Development of the IEC TC114 Technical Specification for mechanical load measurements for Marine Energy Converters

Anton Schaap, Nicholas Fyffe, Kimon Argyriadis, Peter Davies, Alan Henry, Budi Gunawan, Frederick Driscoll, Jeffrey Steynor and Peter Scheijgrond

Abstract—**The field measurement of mechanical loads for marine energy converters (MECs) in situ and at full scale is an important tool to verify predicted loads from simulation and to determine if the MEC can withstand the loads that it will be subjected to during its service life. This type of testing helps to reduce risks and thus increase investor confidence in the technology.**

Within the Technical Committee TC 114 on Marine Energy (Wave, Tidal and Other Water Current Converters) of the IEC (International Electrotechnical Committee) a project team is developing a Technical Specification (TS) for measurement of mechanical loads (IEC TS 62600-3).

IEC TS 62600-3 describes the measurement of mechanical loads on full scale marine energy converters such as wave, tidal and other water current converters (including river current converters) for the purpose of load simulation model validation and certification.

For MECs with blades connected to a rotor shaft, this standard also contains specifications for the laboratory testing of MEC rotor blades. It focuses on aspects of testing related to an evaluation of the structural integrity of the rotor blade. The purpose of the tests is to confirm to an acceptable level of probability that a production blade type fulfils the design assumptions.

The Committee Draft (CD) has been submitted and reviewed, and work is now in progress on the Draft Technical Specification (DTS).

Keywords—**IEC, marine energy, standard, mechanical load measurement, blade testing, certification, wave energy, tidal energy, river energy.**

I. Introduction

FOUNDED in 1906, the IEC (International Electrotechnical Commission) is the most important organization in the world for the preparation and publication of International Standards for electrical, electronics and related technologies. These standards are being used in the electrotechnical industry for standardization and certification purposes. For the Marine Energy sector the IEC technical committee TC114 is developing standards for Marine Energy (wave, tidal and other marine current converters) [1]. Most countries in the world are member of the IEC, with the IEC standards being accepted in all of these countries. This facilitates international trade and acceptance of industrial devices and products.

See fig. 1 for an overview of the standards that are being developed and have been developed within TC114 [2]. The new IEC TS 62600-3 describes the measurement of mechanical loads on full scale hydrodynamic marine energy converters such as wave, tidal and other water current converters (including river current converters) for the purpose of load simulation model validation and certification [3]. The load measurements standard is a generic standard applicable for different marine energy technologies. It is aimed at the development stages TRL 7 to TRL 9, i.e. full scale prototype up to production device.

See also the publication about the MET-CERTIFIED project for the development of IEC standards [4]. MET-CERTIFIED is an Interreg 2 Seas funded project, which stands for Marine Energy Technologies (MET) – Certified.

Paper ID: 1386, conference track: Structural mechanics – materials, fatigue, loadings.

A. Schaap is with Dutch Marine Energy centre (DMEC), Bergerweg 200 – Gebouw C, 1817 MN Alkmaar, The Netherlands (e-mail: anton@dutchmarineenergy.com).

N. Fyffe is with Blumara, 145 Hobson Lake Dr 405, Halifax, NS B3S 0H9, Canada (e-mail: nick@blumara.com).

K. Argyriadis is with DNV-GL, Brooktorkai 18, 20457 Hamburg, Germany (e-mail: kimon.argyriadis@dnvgl.com).

P. Davies is with Lloyd's Register, 71 Fenchurch Street London, EC3M 4BS, U.K. (e-mail: Peter.Davies@lr.org).

A. Henry is with Rockall Research Ltd, 9 The Court, Binn Eadair View, Sutton, Dublin 13 Ireland (e-mail: alan.henry@rockallsolutions.com).

B. Gunawan is with Sandia National Laboratories, 1515 Eubank SE Albuquerque New Mexico 87123, USA (e-mail: budi.gunawan@sandia.gov).

F. Driscoll is with the National Renewable Energy Laboratory (NREL), 15013 Denver West Parkway, Golden, Colorado 80401, USA (e-mail: frederick.driscoll@nrel.gov).

J. Steynor is with the University of Edinburgh, Sanderson Building, Robert Stevenson Road, The King's Buildings, Edinburgh, EH9 3FB, U.K. (e-mail: jeff.steynor@ed.ac.uk).

P. Scheijgrond is with Dutch Marine Energy Centre (DMEC), Bergerweg 200 – Gebouw C, 1817 MN Alkmaar, The Netherlands (e-mail: peter@dutchmarineenergy.com).

The project's aim is to accelerate the development of standards and certification schemes for marine energy technologies under the umbrella of the International Electrotechnical Commission (IEC)

The IECRE scheme is being developed for international certification (IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications) [5]. Its goal is to offer a harmonized application around the globe, which ensures a uniform implementation and mutual recognition between certification bodies and test labs. The IEC TS 62600-3 can also be used under other certification schemes.

Fig. 1. Overview of the standards that are being developed within TC114. The numbers indicate the 62600 standard.

Apart from the IEC, standards are also being developed by companies such as DNV-GL. The DNVGL-SE-0163 standard describes the certification of tidal turbines and arrays [6]. For testing it references the DNV-GL standard DNVGL-ST-0164 [7]. This standard gives requirements and recommendations on a wide variety of aspects concerning tidal turbines. The new IEC TS 62600-3 is however more specific with respect to the mechanical load measurements on hydrodynamic marine energy converters. This will be a step forward towards the ultimate goal of type certification of marine energy converters with a worldwide acceptance (under IECRE).

An international project team has been formed for the development of the IEC TS 62600-3. The team consists of experts in wave and tidal technology from different countries. At this moment the team consists of:

- Nicholas Fyffe, Blumara (Canada)
- Kimon Argyriadis, DNV-GL (Germany)
- Peter Davies, Lloyd's Register (Great Brittan)
- Alan Henry, Rockall Research (Ireland)
- Budi Gunawan, Sandia (United States of America)
- Frederick Driscoll, NREL (United States of America)
- Jeffrey Steynor, University of Edinburgh (Great Britain)
- Anton Schaap, DMEC (convener; The Netherlands)

The IEC 62600-3 Technical Specification contains the requirements and recommendations for the measurement of mechanical loads for activities such as:

- site selection
- measurand selection
- data acquisition, calibration and verification
- measurement load cases (MLCs)
- capture matrix
- post-processing
- uncertainty determination
- reporting

The methods described in the document can also be used for mechanical loads measurements for other purposes such as:

- obtaining a measured statistical representation of loads
- direct measurements of the design loads
- safety and function testing
- measurement of subsystem or component structural loads

IEC TS 62600-3 also defines the requirements for full scale structural testing of subsystems or parts with a special focus on full-scale structural testing of MEC rotor blades. The Technical Specification focuses on aspects of testing related to an evaluation of the structural integrity of the blade, for use by manufacturers and test laboratories. The purpose of the tests is to confirm to an acceptable level of probability that a production blade type fulfils the design assumptions.

The IEC TS 62600-3 is comparable to the wind international standard IEC 61400-13 for mechanical load measurement [8] and IEC 61400-23 for full scale structural testing of rotor blades [9]. With the new IEC TS 62600-3 we aim to achieve what the wind sector has achieved with the above mentioned standards. These standards are accepted worldwide for wind turbine testing and certification.

II. TECHNOLOGY QUALIFICATION

At the last face to face meetings of the PT 62600-3 project team (Delft, Netherlands, April 2019), the question was discussed whether companies in the marine energy sector are able to perform the mandatory tests that the new TS 62600-3 will prescribe. The tests might be too costly for some companies or not fully applicable for other companies. Therefore the project team has decided to reference the new technology qualification process (TS 62600-4) in the TS 62600-3. This gives the companies the possibility to adapt the test programme to the specific marine energy concept.

Technology qualification is a process for identifying and creating the evidence that the technology will function reliably in a defined operating envelope and duration and with an acceptable level of confidence. Certification normally qualifies technology against existing standards to confirm compliance. Technology qualification differs from ordinary certification in that it allows systems to be qualified that do not conform to an existing standard (or may partially conform to an existing standard).

Technology qualification is used both when the technology is completely novel and when only parts of it are novel. For example some technologies may have been demonstrated in the past but may have some novel subsystems. Technology qualification can help developers demonstrate that the technology has been robustly developed and this can be of assistance to stakeholders (such as financial institutions).

Technology qualification is performed at the beginning of the certification process to identify the uncertainties, novelties, modes of failure, mechanisms of failure, risks and risk control measures. In addition, technology qualification will identify the standards that are applicable, to what extent and what adaptation is required to address the risks. The technology qualification plan is the deliverable from this process and will provide all necessary actions to achieve certification.

Project team IEC PT 62600-4 has been formed to develop a standard for establishing Qualification of New Technology [12]. As soon as this standard is available, it can be used to determine whether separate laboratory testing of parts or systems is necessary. For now, the technology qualification process is also embedded in the updated version of IEC TS 62600-2 (design requirements for marine energy systems) [10].

III. Applicability of the IEC TS 62600-3

Mechanical load measurements have already been performed on a variety of marine energy converters. However these measurements are mostly proprietary to the company that has financed the measurements. The measurands and measurement programme is designed by the company (in some cases aided by a certification body like DNVGL or LR). There is not yet a standardised way to perform these measurements. A big problem is, that there is a wide variety of hydrodynamic marine energy converter types, especially concerning wave energy converters (WECs).

For tidal energy converters (TECs) the working principle of a turbine comprising blades connected to a rotor shaft, is most common, whether seabed mounted or mounted to a floating structure. There are also other types of tidal energy converters under development without blades connected to a rotor shaft and there are wave energy converters under development with blades connected to a rotor shaft. The IEC 62600-3 aims to cover all possible types of hydrodynamic marine energy converters. Leveraging from wind turbine experience and knowledge, the requirements for MECs with blades connected to a rotor shaft are presented in greater details than that for other type of MECs.

For all marine energy converters a subdivision is made between seabed (or shore) mounted devices and floating devices. The seabed mounted devices generally consist of the following subsystems:
- prime mover
- power take-off (PTO)
- control
- foundation and/or substructure

There can be marine energy converter types that do not fit in this characterization such as the magneto hydrodynamic device (MHD), where the seawater itself is the prime mover. For such a device the scheme can be reduced to only “foundation and/or substructure”, “power take-off” and “control”.

The floating marine energy converters generally consist of the following subsystems:
- prime mover
- power take-off (PTO)
- control
- floating device
- mooring system

Other configurations of the subsystems are also possible. For example, for wave energy converters the power take-off and prime mover can be inside the floating device. A marine energy converter can also be composed of more than one subsystem of any kind. The subsystems can be connected in series such as alternating series of prime movers and power take-offs or in parallel. The floating device can also be moored above the seabed but below the free surface.

For marine energy converters with blades connected to a rotor shaft the rotor forms the prime mover of the marine energy converter. The rotor can rotate with respect to a substructure. The power take-off connects the rotor to the substructure and houses an energy conversion from mechanical power to electrical power or some other form of transportable power such as hydraulic power. This is also called the drive train. The power take-off can be housed in a nacelle. The substructure connects the power take-off to the foundation fixed to the seabed or shore. (see Fig. 2). A control subsystem can be applied to control critical functions such as rotor speed, rotor torque and rotor braking.

Fig. 2. TEC with bladed rotor mounted to the seafloor (SIMEC Atlantis).

There are also optional mechanical components in a control subsystem. For example:

- mechanism to allow yawing of the rotor towards the direction of the current (e.g. for the ebb and flood current direction);
- mechanism to allow pitching of the rotor blades i.e. to optimise power production, to shed loads or to adjust to the direction of the current.

The rotor and power take-off can also be supported by a floating device which is connected to the seabed (or shore) by a mooring system (see Fig. 3).

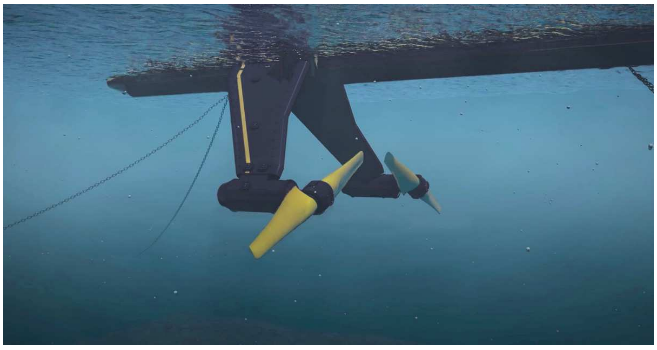

Fig. 3. Floating TEC with bladed rotors moored to the seafloor (Orbital Marine Power).

The required measurands, measurement load cases, capture matrix, and post processing methods should be evaluated and adjusted to fit the specific marine energy converter device.

Apart from full scale in situ testing the upcoming standard TS 62600-3 also describes when separate full scale laboratory testing of subsystems or structural components should be considered. This should be considered when:

- a subsystem or structural component is used in another way or in another environment for which it is certified or tested
- the loading of the subsystem or structural component is not well understood
- the subsystem or structural component is constructed from anisotropic or layered materials in which the stresses are not fully predictable or in which the production process has influence on for example the fatigue strength or durability in seawater (for example in rotor blades)
- the complex nature of the subsystem or structural component makes it difficult to predict the stresses in the part (for example a gearbox with a shaft under stochastic multi directional loading and complex internal dynamic effects)
- the calculated reserve against fatigue failure is low

This is centred around discerning risks and the process of mitigating these risks. For a risk analysis method see “Improving Reliability in a Sea of Risk” [11]. The risk analysis is central to the Technology Qualification process.

IV. TEST REQUIREMENTS

The mandatory load tests are concentrated around the interfaces between the subsystems. For MECs with blades connected to a rotor shaft, the requirements are specified in more detail, since in this case there is more knowledge about the technical components of the device. Full scale laboratory blade testing is added to determine the load bearing ability of rotor blades for static loads and fatigue.

The load tests are specified in Measurement Load Cases (MLCs). The standard describes the minimum required MLCs needed for proper model validation. Where applicable the MLCs are defined in relation to the design load cases (DLCs), described in IEC TS 62600-2 [10].

The MLCs define the main external conditions and the operational states of the MEC during the measurements. The external conditions include oceanographic and meteorological quantities. The operating states depend on the MEC configuration and shall be specified for each particular case.

Due to the stochastic character of the external conditions, measurements of some MLCs shall be repeated in order to reduce the statistical uncertainty. The minimum number of measurements at each MLC is specified in the standard.

The measured time histories are classified in two ways: one considering steady-state operation and one considering transient events. During the steady state operation, the MEC should be in a stable condition. For a TEC it can take 5 minutes or less from start-up and for a WEC it can take 20 minutes or more. The averaging period shall conform to the specific standard for the technology:

- IEC TS 62600-100 for wave energy converters [13]
- IEC TS 62600-200 for tidal energy converters [14]
- IEC TS 62600-300 for river energy converters [15]

The TS 62600-3 also describes the way to handle uncertainties in the measurements. Referencing the ISO/IEC guide 98-1 [16] and 98-3 [17]. An informative Annex is added with an example how to deal with uncertainties.

The MLCs that are defined in the standard may not be sufficient. Additional MLCs may be necessary depending on the MEC concept, control strategy, and safety strategy. This should be discerned during the Technology Qualification process. The MLCs should demonstrate that the MEC can reach the safety and reliability levels that resulted from the model simulation calculations. MLCs that are required by local regulations are mandatory.

There is the following hierarchy in the measurement load cases:

- 1: Human safety and station keeping
- 2: Normal circumstances
- 3: Abnormal and extreme circumstances

V. FULL SCALE STRUCTURAL TESTING OF ROTOR BLADES

An example of separate laboratory testing embedded in the IEC TS 62600-3 standard is the full-scale structural testing of MEC turbine rotor blades.

In these tests the structural integrity of the rotor blade is evaluated. The purpose of the tests is to confirm to an acceptable level of probability that the installed production of a blade type fulfils the design assumptions. The following tests are described:

- static load tests
- fatigue tests
- static load tests after fatigue tests
- tests determining other blade properties (e.g. natural frequencies, centre of gravity)

MECs vary strongly in their blade design. Most blades are suspended at one end with a single blade root to the hub of a rotor. There are also blade designs that are suspended at both ends of the blade. For example, this can for be the case with the Darrieus type of rotor. For these type of rotors the test programme shall be reformulated accordingly.

For each test, the target loads shall be defined in the test plan. Sufficient information shall be provided to allow the test load to be accurately assessed against the target load. In principle, the six load components should be given (forces in 3 perpendicular directions and moments in 3 perpendicular directions), including phase and frequency information required to generate combined load cases. The flatwise and edgewise moments are the most important components. Only for more specialised blades will the torsion and lengthwise forces have to be considered. It is recommended to monitor the blade displacement and rotation in all six degrees of freedom as well as the loading vector in the x, y and z direction.

Since the test should prove that the blade can survive the target loading, the test loading shall be evaluated. Areas of the blade where the severity of the test loading is indeed equal to or more severe than the target loading should be identified. Because the severity of the test loading compared to the target loading will vary over the blade area, in principle the evaluation must be done at all locations of the blade area that are to be tested.

Loads on critical mechanical and electrical blade subsystems (e.g., hydrodynamic braking subsystem, monitoring subsystem, hydrodynamic control subsystem, etc.) are often different in character from the general loads on the blades and may need extra specification and specific tests (if applicable). In the case of internal mechanisms, it is unlikely that sufficient loading conditions will be present in the standard tests to qualify the mechanism integrity. Additional testing may be necessary to simulate special loading cases, including torsion and radial loading. For systems whose failure may result in unsafe operation of the MEC, special consideration shall be given to verify the appropriate level of structural integrity. The accumulated damage should not cause functional failure of these subsystems. Loads for testing of blade subsystems are not covered further in this standard.

VI. ORGANISATION AND PLANNING

A committee draft (CD 62600-3) was published in November 2018. All IEC member countries have had the opportunity to comment on the CD and these comments have been reviewed. The Project Team is now developing a draft technical specification (DTS). This will be available this summer. If the development goes according to plan the technical specification (TS) will be available in the first half of 2020.

CONCLUDING REMARKS

The Committee Draft (CD) that is already available can give a good idea of the TS under development. However it is certain that changes will be made during 2019, to accommodate for the comments that were collected during the international review of the CD. The CD can be obtained through the national IEC representation.

Since the team is relatively small and the geographic spread could be improved, we invite experts to join through their national IEC committee.

ACKNOWLEDGEMENT

The work of DMEC and Lloyd's Register in this Project Team is part of the the international MET-CERTIFIED project. The project aim is to accelerate the development of standards and certification schemes for marine energy technologies under the umbrella of the IEC. It is executed by ten partners from the so called “2 seas region” of the EU. The project is funded by the European Interreg 2 Seas programme. Also the Ministry of Economic Affairs in the Netherlands, Province of South-Holland and North-Holland and the Belgian Province of West Flanders are offering financial support.

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-NA0003525.

The work of the other committee members is funded by their employers, with the common goal to establish international standards.

REFERENCES

[1] IEC TC114: Marine energy- wave, tidal and other water current converters, IEC Geneva, Switzerland.

[2] G. Germain, A. Chapeleau, B. Gaurier, L.M. Macadré and P. Scheijgrond, “Testing of marine energy technologies against international standards. Where do we stand?”, in *EWTEC2017 Cork Ireland*, 2017, pp. 909-1 – 909-8.

[3] Marine energy - Wave, tidal and other water current converters - Part 3: Measurement of mechanical loads, IEC CD 62600-3: 2018

[4] P. Scheijgrond, A. Southall, C. Bittencourt, P. Davies, P. Mathys, “Advancing IEC standardization and certification for tidal energy converters”, in *EWTEC2019 Naples Italy*, 2019.

[5] IECRE, IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications, Geneva, Switzerland.

[6] Certification of tidal turbines and arrays, DNVGL-SE-0163, October 2015.

[7] Tidal turbines, DNVGL-ST-0164, October 2015.

[8] Wind turbines – Part 13: Measurement of mechanical loads, IEC 61400-13: 2016.

[9] Wind turbines – Part 23: Full-scale structural testing of rotor blades, IEC 61400-23: 2014.
[10] Marine energy - Wave, tidal and other water current converters - Part 2: Design requirements for marine energy systems, IEC 62600-2: 2018.
[11] C. Jia, C. Chong, P. McKeever, P. Johannesson, T. Svensson, E. Buck and A. Shanks, "Improving Reliability in a Sea of Risk" in *EWTEC2017 Cork Ireland*, 2017, pp. 1037-1 – 1037-8.
[12] Marine energy - Wave, tidal and other water current converters - Part 4: Standard for establishing qualification of new technology, IEC 62600-4: under development.
[13] Marine energy - Wave, tidal and other water current converters - Part 100: Electricity producing wave energy converters - Power performance assessment, IEC TS 62600-100:2012.
[14] Marine energy - Wave, tidal and other water current converters - Part 200: Electricity producing tidal energy converters - Power performance assessment, IEC TS 62600-200:2013.
[15] Marine energy - Wave, tidal and other water current converters - Part 300: Electricity producing river energy converters - Power performance assessment, IEC DTS 62600-300:2019.
[16] Uncertainty of measurement - Part 1: Introduction to the expression of uncertainty in measurement, ISO/IEC guide 98-1:2009.
[17] Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement, ISO/IEC guide 98-3:2008.