Open Sea Operating Experience to Reduce Wave Energy Costs

Deliverable D5.1

Wave Energy Measurement Methodologies for IEC Technical Specifications

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Author(s)	Joannés Berque (Tecnalia); Sara Armstrong, Wanan Sheng (UCC); David Crooks, Adrian de Andres, Encarnacion Medina-Lopez (UEdin); Sam Weller (UnExe), Urtzi Lazkano (Oceantec)
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EXECUTIVE SUMMARY

This document represents deliverable 5.1 (D5.1) of OPERA Work Package 5 (WP5).

OPERA is a European Commission funded project that ultimately aims to reduce the time to market and costs of wave energy. OPERA WP5, entitled, "Applicability and Extension of IEC Technical Specifications using Open Sea Data" is dedicated to providing the first documented application of the ongoing normative process for the wave energy sector, the International Electrotechnical Commission (IEC) Technical Specifications (TS) for marine energy, reduce the uncertainties in their application and provide recommendations to the relevant marine technical committee of the IEC (TC114) that will accelerate the establishment of standards based on these technical specifications.

The following IEC TS are studied within OPERA:

- 62600-10 Part 10: Assessment of mooring system for marine energy converters.
- 62600-30 Ed. 1.0 Part 30: Electrical power quality requirements for wave, tidal and other water current energy converters.
- 62600-100 Ed. 1.0 Part 100: Electricity producing wave energy converters - Power performance assessment.
- 62600-101 Ed. 1.0 Part 101: Wave energy resource assessment and characterization.
- 62600-102 Ed. 1.0 Part 102: Wave energy converter power performance assessment at a second location using measured assessment data.

This WP is approached in two stages; firstly, the IEC TS are investigated as they are in their current publication state. Secondly, the application of the TS are evaluated and investigated in further detail in areas such as the effect of the measurement resolution on power performance scatter, and grid compliance, so that these results can provide recommendations and enhancements to the IEC TS.

Deliverable D5.1 represents the first stage in the examination of the practical application of the TS by extracting the necessary methodologies to enable their execution. More specifically, this deliverable examines:

- Basic methodological requirements, including data and models requirements.
- Practical implementation of methodology in a real sea deployment.
- Data processing and reporting requirements.
- Any technical issues or limitations of the TS, if applicable.

It should be noted that the emphasis of WP5 is on the practical application of the TS, and not the performance of the wave energy device itself.

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ABBREVIATIONS AND ACRONYMS

AHG	Ad Hoc Group
ALS	Accidental Limit State
BiMEP	Biscay Marine Energy Platform
DFT	Discrete Fourier Transform
EMEC	European Marine Energy Centre
FLS	Fatigue Limit State
GOW	Global Ocean Wave
HV	High Voltage
IEC	International Electrotechnical Commission
LV	Low Voltage
LVRT	Low Voltage Ride Through
MAEP	Mean Annual Energy Production
MCP	Measure-Correlate-Predict
MEC	Marine Energy Converter
MLBE	Mooring Line Buoyancy Elements
MODIS	Moderate resolution imaging spectroradiometer
MV	Medium Voltage
NM	Numerical Model
OPERA	Open Sea Operating Experience to Reduce Wave Energy Costs
OWC	Oscillating Water Column
PQ	Power Quality
PTO	Power Take-Off
SLS	Serviceability Limit State
TC	Technical Committee
THD	Total Harmonics Distortion
TS	Technical Specification
TS10	62600-10 Part 10: Assessment of mooring system for marine energy converters
TS100	62600-100 Part 100: Electricity producing wave energy converters - Power performance assessment
TS101	62600-101 Ed. 1.0 Part 101: Wave energy resource assessment and characterization.
TS102	62600-102 Ed. 1.0 Part 102: Wave energy converter power performance assessment at a second location using measured assessment data
TS30	62600-30 Ed. 1.0 Part 30: Electrical power quality requirements for wave, tidal and other water current energy converters.
UCC	University College Cork
ULS	Ultimate Limit State
VIM	Vortex Induced Motion
VIV	Vortex Induced Vibration
WEC	Wave Energy Converter
WMI	Wave Measuring Instrument
WP	Work Package
2D	Two-dimensional

SYMBOLS (AND UNITS)

H_{m0} Significant wave height (m)
H_{max} maximum wave height (m)
T_p Peak period (s)
θ_m Mean wave direction (˚)

1. INTRODUCTION

A key element of WP5, “Applicability and Extension of IEC Technical Specifications using Open Sea Data” within the OPERA project is to accelerate the establishment of standards for the wave energy sector. The lack of established standards introduces uncertainties at every level of the value chain of the wave energy sector, for example, on the specifications necessary for operation at acceptable level of risk within specified conditions, or on the ways to measure and report power production and quality. This results in technological and business uncertainty which strongly impacts on the cost of capital and reduces the range of investment opportunities.

A normative process for wave energy is ongoing with the International Electrotechnical Commission Technical Committee (IEC TC) 114 and first editions of sector-specific Technical Specifications (TS) have recently been approved. To become established practices and standards, these TS need documented real-case application to open-sea deployment and operation. OPERA will provide the first such documented application to these emerging standards in the areas of mooring, power performance, power quality, and resource assessment.

The relevant IEC TS are:

- 62600-10 Part 10: Assessment of mooring system for marine energy converters
- 62600-30 Part 30: Electrical power quality requirements for wave, tidal and other water current energy converters.
- 62600-100 Ed. 1.0 Part 100: Electricity producing wave energy converters - Power performance assessment
- 62600-101 Ed. 1.0 Part 101: Wave energy resource assessment and characterization.
- 62600-102 Ed. 1.0 Part 102: Wave energy converter power performance assessment at a second location using measured assessment data

The purpose of deliverable D5.1 is to:

- Extract the necessary methodologies and requirements from each TS,
- Define the practical implementation of the methodology – and how it will be addressed in the real sea deployment, and
- Document any known limitations or technical issues of these TS, if applicable.

Deliverable D5.1 represents the first stage in the examination of the practical application of the TS by extracting the necessary methodologies to enable their execution. It should be noted that the emphasis of this work package is on the application of the TS, and not the performance of the wave energy itself.

This document is organised as follows: Sections 2 through 6 describe the moorings, power quality, power performance, wave resource, and power performance at a second location TS respectively. Each section details the data or sensor requirements, measurements, data processing, and reporting methods, where appropriate.

2. IEC TS 62600-10: ASSESSMENT OF MOORING SYSTEMS FOR FLOATING MARINE ENERGY CONVERTERS

2.1 TECHNICAL SPECIFICATION SCOPE

The IEC/TS 62600-10 Ed. 1.0 (hereafter TS10) is applicable to mooring systems for floating marine energy converter (MEC) units of any size or type, and in any open water conditions. It highlights the different requirements of MECs from existing and well-established mooring standards, and its intention is not to duplicate existing processes and standards.

The aim of TS10 is to provide uniform methodologies for the design and assessment of mooring systems for floating MEC, and to be applied at various stages, from mooring system assessment to design, installation and maintenance of floating MEC plants.

2.2 INTRODUCTION

The application of TS10 will follow the general target set out in WP5, that is, firstly the IEC TS are investigated as they are in their current publication state. Secondly, the application of the TS is evaluated and investigated so that these results can provide recommendations and feedback to the IEC TS. In this case, the TS10 will be compared to the existing industry standard, DNVGL-OS-E301.

The practical application of TS10 is coupled with WP2 (more specifically Task 2.4 “Evaluation of shared mooring configurations”), in which Task 2.4 will draw upon the latest state of the art standard developments (such as IEC, DNV, EMEC, etc.) and will use the collected data from the OPERA open sea demonstrations to search for potential additional requirements which are not introduced in TS10 that will feed into WP5.

For the purposes of practicality, the mooring design for the Oceantec Marmok OWC device was based on the industry standard: DNVGL-OS-E301. This also provides an opportunity to verify the applicability of the TS10 standard.

2.3 IEC TS10 DATA REQUIREMENTS

The TS10 data collection requirements can be considered the same as those in WP2 (though the TS10 does not explicitly state such requirements). It must be noted that within the Scope section of TS10, it is stated that the technical specification aims to highlight the different requirements of marine energy converters, and does not aim to duplicate existing standards where the processes are presented in far greater detail. For example, Section 11 of TS10 is named "In-service inspection, monitoring and maintenance" but does not contain any information about monitoring of mooring systems. In Section 8, named "Design consideration" several criteria to be considered in mooring design are specified, but no specific details are given. The DNV, API and ABS standards provide a lot more detail. Subsequently, for the application of the TS10 technical specification, the user must also refer to other standards, such as ISO and API standards as stated in the TS10 Scope and Normative References.

2.4 IEC MOORING TS AND DNVGL-OS-E301 COMPARISON

Table 1 outlines the basic relationship between TS30 and DNVGL-OS-E301, while in Table 2, the DNVGL-OS-E301 is compared to the TS10 in order to identify the differences in guidelines, gaps, commonalities, data requirements, etc.

In Table 1, the double arrowed lines show the TS10 sections which correspond to the relevant sections in the DNVGL-OS-E301. Evidently, the sections are mostly comparable.

TABLE 1. BASIC RELATIONSHIP BETWEEN TS10 AND DNVGL-OS-E301 (APPROXIMATION)

IEC TS62600-10	DNVGL-OS-E301
Scope	**Introduction (Ch. 1)**
Mooring systems (Clause 6)	**Environmental conditions and loads (Ch.2 sec. 1)**
Design consideration (Clause 7)	**Mooring system analysis (Ch.2 sec. 2)**
Safety and risk conditions (Clause 8)	**Mooring equipment (Ch.2 sec. 4)**
Analysis procedure (Clause 9)	**Tests (Ch.2 sec. 5)**
In-service inspection, monitoring, testing and maintenance (Clause 10)	

The DNVGL-OS-E301 provides considerably more detail than the IEC TS10. Neither standards are standalone, TS10 contains a list of normative references and DNVGL-OS-E301 also refers to other DNV standards (e.g. DNV-RP-C205).

TABLE 2. DNVGL-OS-E301 AND TS10 COMPARISON

Title	DNVGL-OS-E301	IEC 62600 TS10	Notes
Introduction	**Objectives:** - Give a uniform level of safety for mooring systems. - Serve as a reference document in contractual matters between purchasers and contractors. - Serve as a guideline for designers, purchasers and contractors. - Specify procedures and requirements for mooring systems for certification and classification.	**Objectives:** - Provide uniform methodologies for the design and assessment of mooring systems for floating MECs (marine energy converters). - Highlight the different requirements of MECs.	Neither standards are standalone. Refer to references within documents.
	Scope and application: All types of floating offshore units and the mooring system components: - Stud chain - Stud-less chain - Shackles on ISO 1704 - LTM shackles - Suction-friction components - Purpose built connection elements - Buoyancy and weight elements - Steel wire ropes - Fibre ropes - Windlass, winch and stopper - Fairleads - Anchors - Turrets	**Scope and application:** - mooring systems for floating MEC units of any size or type in any open water conditions. - **details in the existing and well-established mooring standards are not given.**	May not be sufficient within OPERA. Appears that TS10 adopted the ISO 19901-7:2013 and API RP 2SK. DNVGL standards are not included.

Title	DNVGL-OS-E301	IEC 62600 TS10	Notes
Environmental conditions and loads	**Objective:** Environmental data for mooring analysis.	**Objective:** Basic consideration for parameters and data for designing a mooring system.	n/a
	Application: The following environmental effects shall be taken into account: - waves - wind - current - marine growth - tide and storm surge - temperature - snow and ice - other effects	**Application:** The following environmental effects shall be taken into account: - limit states - external conditions - assorted loading - umbilical considerations - anchors	Insufficient detail on the umbilical design is given in TS10.
	Environmental conditions: - general - waves - wind - current - direction of wind, wave and current - soil condition - drag without marine growth - marine growth	**Environmental conditions:** - waves - wind - current - sediment and rock condition - drag without marine growth - marine growth	n/a

	Environmental loads: - wind loads - current loads - wave load - wave drift forces - vortex induced motion (VIM) * Condition for VIM to occur * VIM analysis * Ultimate limit state (ULS) and accidental limit state (ALS) with VIM * Fatigue limit state (FLS) with VIM	**Environmental loads:** - wind loads - current loads - wave load - wave drift forces - vortex induced vibration (VIV) - vortex induced motion (VIM) - MEC PTO responses	No details on MEC PTO responses have been included in TS10.
Mooring system analysis	**Objective:** - provide a structural design procedure, including single point mooring	**Objective:** - Provide an overview of modelling considerations and analysis procedures to design moorings for MECs.	n/a
	Application: - Design criteria for ULS, ALS and FLS - Safety factors with the calibrated limits: turrets 70m-2000m and environmental conditions for the Norwegian continental shelf and the Gulf of Mexico. - Safety factors for deep draft platforms - Floating units w/ position mooring systems consisting of chain links, steel wire ropes, synthetic fibre ropes & their combinations. - Other geographical locations, where the environmental conditions are more or less severe than considered in the calibration. - Drilling units, floating production units, loading buoys and floating accommodation units.	**Application:** Applicable to all floating MECs, with the special challenges on: - High energy density and the likelihood of shallow water condition - Tidal range in relation to the mean water depth - Complex and highly dynamic motion characteristics - Interrelation between PTO and mooring systems in some special cases.	n/a

	Method: - *general* - *general system response analysis* - *wave frequency motions* - *low frequency motions* - *floating platform response analysis* - *mooring line response analysis* - *line tension for ULS* - *Line tension for ALS*	**Method:** - *general system response analysis* - *wave frequency motions* - *low frequency motions* - *floating platform response analysis* - *mooring line response analysis* - *line tension for ULS* - *Line tension for ALS* - *Line tension for FLS* - *Line tension for SLS*	n/a
	Characteristic capacity: - *Capacity for ULS and ALS* - *Main body of mooring line* - *Links and terminators* - *Soft yoke connection arms*	**Characteristic capacity:** - *Capacity for ULS and ALS* - *Main body of mooring line* - *Links and terminators*	n/a
	Partial safety factors and premises - *Consequence classes: 2* - *Safety Factors for ULS* - *Safety Factors for ALS* - *Safety factors for the connection between buoyancy element and mooring line* - *Operation covered by consequence class 1* - *Operation covered by consequence class 2* - *Permissible line length* - *Clearance*	**Partial safety factors and premises** - *Consequence classes: 3* - *Safety Factors for ULS* - *Safety Factors for ALS* - *Operation covered by consequence class 1* - *Operation covered by consequence class 2* - *Operation covered by consequence class 3*	n/a
	Additional requirements for long term mooring - *General* - *Corrosion allowance*	- in-service inspection	n/a

	Fatigue limit state (FLS) - *Accumulated fatigue damage* - *Fatigue properties* - *Fatigue analysis* - *Design equation format* - *Effect of number of fatigue tests on design curve* - *Design equation format for fibre ropes* - *Vortex induced vibrations*	- **Fatigue limit state (FLS)** - **Serviceability limit state (SLS)**	n/a
	Reliability analysis: Target annual probabilities Limit state / consequence class / probability of failure ULS / 1 / 10^{-4} ULS / 2 / 10^{-5} ALS / 1 / 10^{-4} ALS / 2 / 10^{-5} FLS / single line / 10^{-3} FLS / multiple lines / 10^{-5}	Safety and risk considerations: - To identify the potential risks - Risk definition and mitigation - Risk assessment methodologies - Consequence considerations for mooring failure - Consequence classification - Risk mitigation considerations - Risk acceptance	n/a
		Consequence class associated design factors Consequence class / design factor(DF) 1 / 1.5 2 / 1.3 3 / 1.0	

Title	DNVGL-OS-E301	IEC 62600 TS10	Notes
Mooring equipment	**Objective:** Requirements regarding equipment and installation for temporary mooring, position mooring and towing.	**Objective:** Provide an overview of mooring and anchor types that may be used with floating MECs	n/a
	Anchor types	**Anchor types**	n/a
	Structural design and materials - *Structural strength* - *Design of anchor pad eye* - *Anchor shackle* - *Pile, gravity and suction anchors*	–Pile anchor –Screw anchor	n/a
	Fluke anchors - *General* - *Fluke anchor components* - *Materials for fluke anchors* - *Definition of fluke anchor resistance* - *Verification of anchor resistance-mobile mooring* - *Verification of fluke anchor resistance long term mooring*	Drag embedment anchor (similar to the Fluke anchor in DNVGL-OS-E301)	n/a
	Plate anchors - *General* - *Drag-in plate anchors* - *Other types of plate anchors* - *Installation depth*	Plate anchor	n/a
	Anchor piles		n/a
	Suction anchors	**Suction anchor**	n/a
	Gravity anchors	**Gravity anchor** **Gravity installed anchor**	n/a

	Mooring chain and accessories	Mooring chain	n/a
	Steel wire ropes - *General* - *Structural strength of end attachment*	Wire rope	n/a
	Synthetic fibre ropes - *General* - *Operation* - *Documentation requirements*	Synthetic rope	n/a
	Windlasses, winches and chain stoppers - *General* - *Materials* - *Windlasses for temporary mooring* - *Winches for temporary mooring* - *Windlasses and winches used in position mooring* - *Stoppers* - *Strength and design load* - *Other type of winches* - *Gear for windlass or winch*	n/a	n/a
	Winches for pull-in of mooring and riser systems - *General* - *General design* - *Materials* - *Capacity and system requirements* - *Pull-in rope* - *Shackles and connecting elements* - *Sheaves* - *Support structure* - *Test requirements*	Connectors and accessories, shackles' types are included.	n/a

	Fairleads - *General* - *Materials* - *Strength and design load*	n/a	n/a
	Tension measuring equipment	n/a	n/a
	Structural arrangement for mooring equipment for mobile mooring	n/a	n/a
	Arrangement and devices for towing of mobile units - *General* - *Materials* - *Strength analysis*	n/a	n/a
	Mooring line buoyancy elements (MLBE) - *General* - *Permanent mooring* - *Materials for MLBE* - *Design of element between mooring line and MLBE*	Buoyancy aids	n/a
	Bearings - *General* - *Design loads* - *Friction factor and wear rate*	n/a	n/a

Title	DNVGL-OS-E301	IEC 62600 TS10	Notes
Tests/in-service inspection…	**Objective (tests of mooring components):** All chain and accessories, except anchor shackles for mobile mooring which are not of R-quality, shall be tested according to requirements given in DNVGL-OS-E302.	**Objective (in-service inspection, Monitoring…)** Give an overview for maintenance and inspection requirements using existing offshore standards. The example standard is API RP 2I.	Reference is also made to other DNV standards such as DNV-RP-E304, "Damage assessment of fibre ropes for offshore mooring".
	Testing of mooring chain and accessories - General - Anchor shackles	Corrosion or physical damage inspection	n/a
	Test of steel wire ropes:	Mooring system proof loading	n/a
	Test of windlass and winch and chain stoppers - *Test of windlass and winch* - *Test of chain stopper*	Component replacement	n/a
	Test of manual and automatic remote thruster systems - *General* - *Functions* - *failures*	In air and splash zone mooring line sections	n/a
	Testing of synthetic fibre ropes	Submerged mooring line sections	n/a
	Testing of mooring line buoyancy element	Commissioning and decommissioning procedures	DNVGL-OS-E301 standard refers to DNVGL-OS-C401, "Fabrication and testing of offshore structures".

Figure 1 shows a flowchart diagram of the approach to be followed for the specific application of TS10 during the OPERA project. As shown previously in Table 2, the differences between DNVGL-OS-E301 and TS10 are identified. In the second step, OPERA actions refers to research that will be carried out to identify areas for further investigation that may be useful to bridge the knowledge gaps between these two standards. After sea trial data has been obtained, validation will be carried out for both the standards, which will give a better indication of the information gaps in the TS10 technical specification for its practical application. Subsequently, recommendations and feedback will be made to the IEC Ad Hoc (AHG) group for TS10. It is anticipated that the recommendations will be used to improve the technical specification in the future.

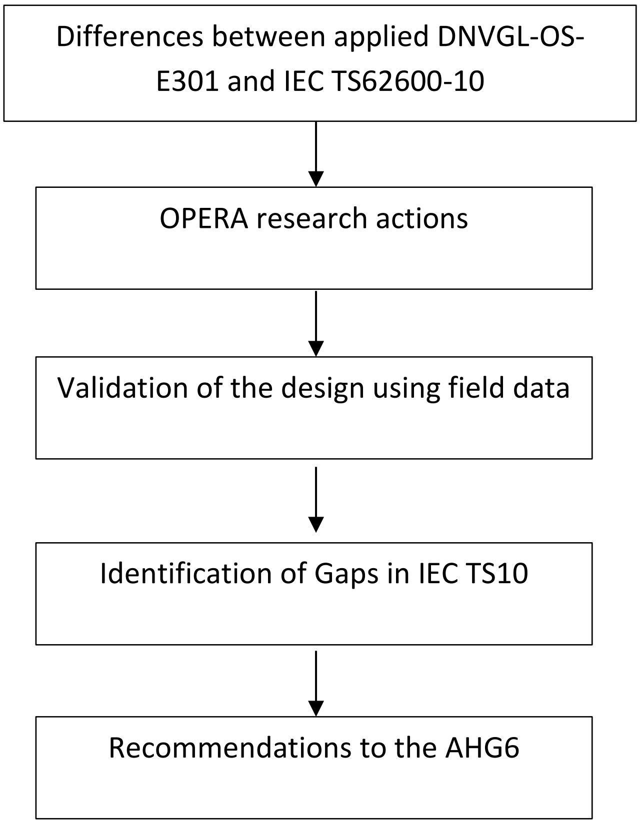

FIGURE 1. MOORING COMPARISON APPROACH

2.4.1 COMPARISON CONCLUSIONS

It appears that the TS10 is mainly based on API RP 2I standard, which may be significantly different from the DNVGL-OS-E301. Unfortunately, API RP 2I was not available for comparison at this stage.

The main conclusion that can be drawn is that whilst the IEC guideline has been developed for marine renewable energy devices and as such recommends that the PTO system is accounted for in mooring system design, only high level guidance on the subject is provided. Conversely the DNVGL-OS-E301 guidelines have been developed over a long period of time and (in conjunction with other DNV guidelines, such as DNV-RP-C205) and provide a high level of detail for designing, installing and maintaining mooring systems for offshore equipment. DNVGL-OS-E301 has been developed for the moorings of large equipment such as oil and gas platforms and DP vessels and hence the application to small marine renewable devices is unknown (particularly the consequence classes and safety factors specified). Nevertheless, the methodology and information provided are still relevant to MRE mooring design. (It should also be noted that an additional DNV standard exists DNV-OS-J103 which is a standard for floating wind turbines, which considers position keeping and the infancy of the sector, and lack of data/ maturity. DNV-OS-J103 refers to the DNVGL-OS-E301 but also has a more adequate risk approach from the point of view of renewable energy sector instead the Oil & Gas approach. In WP5, this standard will also be referred to).

For the IEC guidelines, recommendations will be made based on the operational experience and data acquired during the two planned Oceantec Marmok OWC deployments.

3. IEC TS 62600-30: ELECTRICAL POWER QUALITY REQUIREMENTS FOR WAVE, TIDAL AND OTHER WATER CURRENT ENERGY CONVERTERS

3.1 TECHNICAL SPECIFICATION SCOPE

The aim of the IEC/TS 62600-30: Ed. 1.0 (hereafter TS30) is to provide definitions of the quantities which characterise the power quality of a marine energy converter (wave, tidal and water current converters). Power quality characterises the power supplied to end-users in terms of continuity and reliability of supply, and which has voltage and frequency characteristics that are within pre-defined tolerances. TS30 specifies the measurement methods of these power quality phenomena, the application and measurement techniques (including test equipment and resource requirements) and result-interpretation guidelines for assessing the power quality. Additionally, a simplified reporting schedule is provided in TS30 for tabulating the results (see Appendix).

The measurement procedures provided are designed to be as non-site-specific as possible, so that power quality characteristics measured at one test site can also be considered valid at other sites (providing no control operations have been altered). The measurements and analysis required in TS30 aim in general to verify the characteristic power quality parameters for the full operational range of the assessed marine energy converter.

Specifications are given for both medium voltage (MV) and low voltage (LV). MV connected units are typically defined as three converters operating as a marine power farm and delivering bulk power through a HV or MV network. LV connected are typically single or three phase units deployed in isolated, hybrid or micro-grid type systems. In the case that the WEC is connected to a MV network, additional guidelines are given within TS30 to extract results that are independent of the of the grid conditions at the test site.

3.2 INTRODUCTION

Within OPERA, TS30 will be applied at Mutriku and/or BiMEP to firstly assess the practical aspects of implementing the TS, and secondly, to assess the power quality of the deployed WEC.

The following power quality phenomenon of the WEC will be assessed:

- Voltage fluctuations (including flicker)
- Harmonics (including current harmonics, inter-harmonics and higher frequency components), and
- Voltage drop response.

The rated data of the WEC (referred to at the WEC terminals), including the WEC rated active power, rated apparent power, nominal phase-to-phase voltage, and rated phase current, are used in TS30 for normalising purposes.

An explanation of the power quality phenomenon follows.

Flicker:
Flicker describes the phenomenon of unwanted, rapidly fluctuating light levels due to voltage fluctuations which are caused by regularly oscillating active and reactive power. This leads to voltage fluctuations at the point of connection. It is defined as a statistical index of visual disturbance, and was developed in order to evaluate the level of annoyance caused by light intensity variations on the average individual. Flicker can cause general discomfort and fatigue in humans, and may also induce deterioration and ultimately result in failures in electrical equipment.

Harmonics:
In recent years, increasing amounts of power electronics, reactive power compensators and other non-linear loads used in renewable energy systems are injecting more harmonic currents onto the transmission grid, resulting in the distortion of the three-phase voltage waveform. These harmonics cause electrical equipment to overheat, which results in failure or premature aging of the equipment. Typically, the onus is on the project developer to ensure that the farm is compliant, and does not result in the level of distortion or fluctuation of the supply voltage at their connection point to exceed that allocated to them, as per IEEE 1547 (Standard for Interconnecting Distributed Resources with Electric Power Systems). Total harmonic distortion (THD) is a common measurement of the level of harmonic distortion present in power systems, and is defined as the ratio of total harmonics to the value at fundamental frequency.

Voltage drop response:
Voltage drop response of a WEC under a short circuit grid fault is examined to ensure that the WEC is capable of performing low voltage ride through (LVRT). This is a regulatory requirement stating that generators must remain connected to the grid as per the fault ride through curve until the faulted element of the grid has been cleared. This is depicted in Figure 2. The generator must stay connected if the voltage sag lies under the line for the country of interest. LVRT is becoming an important issue as the level of non-synchronous generators connected to the transmission grid increases. If a significant percentage of generators were to disconnect from the grid due to a grid fault such as a short-circuit or an over-load condition, there would be serious implications on the stability of the grid. Within TS30, these tests also provide a basis for the WEC simulation model validation.

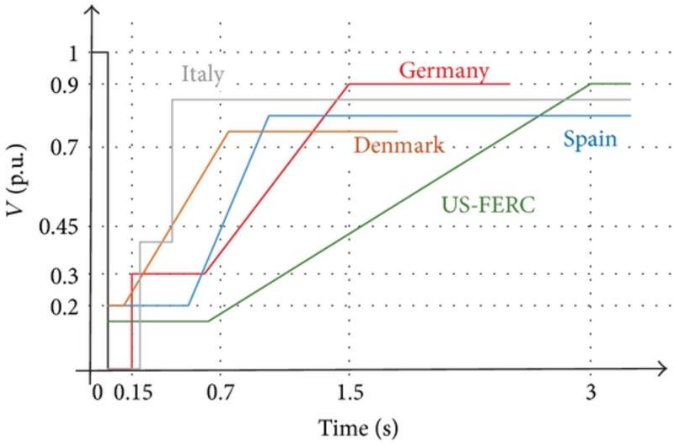

FIGURE 2. LVRT CURVE VARIATION FOR MULTIPLE COUNTRIES [YANG]

3.2.1 TS30 SECTIONS EXCLUDED WITHIN OPERA

Voltage fluctuations, harmonics and voltage drop response will be assessed using real operating data obtained during the OPERA project. (In the case of the voltage drop response, the UCC rotary test rig will be used; further details are given in Section 3.8).

There are some aspects of TS30 which will not be examined during OPERA. These include:

- Power control (i.e. ability of the WEC to operate in ramp rate limitation mode, set point control, reactive power capability and reactive power set point control)
- Grid Protection and Disconnection times (i.e. how the WEC functions in over and under-voltage, and over and under-frequency conditions in relation to the grid operator's disconnection levels and times)
- Reconnection times (i.e. reconnection time of the WEC after it has been disconnected after a grid failure or frequency event).

These are functions that must be considered by developers that are at a commercial and grid connection stage, and must be proven in order to obtain grid connection access. Therefore, these WEC functions are beyond the development scope of the Oceantec WEC at this stage within the OPERA project.

3.2.2 SUPPLEMENTARY DOCUMENTATION NEEDED FOR TS30 ANALYSIS

The following IEC TS are required for the complete implementation of the TS30:

- IEC 6100-4-7: 2002 Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and inter-harmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

- IEC 61000-4-15: Electromagnetic compatibility (EMC) –Part 4: Testing and measurement techniques – Section 15: Flickermeter – Functional and design specifications.

3.3 IEC TS DATA REQUIREMENTS

The data and sensor specification requirements as per TS30 are detailed in Table 3, with information given on the sensor location, the sensor location, sampling frequency and time, and overall comments, if applicable.

TABLE 3. TS30 MEASUREMENT REQUIREMENTS

Measurement Required	Location	Accuracy	Sampling Frequency	Sampling Time	Comment
Wave Resource	N/A	± 0.5 m/s	At least 1 Hz	10-minute time series as below	N/A
Current (Three x instantaneous line currents)	WEC terminals	Class 1	(1) **At least 2 kHz/channel** (calculation of RMS voltage, active and reactive power)	10 mins x Five tests	Mutriku update rate (LV Network Subsystem) Electrical Subsystem: 4 Hz Mutriku LV Power Analyser: Power Meter PM710: Accuracy Class 1
			(2) **At least 20 kHz/channel** for harmonic measurements	10 mins x Three tests	
Voltage (Three x instantaneous phase-to-neutral)	WEC terminals	Class 1	(1) **At least 2 kHz/channel**	10 mins x Five tests	
			(2) **At least 20 kHz/channel**	10 mins x Three tests	
Grid frequency					Not essential, but would be useful
Active power, Reactive power, Active current, Reactive power, Active current, Voltage	Calculated from time series measurements				

3.3.1 ADDITIONAL SENSOR REQUIREMENTS

The power analyser to be used in the Oceantec WEC is the Bender LINETRAXX® PEM575, pictured in Figure 3. It incorporates a 12.8 kHz waveform measuring capability that can be triggered by the user. These may be used for the 2 kHz three phase voltage and current requirements, as summarised in Table 3. It must be further determined whether this analyser has the storage capacity for 10-minute measurements.

FIGURE 3. BENDER PEM575 POWER ANALYSER

For the 20 kHz measurement requirements, it is anticipated that a network analyser or oscilloscope will be used, for example, the LeCroy Model WaveJet 324 (200 MHz). This may be programed to trigger measurement under a certain resource condition, and/or WEC power level.

3.4 REQUIRED TESTING CONDITIONS

There are a number of conditions that must be met whilst the power quality tests are being carried out:

(1) Resource range

The power quality measurements should be carried out at three different resource levels as specified in Table 4. The high resource level should allow for the specified rated active output of the WEC to be reached. The sea states shall be measured and reported as part of the test procedure.

Measurements are not required for wave heights greater than 5m, and waver periods less than 5s and greater than 14s, or alternatively, conditions which occur less than 5% in a year. This is because these sea states would require a significantly longer measurement period due to the rare occurrences of these conditions. The resource conditions shall be measured according to relevant IEC 62600 standards (TS101).

TABLE 4. WAVE RESOURCE CLASSIFICATIONS

Converter	Wave
Low	$H_{m0} \leq 1.5m$ and/or $T_{-10} \leq 7s$
Medium	$1.5m < H_{m0} \leq 4.5m$ and/or $7s < T_{-10} \leq 10s$
High	$4.5m < H_{m0}$ and/or $10s < T_{-10}$

(2) Continuous Operation

The measurements should only be taken during continuous operation, which is defined as the normal operation of the WEC, and excludes start-up and shut down operations.

(3) WEC Control and Operation Parameters

The reactive power control of the WEC should be as close as possible to zero - if applicable the reactive set-point control shall be set to 0.

The measured characteristics are valid for the specific configuration and operational mode of the assessed marine energy converter type only. Other configurations, and operational modes including altered control parameters that cause the WEC to behave differently with respect to power quality, require separate measured characteristics assessment.

(4) Characteristics of Connected Power System

a. MV and HV connections: frequency must be in within ± 1 Hz (of 50 Hz), with sufficient active and reactive power capabilities and voltage regulation. If the grid frequency is known to be very stable and well within the above requirements, this does not need to be assessed any further. Otherwise, the grid frequency shall be measured during the test.

b. The total harmonic distortion (THD): The THD of the voltage (up to the 50^{th} harmonic) measured as 10-minute average data while the WEC is not generating must be less than 5% (or the percentage defined by the local system operator).

c. Voltage levels: The 10-mintute averaged voltage levels measured at the WEC terminals shall be within ± 10 % of the nominal voltage (or the percentage defined by the local system operator).

d. Voltage unbalance factor: The 10-minute averaged voltage unbalance factor measured at the WEC terminals shall be less than 2 % (or the percentage defined by the local system operator). The voltage unbalance factor may be determined as described in IEC 61800-3:2004, Clause B.3. If the voltage unbalance factor is known to be well within the above requirement, it does not need to be assessed any further. Otherwise, the voltage unbalance factor shall be measured during the test.

3.5 TS30 VOLTAGE FLUCTUATION METHODOLOGY

This section details the methodology for determining the voltage fluctuations (flicker) of the WEC. The data processing and reporting approached are also detailed. The flicker is determined using a combination of measurements and simulation. Alternative approaches are given, depending on whether the WEC is connected to a LV or MV system. This is relevant depending on whether the measurements are taken on the single device (Oceantec), or at the MV connection point of the aggregated chambers at Mutriku.

3.5.1 MEASUREMENTS

- The flicker must be assessed under three resource levels, as per Table 4.
- At least fifteen 10-minute time-series of three-phase instantaneous line currents and three-phase instantaneous phase-to-neutral voltages at the WEC terminals shall be measured.

Note it does not matter if the WEC terminals are defined at the lower or higher voltage side of the transformer, as changing the voltage is not expected to cause the WEC to behave differently in terms of power quality.

3.5.2 DATA PROCESSING – MV SYSTEMS

MV network will normally have other fluctuating loads that may cause significant voltage fluctuations at the WEC terminals where the test measurements are taken. Additionally, the voltage fluctuations caused by the WEC will depend on the grid characteristics. It is required that the results obtained are independent on the conditions of the grid. Therefore, a method using “a fictitious grid” is introduced that uses the current and voltage time-series measured at the WEC terminals to simulate the voltage fluctuations on a fictitious grid with no source of voltage fluctuations other than the WEC. The equivalent circuit diagram for the fictitious grid is illustrated in Figure 4.

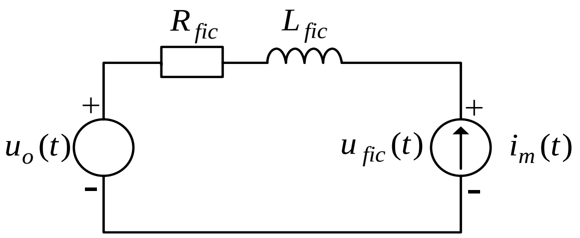

FIGURE 4. FICTITIOUS GRID FOR SIMULATION OF FICTITIOUS VOLTAGE

The fictitious grid is represented by an ideal phase-to-neutral voltage source with the instantaneous value, $u_o(t)$, and a grid equivalent impedance given as a resistance, R_{fic}, in series with an inductance, $L_{fic.}$ The WEC is represented by the current generator source, $i_m(t)$, which is the measured instantaneous value of the line current. This simple model is used to provide a simulated voltage using the measured instantaneous measurements. Further details are given in the TS30.

The measurements shall be adapted to determine the flicker coefficient of the WEC as a function of the network impedance phase angle and resource conditions. This shall be done repeating the following procedure for each of the network impedance phase angles, for each of the 10-minute measurements:

- The measured time-series are combined with the equation defining the fictitious grid to give a simulated voltage time-series.
- The simulated voltage time-series is then input to the flicker algorithm in compliance with IEC 61000-4-15 to give one flicker emission value on the fictitious grid for each 10-minute time-series, from which the flicker coefficient may be determined.

All relevant equations are given in TS30.

3.5.3 DATA PROCESSING – LV SYSTEMS

There is a simplified approach for the LV connected system.

- Each set of measured instantaneous voltage time-series is used as input to the voltage flicker algorithm described in IEC 61000-4-15 to generate the flicker coefficient.
- The 99 % percentile of the disturbance factor is then reported in tabular format.
- The measured flicker is reported (in tabular, graphical and/or equation format) for the whole range of the converter's operation.

3.5.4 REPORTING (LV AND MV)

- The flicker coefficient, $c(\Psi_k)$, shall be stated as the 99th percentile (coefficient value below which 99 % of the observed values fall), and in the case of MV connected systems, for network impedance phase angles of ψ_k = 30°, 50°, 70° and 85°.
- Measured flicker coefficients should be reported for the whole range of the WEC's operation.
- The WEC operational modes must be clearly stated.

3.6 TS30 HARMONIC METHODOLOGY

Current harmonics, inter-harmonics and higher frequency components will be measured and recorded as per the TS30.

3.6.1 MEASUREMENTS

- Background harmonic distortion from the grid shall be measured and recorded at the point of connection.
- At least nine 10-minute time-series of instantaneous current measurements (three tests and three phases) shall be collected for each power bin (0, 10, ...90, 100 % of rated power).

3.6.2 DATA PROCESSING

- The measurements and grouping of the spectral components shall be performed according to IEC 61000-4-7 (Testing and measurement techniques – General guide on harmonics and inter-harmonics measurements and instrumentation, for power supply systems and equipment connected thereto).
- The 10-cycle window for 50 Hz is recommended; the window size shall be recorded.
- The DFT (Discrete Fourier Transform) is applied to each of measured currents with rectangular weighting.
- The output of raw DFT shall be grouped in bands of 200 Hz, and the total harmonic current distortion shall be calculated.

3.6.3 REPORTING

- The values of the individual current components (harmonics, inter-harmonics and higher frequency components) and the total harmonic current distortion shall be given in tables in percentage of the rated current, and within the active power bins 0, 10, 20, …, 100 % of the rated power.
- The specified subgroup values are given in Table 5.

- The 10-minute averages of each frequency band (i.e. each sub grouped harmonic, inter-harmonic and higher frequency current component) shall be calculated for each 10-minute time-series, and subsequently the maximum 10-minute averages of each frequency band in each 10 % power bin shall be reported.
- The total harmonic current distortion shall be derived from the individual harmonic current components sub grouped values.
- Harmonic currents below 0.1 % of rated current for any of the harmonic orders do not need to be reported.

TABLE 5. HARMONIC SUB GROUPING

Harmonic Components	**Frequency Range**	**Source**
Individual harmonic current components	Up to 50 times the fundamental grid frequency (2.5 kHz).	n/a
Inter-harmonic current components	up to 2 kHz	Annex A of IEC 61000-4-7:2002 (equations (A3)
Higher frequency current components	for frequencies between 2 kHz and 9 kHz	Annex B of IEC 61000-4-7:2002 (equation (B1)).

3.7 TS30 RESPONSE TO VOLTAGE DROP METHODOLOGY

The response of the WEC to a temporary voltage drop (due to grid faults) shall be measured. The tests shall be carried out for the WEC operating at a) between 10% and 30% of the rated power of the WEC, and above 90 % rated power. The specification of per unit voltage drops is given in Table 6. The purpose of the VD1 and VD4 is for testing of WECs that have no capabilities to ride through any deep voltage drops, and the tests are generally used as basis for validation of numerical simulation models.

3.7.1 MEASUREMENTS

- Time-series of active power, reactive power, active current, reactive current and voltage at WEC terminals for the time shortly prior to the voltage drop and until the effect of the voltage drop has abated. These shall be given for each phase.
- Should be carried out for two consecutive tests.
- Converter operational mode should be recorded.
- 10-minute average wave conditions should be recorded.

TABLE 6. RESPONSE TO VOLTAGE DROPS

Case	Magnitude of voltage phase to phase (as a fraction of voltage immediately before the drop occurs)	Magnitude of positive sequence voltage (as a fraction of voltage immediately before the drop occurs)	Duration (s)
VD1 – symmetrical three-phase voltage drop	0.90 ± 0.05	0.90 ± 0.05	0.5 ± 0.02
VD2 – symmetrical three-phase voltage drop	0.50 ± 0.05	0.50 ± 0.05	0.5 ± 0.02
VD3 – symmetrical three-phase voltage drop	0.20 ± 0.05	0.20 ± 0.05	0.2 ± 0.02
VD4 – two-phase voltage drop	0.90 ± 0.05	0.95 ± 0.05	0.5 ± 0.02
VD5 – two-phase voltage drop	0.50 ± 0.05	0.75 ± 0.05	0.5 ± 0.02
VD6 – two-phase voltage drop	0.20 ± 0.05	0.60 ± 0.05	0.2 ± 0.02

3.8 DESCRIPTION OF UCC TEST RIG FOR SUPPLEMENTING DATASETS

The UCC test rig, housed within the Lir National Ocean Test Facility (NOTF), will be used in WP5 for two reasons. Firstly, to investigate the response to voltage drop (as per Section 3.7), and, secondly, to extrapolate the measured power quality profiles of the WEC for other operating conditions, such as varying control algorithms, and resource conditions. A brief description of the test infrastructure follows.

The main components in the test rig are two electrical machines, a variable flywheel, gearbox, torque transducer, back-to-back converter, associated drives and sensors to measure the quantities of interest (Figure 5). An electrical motor, configured as the WEC prime mover, is used to re-create the dynamic response exhibited by the WEC. The prime mover motion is emulated by a drive-controlled electrical motor which can be coupled to a flywheel via a gearbox. Then, the electrical power take-off is the same physical equipment that would exist on a full scale ocean energy device. The connection between the emulated part and the physical part of the test bench is the mechanical shaft linking the motor and the generator. On the other side, the mechanical power applied to the shaft feeds a generator that produces electricity. A back-to-back power converter applies the control laws embedded in a programmable logic controller. The power from the test rig generator can be dissipated in an islanded method to an isolated grid and a resistive load bank. Alternatively, this power can be fed into a micro-grid with fully controllable loads and grid emulation.

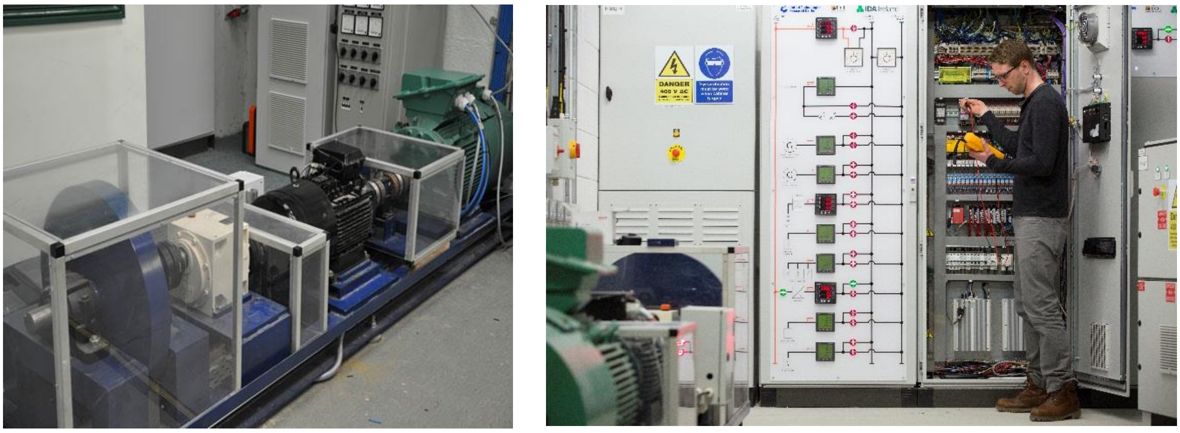

FIGURE 5. (1) UCC TEST RIG (2) ELECTRICAL MEASUREMENT PANELS

3.9 TECHNICAL ISSUES

Some issues foreseen in the implementation of TS30 are:

- **Sampling rates of power meters:** The power analysers typically used by developers would not store data at a sampling frequency of 20 kHz as this is beyond the requirements needed for device control etc.
- **Measurement requirements:** Measurements are required under three different resource levels, and for each bin (from 0, 10 % …100 % of rated power). It is not known whether this would be achievable to a developer within a reasonable time frame. However, this should not be an issue within the OPERA project.

4. IEC TS 62600-100: POWER PERFORMANCE ASSESSMENT

This section reviews the application of IEC/TS62600-100: Ed1.0-2012-08 (hereafter TS100) on power performance assessment with relation to the instrumentation and data collection within OPERA. Most of the information is provided within the table herein. This format should facilitate the final checks that the data collected will permit compliance with TS100 at Mutriku and BiMEP, and identify any point of concern.

4.1 TECHNICAL SPECIFICATION SCOPE

The scope of TS100 is defined in Clause 1 of TS100. The reader is invited to consult the TS itself for a precise delimitation of its scope. Briefly, TS100 provides technical specifications for a method to assess the electric power production of a wave energy converter at a testing site.

There is no clear definition of what a testing site is in TS100 or any other in IEC62600. While clearly BiMEP corresponds to what is commonly viewed as a testing site, it is less clear for Mutriku.

4.2 OVERVIEW OF THE METHODOLOGY

In short, TS100 specifies how wave measurements should be made, how power output measurements should be made, and how these should be combined to obtain a power matrix and estimate mean annual energy production based on this matrix and the mean wave climate.

At this time of the project the focus is on the specifications for the pre-testing and testing phases so most the experience reported in this section focusses on these steps. Some post-processing considerations are also reported.

4.3 IMPLEMENTATION AND COMPLIANCE OF TS100 IN OPERA

Table 7 summarises the implementation of TS100 within the OPERA project as of October 2016. Additional instrumentation should be deployed in the next few months meaning that the table may need to be updated later on in the project. Oceantec provided most of the information on power measurements in this table. The buoy deployment locations relative to the WEC deployment are depicted in Figure 6.

FIGURE 6. POSITION OF OCEANOGRAPHIC BUOYS RELATIVE TO THE WEC (OCEANTEC MARMOK A) AT BIMEP

TABLE 7. IMPLEMENTATION OF TS100 WITHIN OPERA

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
WAVE DATA					
1. Analysis of bathymetry and currents	Shall be sufficient to determine whether a wave transfer model is necessary between the Wave Measuring Instrument (WMI) and the WEC.		5.1	**NO**. The WMI will be placed 200 m upwave at some 15 m depth, but significant changes are expected in the wave field as it reaches the shore. The TS100 is difficult to apply for a shoreline device like Mutriku due to complex bathymetry and reflected waves which are important to at least 200 m offshore.	**YES**. The Triaxys g3 wave buoy, a particle following buoy that provides directional spectra, is moored some 200 m upwave of the WEC, at some 90 m depths, no significant change in the wavefield is expected in between. A wave transfer model can also be calibrated between this location and the BiMEP reference buoy (2 km away) or other buoys, likely complying with TS100/Annex D.
2. One WMI at WEC location and a second WMI at measurement location during deployment.			5.2.1	**NO**. The WMI will be deployed 200-m upwave of the plant and the wave field is expected to change to shore. Another instrument may be deployed later but it will also probably be too far. Compliance of this clause difficult for shoreline devices (problem of reflected wave).	**YES**. BiMEP's Fugro Wavescan buoy, a surface following, heave, pitch and roll buoy, at measurement location during deployment, and Triaxys buoy expected to provide excellent approximation of wave field impacting WEC during the whole testing as well.

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
3. Deployment time of both WMI	- Minimum: **3 months** prior to testing. - Recommended: **12 months** to observe at least one seasonal cycle.		5.2.1	**NO** because only one WMI. However, deployment planned before Nov 2016 so 3 months prior to algorithms testing at Mutriku should be complied with.	Arguing that **YES**: BiMEP Fugro buoy observing since 2009 so complying. The Triaxys buoy will be deployed mid-Nov 2016, at beginning of testing 1st Oceantec configuration (double Wells turbine + standard tether). This should however comply with the 3 months' requirement prior to testing of 2nd Oceantec WEC configuration (with biradial turbine + elastomeric tether). Note also that the Triaxys buoy should remain for several years thereon, so the 12 months of data for observing the seasonal cycle can easily be obtained for post-processing of data and power production prediction.
4. Parameters to be included when evaluated the power matrix: spectral shape, directionality of waves, directional frequency spectrum, water depth including tidal effect	Parameters recorded or rationale provided for their exclusion from the power matrix estimation		5.2.1	**YES**. Spectral shape will be obtained from bottom pressure time series. Wave direction is approximately cross-shore (NNE) and constant. Depths and tides available from Bermeo/Bilbao & 10-minute mean pressure.	**YES**. Both reference (heave-pitch-roll) BiMEP buoy and the Triaxys buoy to be deployed provided all these parameters. Depth changes unimportant given typical tidal ranges but can be estimated from nearby gauges (Bermeo, Bilbao).

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
5. Current measurements	Simultaneous with wave measurement and extend for 30 days.		5.2.2	**NO**. No measurements are available at this point yet. An operational tidal model is maintained by Azti and its archives may be consulted. Currents are not expected to be one of the significant sources of uncertainty in power performance evaluation at Mutriku.	**Not known**. The heave pitch and roll buoy at BiMEP is equipped with an ADCP but at this point it is not decided if/when it will be run.
6. Tidal measurement	30 days and analysed to estimate tidal ranges.		5.2.3	**YES.** The pressure sensor should provide adequate tidal measurements.	**NO** but this is not expected to be important at the depth of deployment (>80 m, 50-year tidal range of 5 m).
7. Bathymetric survey	Resolution sufficient to support the wave spatial transfer model.		5.2.4	**NO.** At the moment no high-resolution bathymetry is available and budget will probably not allow a survey.	**YES.** Extensive multi-beam survey has been conducted at BiMEP.
8. Calculation of wave spatial transfer model	The sea-state at the WMI must be representative of that impacting the WEC, if not a wave spatial transfer model must be set and evaluated as per Annex D.		5.2.5	**NO**. Significant changes in the wavefield are expected and there are no affordable ways to evaluate a wave transfer model (reflected wave, impossibility to have a sensor right at the plant during energetic sea-states).	**YES.** The Triaxys buoy 200 m upwave will measure a wavefield that complies with the <10% change 90% of the time. This could be verified post deployment but doesn't appear necessary.
9. Modelling of the test site	Wave transfer model between WMI and WEC predicts energy flux to 10% accuracy 90% of the 3 months of concurrent data.		5.2.6		**Yes**. Triaxys buoy to provide an accurate estimate of the wavefield at the WEC.

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
10. Sample duration and frequency (for sea-state data)	20 minutes		6.2	**Yes**. The pressure sensor will be measuring continuously at 1 Hz or 2 Hz.	Probably **YES**: should be near continuous depending on power usage and insolation. However, the standard sample duration is 1024 seconds (17 min) in order to permit efficient FFT. This is the practice in oceanography. We may be able to adjust this sample time for the Triaxys buoy which uses different methods to provide spectral estimates.
11. Minimum reporting frequency in power assessment data time series	Hourly	Until recently common practice was to report sea-states 3-hourly.	6.2	**YES**. Continuous.	**YES**, will be at least hourly.
12. Must be simultaneous with the power production measurement		This means the 20 minutes samples every hours should be simultaneous with the 20-minutes sample of power production	6.3	**YES**, to be checked in post-processing.	**YES**, this is not an issue as the wave power measurements are continuously reported.
13. Minimum testing duration	6 months	Must also be representative of the deployment location and permit the evaluation of the power matrix on operating envelope of interest	6.4.1	**NO** for biradial turbine. **NO** for Oceantec Wells turbine. **YES** for other chambers.	**YES** according to plan, however some of the control algorithms may be tested for a shorter time.
14. Time stamping	ISO8601	Combined data and time in UTC. Ex.: 2016-09-26T09:26:36Z	6.4.2	To be checked with Oceantec.	To be checked, should this be needed conversion to UTC will be easy.
15. Quality control flags			6.4.2	To be checked with Oceantec.	

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
16. Minimum sampling frequency	1 Hz		7.1	**YES.** Sampled at 2 Hz.	**YES.** Sampled at 1 Hz or higher. Note that standard configuration of particle following buoys does not provide high frequency sampling. But a special sensor is installed to provide heave at 2 Hz.
17. Calibration and accuracy of the WMI	Documented to reference NDBC:2009 Technical Document 09-02.		7.2	Can be argued that **YES.** As this is not a buoy reference to NDBC may be irrelevant, but a pressure sensor at 15-20 m depth is expected to provide accurate measurements.	Not checked. Buoy is from one of three major manufacturers and can be expected to provide data within competitors' accuracy.
18. WMI location	Chosen to best represent sea-state at WEC. Effects of reflection, radiation, diffraction, shadowing must be considered.		7.3.1	**YES**? Location upwave chosen to best represent incoming wavefield taking into account of the minimum distance necessary to reduce the effect of the reflected wave.	**YES**. Buoy located 200 m upwave of WEC in dominant wave direction. Modification of wavefield from this 70 kW WEC is negligible at this distance.
Direct measurements or spatial transfer model	Direct measure of sea-state allowed if representative of WEC, otherwise use spatial transfer model		7.3.2 and 7.3.3	**NO?** Wavefield will change from WMI to shoreline plant, and no easy way to calibrate a spatial transfer model is available at the moment.	**YES.** As argued above thebuoy measurements 200 m upwave will be adequately representing the wavefield at the WEC, except possibly for very rare wave direction.
Correction for WEC interference	WMI placed where average radiated energy decayed at least 90%	This criterion may need to be updated to depend on the WEC power.	7.3.4	**YES?** The reflected wave from the breakwater will have decayed significantly at 200 m. This will be difficult to evaluate due to challenge of measuring wave right at the	**YES.** The WEC is a full scale but low power prototype, with a horizontal cross section of less than 5 m diameter, it can be safely assumed that the radiated wave will be

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
				plant.	negligible 200 m upwave.
Metocean data	Record all parameters that may influence WEC production.		7.4	**NO.** Current measurements, for example, will not be available.	**?** Availability of current record will depend on availability of ADCP data during testing campaign. However, currents are mostly wind-driven in this area so that a simple but relatively accurate current model could be set up easily.
POWER PRODUCTION DATA					
1. Minimum sample duration	20 minutes		6.2	**YES**, sampled continuously.	**YES**, sample continuously.
2. Minimum reporting frequency in power assessment data time series	Hourly		6.2	**YES**, all the data is kept continuously.	**YES**, all the data is kept continuously.
3. Simultaneous with wave measurement		This means the 20 minutes samples every hour of power production should be simultaneous with the 20-minutes sample of sea-state parameters	6.3	**YES**, as continuous.	**YES**, as continuous.
4. Minimum testing duration	6 months	Must also be representative of the deployment location and permit the evaluation of the power matrix on the operating envelope of interest	6.4.1	Probably **NO**. - If, as is logical, changes in control algorithms are not allowed, this will be difficult to comply with. But this is not specified in TS100. - For the Wells turbines of Oceantec, it is likely that this will complied with in the next weeks. - For the biradial turbine it will be difficult as it will not	Probably **NO**. Depends on whether changes in control algorithms are allowed. As these are expected to impact power produced, the logic would be that such changes are not allowed. Up to 7 control algorithms will be tested at BiMEP, and this will probably not be complied.

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
				be delivered before March ’17and probably will be moved to the floating WEC in July ’17.	However, both the Wells and biradial turbines should be tested significantly longer.
5. Output Terminal: case of grid connected WEC.	-Point where output power in AC at network frequency. -Output terminal point should be clearly stated.		8.1	- **Yes** for the plant as a whole. **No** at the moment for individual chambers and generators/turbines. - The power analysers measures the power generated by all the generators of Mutriku. - There is one power analyser measuring at low voltage (460 V), and another measuring at medium voltage (13 kV). - At least one additional power meter will thus be needed for a power assessment of the turbines being tested in OPERA.	**Yes**. - Output terminal just before connector to the umbilical cable. - Power analyser at 690V at this point. - Another power analyser will be installed onshore.
6. Output terminal: case of non-grid connected WEC.	Should be at the point where power is connected directly to the load, at a common network frequency (e.g. 50 Hz, 60 Hz) and at a common grid connection voltage			N/A	N/A

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
	(e.g. 400 V, 6,6 kV), and these deteails should be stated.				
7. Power measurement point	Output terminal or at a point where losses and changes from output terminal can be determined		8.2	- **YES** for the plant as a whole. - For individual chambers including that being used for testing in OPERA, this clause should be complied with once an additional power analyser is installed.	**YES**.
8. Subtract electric consumption from the WEC from recorded output power		Consumption such as ancillary power and energising of the WEC to be subtracted from output power to get power production		**NO** At the moment this is not done.	**NO** at the moment. However, although some measurable peaks in consumption will occur, average consumed power is small and does not affect net power output in significant ways.
9. Minimum power recording frequency	2 Hz Use suitable anti-aliasing filter		8.3.1	**YES**. Recording power at least at 2 Hz.	**YES**. There is no problem recording at this frequency as the server allows for large amounts of data.
10. Record mean, standard deviation, maximum and minimum of the digitized values within each sample			8.3.1	**YES**.	**YES**
11. Assess potential limitations on power export due to grid (e.g. connection capacity, reactive power export).			8.3.2	**YES**. Limitation to export should be quite small, and the power analyser gives both true power and reactive power.	**YES**. Power electronics will adjust to minimise loss between the WEC power output and the onshore substation. At the moment

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
					Oceantec does not see major issues here.
12. If any limitation to power export may occur: a method is in place to identify when they do. Data on output during these conditions must be identified and may be removed to calculate the power performance matrix.			8.3.2	**NO**.	**NO.**
13. If any limitation to power export may occur: recommended that external dump load is installed to eliminate power output constraint			8.3.2	No limitation to power export seen.	**NO**.
14. Minimum number of phases for measurement of current and voltage	2		8.4	**YES**, measured at 2 phases.	**YES**, measuring 3 phases in the WEC.
15. Minimum class of power measurement device	0.5		8.4	**NO**. Class 1.	**YES**. Class 0.2s.
16. Power measurement device calibrated to traceable standards				**YES**. See below.	**YES**
17. Power measurement device meets requirement of: - Power transducer: IEC60688 - Current transformers: IEC60044-1 - Voltage transformer: IEC61869			8.4	Probably **YES.** It meets requirement of DIN EN 62053-21 (German normative requirements. Likely complies with IEC requirements).	Probably **YES.** It meets requirement: DIN EN 62053-22
18. Minimum operating range of power measurement device for exported power	1 % to 200 % of rated power		8.4	**?** Maximum current measurable with installed equipment to be checked.	**YES**. The installed equipment can support more than 200% of the rated power.
19. Minimum operating range of power measurement device for imported power	-1 % to -50 % of rated power		8.4	**YES.**	**YES**

Parameter	Value specified	Comment	Clause in TS100	Compliance at Mutriku	Compliance at BiMEP
20. Record 0 when power range of +/- 1% of rated power does not allow for class 0,5 measurement. (When low power does allow class 0,5 measurement, record value)			8.4	**NO**. Class 1. But a more accurate power analyser could be implemented easily.	**YES**. The implemented power analyser is class 0.2s. This supposes an accuracy of +-0.75% at 1% of rated power. If necessary, the registered power value could be replaced with 0 for such cases. .

5. IEC TS 62600-101: WAVE ENERGY RESOURCE ASSESSMENT

5.1 TECHNICAL SPECIFICATION SCOPE

IEC TS 62600-101:2015 (hereafter TS101) is the first edition of the IEC TS 63600-101 TS developed by IEC Technical Committee 114. TS101 is one of three published TS 62600 documents specific to wave energy conversion; IEC TS 62600-100:2012 (included in the Normative references listed below), and IEC TS 62600-102, "Wave energy converter power performance assessment at a second location using measured assessment data", detailed in Section 6.

TS101 establishes a system for estimating, analysing and reporting the wave energy resource at sites potentially suitable for the installation of WECs. Wave energy resource is defined in TS101 as the amount of energy that is available for extraction from surface gravity waves.

TS101 is to be applied at all stages of site assessment from initial investigations to detailed project design. In conjunction with IEC TS100 (WEC power performance) it enables an estimate of the annual energy production of a WEC or WEC array to be calculated.

TS101 is not intended for estimation of extreme wave conditions.

The TS aims to ensure that only adequate and successfully validated numerical models are used and applied in an appropriate manner to ensure confidence and consistency in reported results. The document prescribes methods for analysing metocean data in order to properly quantify and characterise the temporal and spatial attributes of the wave energy resource. It also describes how results should be reported comprehensively and consistently.

The *Normative* references listed in the TS, and therefore those essential for its application, are:

- IEC TS 62600-100, Marine Energy – Wave, tidal and other water current converters – Part 100: Electricity producing wave energy converters – Power performance assessment,
- ISO/IEC Guide 98-3:2008, Guide to the expression of uncertainty of measurement,
- ASME 20-2009, Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer and
- IHO (International Hydrographic Organisation), 2008, Standards for Hydrographic Surveys, Special Publication No. 44, 5th Edition.

5.2 INTRODUCTION

The practical implications of the application of TS101 will be evaluated by comparing its recommendations with what was found to be reasonably practicable during BiMEP's site assessment.

5.3 IEC TS101 METHODOLOGY

TS101 specifies the procedures for correct wave energy resource characterisation. The following actions are summarised as follows, particularly in relation to data processing and management. Note that the Class of Assessment is referenced throughout the document, as the different parameters depend on this. It is determined by the dimensions of the long-shore extent.

5.3.1 DATA COLLECTION AND RESOLUTION

- **Bathymetry**: a bathymetric contour map shall be prepared. This should be used to construct a Digital Elevation Model for the wave propagation model. The resolution requirements depend on the Class of Assessment.
  The Class of Assessment depends on the long-shore extent and the uncertainty of wave energy resource parameter estimation. For example, a Class 1 Assessment will be used for reconnaissance purposes, where the uncertainty in the parameter estimation is high, and the long-shore extent is greater than 300 km. This classification is used in order to choose the type of data needed.
- **Existing wave data**: for Class 1 Assessment, archived data may serve as primary data source (if follows requirements from the TS). If the archived wave data is characterised using parameters different from those on the TS, the data shall be converted to match. The uncertainty with this existing data shall be calculated.
- **Wave measurement**: are used to validate the wave resource numerical model. Wave measurements can also be used to develop boundary conditions for wave modelling, but this data has to be independent of the data used for model validation. When validating a numerical model, depending on the class, analysis of measurement shall provide significant wave height, energy period and omni-directional wave power (Class 1) in addition to spectral width and directional spreading index (Class 2 & 3).

Moreover, the selection of measuring instruments must be able to give certain precision, capturing a full range of wave conditions, with a minimum record of 1200 s per sampling period.

One or more locations close to the WEC deployment zone shall be used for instrument deployment, or in the case where this is not possible, using locations with representative conditions is recommended, deploying more than one instrument for redundancy.

- **Wind data**: height of wind data shall be consistent with the wave model. If the data is of a coarser resolution, it can be extrapolated.
- **Tide data**: a sensitivity analysis shall be used to assess the importance of water level fluctuations.
- **Current data**: it shall be presented, and a sensitivity analysis shall be done.
- **Ice coverage or exceptional environmental conditions**: if applicable, it shall be taken into account, together with a sensitivity analysis.
- **Water density**: near surface, water density shall be determined directly, or from temperature and salinity measurement. Seasonal variations shall be considered when appropriate.

5.3.2 DEVELOPMENT OF A NUMERICAL MODEL FOR WAVE ENERGY RESOURCE ESTIMATION

Data shall be generated using numerical models (NM). These shall be calibrated and validated with physical measurements. The NM should produce at least 10 years of sea state data (if the time frame is less than this, an estimate of the uncertainty of the wave resource has to be done). Wave resource has to be taken as stationary in the 10 years' study (related to climate change and anthropogenic induced changes). Minimum frequency for sea state data is 1 data set every 3 hours. Archived data may be used, if the methods to generate the data are consistent with the TS.

5.3.2.1 BOUNDARY CONDITIONS

- Boundary conditions shall be defined using either:
    - Physically recorded metocean data (at least 10 years' data with data return rate greater than 70%).
    - Historical data predicted with a more extensive NM (at least 10 years, validated against physical recorded data).
    - A combination of above (e.g. filling gaps from the other, or add directional info to non-direct. physical data).
- Missing data may be estimated using MCP (see next section).
- Boundaries shall be located in zones with homogeneous wave conditions.
- It is recommended that Class 3 resource assessment use results from a Class 2 to establish a suitable spatially varying boundary condition.

- Numerical modelling: linear seaway interpolation may be used to approximate the spatial variation in wave conditions along the model boundaries.

5.3.2.2 MODELLING NEARSHORE RESOURCE

- A wave model including non-linearity and depth-limited wave breaking (if under 16 m depth) shall be included.
- If information on shallow water wave resource is not required, then depth shall be limited to the 16 m contour.

5.3.2.3 EFFECT OF WEC ARRAY

- If an energy production estimation for a particular WEC array is required (WEC array effects on wave propagation cannot be neglected), this shall be included and justified in the numerical model.
- If the WEC array is not present when the wave data used for validation is measured, the WEC array effects shall not be included in the validation of the wave propagation model.

5.3.2.4 VALIDATION OF NUMERICAL MODEL

- The NM shall be validated using measured data from one or more locations near the WEC proposed location.
- Wave climate and depth for the validation sites chosen shall be similar to those on the WEC proposed location.
- The validation data set shall be used to construct an omni-directional characteristic wave height-period scatter of the proportional frequency of occurrence of a sea state over the duration of the resource assessment, with periods of 6 hours.

5.3.2.5 DATA PROCESSING

Obtaining the main two-dimensional (2D) parameters and their uncertainty is needed for the sea state characterisation. Particularly, the parameters needed are:

- Mean omni-directional energy flux per unit width / wave power.
- Characteristic wave height.
- Characteristic wave period.
- Spectral width.

- Direction of maximum directionally resolved wave power.
- Directionality coefficient.

These parameters can be added or excluded from the list following a sensitivity analysis depending on the type of WEC.

Wave power can be estimated through characteristic wave height and period, depth, group celerity and water density. The spectral shape is assumed based on analysis of wave data (it is scaled using characteristic wave height and period, and depth).

- **Aggregation and statistics**

  Annual and monthly statistics for all wave energy resource shall be calculated, including:

  - Mean
  - Standard deviation
  - Median for 50th percentile
  - 10th percentile
  - 90th percentile
  - Maximum
  - Minimum
  - Monthly variable
  - Uncertainty of the resource assessment: measurement, modelling, long-term variability and combined uncertainty have to be considered.
- **Formation of data bins: digital database**

  The main results of the resource assessment shall be stored in an accessible, georeferenced, digital database. It shall include:

  - Information for each model grid point (or MCP measurement site) where wave resource has been obtained.
    - Location (latitude, longitude).
    - Water depth below mean sea level.
    - Full time histories for all wave parameters derived.
    - Full directional wave spectrum at every time step.
    - If MCP method used: also need to store wave resource parameter time-histories.
    - If numerical wave propagation model is used, the following must also be stored:

        - Time varying boundary conditions.
        - Wind fields.
        - Current fields.
        - Measurements use to validate the numerical model.
        - If MCP methods are used: data from MCP reference location.
- A set of maps shall be prepared if spatial variation of the resource parameters is available.
- Other figures are required:
    - Annual scatter table (proportional frequency of occurrence of sea states, parameterized in terms of characteristic wave height and period).
    - Graphical and /or tabular representation of annual variation of long-term monthly mean values of:
        - Characteristic wave height.
        - Characteristic wave period.
        - Omni-directional wave power.
        - Maximum directionally resolved wave power.
    - Annual wave rose with:
        - Maximum directionally resolved wave power.
        - Direction of maximum directionally resolved power.
- The following figures are optional:
    - Directionally resolved annual scatter tables.
    - Graphical and/or tabular of annual variation of the long-term monthly mean values of:
        - Direction of maximum directionally resolved wave power.
        - Directionality coefficient.
        - Spectral width.
    - Graphical of the annual and monthly cumulative distributions of:
        - Characteristic wave height.
        - Characteristic wave period.
        - Omni-directional wave power.
        - Maximum directionally resolved wave power.
        - Direction of maximum directionally resolved power.
        - Directionality coefficient.
        - Spectral width.
- Temporal fluctuations over selected periods of the previously mentioned variables.

5.3.2.6 DEALING WITH MISSING DATA

In the case where data in the specified location is unavailable or missing, prediction from a different site with similar conditions is permitted. Measure-Correlate-Predict (MCP) methods shall be used. Measured wave conditions at the location are needed for a certain time period. The use of correlation functions to link measurements with data from another locations is valid under certain conditions.

For the numerical model, linear seaway interpolation may be used to approximate the spatial variation in wave conditions along the model boundaries. Linear interpolation is suggested for the Statistic Result calculations.

5.4 BIMEP METHODOLOGY

BiMEP represents an offshore infrastructure for the demonstration and proving of wave energy generation devices over a sustained period of time. It consists on an 8 km^2 sea area, 1.7 km away from the coast, with depths between 50 and 90 m where four static submarine cables are placed, operating at 13 kV and 5 MW. Wave energy generation devices can be connected to these cables through dynamic submarine cables. In-land, BiMEP provides a research centre in Arminza (Bizkaia, Spain).

The methodology followed by BiMEP to develop the NM used in their research centre is summarised.

The dataset used was provided by two buoys:

- BiMEP WAVESCAN Buoy, and
- Bilbao-Vizcaya REDEXT Buoy.

Further details of these buoys follow.

5.4.1 BIMEP WAVESCAN BUOY

This buoy provided data related to wind, waves and current conditions. Wave data was available for the period 2/Feb/2010 to 24/Nov/2010, two miles offshore the coast (longitude: -2.8848˚E; latitude: 43.4682˚N).

The buoy is equipped with wave and surface current sensors as well as a current profiler within the water column. The buoy is equipped with a mast to support meteorological sensors to measure air temperature, sea level pressure and wind.

Several wave parameters are provided by the instrument in hourly basis: H_{m0}, significant wave height from the zero order moment (in m); H_{max}, maximum wave height (in m); T_{m02}, mean absolute wave period (in m); T_p, peak period (in s) and θ_m, mean wave direction (in ˚, nautical convention).

Based on validation inter comparison trials, the WAVESCAN instrumentation suitably fulfils the requirements described in the TS for Class 3 resource assessment. Overall bias in the significant wave height is less than 5 cm, 0.05 s in the mean period and 2˚ in the mean direction. Likewise, precision is less than 10 cm in wave heights, 0.3˚ in directions and less than 2% of the value of the measured period (always less than 1 s, following the TS).

5.4.2 BILBAO-VIZCAYA REDEXT BUOY

As advised in TS101, more than one wave measuring instrument shall be used whenever possible. For this reason, and in order to demonstrate the extent of the validation of the model outputs, it has been also used the REDEXT Bilbao-Vizcaya buoy.

Bilbao-Vizcaya REDEXT buoy is located northwest BiMEP area, offshore Bilbao port [-3.05˚E, 43.64˚N, 600 m deep]. Wavescan/Seawatch directional buoy operates under the Spanish Port Authority (*Puertos del Estado*). Data spans from 1990 to 2015 providing hourly records of wind at 3 meters and the main wave parameters as well as the full wave spectra.

5.4.3 MODELLING METHODS

5.4.3.1 WIND

A historical wind dataset for the period 1985-2015 has been reconstructed using the limited area model (LAM), WRF-ARW version 3.5.1 (Weather Research & Forecasting model with the Advanced Research dynamical solver). It is composed of a non-hydrostatic core, grid- and spectral-nudging capabilities, providing a large number of different options to parameterize key sub-grid scale physical processes. Model simulation was performed in a re-forecast mode (daily independent simulations). Specific numerical schemes and physics for the specific wind modelling were used obtaining fairly satisfactory.

Boundary data used in the simulations were taken from CFSR (Climate Forecast System), which is the latest reanalysis product available from NOAA-US, and the source of static data used to get the simulation domain was MODIS (Moderate Resolution Imaging

Spectroradiometer). Three different domains have been used in the simulations with spatial resolutions of 9 km, 3 km and 600 m in the test site. Wind speed and direction at five different heights of 10, 55, 90, 120 and 150 m are produced hourly in order to capture high frequency variability of the wind fields.

5.4.3.2 WAVE

In order to obtain a realistic representation of the wave climate over the BiMEP area, the SWAN model (Simulation Waves Nearshore) version 41.01 has been used. The temporal domain of the simulation covers from 1/Jan/1985 to 31/Dec/2015 with hourly resolution. From the bathymetries, by means of linear interpolation, two computational grids have been constructed. The borders of the general grid G (≈ 500 m spatial resolution) are located far away from the study area. In order to cover the BiMEP site with higher resolution and to better resolve refraction and bottom friction, a second grid of ≈ 50 m resolution is nested to the G grid.

The model has been run in non-stationary mode splitting the reconstructed time period in 360 monthly blocks. The spectral domain is defined by a number of 32 frequencies (from 0.0373 Hz to 0.7159 Hz) and 48 directions. Sea-state parameters in both domains are stored hourly. Furthermore, the full spectra have been recorded in the two available buoys and several locations within the BiMEP area.

Wind forcing fields used are the outputs from the atmospheric downscaling. The generated wind database is interpolated to the SWAN grid coordinates to consider wind-wave generations within the model domains. A constant sea level corresponding to the mean sea level (0.48 m with respect to the mean sea level in Alicante) has been used for the whole run due to the relatively deep waters in which the WECs will be located.

Wave boundary conditions are defined based on an offshore Global Ocean Wave (GOW) wave hindcast from IH Cantabria. Apart from the typical wave parameters, GOW dataset also provides significant wave heights, peak periods, directions and directional spreading for the 3 dominant spectral components. Based on altimetry data, the spectral component wave heights are directionally corrected in the boundaries.

The spectral boundary conditions are then constructed at 14 points covering the sea borders of the grid G. Instead constructing the spectra based on the common sea state parameters, in this work a combination of three different JOSNWAP spectra is used to consider the wave energy associated to each one of the three spectral components. Considering wave partitions substantially improves the characterization of the frequently composed sea states in the area.

5.4.4 MODEL VALIDATION

5.4.4.1 WIND VALIDATION

Wind data from the two in-situ buoy records are compared with the historical reconstruction in order to validate the modelling. The validation is focused on 10 m wind speed and direction in the closest grid point to each buoy. The numerical model fairly reproduces the temporal structure of wind speed and direction at the two locations, even when the wind came from the south (offshore winds).

Although model results better correlate with the Bilbao record, the bias is smaller when comparing wind speeds at the BiMEP buoy (+ 0.18 m/s at Bilbao and - 0.018 m/s at BiMEP). Differences between the error estimates on both locations can be partially ascribed to the short length of the record of the BiMEP buoy.

5.4.4.2 WAVE VALIDATION

As advised in TS101, all numerical modelling shall be validated using measured wave data close to where wave energy converters might realistically be deployed. In this section, the validation based on the described buoy data is achieved by means of the state of the art validations methods (i.e. determining bias, correlation and data dispersion) as well as the method proposed in the TS.

The model fairly reproduces the time evolution of the different wave parameters over the entire buoy record. Correlation in the wave power (J) is 0.96, 5.8 KW/m in the mean square error, -0.3 KW/m in the overall bias and 0.53 KW/m in the scatter index, indicating a very good agreement between modelled and measured wave energy resource.

Model validation should be based on the model skill in predicting the key resource parameters describing the energy resource. In the TS, a specific validation method for the wave energy resource assessment is described. The method is based on the determination of the systematic and random error in the characteristic wave height-period scatter table weighted by the mean incident wave power and the occurrence frequency.

BiMEP presents a complete NM based on measured data. Moreover, wave and wind data are taken from two different sources in order to validate the model. The BiMEP methodology fits the procedures required at the TS. In this case, BiMEP’s procedures fulfil the requisites for a Class 3 assessment, which is the most demanding assessment.

6. IEC TS 62600-102: POWER PERFORMANCE ASSESSMENT AT A SECOND LOCATION USING MEASURED ASSESSMENT DATA

6.1 TECHNICAL SPECIFICATION SCOPE

The technical specification IEC TS 62600-102:2016 (hereafter TS102), provides a methodology for determining the mean annual energy production (MAEP) for the WEC at a second location (hereafter Location 2). Note: it is recommended that a location will be chosen, rather than BiMEP (Location 1) for testing the Oceantec Marmok OWC device based on some agreed conditions. Other technical specifications in this series (IEC/TS 62600-101 and -100) are drawn upon to provide the wave resource and WEC performance information needed to enable this analysis. The methodology involves:

- Assessment of the wave resource at Location 1 (BiMEP) and Location 2 (the chosen location);
- Characterization of the WEC performance at Location 1;
- Assessment and compensation for the impact of discrepancies in the metocean conditions between Location 1 and Location 2 on the WEC performance characterization;
- Assessment of the impact of changes to the WEC configuration between Location 1 and Location 2 on the WEC performance characterization;
- Complementing the performance observations from Location 1 with fit, experimental or numerically modelled data;
- Estimating the MAEP based on the composite performance characterization of the WEC.

This specification provides guidance on the use of observations from Location 1, methods for assessing and reporting the validity of numerical and physical models, limits on the permissible changes to the WEC between Locations 1 and 2, limits on the use of data fitting techniques, and requirements for reporting.

6.2 INTRODUCTION

A methodology similar to the application of the TS100 will be applied to obtain the energy yield at other test locations based on TS102, and assessing and examining the issues of the wave spectrum shape and wave conditions on the energy yield. Detailed assessment of the energy yields will also be determined using sea state assessment, using inputs of the modified 3D power matrix analysed in T5.2, “Documented real-case application of IEC Specifications”. Predicting power performance with a scaled prototype will also be investigated to examine the issues involved in scaling power performance, and detailing problems and solutions that developers face when testing at sea with scaled prototypes. The outputs from this task will feed into WP7 to inform LCOE modelling.

6.3 DATA AND MODEL REQUIREMENTS

For the application of TS102 within OPERA, the wave resources at Location 2 will not be measured. Therefore, the choice of Location 2 will be fully dependent on the available measured or modelled data. The following are the parameters or factors which can be used to determine the location referred to as Location 2:

- Availability of wave resources (measured or modelled data, or a combination of both. According to TS100, the statistic wave data should cover a period of at least 10 years);
- Water depth. Ideally, this would be similar to BiMEP, Location 1.
- Wave resources (mean annual wave energy).
- Other factors, such as wave spread angle.

6.4 METHODOLOGY AS PER IEC GUIDELINES

The procedure and modelling approach which will be taken within OPERA can be seen in Figure 7. The availability of the wave and environmental conditions must be checked to ensure that the relevant IEC standards are satisfied, for instance, 10-year data from either measurement or numerical modelling for the specific site. However, it is not planned within OPERA to carry out any measurement or numerical modelling of the wave data, hence the condition may be only satisfied with the selection of a specific site for which the wave data are already available. Additionally, the device power performance must be examined or appropriately modified for Location 2, because it will be difficult to simply apply the same marine energy converter for the second location. Although it is allowed within TS102 to modify the device for the second location, it is not clear how these modifications can be made. These device modifications, for example, may include changes in the mooring system design due to varying water depths, or changes in device target period depending on wave conditions etc. In the OPERA project, further investigation may be needed in this regard.

When both conditions (wave data and device performance) are satisfied, the application of TS102 will be straightforward. In the OPERA project, the knowledge and information gaps will be identified, and the recommendations will be made to the IEC Ad Hoc group.

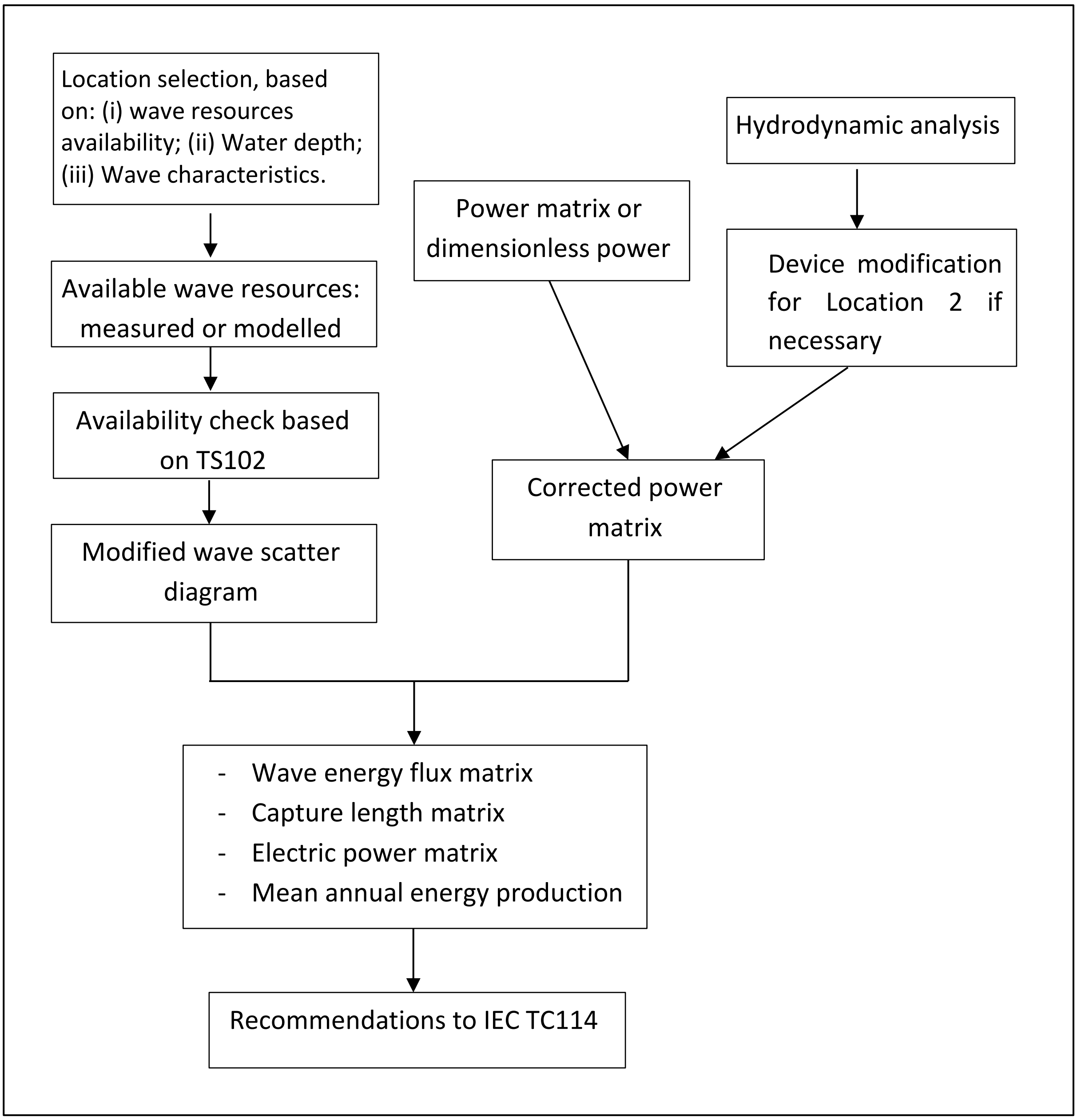

FIGURE 7. PROCEDURE AND MODELLING APPROACH OF THE TS102 APPLICATION WITHIN OPERA

6.4.1 TECHNICAL ISSUES

The technical issue for the application of TS102 may be its dependence on the available power performance, either in the form of a power matrix or the detailed non-dimensional power curve, which is one of the two basic requirements of the TS application (the other is the wave resources).

The other issue may be the difficulty in correcting/modifying the device which is optimised based on Location 1 in order to make it more suitable for Location 2. For reasonable application, the device may need to be modified for the Location 2 if the wave resources and water depth vary significantly from Location 1. For this purpose, the selection of Location 2 may be the one with a wave resources and similar water depth. Location 2 will be chosen from a list of locations for which the modelled wave data is available. Another potential difficulty is the quantity of information available in order to successfully apply the IEC technical specification.

7. CONCLUSIONS

A key element of WP5, "Applicability and Extension of IEC Technical Specifications using Open Sea Data" within the OPERA project is to accelerate the establishment of standards for the wave energy sector. OPERA will provide the first such documented application of the marine 62600 series of technical specifications.

The relevant IEC TS are:

- 62600-10 Ed. 1.0 Part 10: Assessment of mooring system for marine energy converters
- 62600-30 Part 30: Electrical power quality requirements for wave, tidal and other water current energy converters.
- 62600-100 Part 100: Electricity producing wave energy converters - Power performance assessment
- 62600-101 Ed. 1.0 Part 101: Wave energy resource assessment and characterization.
- 62600-102 Ed. 1.0 Part 102: Wave energy converter power performance assessment at a second location using measured assessment data

This deliverable represents the first stage in the examination of the practical application of the TS by extracting the necessary methodologies to enable their execution. This deliverable summarised the necessary methodologies and requirements from each of the TS, defined the practical implementation of the methodology for a real sea deployment, and highlighted any technical issues.

8. REFERENCES

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[Yang] Y. Yang, F. Blaabjerg, Low-Voltage Ride-Through Capability of a Single-Stage Single-Phase Photovoltaic System Connected to the Low-Voltage Grid, International Journal of Photoenergy 2013(1) · February 2013 (DOI: 10.1155/2013/257487).

APPENDIX: TS SAMPLE REPORT TEMPLATES

IEC TS 62600-30 SAMPLE REPORTING TEMPLATE

This sample report format gives a suggested format for reporting the results of tests for characterizing the power quality parameters of a marine energy converter. The assessor should fill in the empty tables and insert graphics at the Figure captions.

REPORT ON RESULTS OF MARINE ENERGY CONVERTER POWER QUALITY TESTS

The reported characteristics are valid for the specific configuration of the assessed marine energy converter type only. Other configurations, including altered control parameters, that cause the marine energy converter to behave differently with respect to power quality, require separate assessment.

Table 1: General marine energy converter information

Name of test organization	
Report number	
Marine energy converter type designation	
Marine energy converter manufacturer	
Serial number of marine energy converter tested	

The Marine energy converter identified above has been tested in accordance with IEC 62600-30. General marine energy converter data are given below:

Table 2: Converter nameplate ratings

Marine energy converter type (wave, tidal, water current)	Wave ☐ Tidal ☐ Water current ☐
Mechanical conversion scheme (wave: heave, pitch, yaw, sway, surge; tidal & water current: horizontal, vertical; other - specify)	
Unit rating(s) (kW)	
Generator type (synchronous, induction, doubly-fed, full converter, other - specify)	

Frequency converter type and rating (kVA)	
Reactive compensation type and rating (kVAr)	
Transformer ratio and rating (kVA)	
Identification of marine energy converter terminals	

This test report is accompanied by the documents specified below.

Table 3: Test information

Type of information	**Document name and date**
Description of the tested marine energy converter, including settings of the relevant control parameters	
Description of test site and grid connection	
Description of test equipment	
Description of test conditions	
Note of exceptions to IEC 62600-30	
Author	
Checked	
Approved	
Date of issue	

Characteristic parameters that are determined otherwise than outlined in IEC 62600-30 are marked. This includes parameters that are calculated instead of measured. The document(s) with exceptions to IEC 62600-30 describes the alternative procedure(s) that has been applied.
The resulting characteristic parameters are stated below.

A.1 Marine energy converter rated data at terminals

Table 4: Marine energy converter rated data at terminals

Rated power, P_n (kW)	
Rated resource condition, [wave: H_{m0} (m), T_{-10} (s); tidal: v_{ta} (m/s); water current: v_{wa}	

(m/s)]	
Rated apparent power, S_n (kVA)	
Rated current, I_n (A)	
Rated voltage (at measurement point), U_n (V)	
Rated frequency, f_g (Hz)	

A.2 Voltage fluctuations (continuous operation)

The operational mode of the marine energy converter during the test was:

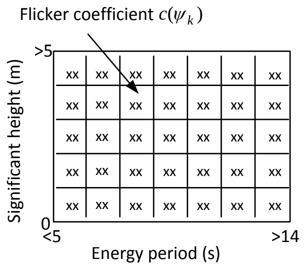
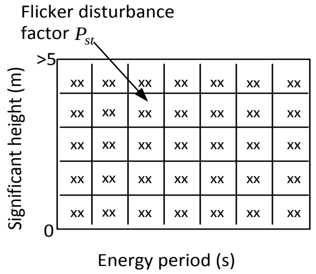
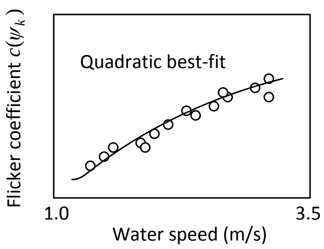
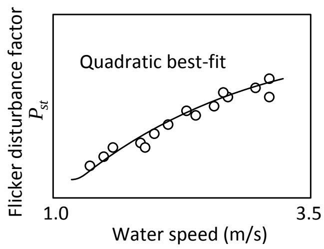
Table 6: Reactive set-point control

Method	**Select/Specify**
Zero reactive power (Q = 0)	
Constant reactive power (specify Q)	
Voltage control	
Constant power factor	
Other mode (specify)	

Table 7: Flicker index (coefficient or disturbance factor) data:

Resource condition at site (select one or more)	**Marine energy converter type (check one)**			**MV-connected**				**LV-connected**
				Flicker coefficient $c(\psi_k)$				**Flicker disturbance factor** P_{st}
				Network impedance phase angle, ψ_k **(°)**				
				30	**50**	**70**	**85**	
	Wave ☐	Tidal ☐	Water current ☐					
	H_{m0} (m), T_{-10} (s)	v_{ta} (m/s)	v_{wa} (m/s)					
Low								
Medium								
High								

Table 8: Flicker coefficient as a function of resource conditions:

Marine energy converter type (check one)	Graphical/Tabular/Look-up data and/or Best-fit equation	
	Flicker coefficient $c(\psi_k)$ for MV-connected converter, present for ψ_k = 30°, 50°, 70° and 85°)	**Short-term flicker disturbance factor P_{st}, for LV-connected converter, presented for measured conditions)**
Wave ☐		
Tidal ☐		
Water current ☐