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Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact

Grant agreement number: 213380

EquiMar

Deliverable D1.2
Recommendations from other sectors

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Summary

This report presents a brief critical list of existing international standard and guidelines that have been defined and applied successfully to different business sectors and whose content is believed to be useful for wave and tidal energy technology development.

It is intended to provide a review of established standardisation processes and a general input basis for future work within the EquiMar Consortium which will be primarily aimed at defining protocols for marine energy performance assessment. Background information is taken from established industrial sectors that have faced challenges and difficulties similar to the ones being encountered by wave and tidal technologies and is mainly based on standards or guideline documents that have proven their applicability through different experiences.

The idea is to provide a global understanding of how standards and recommendations are specified and to identify which areas are covered by these documents in such a frame that knowledge can be transferred to the marine energy sector.

This deliverable is subdivided in 7 chapters: The first one represents an introduction to the scope of this report and a general presentation of the EquiMar project.

Chapters from 2 to 7 summarise background information available in different specific technical subjects related to deployment and operation of marine energy technologies in such a way that information is classified depending on the area it is thought to be relevant to. The six areas covered are:

- Environmental conditions specification
- Structural design and material selection
- Components, instrumentation and control systems
- Reliability and safety requirements
- Measurements for assessment, grid connection and power quality requirements
- Environmental impact requirements

Each of these sections includes tables and a list of references for deeper knowledge. Even if most of the documents described represent fundamental outcomes generally acknowledged by the partners of the Consortium it has to be said that, for reasons of space, such list cannot be exhaustive and that more detailed insight of specific issues might be found consulting the cited literature and referring to other sources.

Even if some of the contents here introduced represent established results for industries like offshore oil and gas and wind energy, due to the early stage of development of marine energy technologies, it is likely that some of this information could prove to be in the future outdated or not useful for further development as well as upcoming evolutions of the marine energy sector could suggest similarities with different technologies from the ones covered by this report.

For such reasons, the information contained in this report could be subject to rapid modification and reviews and updates might be provided in the future in conjunction with partners and outside stakeholders.

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1. INTRODUCTION

1.1 THE CHALLENGES OF MARINE ENERGY

Marine energy technology has recently come to a pre-commercial phase with several projects going under nearly full-scale deployment.

The number of developers and private or public entities involved in this field is continuously growing and a list of all the ongoing projects and devices being developed at the moment would be long and necessarily incomplete. A global overview of the current research and deployment marine energy activities in 24 countries can be found in the 2007 annual report issued by the International Energy Agency – Implementing Agreement on Ocean Energy Systems ([1]).

Even though many encouraging results have been obtained in the recent years with remarkable engineering solutions, several design choices are yet questioned and many important aspects, such as environmental impacts, life cycles and reliability, are often underestimated despite their crucial importance in established technologies.

Even today few prototypes have already undergone the real sea testing phase and therefore the available experience in this specific field can be too scarce and fragmentary to provide a complete set of guidelines and recommendations.

In many cases, however, marine energy developers have successfully applied recommendations and standard coming from other sectors and proved that the definition of standard rules in marine energy should take into account all the previous normative experience in similar business sectors that have come to a consistent level of maturity after years. This is particularly true for offshore oil and gas extraction and wind energy industry, which share with marine energy in some issues almost the same requirements.

The observation of the experience in these fields can help to define strategies to overcome some important challenges that still need efforts. However it is important that techniques used in the oil and gas industry are applied appropriately, given the different market in which they operate. A key engineering issue is that such guidelines should not be applied blindly, without consideration of particular engineering needs of the marine renewable device and its operational requirements.

One key aspect is, for example, the reliability guaranteed by the devices, not only in terms of the additional costs and risks for the environment produced by failures but also of the effect that a non continuous production of electricity may generate on the whole investment. The cost-effectiveness of the design and the chosen components is also another critical issue that could benefit from the application of standard procedures defined for other technologies.

Concern for the environmental impact of marine energy devices is also becoming greater as the installation of full-scale prototypes and wave farms becoming a real possibility. In this case reference must be made to several existing laws and recommendations since marine environment is very sensitive to human activity effects.

Other important unsolved issues regard grid connection and power quality. The random nature of renewable sources could create problems as it was seen for the case of the wind energy, determining, for example, power peaks in moments of low energy consumption. The existing regulations for wind energy could provide with a preliminary guideline for marine energy in this field and indications on the measurement of the electrical output power.

Other aspects concerning design and modelling, including estimation of the loads and fatigue analysis, have been subject of intensive research. Marine energy has already often made use of several concepts and techniques coming from other fields of application. Existing standards for these cases can provide with a consistent basis for future development.

1.2 THE SIMILARITIES TO OTHER SECTORS

As a type of renewable energy, marine energy shares many requirements and practical needs with other kind of energy-generating technologies.

The principal sector that is often compared and taken as a business model for ocean wave and tidal energy is the wind energy industry.

The similarities between the two fields are mostly due to the random nature of the energy source and the similar market conditions. A feed-in tariff system, for example, has been proposed in several countries to favour the development of marine energy technologies following the example of the application of such policies for the wind energy industry.

Although currently operating at different scales of production, wind energy experiences a similar variability of the energy input and the issues in marine energy generation related to electrical power production and feeding into the grid could be addressed considering the strategies applied in wind industry.

Marine energy technologies in some cases make also use of power take-off components and machines that had proven to be successful when applied to other energy generating technology. Examples of this kind can be hydraulic turbines normally utilised in hydroelectric industry or the direct driven conversion system based on permanent magnets generators previously conceived for wind turbines.

Other typical industry sectors that present many similarities are other kind of marine technologies like offshore structures for oil and gas extraction, ships and coastal structures like breakwaters. The principal factor of analogy is in this case the environment that determines similar loads and similar requirements for construction and design. The assessment of marine energy device is actually already largely based on theories and results developed for standard offshore and in-shore applications.

Moreover, the selection of the components and the problems related to the reliability and the safety of the machines are basically very similar. Main differences in application of such procedures are due to different safety and risk management requirements that require careful evaluation and reflection in the utilisation of offshore engineering standards in the design and production of marine energy converters.

These sectors can also be considered practically equivalent in many cases in terms of environmental impact assessment techniques and procedures. Consistent guidance from these fields can be applied to marine energy.

1.3 THE EQUIMAR PROJECT

The EquiMar project is funded by the European Commission as part of its 7th Framework programme under the Energy topic. It is a collaborative research and development project involving a consortium of 23 partners and will run for three years from the 15th of April 2008. A list of the partners involved is given below:

1. **The University of Edinburgh (UEDIN)**, United Kingdom
2. **Fundación Robotiker (TECNALIA-RBTK)**, Spain
3. **University of Strathclyde (UOS)**, United Kingdom
4. **Electricité de France SA (EDF SA)**, France
5. **EU Ocean Energy Association (EUOEA)**, Belgium
6. **University of Exeter (UNEXE)** United Kingdom
7. **University College Cork (UCC)**, Ireland
8. **Wave Energy Centre (WAVEC),** Portugal
9. **The University of Manchester (UniMAN),** United Kingdom
10. **Southampton University (SOTON),** United Kingdom
11. **Institut Français de recherche pour l'exploitation de la mer (IFREMER),** France
12. **Consiglio nazionale delle ricerche: Istituto di Scienze Marine (CNR-ISMAR),** Italy
13. **Det Norske Veritas (DNV),** Norway
14. **Teamwork Technology (TT),** The Netherlands
15. **Pelamis Wave Power Ltd (PWP),** United Kingdom
16. **European Marine Energy Centre (EMEC)** United Kingdom
17. **Wave Dragon (WD),** Denmark
18. **Uppsala University (UU),** Sweden
19. **Sea Mammal Research Unit (USTAN),** United Kingdom
20. **Scottish Association of Marine Sciences (SAMS),** United Kingdom
21. **Feisty Productions Ltd (FPL),** United Kingdom
22. **Aalborg University (AAU),** Denmark
23. **Actimar (ACTIMAR),** France

The aim of EquiMar is to deliver a suite of protocols for the equitable evaluation of marine energy converters (based on either tidal or wave energy). These protocols will harmonise testing and evaluation procedures across the wide variety of devices presently available with the aim of accelerating adoption through technology matching and improved understanding of the environmental and economic impacts associated with the deployment of arrays of devices. EquiMar will assess devices through a suite of protocols covering site selection, device engineering design, the scaling up of designs, the deployment of arrays of devices, the environmental impact, in terms of both biological & coastal processes, and economic issues. A series of protocols will be developed through a robust, auditable process and disseminated to the wider community. Results from the EquiMar project will establish a sound base for future marine energy standards.

The activity within the project is structured through the definition of ten different Work Packages (including the project management), each one covering a specific part of the project with specific objectives. Six of them (WP2, WP3, WP4, WP5, WP6 and WP7) are mainly focused on technical issues, WP1 is intended to build a knowledge base for marine energy systems, WP8 will deal with the synthesis of the protocols and the organization of the documentation while WP9 will focus on dissemination of the project activity through the wider community. Finally WP10 will include all the coordination and management issues.

A scheme of the structure of the project is given in figure 1.1.

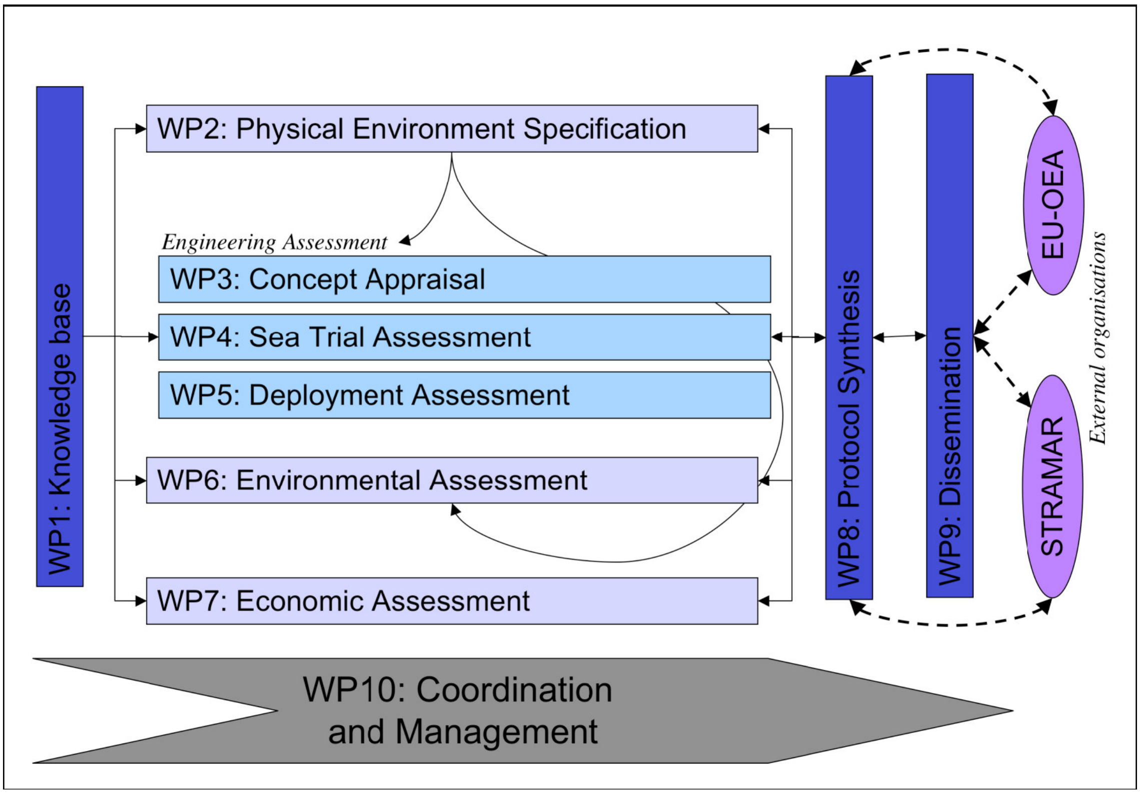

Figure 1.1 EquiMar project work package structure.

1.4 WORK PACKAGE 1 – KNOWLEDGE BASE FOR MARINE ENERGY SYSTEMS

The work package 1 ("Knowledge base for marine energy systems"), led by ROBOTIKER-Tecnalia, aims to build a knowledge base for marine energy systems with respect to all the areas covered by EquiMar project. Through the analysis of the relevant pre-existing information in the sector of marine energy and other similar industries it will provide important guidelines for other technical Work Packages. It will be also important to collect impressions and needs directly from the stakeholders that will address the future work.

The objectives of this Work Package can be summarised into three main tasks:

-**Task 1.1** - To analyse results from previous National, European and International activities in the field of pre-normative research for marine energy. A global analysis report will be the outcome of this task: "Global analysis of pre-normative research activities for marine energy".

-**Task 1.2** - To identify lessons learnt from other sectors, which can be applied to produce harmonised testing and assessment of marine energy extraction devices. This task will produce the report: "Recommendations from other sectors"

-**Task 1.3** - To understand and take account of explicit stakeholders' needs and practical constraints for matching different system designs to various marine environments. For that purpose a consultation to key stakeholders will be carried out. Different actors and interested parties in marine energy, such as developers, investors, certification bodies, power distributors and policy makers, will be invited to contribute with a questionnaire to determine needs and constraints.

This report constitutes the principal result of the second task. Standards, recommendations, protocols from different mature industrial sectors were collected and classified depending on the specific field of contribution. The main criterion for the selection of this material was the similarity to the requirements and needs of marine energy with the conviction that many technical and non-technical issues could be addressed following procedures defined for other technologies.

The principal sectors that were considered to be significantly similar to marine energy are offshore oil and gas extraction and wind energy. Some good background information can be provided also by normative activities in coastal structures and other fields related to the ocean, like exploitation of marine resources. Within energy generation sectors, hydropower could share some issues with marine energy, for example on what refers to the selection of the components.

Since marine energy technologies are very often innovative concepts that involve specific designs and verifications, the application of common standards from other field is not straightforward. Even though the documents here presented are rather general and attempt to address to a number of applications as large as possible, it is likely that several recommendations need to be reviewed in consideration of the specific conditions and requirements imposed by marine energy devices.

This work has been primarily intended to collect and sort only standards and international protocols. Since knowledge and practices for the considered fields are relatively established, the recursion to research and scientific papers was limited to few specific cases.

This report is intended to provide an important input to the other Work Packages of the project and possibly to other stakeholders not directly involved in EquiMar even if it is not aimed to the presentation of any original result nor innovative technology. All the information contained in this document was obtained through a preliminary compiling and comparing activity therefore the reader interested in acquiring deeper understanding of any particular subject outlined in this report is advised to consult the cited references.

1.5 STRUCTURE OF THE REPORT.

In order to ease the readiness and the comprehension, this report has been subdivided in different sections, which focus on different technical subjects.

Marine energy is a largely multidisciplinary field where competences and knowledge from several different research areas are needed. The choice of dividing the collected information in different subsections, depending on their content, is due, therefore, to allow experts from different areas to easily find information relevant to their own field.

Environmental conditions specification

In this chapter a general list of documents including standard, recommendations and guidelines on the estimation and specification of the environmental conditions will be presented.

Much of the standard procedures for wave and current loads calculation can be found in offshore engineering literature, standards and norms often provided by certification bodies. This includes indications on how to model mathematically waves, currents, wind and other environmental phenomena that influence the design of the device.

It should re-emphasised that although the offshore and marine industry can provide much of the basis for technical design, certification, deployment and operation, we should always be careful not to impose wholesale the needs of the oil and gas industry to wave and tidal generation devices. For example the marine energy industry need different models to take into account energy absorption, several of these methodologies are likely to be useful as starting point and preliminary assessment.

Structural design and material selection

This section outlines a comprehensive list of references mainly concerning the structural design of offshore and coastal structures and the definition and estimation of the critical loads. These standards often include also recommendations on the safety factors and the computational techniques to be utilised depending on the application and the design requirements. The selection of the proper material for each part of the final assembly is also subject of purposely developed standards.

Since the majority of the marine energy converters are indeed to be deployed in the same environment as offshore platforms or coastal structures like breakwaters, it is likely that many of these standards are applicable to their case. Again these standards should not be seen as a block to innovative solution in terms of design, materials and operations. Besides, although the same techniques and assessment methodologies might be successfully applied, it should be stressed once more that experience from offshore industry sector should be taken with extreme care when considering its application to marine energy devices.

Components, instrumentation and control systems

The deployment and operation of most of the marine technologies require a certain number of additional components and monitoring equipment, including instrumentation and control systems. There exist already guidelines and proper standards that address the requirement that electrical and mechanical equipment as well as monitoring and control tools have to satisfy to be successfully utilised.

Due to their different function, that is generating energy, marine energy devices may adopt, depending on their concept, particular components for power take-off. Even though some of these concepts make use of commercial components, likely to be treated in offshore engineering standard publications, these could imply different requirements from the ones considered in these documents. In some other cases, such as for moorings and foundations, the search for a good power performance may impose additional constraints. It is believed, however, that these existing standards could be successfully applied to several other cases, particularly when the concern is more focused on the cost and reliability of the component.

Reliability and safety requirements

Marine energy devices are supposed to operate in a harsh environment with high probabilities of unpredictable extreme conditions. A key issue that needs to be addressed for their development is the proof of a satisfactory reliability that assures the return of the investment. Moreover, although they are generally unmanned for most of their lifetime, safety has to be certified for maintenance interventions that require human contribution. A key aspect is that the available data on component properties (particularly failure rates) might not be accurate for the wave or tidal devices as they are deployed in unusual ways or under different duty cycles.

Certification and qualification procedures established for offshore technologies can provide a good frame for the development of the same recommendations for marine energy even though it has to be pointed out that the requirements might be less restrictive for the latter.

Measurements for assessment, grid connection and power quality requirements

The power output of a marine energy device needs to be carefully measured not only to assess its performance but also to provide reliable and comprehensible parameters on its production to other stakeholders of the energy market. The definition of standards for measurements is fundamental for the verification of a device and the correct management of the generated power.

Research in wind energy has produced some recommendations and one standard on this subject. A similar research effort is being carried out for marine energy and some of the procedures commonly applied in wind energy are being taken into account within the definition of performance assessment standards for wave and tidal energy devices.

Most of the marine energy devices are likely to feed directly into the grid the electrical power they produce through various intermediate power electronics equipment and components. The feeding of electrical power is usually related to a series of requirements on the quality of the power itself, meaning that the amplitude and frequency of the output voltage must be kept within defined ranges.

These problems involve also the design and selection of specific electrical equipment as well as properly designed grid connectors.

Wind energy has produced standards and guidelines in this field. Due to the similarities between offshore wind turbines and marine energy devices in terms of electrical requirements, most of this information could prove to be useful for wave and tidal devices.

Environmental impact requirements

Sectors such as aquaculture, offshore wind energy and oil and gas industry, which have wide experience on the maritime environment, have acquired valuable knowledge of the impacts that their activities have on the marine environment and the biological species.

Research in these different areas has produced some documents regarding standards and recommendations for the account of environmental effect of the installation of such technologies that, in some cases, may be particularly useful for marine energy applications.

1.6 LIST OF THE REFERENCES.

[1] IEA-OES, International Energy Agency – Implementing Agreement on Ocean Energy Systems – Annual Report 2007 – 2007, available at: http://www.iea-oceans.org/_fich/6/IEA-OES_Annual_Report_2007.pdf

2. ENVIRONMENTAL CONDITIONS SPECIFICATION.

2.1 INTRODUCTION

The specification of environmental conditions is the first fundamental step needed for the design of a marine structure. Waves, currents and wind effects have to be carefully modelled because of their influence on the structure behaviour.

The literature that can be found on this subject is quite vast and it focuses mainly on techniques for the estimation of the loads derived by these combined natural phenomena. The values of these loads constitute the primary base for the design of the devices. A large part of the standards is therefore usually devoted to the definition of proper extreme maximum conditions and maximum operational conditions.

This means that part of the design process consists in defining a limited set of environmental parameters for design validation and verification.

This approach could be consistently different from what is required in marine energy technology, where the environmental loads defined above, especially if originated by waves or currents, are also functional to the production of electrical power and their detailed estimation and knowledge is therefore needed for every kind of performance assessment or application of control system to optimise production.

Existing standards on offshore structures and ships provide designers with wave and current models which are widely spread as well among wave and tidal energy developers. Moreover the design of the structure and other components such as foundations and moorings in marine energy devices could be performed in some cases using these techniques since their reliability requirements are for these issues quite similar to the ones imposed by offshore industry.

2.2 ENVIRONMENTAL DATA.

Table 1 Standards on physical environmental data description

	Year	Description
DNV-RP-C205	2007	Recommended practices for environmental conditions representation
DNV-OS-J101	2007	Standard for offshore turbines. Recommendations on wave modelling
API RP 2A	2000	Design of fixed offshore platforms: Indications on waves and current representation
API RP 2T	1997	Tension Leg Platforms: Indications on waves and current representation. Wind spectrum description
ISO 19901-1	2005	Requirements for offshore structures. Recommendations on use of oceanographic data
ISO 21650	2007	Determination of wave and current actions on coastal structures

Models leading to the design responses of interest should consider the jointly distributed environmental phenomena. Environmental data, such as wind, wave, current and tide, have site-specific relationships governing their interaction. When collecting data, various relationships should be included. Of particular importance are the wind/wave, wave height/period, and wave/current relationships and their relative directions. The directions of various environmental phenomena could be especially important. The effects of these interactions could be different for the ocean energy industry because of the different scales (of vessel) and expected response.

A general reference for mathematical modeling and treatment of sea environment is represented by Faltinsen’s book ([1]). Water wave effects have been extensively treated by Sarpkaya and Isaacson ([2]).

Det Norske Veritas (DNV) has issued several publications concerning the design of offshore structures that included also guidelines on wave, wind and current modeling.

Recommended Practices ([3]) have been specifically devoted to this subject and give practical examples of design solutions, calculation methods, specifications of test procedures. DNV also published another document ([4]) specifically directed to wave energy conversion, that includes references to many existing protocols and provide interpretation and guidance on the application of existing codes and standards. Concerning wave modelling reference is made to a standard produced for offshore wind turbines

([5]). It is suggested to use a JONSWAP spectrum for the representation of sea elevation processes characterized by wind-sea while applying double-peak spectra to take swell into account.

The American Petroleum Institute (API) has produced standards that give indications on environment modelling. The main indications can be found in API RP 2A [6], which deal with the design of fixed offshore platforms and API RP 2T [7], whose subject is the design of Tension Leg Platforms. API has also developed a wind spectrum to take into account variability of wind loads on offshore structures, although wind is often considered constant in direction and speed in many design procedures.

General requirements for the determination and use of meteorological and oceanographic (metocean) conditions for the design, construction and operation of offshore structures of all types used in the petroleum and natural gas industries can be found also in ISO 19901-1 ([8]).

The modeling of environmental interactions is very similar for offshore and nearshore locations with existing procedures to take into account the depth variation as it is outlined in the references previously cited. For the case of inshore and coastal installations, however, some additional factors could have to be included, particularly when the steepness of the waves is of concern because of overtopping phenomena.

ISO 21650:2007 ([9]) describes the principles of determining the wave and current actions on structures like breakwaters in the coastal zone and estuaries. Another good reference that provides designers with an extensive mathematical treatment of nearshore waves and sediment phenomena is the Coastal Engineering Manual ([10]).

Guidelines and techniques for predicting the mean overtopping discharge, and the consequent flood volumes and drainage requirements, for a range of seawall types are given in the Overtopping Manual ([11]). The analysis of environmental parameters that affect this phenomenon is particularly fit for inshore wave energy devices based on overtopping principles.

2.3 ENVIRONMENTAL LOADS EVALUATIONS.

Table 2 Standards on environmental loads evaluation

	Year	Description
API RP 2T	2007	Criteria for loads evaluation and distinction
DNV OS-C101	2007	Guideline to the ULS sea-states method for structural design

Following API RP 2T ([7]), environmental loads can be categorized according to the following three distinct frequency bands:

- Steady loads such as wind, current, and wave drift forces are constant in magnitude and direction for the duration of interest.
- Low frequency cyclic loads that excite the platform at its natural periods in surge, sway, and yaw. Typical natural periods range from 1 to 10 minutes.
- Wave frequency cyclic loads with typical periods ranging from 5 to 30 seconds. Wave frequency cyclic loads result in wave frequency motions.

The cited reference provides criteria for determining appropriate parameters for the estimation of these loads.

The DNV OS-C101 Standard ([12]) suggests using ULS (Ultimate Limit States) sea-states for testing the structural design applying a combination of environmental loads correspondent to a specified level of probability of occurrence. Guidelines for the choice of these probabilities are summarised in a table.

When considering near-shore and shoreline devices, wave loads from breaking waves shall be considered in the design of the structure. For these specific cases, indications are shown in [10] and [11].

2.4 LIST OF REFERENCES.

[1] Faltinsen O.M. – *Sea Loads on Ships and Offshore Structures* – 1993, Cambridge University Press.

[2] Sarpkaya T. and Isaacson M. – *Mechanics of Wave Forces on Offshore Structures* – 1981, Van Nostrand, Reinhold Company, New York.

[3] Det Norske Veritas – *DNV-RP-C205 Environmental Conditions and Environmental Loads* – 2007, available at: http://webshop.dnv.com/global/category.asp?c0=2624

[4] DNV for Carbon Trust – *Guidelines on design and operation of wave energy converters* – 2005, available at: http://www.dnv.no/Binaries/WECguideline_tcm28-181675.pdf

[5] Det Norske Veritas – *DNV-OS-J101 Design of Offshore Wind Turbine Structures* – 2007, available at: http://webshop.dnv.com/global/category.asp?c0=2624

[6] American Petroleum Institute - *RP 2A-WSD Planning Designing and Constructing Fixed Offshore Platforms-Working Stress Design*, 2000, available at:

http://global.ihs.com/standards.cfm?currency_code=USD&customer_id=21254F2C2B0A&shopping_cart_id=2824583F2D4A502040595D202F0A&rid=API1&country_code=US&lang_code=ENGL&input_doc_number=&input_doc_title=&selected_org=API

[7] American Petroleum Institute - *RP 2T Planning, Designing, and Constructing Tension Leg Platforms-Working Stress Design*, 1997, available at:

http://global.ihs.com/standards.cfm?currency_code=USD&customer_id=21254F2C2B0A&shopping_cart_id=2824583F2D4A502040595D202F0A&rid=API1&country_code=US&lang_code=ENGL&input_doc_number=&input_doc_title=&selected_org=API

[8] International Organization for Standardization – *ISO 19901-1 Specific requirements for offshore structures – Part 1: Metocean design and operating considerations* – 2005, available at:

http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=34586

[9] International Organization for Standardization – *ISO 21650:2007 Action from waves and currents on coastal structures* – 2007, available at:

http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=35955

[10] US Army Corps of Engineers – *Coastal Engineering Manual* – 2006, available at: http://chl.erdc.usace.army.mil/cemtoc

[11] EurOtop Team – *Wave Overtopping of Sea Defences and Related Structures: Assessment Manual* – 2007, available at: http://www.overtopping-manual.com/

[12] Det Norske Veritas – *DNV-OS-C101 Design of Offshore Steel Structures using LRFD method* – 2007, available at:

http://webshop.dnv.com/global/category.asp?c0=2624

3. STRUCTURAL DESIGN AND MATERIAL SELECTION.

3.1 INTRODUCTION.

Marine energy devices are to be deployed in real sea and kept operational for a time of the order of decades. Throughout their life they are supposed to be subjected to various loads and solicitations, very often originated by the environmental conditions summarised in the previous chapter.

When these devices evolve from early-stage concepts to large-scale prototypes, it is clear that their design have to include a proper verification of the structural solidity and cost-efficiency. This includes an adequate choice of the material to be used for the construction as well as a detailed analysis of the possible effects of the structural tensions and deformations on the device performance.

There exist many standards, recommendations and guidelines regarding structural analysis and design of offshore structures. These documents include also specific guidelines for materials and fatigue analysis. Different considerations might arise whether the device to be considered is a floating or fixed structure but these approaches are likely to be applicable to marine energy devices.

3.2 STRUCTURAL DESIGN METHODOLOGIES.

Table 3 Standards on structural design

	Year	Description
DNV OS-C101	2007	Design of offshore steel structures with LRFD method
DNV OS-C502	2007	Design of offshore concrete structures
DNV OS-C501	2003	Standards for composite components
DNV RP C203	2003	Recommendations on fatigue analysis
API RP 2A WSD	2007	Practices for design of fixed offshore structures (WSD method)
API RP 2A LFRD	2003	Practices for design of fixed offshore structures (LFRD method)
ISO 19900	2002	General requirements for offshore structures (not specific as the aforementioned documents)
API RP 2RD	2006	Focused on risers but containing general information on offshore platform design
DNV OS-C102	2007	Design of offshore ships
BS 6349-7	1991	Guide to design of breakwaters
IEC 61400-3	2009	Design requirements of offshore wind turbines
IEC 61400-1	2005	Design Requirements for wind turbines in general (onshore)
Germanischer Lloyd	2005	Guideline for the certification of offshore wind turbines
DNV OS-J101	2008	Design of offshore wind turbine structures

A number of DNV standards are dedicated to structural design methodologies of offshore structures. The DNV "Guidelines on design and operation of wave energy converters" ([1]) reviews the contents of these, and addresses them to the case of the wave energy converters.

Distinction is to be made, for instance, between steel structures ([2]), concrete structures ([3]) and composite structures ([4]). DNV OS-C101 ([2]) is the general part of the DNV offshore standards for structures. The design principles and overall requirements are defined in this standard and can be applied to the other cases. The approach followed in the design process is the so-called LRFD (Load and Resistance Factor Design) method where uncertainties in loads are represented with a load factor and uncertainties in the resistance are represented with a material factor. A table of load factors recommended for different combinations is given for the extreme case of Ultimate Limit State (ULS), corresponding to the maximum load carrying resistance. Accidental Limit State (ALS) loads, related to abnormal operations or technical failure, should also be included in the analysis.

DNV Guidelines includes also an appendix on fatigue analysis methodology that recalls the Recommended Practice DNV RP-C203 ([5]). The fatigue analysis should be based on S-N data, i.e. graphical presentation of the dependence of fatigue life (N) on fatigue strength (S), determined by fatigue testing of the considered detail, and the linear damage hypothesis. When appropriate, the fatigue analysis may alternatively be based on fracture mechanics.

Alternative standards for offshore structures useful as references are represented by API RP 2A ([6] or [7]), ISO 19900:2002 ([8]) and API RP 2RD ([9]). DNV OS-C102 ([10]) provides an internationally acceptable standard for design of ship-shaped offshore structures.

Further, the following organisations have contributed with relevant publications and meetings to pre-normative work in this sector: ISOPE (ISOPE (International Society of Offshore and Polar Engineers; www.isope.org),, ASME – Ocean, Offshore and Arctic Engineering (American Society of Mechanical Engineers; www.ooae.org) and the International Navigation Association (PIANC/AIPCN; www.pianc-aipcn.org).

The latter also published a number of guidelines for coastal structure design. The structural design of wave-absorbing coastal structures has been highlighted as a somewhat problematic field, as common applicable design methods are normally based on heavy monolithic structures (vertical breakwaters). However for example an OWC caisson (e.g. Mutriku; Foz do Douro) or an overtopping caisson (e.g. WaveSSG) would require largely hollow caissons, posing some challenge both to local (front wall integrity) and global stability (sliding and overturning), due to breaking wave impact loads.

Further good reference for breakwater design is provided by BS 6349-7 ([11]) while the Coastal Engineering Manual ([12]) presents an extensive analysis of the methodologies to be used for loads estimation and design of coastal structures, including examples of calculation. Also the Spanish recommendations on maritime structure design (R.O.M. 0.0 and follow-ups) contain comprehensive guidance relevant to coastal wave energy concepts.

Up to the last decade, also PARI (Port and Airpot Research Institute – former PHRI), released widely accepted reference documents for coastal structure design, whose applicability and up-to-dateness however are limited for the present purpose.

Within international collaboration on this aspect and starting from the European MAST-PROVERBS project (1996-1999), the design of breakwater structures based on probabilistic methods has gained importance in Europe and overseas. Such methods would have to be revised in the case of wave energy integration in coastal structures, because the loss in case of failure would be higher and more complex.

Recent efforts from certification bodies have also been drawn to another growing renewable: the offshore wind industry. API RP-2A ([6]) is specifically applicable to the design of offshore oil and gas platform and, as such, does not include provisions that have been development specifically for Offshore Wind Turbines support structures.

IEC 61400-3 ([13]) specifies the requirements for the definition of site conditions and, together with IEC 61400-1 ([14]), provides essential design requirements for offshore wind turbines. The guideline is intended to provide an appropriate level of protection against damage from all hazards during the planned lifetime of the structure and focuses on the engineering integrity of the structural integrity of the structural components of an offshore wind turbine but also provides requirements for subsystems such as control and protections mechanisms, internal electrical systems and mechanical systems.

The Germanischer Lloyd Wind Guideline for the Certification of Offshore Wind Turbines ([15]) provides a specification of requirements for the entire wind turbine design process and includes a clarification of certification extent, loads, materials, structures, machinery and other kind of components. It is interesting to note that material safety factors are here specified depending on the material, differently from the general factors as found in the IEC standard.

DNV-OS-J101 ([16]) is intended to be used for the design of support structures and foundations for offshore wind turbines and may be used as a stand-alone document or in conjunction with other standards. It does not cover design of additional components.

An important distinction between offshore wind turbines and offshore structures that emerges from the analysis of the cited documents is the fatigue demand. For example, purposely built documents for offshore wind took into account cyclic wind loading while typical standards conceived for petroleum and gas application consider only wave induced cyclic loads for fatigue analysis. For wave and tidal converters, for example, some differences in the estimation in the fatigue cycles might occur because of the different dynamic behaviour of such structures and the example of wind industry in identifying independent methodologies might be beneficial.

Other important issues connected with structural design are the definition of the return period for the environmental conditions such as wind, wave and current. While API RP-2A and ISO 19900 specify return periods of 100 years, IEC 61400-3, GL-GCOWT and DNV-OS-J101 all indicate a 50 years return period of external conditions for ultimate load cases. These parameters are clearly related to the expected service life of the device and to the required safety levels. It might be questioned whether proper criteria and definitions will have to be determined for marine energy converters as well.

3.3 MATERIALS.

Table 4 Standards on material selection

	Year	Description
DNV OS-B101	2001	Standard on metallic materials for offshore structures
DNV OS-C201	2008	Structural design of offshore units. Gives guidance for steel selection
DNV OS-C502	2007	Design of offshore concrete structures
DNV OS-C502	2003	Standards for composite components

Materials commonly used for marine technologies are steel, concrete and composites.

The offshore standard DNV OS-B101 ([17]) provides principles, technical requirements and guidance for metallic materials to be used in the fabrication of offshore structures and facilities, and could be also relevant for marine energy devices. Selection of steel is given in DNV OS-C201 ([18]) Section 4, based on design temperature (normally based on lowest daily mean temperature), structural categories and plate thickness.

Requirements to material properties, composition, extent of testing, inspection of concrete parts are given in Section 3 of DNV OS-C502 ([3]). Composite components are treated in DNV OS-C501 ([4]). In these references, recommendations on protection against corrosion are also given.

3.4 FABRICATION AND MANUFACTURING.

Table 5 Standards on fabrication and manufacturing procedures

	Year	Description
DNV OS-C401	2007	Guidelines for fabrication and testing of offshore structures

The requirements for fabrication and testing of marine energy devices are, in general, in line with the requirements for offshore installations. However, special considerations should be implemented considering the access to structure and equipment during the in-service life, the planned maintenance regime and required reliability of the device.

The DNV OS-C401 ([19]) standard contains guidelines for fabrication and testing of offshore structures with information on welding procedures, required tolerances, testing practices and corrosion protection systems.

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4. COMPONENTS, INSTRUMENTATION AND CONTROL SYSTEMS.

4.1 INTRODUCTION.

The operation of marine energy converters requires the design and selection of a large number of components assigned to different specific functions. Floating marine energy devices need to maintain their position with a mooring and anchoring system. Fixed devices need instead an appropriate definition of the foundations.

The Power Take-Off equipment jointly with a control system will include several mechanical and electrical components including umbilical cables and connectors while monitoring of the operational conditions will also imply the use of a proper instrumentation system.

There are a variety of design choices that can determine the kind of components required for one system compared to another one. However it is likely that many of such elements, at least in the first years of development, are commercial standard components.

For most of the equipment utilised on marine energy devices, there exist specified standards and guidelines for the usage. It is possible that, being the requirements imposed by marine energy consistently different from the ones of the offshore industry, some of the recommendations outlined in the existing standards will have to be modified and it is expected that in the future specified guidelines for marine energy converter components will be defined.

4.2 MOORING SYSTEMS AND FOUNDATIONS.

Table 6 Standards and guidelines on mooring and foundations design

	Year	Description
DNV OS-C101	2007	Design of pile foundations
API RP 2A LFRD	2003	Design of offshore fixed structures
BSH Standard for Geotechnical and Route Surveys	2003	Focused on offshore wind turbines. Specifies methods and criteria for foundation site surveys
DNV CN-30.4	1992	Classification note on different types of foundations
DNV OS-E301	2004	Guidelines on design and construction of position mooring systems
API RP 2SK	2005	Extensive standard on design of moorings and criteria for analysis of floating structures
ISO 19900	2002	General requirements for offshore structures. It includes recommendations on moorings and foundations
DNV RP E301	2000	Recommendations on fluke anchors
DNV RP E302	2002	Recommendations on drag-in plate anchors
DNV RP E303	2005	Recommendations on suction anchors

All the marine technologies installed at the sea need, during short amount of time or their whole service life, a supporting structure to keep fixed within a specified range their position.

Among the different marine energy technologies, distinction can be made between floating and fixed devices. The position of the fixed devices is generally maintained the same in all the three co-ordinates while floating devices usually need to keep their position at the sea surface within a prescribed range, or excursion on the horizontal plane, whilst allowing a certain degree of compliance in the vertical direction.

Fixed devices that are to be installed onshore have very different requirements from offshore and the design of their foundations is strictly related to their proper structural design. In this case normal civil engineering practices are followed and reference should be made to existing recommendations for coastal structures that were outlined in the previous sections.

Other kind of fixed devices may be installed at open-sea locations at relatively moderate depths (20~35 meters). For these cases pile foundations are usually utilised. Section 11-C of DNV OS-C101 Standard ([1]) is focused on the design of pile foundations and provides a guideline of the design process and recommendation on the adequate safety factors. Another reference for fixed structures is the API RP 2A ([2]). The design of foundations shall consider both the strength and deformations of the foundation structure and of the foundation soils. To this aim a geotechnical survey is often required. Due to the similar requirements reference could be made also to existing experience on offshore wind turbines. The Bundesamt für Seeschifffarht und Hydrographie (BSH) has issued a standard ([3]) for geotechnical site and route surveys for foundations of offshore wind turbines. For a deeper insight of the different types of foundations, DNV has issued also a classification note ([4]).

Floating marine energy devices resemble more the case of offshore floating platform and usually require specifically designed mooring systems that should be capable in some cases to allow the floater to change its orientation. For these applications a widespread solution is the design of a catenary mooring. DNV OS-E301 ([5]) contains criteria, technical requirements and guidelines on design and construction of position mooring systems. A suggestion for the load and safety factors to be utilized is also given. Other relevant references are API RP 2SK ([6]) and ISO 19900:2002 ([7]).

A mooring system implies also the usage of anchors. DNV has issued recommendation practices for fluke, drag-in plate and suction anchors ([8], [9] and [10]).

It should be noticed that moorings are an essential component of floating offshore wave and tidal energy devices and might have in many cases a non-negligible influence on the power absorption. Such an interaction could constitute a reasonable argument for defining independent design criteria for moorings of marine energy converters and might lead to radically different solutions from the ones normally applied to oil and gas extraction. Applicability of typical standard for foundations for the case of fixed devices could be perhaps more appropriate because of the similar requirements shared by marine energy devices and offshore platforms but care should be taken here as well particularly when trying to determine correct safety factors.

4.3 MECHANICAL EQUIPMENT.

Table 7 Standards on mechanical equipment design and selection

	Year	Description
DNV OS-D101	2007	Standard on selection and design of marine and machinery equipment
API STD 674	1995	Recommendations on selection of positive displacement pumps of the reciprocating type
API STD 675	1994	Recommendations on selection of positive displacement pumps of the controlled volume type
API STD 676	1994	Recommendations on selection of positive displacement pumps of the rotary type
API RP 14E	2000	Practices for piping system design
API RP 17B	2000	Recommendations specifically aimed at flexible pipes
DNV CN41.2	2003	Calculation procedures for gears design
ISO 6336	2006	Procedures for the evaluation of the loads on spur and helical gears
IEC 60545	1976	General guidance to selection and operation of hydraulic turbines

Different marine power converters may use a wide range of systems and components to convert the energy of the wave to electrical power. The number of the different elements that are required for operation is very large and for many cases there exist specific standard and recommendations directly provided by suppliers (for example the guide on bearings provided by SKF).

The DNV OS-D101 ([11]) standard provides principles, technical requirements and guidance for design, manufacturing and installation of marine and machinery systems and equipment for mobile offshore units and floating offshore installations. This document collects information on different components for piping and hydraulic systems such as valves, hoses, accumulators and pumps. For mechanical elements like gears and bearings a list of industrial standards is presented and commented.

API has published a large number of standards for hydraulic machinery like pumps ([12], [13] and [14]) or piping systems ([15] and [16]). Reference for gearboxes and gear transmission has also been addressed in DNV CN41.2 ([17]) and ISO general standard ([18]).

Some marine energy devices make use of hydraulic turbines for power production. A general reference for such machines has been issued by IEC ([19]) but specific indications on the different machine types are contained in several standards that can found at the IEC website. ASME has issued a Code ([20]) that defines procedures for field performance and acceptance testing of hydraulic turbines and pump-turbines operating with water in either the turbine or pump mode. This Code applies to all sizes and types of hydraulic turbines or pump-turbines.

4.4 ELECTRICAL EQUIPMENT.

Table 8 Standards on electrical equipment design and selection

	Year	Description
DNV OS-D201	2008	Electrical installations on offshore units
IEC 60034	2004	Rotating electrical machines
IEEE Std. 519	1992	Electro-magnetic compatibility
IEC 60092	1995	Electrical installations on ships

DNV OS-D201 ([21]) standard provides principles, technical requirements and guidance for design, manufacturing and installation of electrical installations on mobile offshore units and floating offshore installations.

Rotating Electrical machines could be designed in accordance with IEC 60034 ([22]) which covers both general requirements and specification of these machines.

The system should be designed to meet EMC (Electro Magnetic Compatibility) requirements as laid down in IEEE Std. 519 ([23]).

IEC has also produced a series of standards ([24]) focused on electrical installations on ships.

4.5 INSTRUMENTATION AND CONTROL SYSTEMS.

Table 9 Standards on instrumentation and control systems

	Year	Description
DNV OS-D202	2008	Requirements for automation and telecommunication systems
IEC 61000	2008	Electro-magnetic compatibility

Instrumentation and control systems are addressed in OS-D202 ([25]) that outlines general requirements to safety, automation, and telecommunication systems by defining minimum requirements for design, materials, fabrication, installation, testing, commissioning, operation, maintenance, re-qualification, and abandonment

Electrical and electronic equipment should be designed to function without degradation or malfunction in their intended electromagnetic environment. Reference is made in this case to IEC 61000 standards ([26]).

4.6 UMBILICAL AND CABLE CONNECTIONS.

Table 10 Standards on cable connections specifications

	Year	Description
API 17E	2003	Subsea umbilicals specification and design criteria
DNV OS-F201	2003	Guide to design of dynamic risers

The umbilical design, fabrication and operation are described in ISO 13628-5:2002. The same contents are also specified in the API 17E Specification ([27]), where information on testing and analysis is given

The guidelines given in DNV OS-F201 ([28]) could be applied for global load effect analysis also involving system modelling, non-linearities, analysis methodology and model verification.

The connection arrangements have to be in accordance with national standards for embedded generation.

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5. RELIABILITY AND SAFETY REQUIREMENTS.

5.1 INTRODUCTION

In the marine energy sector there is still a consistent lack of experience of real sea testing and operation. The few prototypes that have undergone open sea grid-connected experiments have run for a very limited amount of time, making often impossible to directly verify the reliability of the design.

Many of the components utilised in these devices are proved to be reliable in normal conditions but no information is available on the occurrences of failure in real sea environment and considered the side-effects that may appear because of energy extraction.

A preliminary investigation of the reliability of the device could be addressed using existing standards for offshore structures for which long-time experience is certified in several conditions. It is likely that new failure causes may arise from the different functional requirements and operation principles imposed by marine energy technologies but it is however evident that they share many common risks with offshore oil extraction devices.

Safety principles applied to offshore installations might as well be useful for ocean energy machines. In this case it should be noticed that the fact that the latter ones are usually unmanned may imply less restrictive requirements.

5.2 QUALIFICATION PROCESS

Table 11 Standards on qualification processes

	Year	Description
DNV RP-A203	2001	Recommendations on qualification process

Marine energy devices are developed using new or unproven technology or using well-established technology in a non-conventional way. In order to speed up the development process and improve the reliability of devices a qualification process should be applied. Reference can be made to DNV RP-A203 ([1]).

In the concept stage, when the knowledge of the technology is limited, the uncertainty regarding failures during the in-service life is large. The aim of the qualification process is to reduce the uncertainty to an acceptable level in order to determine the service life performance and cost.

5.3 FAILURE ANALYSIS AND RELIABILITY REQUIREMENTS.

Table 12 Standards on reliability and failure analysis

	Year	Description
ISO 14224	2006	Methodologies for collection of reliability and maintenance data including database on general failure modes
ISO 20815	2008	Guidelines on production assurance
IEC 60300-3	2004	Techniques for dependability analysis
ISO 2394	1998	Reliability of structures
ISO 15563	2000	Life cycle costing for offshore industry

A reliability analysis is usually preceded by a careful individuation and qualitative estimation of all the possible failure modes through the application of different techniques like Fault Tree Analysis (FTA), Failure Mode and Effect Analysis (FMEA).

There are several standards addressing issues related to reliability covering data collection, techniques for FMEA, fault tree analysis and life cycle costs.

ISO 14224:2006 ([2]) provides a comprehensive basis for the collection of reliability and maintenance data in a standard format for equipment in all facilities and operations within the petroleum, natural gas and petrochemical industries during the operational life cycle of equipment. It describes data-collection principles and associated terms and definitions that constitute a "reliability language" that can be useful for communicating operational experience. The failure modes defined can be used as a "reliability thesaurus" for various quantitative as well as qualitative applications. The standard also describes data quality control and assurance practices to provide guidance for the user.

ISO 20815:2008 ([3]) introduces the concept of production assurance within the systems and operations associated with exploration drilling, exploitation, processing and transport of petroleum, petrochemical and natural gas resources. It covers upstream (including subsea), midstream and downstream facilities and activities. It focuses on production assurance of oil and gas production, processing and associated activities and covers the analysis of reliability and maintenance of the components.

For standards on equipment reliability and maintenance performance in general, the IEC 60300-3 series ([4]) give a general overview of commonly used dependability analysis techniques. They describe the usual methodologies, their advantages and disadvantages, data input and other conditions for using various techniques and are intended to provide the necessary information for choosing the most appropriate analysis methods.

Reliability of structures is addressed in ISO 2394:1998 ([5]). Life cycle costing techniques are outlined in ISO 15563:2000 ([6]).

5.4 RISK ASSESSMENT AND SAFETY REQUIREMENTS.

Table 13 Standards on risk and safety assessment

	Year	Description
DNV OSS-121	2001	Risk assessment techniques
DNV OS-A101	2005	General safety principles for offshore units
API RP 14J	2000	Risk assessment of offshore structures
DNV OS-D301	2005	Fire protection on offshore installations

It is very important to use the information generated from failure mode identification to feed into the overall risk assessment. This is because the overall risk assessment normally aims at very high-level failure events and other external influences. The failure mode identification process is specific to the device and it is ideal to fill any gaps in the overall risk assessment.

Any significant offshore development will have to bear in mind the risk involved with the lifecycle risk of the development. A typical offshore development risk assessment would include events like mooring failure, instability, interference with other marine activities etc.

DNV OSS-121 ([7]) presents the DNV service specification for classification of offshore installations based on risk assessment techniques. DNV-OS A101 ([8]) provides general safety and arrangement principles for offshore units and installations and is applicable to overall safety and integrity aspects of all types of floating offshore units and fixed installations.

Another reference on risk assessment of offshore structures is represented by the API RP 14J ([9]). Additional documentation could be found on pressurized components.

Fire protection should be considered for protection of personnel during maintenance and inspection activities and protection of the device during in-service and maintenance. OS-D301 ([10]) provides the requirements for fire protection for offshore installations.

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6. MEASUREMENTS FOR ASSESSMENT, GRID CONNECTION AND POWER QUALITY REQUIREMENTS

6.1 INTRODUCTION.

Future implementation of marine energy at a large scale as a significant contribution to energy consumption will require the development of strategies for its successful integration within the energy market.

The power output of the devices will have to be previously estimated and subsequently measured with a reasonable accuracy while the connection to the grid will have to include systems for enhancing the quality of the produced power and reducing the voltage fluctuations due to the random nature of the source.

This will necessarily result in the definition of a set of standard parameter and procedures to evaluate measure and adapt the power performance of the machines.

Being characterised as well by a random energy source, wind energy has addressed this problem before and has produced a set of widely recognized standards. Some of the conclusions outlined by this work are relatively specific and likely not applicable to marine energy but can often provide guidelines and identify solutions for similar needs.

The example of the recent development of offshore wind farms can be particularly important for future wave and tidal energy installations. Grid connection infrastructure and power quality issues appear to be very similar for these sectors and many of the challenges faced by the initial offshore wind deployments are very likely to be shared by future marine energy farms. Besides, the growing integration of wind energy at a large scale into the market has been posing problems and alternative approaches for grid integrations that might occur as well in wave and tidal development at future large scales.

It is clear that any guideline for grid and electrical connection purposely defined for marine energy devices will have to be developed through an independent process that takes into account all the specificities of these technologies. Nevertheless offshore wind turbines installation and operation experiences should be studied and analysed carefully and possibly within a common frame because design improvements and cost-effective solutions might be applicable to all these sectors.

6.2 PERFORMANCE MEASUREMENTS.

Table 14 Standards on wind turbines performance measurements

	Year	**Description**
IEC 61400-12	2005	Procedures for power performance measuring

IEC 61400-12-1 ([1]) specifies a procedure for measuring the power performance characteristics of a single wind turbine and applies to the testing of wind turbines of all types and sizes connected to the electrical power network. In addition, this standard describes a procedure to be used to determine the power performance characteristics of small wind turbines when connected to either the electric power network or a battery bank. The procedure can be used for performance evaluation of specific turbines at specific locations, but equally the methodology can be used to make generic comparisons between different turbine models or different turbine settings. The wind turbine power performance characteristics are determined by the measured power curve and the estimated annual energy production (*AEP*). The measured power curve is determined by collecting simultaneous measurements of wind speed and power output at the test site for a period that is long enough to establish a statistically significant database over a range of wind speeds and under varying wind and atmospheric conditions. The *AEP* is calculated by applying the measured power curve to reference wind speed frequency distributions, assuming 100 % availability.

The standard describes a measurement methodology that requires the measured power curve and derived energy production figures to be supplemented by an assessment of uncertainty sources and their combined effects.

This document is indeed the result of an international research activity that was favoured by several project financed by the European Commission. The European Wind Turbines Standard project ([2]), for example, has addressed the issue of performance measurement in complex terrain with recommendations specifying methodologies and instrument at a detailed level.

This is nowadays quite an established procedure but it is interesting to notice the degree of specification for the measurements that involve the resource assessment (i.e. the velocity of the wind) for the definition of the power curve. Current standardisation groups on wave energy performance, such as the IEC TC 114 ([3]), are referring to the example of the wind energy industry but problems are arising from the large range of deployment sites and water depths for which the ensemble of the existing wave energy technologies is designed for. Early harmonisation of performance assessment indicators for marine energy devices will probably require less specification than that required by wind industry, especially when considering that winning typologies of device have not yet emerged.

Moreover the wind energy sector itself is still in continuous development and new research projects are already focusing at larger size turbines. The UpWind consortium ([4]) is carrying out work in performance assessment and has issued a list of measurement parameters with the objective of identifying the relevant parameters utilised by the wind energy community and improving the current methodologies with appropriate analysis of the uncertainties.

6.3 GRID CONNECTION AND POWER QUALITY.

Table 15 Standards on wind turbines power quality requirements

	Year	Description
DanskiEnergi	1998	Guidelines for connection to low and medium voltage of wind turbines
IEC 61400-21	2001	Standard on power quality requirements

The development of wind energy into a grown industry has been possible also through the analysis and solutions of the problems related to grid connection and power transmission. This example might be very useful for marine energy developers particularly with respect to the progressive increase of the scale of wind energy projects since a similar evolution could be expected for ocean energy technologies.

A very general summary of the technical issues related to grid connection of wind turbines is represented by a report issued within the 5th European Framework Programme ([5]) that includes general information about connection configurations and calculations methods for some quantities of interest in assessing the perturbations to the grid (flickers and harmonics).

In the beginning of wind energy commercial development, wind turbines have been treated as embedded generators, and they were not expected to contribute to the control of power system voltage or frequency. In addition, wind farms were required to disconnect from the grid under abnormal operating conditions. Until recently, wind farms connected to the grid were small-sized installations, connected at distribution voltage levels and the total amount of wind power generation capacity was (and still is in most countries) small in proportion to the total amount of installed generation capacity. Early ocean energy generating installations are likely to go through the same development and the most important requirements for connection to the grid will probably be determined, for these cases, mainly by economical and practical reasons.

The Danish Energy Association has provided guidelines for the connection of wind turbines to low and medium voltage networks through an early report ([6]) aimed at power utilities and wind turbine manufacturers whose object is to establish recommendations for wind turbines and networks in compliance with applicable standards for voltage quality and reliability of supply.

With the objective of enabling wind generation to connect to the transmission system without unnecessary restrictions and at the same time ensuring the security of supply, different transmission system operators have to adapt their grid codes. Wind farms are no longer only considered as embedded generation but are more and more required to contribute to grid stabilisation and voltage and frequency control therefore new regulations are taking into account wind power integration in many countries. A report from the European Wind Energy Association ([7]) delivered in 2005 summarises the principal issues related to the connection to the grid of large wind farms and includes analyses and recommendations on grid operational procedures and infrastructures. It also details a general review of the applicable national grid codes to wind energy integration for every European country.

As mentioned before, the contemporary development of the offshore wind industry could also provide important information for the future installation of marine energy farms. Offshore wind energy farms need to be deployed at large scales to be economically feasible and share many similar difficulties with ocean energy converters at such a level that some recent research efforts have been aiming at integrating offshore wind and ocean converters into a unique configuration.

Results from the Concerted Action on Offshore Wind Energy in Europe (CA-OWEE) have generated a report on grid integration ([8]) and a more up to date project was also commissioned by the UK Department of Trade and Industry (DTI now BERR: Department for Business Enterprise and Regulatory Reform) that result in a report ([9]) that includes an economic analysis of possible connection configuration of offshore wind farms off the UK coasts.

Grid connection of generating technologies is also related to power quality requirements that those need to comply with. These requirements are typically specified by national codes but procedures and methodologies for assessment and measurement of the quality of the generated power need however to be defined. The IEC 61400 committee has issued a standard on power quality characteristics of wind turbines. The IEC 61400-21 ([10]) includes:

- definition and specification of the quantities to be determined for characterizing the power quality of a grid connected wind turbine;
- measurement procedures for quantifying the characteristics;
- Procedures for assessing compliance with power quality requirements, including estimation of the power quality expected from the wind turbine type when deployed at a specific site, possibly in groups.

The measurement procedures are valid for single wind turbines with a three-phase grid connection, and as long as the wind turbine is not operated to actively control the frequency or voltage at any location in the network. The measurement procedures are valid for any size of wind turbine, though this standard only requires wind turbine types intended for points of common coupling (PCC) at medium (MV) or high voltage (HV) to be tested and characterised as specified in this standard.

The measured characteristics are valid for the specific configuration of the assessed wind turbine only. Other configurations, including altered control parameters that cause the wind turbine to behave differently with respect to power quality, require separate assessment. The measurement procedures are designed to be as non-site-specific as possible, so that power quality characteristics measured at for example a test site can be considered valid also at other sites. The procedures for assessing compliance with power quality requirements are valid for wind turbines with PCC at MV or HV in power systems with fixed frequency within ±1 Hz, and sufficient active and reactive power regulation capabilities and sufficient load to absorb the wind power production. In other cases, the principles for assessing compliance with power quality requirements may still be used as a guide.

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7. ENVIRONMENTAL IMPACT REQUIREMENTS

7.1 INTRODUCTION.

Marine energy devices are destined to operate in a natural environment particularly sensitive to external agents. Installation and operation of wave and tidal farms could determine a relevant impact on the quality of the water and on human and biological activities.

Because a long history of various kinds of human-built structures and machines installed at sea exists, some general practices for environmental impact assessment and monitoring can be found for such cases. Oil extraction industry has long experience offshore and younger wind energy farms are likely to share many concerns with marine energy developments.

Standards for offshore oil and gas extraction could be however not always applicable because of the high risk of pollution of the materials they handle, and the need of more strict regulations in their case, for events of accidents, since oil and gas are flammable substances. Oil and gas offshore platforms need also noisier and more disturbing installation processes, with deep pile driving to secure their structures.

The example of offshore wind turbines is perhaps more similar to the case of marine energy devices, since in both cases they are electricity generating devices placed offshore. Wind energy industry has published many guidelines and recommendations that we consider useful and some of them are mentioned below. Still, the different morphology of the structures and their position on the water column might imply different impacts.

7.2 ENVIRONMENTAL IMPACT RECOMMENDATIONS.

Table 16 Existing standard documents for environmental impact requirements for different sectors

	Year	**Description**
BSH Standard: Investigation of the Impacts of Offshore Wind Turbines on the Marine Environment	2003	Environmental Impact of Offshore Wind Turbines
ISO 16665	1997	Guidelines for sampling soft-bottom macrofauna
ISO 9391	2005	Guidance for sampling in deep waters
ISO 19493	2007	Guidance on hard substrate communities
IMO: Anti-Fouling Systems	2001	A list of harmful antifouling systems and alternatives
IEC 61400-11	2006	Measurement of noise produced at offshore wind farms

Concerning EIA, wind energy is a renewable energy industry that has moved recently towards the sea. Despite being a young sector, the Danish experience on the offshore wind farms has allowed producing results and gaining valuable knowledge on the impacts through monitoring. The document [1] has been released by several companies and public bodies and describes the key issues they have encountered in this time.

Environmental impact assessment and permitting procedures are usually addressed through consultation processes among the stakeholders. The British Wind Energy Association (BWEA) has issued a document ([2]) containing guidelines for this phase.

A standard ([3]) for the environmental impact on the marine environment of offshore wind turbines has been defined by the Bundesamt für Seeschifffahrt und Hydrographie.

The OSPAR Commission has published a document ([4]) with the same purpose for offshore oil and gas extraction constructions.

Another important issue is the procedure to obtain permit for the occupation of the marine environment, often subject to special regulations. Guidelines on applying for permits for the occupation of the territorial waters and the commercial activity offshore have to be followed. For this purpose, the UK Department for Business, Enterprise and Regulatory Reform has issued a protocol ([5]).

Environmental Impact Assessments involve a later phase of monitoring of the biotic and abiotic factors potentially affected by the presence of the infrastructures. This monitoring, in the case of benthic fauna or water quality, for example, is carried out by taking samples periodically. When these campaigns are done, it is recommendable to follow best practices to minimise the affection to the environment by the sampling and to obtain as good as possible quality results. ISO standards provide guidelines for surveys on marine fauna ([6], [7] and [8]).

One of the problems navigation has had to face was the attachments of living organisms to the hulls, which makes ships heavier and more resistant to movement, increasing the energy they need to sail at the same speed. This phenomenon known as bio-fouling is likely to affect WECs as they are deployed, and could modify the performance of the device. To solve this problem, several methods have been used in the past, from mechanically detaching the organisms, to using different coating substances. These substances have turned out in many cases to be effective but harmful to many other species apart from those on the ship hulls, causing damage to mollusc species making them unable to reproduce. An International Convention on the Control of Harmful Anti-fouling Systems on Ships has set the norm so that toxic substances are not implemented in the future. A general resume ([9]) of the allowed anti-fouling systems has been published by the International Maritime Organisation.

The development of marine energy sites has the potential to interfere with submarine archaeology. The Council for British Archaeology has identified future challenges for archaeological heritage in a publication. ([10])

One of the biggest concerns rising is the way in which marine energy installations will affect marine fauna, from benthic invertebrates to marine mammals. The factors uncertain to have some influence on living organisms are Electromagnetic Fields, underwater noise and vibration and the presence of the moorings on the bottom, amongst others.

As it could be expected, wind farm industry has many recommendations that can be useful for wave and tidal device deployments: Underwater noise and vibrations and the way these can affect wildlife nearby the wave energy test sites or commercial farms cannot be predicted with accuracy, and thus, needs monitoring. COWRIE (Collaborative Offshore Wind Research Into the Environment) have published several reports ([11]) with estimations and interpretation of underwater noise while installation, operation and pile driving, the effects of this noise at different levels and their criteria to assess them.

A standard also exists ([12]) for measurement of the noise generated by wind turbines written by the International Electrotechnical Commission.

A study on the interaction of fish, shellfish and benthos with Electromagnetic Fields is also available ([13]), written by the same body.

Concerning marine mammals, COWRIE released a list of methods to measure and to assess the behavioural changes in marine mammals as a result of the presence of wind farms. ([14])

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