Review of standards on reliability for ocean energy and relation to VMEA

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RiaSoR

RELIABILITY IN A SEA OF RISK

Johan Sandström[1], *John Griffiths*[2], *Thomas Svensson*[1]

[1] SP Technical Research Institute of Sweden
[2] The European Marine Energy Centre

Project Information

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Project Manager	Elaine Buck, EMEC Old Academy Business Centre Stromness, Orkney, KW16 3AW

Project Partners

EMEC ORKNEY THE EUROPEAN MARINE ENERGY CENTRE LTD	The European Marine Energy Centre
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Executive Summary

A review of standards is presented for field of ocean energy. The field is new and standards are not yet widely available. The review is performed in the context of reliability evaluation and relation and usage of method the Variation Mode and Effect Analysis (VMEA). Standards published by the EMEC, ISO, IEC, CEN and DNV GL organizations are here reviewed.

1 Introduction

Methods for the design and operation of ocean energy converters are to some extent given in standards. The focus of this document is on tidal and wave energy converters. Most of the challenges for the designers of these devices are rooted in the fact that these technologies are new and experience on typical performance and reliability levels is scarce. In this case, the method *Variation Mode and Effect Analysis* (VMEA) can be used to perform reliability analyses. Standards related to reliability of for tidal and wave energy converters are here reviewed.

Various organisations produce standards that directly or indirectly can be used for ocean energy applications. In the present work, several organisations and standards have been reviewed in order to investigate the possibility to adapt the existing design guidelines and recommended practices to the VMEA. Reports on ocean energy with focus on design and operations have been published in other projects. In "*State Of The Art In Fatigue And Wear Applications For Ocean Energy Convertors"* (by Liste and Johnson, SP, 2015) the status of research and standards on fatigue and wear are reviewed. Another report, "*Guidelines on design and operation of wave energy converters"* published by Carbon Trust (2005), is a comprehensive report on designing, operating and connecting wave energy converters. The report includes a valuable and extensive list of relevant standards from several organisations. Another report by Carbon Trust, *"Application Guide for the specification of the Depth Lowering using the Cable Burial Risk Assessment (CBRA) methodology*", gives an example of probabilistic evaluation on the related field of cable burying for offshore windfarms.

Wind power, both sea- and land-based, is today more developed and used on larger scales than ocean energy, which explains the larger number of standards and guidelines devoted to wind power technology.

This review covers standards from

- EMEC
- ISO
- IEC
- CEN
- DNV GL

2 Organizations

2.1 EMEC standards

The European Marine Energy Centre (EMEC) has produced a set of guidelines covering different aspects of design, performance and reliability assessment of marine systems for energy conversion. The guidelines are collected in the following series of documents, which are organized according to the structure shown in Figure 1:

1. Assessment of Performance of Wave Energy Conversion Systems*
2. Assessment of Performance of Tidal Energy Conversion Systems*
3. Assessment of Wave Energy Resource*
4. Assessment of Tidal Energy Resource*
5. Guidelines for Health & Safety in the Marine Energy Industry
6. Guidelines for Marine Energy Certification Schemes*
7. Guidelines for Design Basis of Marine Energy Conversion Systems*
8. Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems
9. Guidelines for Grid Connection of Marine Energy Conversion Systems
10. Tank Testing of Wave Energy Conversion Systems
11. Guidelines for Project Development in the Marine Energy Industry
12. Guidelines for Manufacturing, Assembly and Testing of Marine Energy Conversion Systems

*Standards proposed for work programme for IEC TC 114.

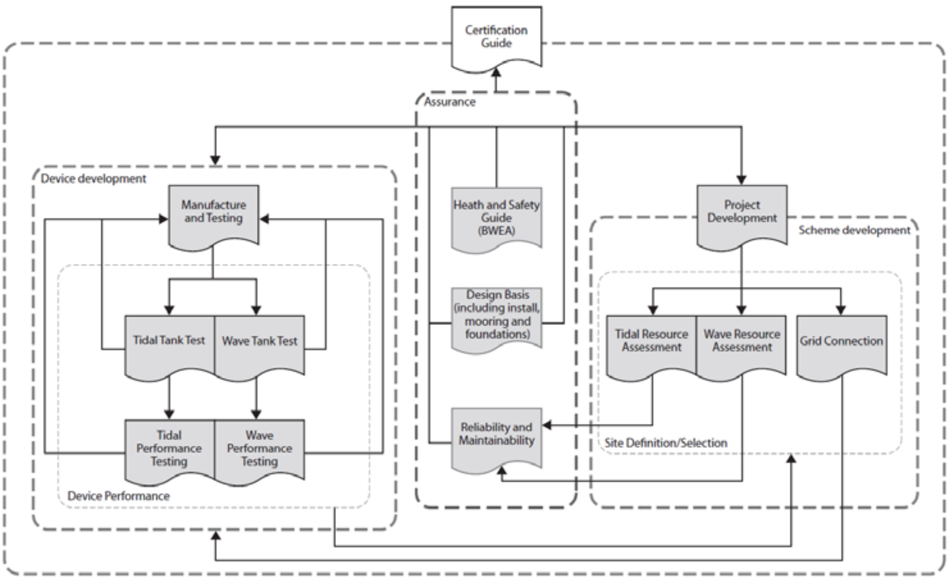

Figure 1 Conceptual relationships among the documents produced by EMEC to provide guidelines for design, performance and reliability assessment of marine energy conversion systems (source: EMEC guidelines).

The two documents “Guidelines for Design Basis of Marine Energy Conversion Systems” and “Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems” are particularly relevant in the context of VMEA. Design against mechanical and structural failure is performed in the classical way based on limit states and required safety is achieved with the introduction of proper partial factors.

The recommended methods for the analysis of potential failure modes are FMEA/FMECA. These are qualitatively methods (FMECA has a degree of quantitatively analysis in the risk/criticality assessment) and should be performed early in the development process. FMEA/FMECA can be complemented with the basic VMEA (the first level of VMEA) to assess and identify the largest sources of uncertainty.

In order to characterize an assessment of the performance of an ocean energy system, the EMEC guidelines refer to evidence. The different categories of evidence are depicted in Figure 2, where the higher levels of VMEA (enhanced and probabilistic) fit into *quantitative calculations*. The VMEA analysis can then be further utilized in the higher evidence categories when more knowledge, better models and uncertainty estimations are attained.

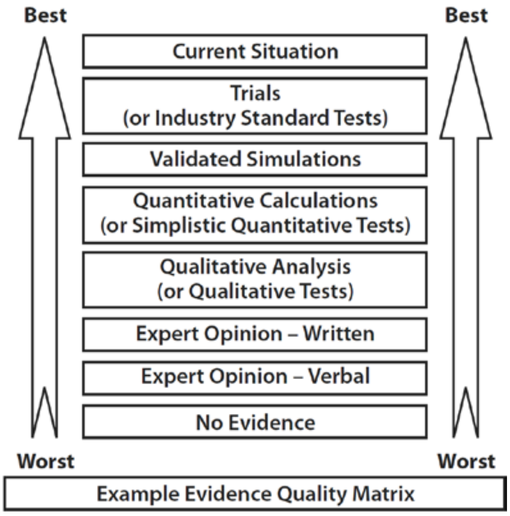

Figure 2. Categories of evidence and corresponding quality levels that characterize the performance assessment of ocean energy systems (source EMEC: guidelines).

The EMEC guidelines for reliability suggest the *mean time between failures* (MTBF) as a measure for availability. Depending on how it is used in the assessment of the system, mean-estimation type of the MTBF may be more appropriate than conservative estimation-type. A mean-estimation type in a system reliability assessment needs to complemented by an uncertainty analysis , where the VMEA methodology can be used after suitable adaptions. Both conservative estimation and mean estimation together with uncertainty analysis can be used to evaluate *maintenance free operating periods* (MFOP) where one wants to assure full operation in periods where maintenance is not preferred or possible.

2.2 ISO standards

The International Organization for Standardization (ISO) produces standards for many fields and the number of standards is very large. The ISO standards are organized in two ways:

International Classification for Standards (ICS)
Classification of standards into fields such as electrical engineering or paper technology.

Technical committees (TC)
Groups of experts focusing on all kinds of different subjects. TCs are further organised in sub committees (SC).

ISO has no dedicated standards for wave and tidal ocean energy applications. For wind energy some standards exist in "*ICS 27.180– ISO/CD 16079-1 Condition monitoring and diagnostics of wind turbines -- Part 1: General guidelines*" (under development) and "*IEC*

61400-4:2012 Wind turbines -- Part 4: Design requirements for wind turbine gearboxes" .ISO standards that could be useful for marine energy converters, although they are made for ships and oil-and-gas offshore equipment, are standards from "*TC 8/SC 13 - Marine technology* and *ICS 75.180 Equipment for petroleum and natural gas industries*".

For reliability and statistical analyses, "*TC 69 - Applications of statistical methods*" and "*TC 98/SC 2 - Reliability of structures* " contain relevant standards(they are to some degree focused on structures). A standard of particular importance is "*ISO 2394:2015 General principles on reliability for structures*" which lays down a general framework how to assess risk and reliability. Another standard that could be interesting for the RiaSoR project is "*ISO 13822:2010 Bases for design of structures – Assessment of existing structures*". This standard describes how to re-assess the reliability of existing structures, which may turn out to be useful as new knowledge is gained during testing.

Tidal and wave energy converters all rely on machinery to operate. "*ICS 21: Mechanical systems and components for general use*", includes e.g. the standard series for gears *ISO 6336*, which are particularly relevant in the context of marine energy applications. The energy converters have mechanical and electrical equipment that are sensitive to water and located near or under the sea level. Water tightness will therefore be essential to assure, so applicable standards need to be identified.

2.3 IEC standards

The International Electrotechnical Commission publishes the IEC standards and are in an early stage of development as Technical Specifications (TS) for marine energy. These are intended to be used as far as they can be and deviations recorded. It is vital that experience is gathered and feedback made on the use of these TS so that when they come to be revised (in about 3 years time) they can be improved significantly by the practical experience arising from use and so become full standards when they are revised. The industry needs to be encouraged to do this.

The key Technical Specs published so far given in Table 1.

Table 1 IEC standards relevant for ocean energy

IEC 62600-1	Terminology
IEC 62600-100	Performance Assessment of Wave Energy Converters
IEC 82600- 101	Assessment of Wave Resource
IEC 62600- 200	Performance Assessment of Tidal Energy Converters
IEC 62600-201	Assessment of Tidal Resource
IEC 62600-10	Assessment of Moorings for Marine Energy Converters

Several others will be forthcoming soon including IEC 62600-2 which is about design of Marine Energy Converters which many people agree is at a very interim stage.

2.4 CEN standards

The European Committee for Standardization (CEN) publishes the European norms. The Eurocode standards *EN 1990 to EN 1999*, which cover structures and other civil engineering objects, are general standards and relevant for reliability. Of particular interests are

- EN 1990: Basis of structural design
- EN 1991: Actions on structures
- EN 1993: Design of steel structures

2.5 DNV GL standards

DNV GL provides classification and technical assurance for ships and off-shore. For ocean energy, a relevant document is "*DNV-OSS-312 Certification of Tidal and Wave Energy*". This is of type "service specification", which means that it states what needs to be assured and gives guidelines about other standards to be used for specific aspects, as those listed in the table below.

More recently, the specification "*DNVGL-SE-0163 Certification of tidal turbines and arrays*" has appeared, replacing the content of the DNV-OSS-312 document for tidal applications. In the same sense as the DNV-OSS-312, the DNVGL-SE-0163 is also a service specification; however it comes along with the technical standard "*DNVGL-ST-0164 Tidal turbines*", which introduces detailed design guidelines. Furthermore, DNVGL-ST-0164 contains references to several other standards. A selection of relevant and important standards for the RiaSoR project, especially for the structural and mooring parts, are given in Table 2.

Table 2 DNV GL standards relevant for ocean energy

DNV-OSS-312	Certification of Tidal and Wave Energy
DNVGL-SE-0163	Certification of tidal turbines and arrays

DNVGL-ST-0164	Tidal turbines
DNVGL-OS-B101	Metallic materials
DNVGL-OS-C401	Fabrication and testing of offshore structures
DNVGL-OS-E301	Position mooring
DNV-OSS-300	Risk-based verification
DNV-OSS-121	Classification based on performance criteria determined from risk assessment methodology
DNV-OS-C101	Design of offshore steel structures, general (LRFD method)
DNV-OS-C501	Composite components
DNV-OS-C502	Offshore concrete structures
DNV-OS-D101	Marine and machinery systems and equipment
DNV-OS-D201	Electrical installations
DNV Classification Note 30.6	Structural reliability analysis of marine structures

3 Relation to VMEA

All standards reviewed here (e.g. ISO, Eurocode, DNVGL) rely on characteristic values for load (S_k) and strength (R_k) combined with partial factors γ, which are multiplied with the characteristic values to establish designing values as $S_d=\gamma_s S_k$ and $R_d=\gamma_r R_k$. These are then used in a limit state condition to be fulfilled as $S_d<R_d$.

The characteristic value for material strength is often taken as the 5% percentile of the strength distribution function. The characteristic value for load is usually defined as the value of some return period e.g. 50 years (this would mean that the characteristic value is expected to be exceeding once in a 50 year-period). The partial factors are set to account for other uncertainties in the design method and most often also to achieve extra safety (i.e., lower probability of failure) than what the characteristic values alone would give.

For novel technologies such as tidal and wave energy converters the appropriate partial factors are difficult or impossible to set as limited knowledge is available. The VMEA method can then be used to derive appropriate safety factors corresponding to the desired level of reliability. A difference between the traditional designing with the standards and VMEA is that VMEA starts the analysis with mean values for material strengths instead of the characteristic value. The uncertainty in load is then included directly in the analysis. This might introduce a practical difficulty since material and component strength data are usually given as characteristic data. For the load, the characteristic value should be suitable also in VMEA if the length of the return period is appropriate. The "*DNV Classification Note 30.6 Structural reliability analysis of marine structures*" can be used to aid the usage of VMEA for reliability analysis.

One problem by using characteristic values appears when several variables are used for calculating the limit state. Assume, for instance, that the strength for a hot spot in a structure is calculated by a finite element analysis, including several uncertain input variables, such as material strength and geometrical dimensions. The characteristic values approach then use the characteristic values as inputs to find the characteristic strength for the structure. If these are chosen as the 5% quantiles of their respective distributions, then the calculated strength will represent an unknown quantile. In fact, if the inputs are statistically independent, then the final quantile will be less than 5%, since the probability of simultaneous occurrence of severe case of all input variables is very small. In practice, the final quantile will depend both on the interaction between the different input variables and their correlation and is usually impossible to assess. Therefore, the characteristic value approach must be complemented by partial factors, which must be based on experience of similar cases. This may be the explanation to why some partial factors in standards are equal to unity, regardless a demand of a much lower probability of failure than 5%.

For novel technologies, the characteristic value approach therefore gives quite arbitary answers, and a more complete probabilistic approach should be adapted. The different VMEA approaches are suitable tools to achieve a picture of how different input uncertainties influence the critical limit state. It avoids the drawback of characteristic value approach mentioned above, by calculating the limit state from expected input values and separately assess the overall uncertainty. However, it shares one important property with the characteristic value approach: the avoidance of complex probabilistic theory in the engineering evaluation of reliability.

4 Conclusions and Remarks

The ISO, IEC and CEN standards are attractive as they are generally accepted and a result of the collaboration of international experts. However, the number of dedicated standards for tidal and wave energy converters is small. The EMEC guidelines are specifically developed for these applications, hence they are a complement to the relevant ISO standards are furthermore, proposed to be included in the ISO standards.

DNVGL has published standards specifically for tidal and wave energy converters and has an advantage in that they are dedicated to marine technology. Furthermore, these standards are available free of charge. However, a drawback in adopting DNVGL guidelines is that they are not accepted generally as international standards. The standard for reliability which is suggested here as the main reference for the adaptation of VMEA is "*ISO 2394:2015"* A useful complement to that is represented by the "*DNV Classification Note 30.6*", since it includes a thorough and general account on statistical methods for reliability whose application is not limited within the framework of DNVGL guidelines.

The VMEA method is proposed as a method to analyse and assure reliability for new technologies where experience and knowledge are limited. VMEA is a probabilistic method in accordance with the ISO standard recommendation. VMEA takes into account uncertainties of all kinds present in a method of analysis to quantitatively assess the total variation. As an outcome will be the possible to formulate appropriate safety factors for the design process to achieve sufficient safety and reliability.