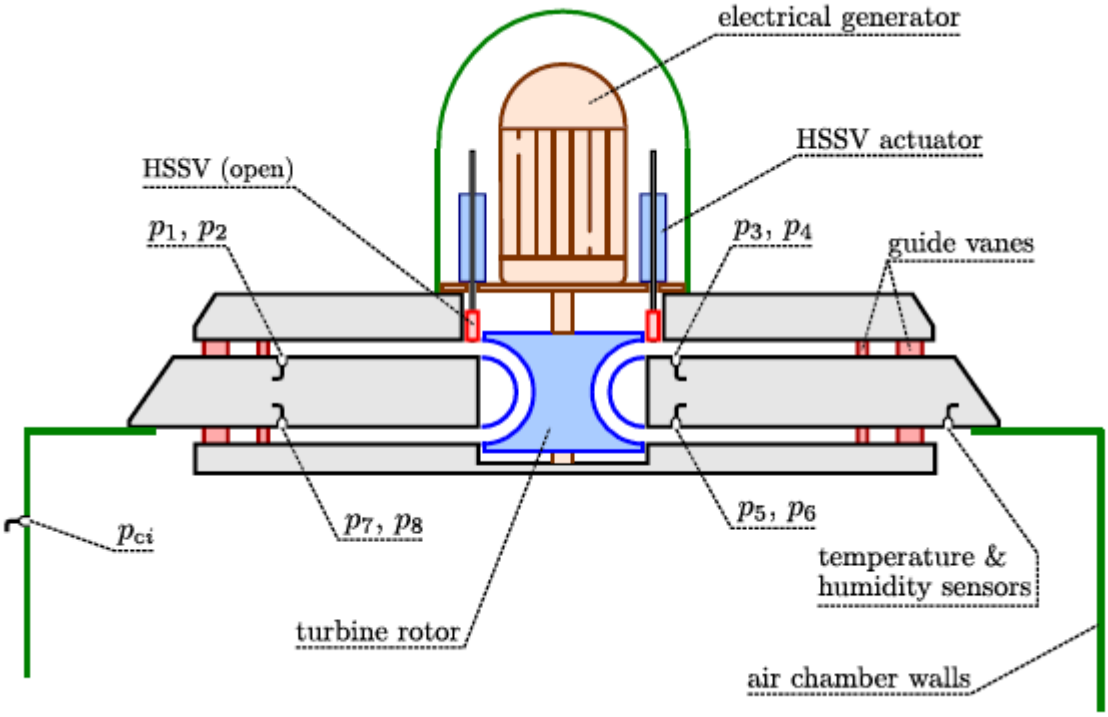

FIGURE 6-1: SCHEMATIC REPRESENTATION OF THE BIRADIAL TURBINE ASSEMBLED INTO THE IDOM MARMOK-A-5 SPAR-BUOY AND KYMANER'S PRESSURE TAPS NOMENCLATURE.

7. ANNEX II: EQUIPMENT/SIGNAL LIST FOR BIMEP TESTING CAMPAIGN

TABLE 7-1: EQUIPMENT/SIGNAL LIST FOR BIMEP TESTING CAMPAIGN

Device ID	Signal Id	Signal	Resolution	Sensor Scale	Scan Rate
Area 02: Air Chamber in the WEC					
P.02.01	**Air pressure inside chamber**				
	P.02.01.001	Pressure Signal	0,005 bar	±0.2 bar Gauge	4 Hz
P.02.02	**Air pressure inside chamber**				
	P.02.02.001	Pressure Signal	0,005 bar	±0.5 bar Gauge	4 Hz
P.02.03	**Air pressure inside chamber**				
	P.02.03.001	Pressure Signal	0,005 bar	±0.2 bar Gauge	4 Hz
P.02.04	**Air pressure inside chamber**				
	P.02.04.001	Pressure Signal	0,005 bar	±0.5 bar Gauge	4 Hz
Area 03: Generator Nacelle					
T.03.01	**Temperature in Generator winding**				
	T.03.01.001	Temperature Signal	0.1 Cº	0..200 ºC	4 Hz
T.03.02	**Temperature in Generator winding**				
	T.03.02.002	Temperature Signal	0.1 Cº	0..200 ºC	4 Hz
T.03.03	**Temperature in Generator winding**				
	T.03.03.003	Temperature Signal	0.1 Cº	0..200 ºC	4 Hz
S.03.01	**Generator Shaft Rotational Speed**				
	S.03.01.001	Encoder Signal	0.1 rpm	0..4500 rpm	4 Hz
Area 04: Turbine					
P.04.02	**Air pressure at the trailing edge of the guide vanes (A)**				
	P.04.02.001	Pressure Signal	0,002 bar	±0.2 bar Gauge	4 Hz
P.04.03	**Air pressure at the trailing edge of the guide vanes (B)**				
	P.04.03.001	Pressure Signal	0,005 bar	±0.5 bar Gauge	4 Hz
P.04.04	**Air pressure at the trailing edge of the guide vanes (A)**				
	P.04.04.001	Pressure Signal	0,002 bar	±0.2 bar Gauge	4 Hz
P.04.05	**Air pressure at the trailing edge of the guide vanes (B)**				
	P.04.05.001	Pressure Signal	0,005 bar	±0.5 bar Gauge	4 Hz
P.04.06	**Air pressure at the stator minimum radius (C)**				
	P.04.06.001	Pressure Signal	0,002 bar	±0.2 bar Gauge	4 Hz
P.04.07	**Air pressure at the stator minimum radius (D)**				

Device ID	Signal Id	Signal	Resolution	Sensor Scale	Scan Rate
	P.04.07.001	Pressure Signal	0,005 bar	±0.5 bar Gauge	4 Hz
P.04.08	**Air pressure at the stator minimum radius (C)**				
	P.04.08.001	Pressure Signal	0,002 bar	±0.2 bar Gauge	4 Hz
P.04.09	**Air pressure at the stator minimum radius (D)**				
	P.04.09.001	Pressure Signal	0,005 bar	±0.5 bar Gauge	4 Hz
C.04.01	**HSSV valve continuous position**				
	C.04.01.001	Latching Valve Position	0.1 mm	0..61 mm	4 Hz
Area 06: Power Electronics					
S.06.01	**Power Electronics**				
	S.06.01.004	Active Current	0.1 A	0..100% of Rated	4 Hz
	S.06.01.007	Output Power	1 W	0..100% of Rated	4 Hz
Area 8: Machinery Room					
S.08.01	**Control System**				
	S.05.01.001	WEC State	-	-	4 Hz
	S.05.01.002	Torque Reference	0.1Nm	0..100% of Rated	4 Hz
	S.05.01.003	Torque Slope for CL1	-	-	4 Hz
	S.05.01.004	Torque Exponent for CL1	-	-	4 Hz
	S.05.01.005	Torque/pressure coeff for CL2	-	-	4 Hz
	S.05.01.006	FeedForward term for CL1	-	-	4 Hz
	S.05.01.007	Avg Torque Slope for CL6	-	-	4 Hz
	S.05.01.008	Avg Torque Exponent for CL6	-	-	4 Hz