



BSI Standards Publication

Marine energy — Wave, tidal and other water current converters

Part 3: Measurement of mechanical loads

National foreword

This Published Document is the UK implementation of IEC TS 62600-3:2020.

The UK participation in its preparation was entrusted to Technical Committee PEL/114, Marine energy - Wave, tidal and other water current converters.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2020
Published by BSI Standards Limited 2020

ISBN 978 0 580 99494 4

ICS 27.140

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 May 2020.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------



IEC TS 62600-3

Edition 1.0 2020-05

TECHNICAL SPECIFICATION

**Marine energy – Wave, tidal and other water current converters –
Part 3: Measurement of mechanical loads**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.140

ISBN 978-2-8322-8105-5

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	8
INTRODUCTION.....	10
1 Scope.....	11
1.1 General.....	11
1.2 Subdivision of marine energy converter types.....	11
2 Normative references.....	14
3 Terms and definitions.....	15
4 Symbols, units and abbreviated terms.....	15
4.1 Symbols.....	15
4.2 Greek symbols.....	16
4.3 Subscripts.....	17
4.4 Abbreviated terms.....	17
5 General.....	17
5.1 Document structure.....	17
5.2 Safety during testing.....	18
5.3 Technology qualification.....	18
5.4 Load measurement.....	18
6 Test requirements.....	18
6.1 General.....	18
6.2 Test site requirements all WEC and CEC.....	19
6.3 Subsystem or structural component laboratory load testing.....	19
6.4 Measurement load cases all WEC and CEC.....	19
6.4.1 General.....	19
6.4.2 MLCs during steady-state operation.....	20
6.4.3 MLCs during transient events.....	21
6.4.4 MLCs for dynamic characterization.....	21
6.4.5 MLC for abnormal operating condition.....	22
6.4.6 Capture matrices.....	22
6.5 Measurement load cases for MECs with blades connected to a rotor shaft.....	23
6.5.1 General.....	23
6.5.2 MLCs for dynamic characterization.....	23
6.5.3 Capture matrices.....	24
6.6 Quantities to be measured for all WEC and CEC.....	25
6.6.1 General.....	25
6.6.2 Load quantities.....	25
6.6.3 Meteorological and oceanographic quantities.....	26
6.6.4 MEC operation quantities.....	26
6.7 Quantities to be measured for MECs with blades connected to a rotor shaft.....	27
6.7.1 General.....	27
6.7.2 Load quantities.....	28
6.7.3 Oceanographic and meteorological quantities.....	28
6.7.4 MEC operation quantities.....	28
6.8 MEC configuration changes.....	29
7 Instrumentation.....	29
7.1 Load quantities for all WEC and CEC.....	29
7.1.1 General.....	29

7.1.2	Types of sensors	30
7.1.3	Choice of sensor location	30
7.1.4	The connection between prime mover and PTO	30
7.1.5	The connection between PTO and substructure and/or foundation	31
7.1.6	The connection between PTO and floating device	31
7.1.7	Measurement of station keeping loads	31
7.1.8	Prime mover absolute and relative position	31
7.1.9	PTO absolute and relative position	32
7.1.10	Substructure or floating device absolute and relative position	32
7.1.11	Water pressure measurements	32
7.2	Operation quantities for all WEC and CEC	32
7.2.1	General	32
7.2.2	Electrical power	32
7.2.3	Hydraulic power	33
7.2.4	Generator speed	33
7.2.5	Brake moment or force	33
7.2.6	MEC status	33
7.2.7	Brake status	33
7.2.8	Draft or freeboard measurement	33
7.3	Load quantities for MECs with blades connected to a rotor shaft	33
7.3.1	General	33
7.3.2	Blade root bending moments	33
7.3.3	Blade bending moment distribution	34
7.3.4	Blade torsion frequency/damping	34
7.3.5	Rotor yaw and tilt moment	34
7.3.6	Rotor torque	34
7.3.7	Tubular column bending	34
7.3.8	Darrieus style rotor bending	35
7.3.9	PTO and blade absolute and relative position	35
7.4	Operation quantities for MECs with blades connected to a rotor shaft	35
7.4.1	General	35
7.4.2	Rotor speed or generator speed	35
7.4.3	Yaw misalignment	35
7.4.4	Rotor azimuth angle	35
7.4.5	Pitch position	35
7.4.6	Pitch speed	36
7.4.7	Brake moment	36
7.5	Oceanographic and meteorological quantities	36
7.5.1	General	36
7.5.2	Measurement and installation requirements	36
7.5.3	Sea or river ice loads and ice accretion	36
7.6	Data acquisition system (DAS)	36
7.6.1	General	36
7.6.2	Resolution and sampling frequency	36
7.6.3	Anti-aliasing	37
8	Determination of calibration factors	37
8.1	Overview	37
8.2	General	37

8.3	Calibration of load channels for all WEC and CEC	38
8.4	Calibration of non-load channels for all WEC and CEC	38
8.5	Calibration of load channels for MECs with blades connected to a rotor shaft	38
8.5.1	General	38
8.5.2	Blade bending moments	39
8.5.3	Main shaft moments	40
8.5.4	Tubular column bending moments	40
8.6	Calibration of non-load channels for MECs with blades connected to a rotor shaft	41
8.6.1	Pitch angle	41
8.6.2	Rotor azimuth angle	41
8.6.3	Yaw angle	41
8.6.4	Oceanographic and meteorological	41
8.6.5	Brake moment or force	41
9	Data verification	42
9.1	Overview	42
9.2	General	42
9.3	Verification checks for all WEC and CEC	42
9.4	Verification checks for MECs with blades connected to a rotor shaft	43
9.4.1	General	43
9.4.2	Blade moments	43
9.4.3	Main rotor shaft	44
9.4.4	Tubular column	44
10	Processing of measured data	45
10.1	Overview	45
10.2	General	45
10.3	Load quantities	45
10.4	Current speed and/or sea state trend detection	45
10.5	Statistics	46
10.6	Rainflow counting	46
10.7	Cumulative rainflow spectrum	46
10.8	Damage equivalent load (DEL)	46
10.9	Current speed or wave energy flux binning	47
10.10	Power spectral density (PSD)	48
11	Uncertainty estimation	48
12	Reporting	48
Annex A	(normative) Full-scale structural laboratory testing of rotor blades	52
A.1	General	52
A.2	Coordinate systems	52
A.3	General principles	54
A.3.1	Purpose of tests	54
A.3.2	Limit states	55
A.3.3	Practical constraints	55
A.3.4	Results of test	55
A.4	Documentation and procedures for test blade	56
A.5	Blade test program	56
A.5.1	Areas to be tested	56
A.5.2	Test program	57

A.6	Test plans	58
A.6.1	General	58
A.6.2	Blade description	58
A.6.3	Loads and conditions	58
A.6.4	Instrumentation	58
A.6.5	Expected test results	58
A.7	Load factors for testing	59
A.7.1	General	59
A.7.2	Partial safety factors used in the design	59
A.7.3	Factors on materials	59
A.7.4	Partial factors on loads	59
A.7.5	Application of load factors to obtain the target load	60
A.8	Test loading and test load evaluation	61
A.8.1	General	61
A.8.2	Influence of load introduction	62
A.8.3	Static load testing	62
A.8.4	Fatigue load testing	63
A.9	Test requirements	64
A.9.1	Test records	64
A.9.2	Instrumentation calibration	64
A.9.3	Measurement uncertainties	64
A.9.4	Root fixture and test stand requirements	64
A.9.5	Environmental conditions monitoring	65
A.9.6	Deterministic corrections	65
A.9.7	Static test	65
A.9.8	Fatigue test	66
A.9.9	Other blade property tests	66
A.10	Test results evaluation	67
A.10.1	General	67
A.10.2	Catastrophic failure	67
A.10.3	Permanent deformation, loss of stiffness or change in other blade properties	67
A.10.4	Superficial damage	68
A.10.5	Failure evaluation	68
A.11	Renewed testing	68
A.12	Reporting	69
A.12.1	General	69
A.12.2	Test report content	69
A.12.3	Evaluation of test in relation to design requirements	70
Annex B (informative)	Example coordinate systems for MECs with blades connected to a rotor shaft	71
B.1	General	71
B.2	Blade coordinate system	71
B.3	Hub coordinate system	71
B.4	Nacelle coordinate system	72
B.5	Tubular column coordinate system	73
B.6	Yaw misalignment	74
B.7	Cone angle and tilt angle	74
B.8	Rotor azimuth angle	75

B.9	Blade pitch angle	75
Annex C (informative)	Recommendations for design and testing of MECs with respect to ice loading and ice accretion.....	76
Annex D (informative)	Offshore load measurements	77
D.1	General.....	77
D.2	Fibre optic strain sensors	77
D.3	Published experience.....	78
D.4	Operational sound.....	79
Annex E (informative)	Uncertainty analysis	80
Annex F (informative)	Load model validation.....	82
F.1	General.....	82
F.2	Methods for loads comparison	82
F.2.1	Statistical binning	82
F.2.2	Spectral functions	83
F.2.3	Fatigue spectra.....	83
F.2.4	Data point by data point.....	83
Annex G (informative)	Formulation of test load for rotor blade testing	84
G.1	Static target load.....	84
G.2	Fatigue target load.....	84
Annex H (informative)	Difference between design and test load condition for rotor blade testing	85
H.1	General.....	85
H.2	Load introduction	85
H.3	Bending moments and shear.....	85
H.4	Radial loads.....	87
H.5	Torsion loads	87
H.6	Environmental conditions	87
Annex I (informative)	Influence of the number of load cycles on fatigue tests of rotor blades.....	88
I.1	General.....	88
I.2	Background.....	88
I.3	The approach used	88
Bibliography	92
Figure 1	– General scheme of marine energy converters fixed to the seabed or shore	12
Figure 2	– General scheme of floating marine energy converters moored to the seabed or shore.....	13
Figure 3	– Marine energy converter with blades connected to a rotor shaft supported by a fixed substructure.....	13
Figure 4	– Marine energy converter with blades connected to a rotor shaft supported by a floating device.....	14
Figure 5	– Turbine loads: rotor, blade and base of tubular column loads.....	28
Figure A.1	– Chordwise (flatwise, edgewise) coordinate system.....	53
Figure A.2	– Rotor (flapwise, lead-lag) coordinate system.....	54
Figure B.1	– Blade coordinate system.....	71
Figure B.2	– Hub coordinate system	72
Figure B.3	– Nacelle coordinate system	73

Figure B.4 – Tubular column coordinate system.....	73
Figure B.5 – Yaw misalignment.....	74
Figure B.6 – Cone angle and tilt angle	74
Figure H.1 – Difference of moment distribution for target and actual test load	85
Figure H.2 – Distribution of the shear force as a function of the spanwise location for different numbers of load application point.....	86
Figure H.3 – Distribution of the bending moment as a function of the spanwise location for different numbers of load application points	86
Figure I.1 – Simplified Goodman diagram	88
Figure I.2 – Test load factor γ_{ef} as a function of the reduction factor H_r	91
Table 1 – MLCs during steady-state operation	21
Table 2 – Measurement of transient load cases	21
Table 3 – MLCs for dynamic characterization.....	22
Table 4 – Capture matrix for parked condition.....	23
Table 5 – Capture matrix for normal transient events	23
Table 6 – Capture matrix for other than normal transient events	23
Table 7 – MLCs for dynamic characterization.....	24
Table 8 – Capture matrix for parked condition.....	24
Table 9 – All WEC and CEC load quantities	26
Table 10 – Oceanographic and meteorological quantities	26
Table 11 – MEC operation quantities	27
Table 12 – MECs with blades connected to a rotor shaft load quantities	28
Table 13 – MEC with blades connected to a rotor shaft operation quantities	29
Table 14 – Summary of suitable calibration methods	39
Table A.1 – Blade test program.....	57
Table A.2 – Recommended value for γ_{ef} as a function of the reduction factor H_r	60
Table A.3 – Examples of situations typically requiring or not requiring renewed testing.....	69
Table E.1 – List of uncertainty components.....	81
Table I.1 – Recommended values for γ_{ef} as a function of the reduction factor H_r	91

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**MARINE ENERGY – WAVE, TIDAL AND
OTHER WATER CURRENT CONVERTERS –****Part 3: Measurement of mechanical loads**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the mature but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62600-3, which is a Technical Specification, has been prepared by IEC technical committee 114: Marine energy – Wave, tidal and other water current converters.

The text of this Technical Specification is based on the following documents:

Enquiry draft	Report on voting
114/326/DTS	114/336A/RVDTS

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62600 series, published under the general title *Marine energy – Wave, tidal and other water current converters*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

This part of IEC 62600 outlines specifications for the full-scale mechanical loads measurement on hydrodynamic marine energy converters (MECs). It is directed at a technology readiness level (TRL) of 7 to 9, meaning the last prototype or the first production device. This document also outlines the demands for full-scale structural testing of rotor blades as well as the interpretation and evaluation of test results.

In the process of structural design of marine energy converters, thorough understanding and accurate quantification of the loading is of utmost importance. In the design stage, loads can be predicted with simulation models and codes. However, such models have their modelling restrictions and uncertainties, and they always need to be validated by measurement.

Mechanical load measurements can be used both as the basis for design and as the basis for certification. The design of marine energy converters is covered by IEC 62600-2: Marine Energy – Wave, tidal and other water current converters – Part 2: Design requirements for marine energy systems.

This document is aimed at the test institute, the marine energy converter manufacturer and the certifying body and defines the requirements for mechanical loads tests resulting in consistent and reproducible test results.

There exists a large variety of marine energy converter working principles. This document aims to cover most hydrodynamic marine energy converter working principles. Therefore, generalised tests are presented at the level of the common subsystems. For Tidal Energy Converters (TECs) and for other water current converters, the most common working principle is a turbine comprising blades connected to a rotor shaft. Therefore, detailed tests are specified for this working principle. For marine energy converter working principles that do not fit partly or completely in the scope of this document, the technology qualification process is introduced. Through the technology qualification process, the user can adapt the test programme to their specific marine energy converter.

This document is comparable to the international wind standards IEC 61400-13: Wind turbines – Part 13: Measurement of mechanical loads and IEC 61400-23: Wind turbines – Part 23: Full-scale structural testing of rotor blades. Since testing laboratories and certification bodies already have experience with these wind standards, it is convenient to adapt the same methods where possible.

There is not much published experience with offshore mechanical load measurement on marine energy converters. This document is a first step towards a future International Standard which can be used as part of a type certification process of marine energy converters. First, experience should be gained with offshore mechanical load measurement and with the application of this document.

Compliance with this document does not relieve any person, organization, or corporation from the responsibility of observing other applicable regulations.

MARINE ENERGY – WAVE, TIDAL AND OTHER WATER CURRENT CONVERTERS –

Part 3: Measurement of mechanical loads

1 Scope

1.1 General

This part of IEC 62600 describes the measurement of mechanical loads on 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. This document contains the requirements and recommendations for the measurement of mechanical loads for such activities as site selection, measurand selection, data acquisition, calibration, data verification, measurement load cases, capture matrix, post-processing, uncertainty determination and reporting.

Informative annexes are also provided to improve understanding of testing methods. The methods described in this 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, or measurement of subsystem or component structural loads.

Through a technology qualification process, the test requirements can be adapted to the specific marine energy converter.

This document also defines the requirements for full-scale structural testing of subsystems or parts with a special focus on full-scale structural testing of marine energy converter rotor blades and for the interpretation and evaluation of achieved test results. This document focuses on aspects of testing related to an evaluation of the structural integrity of the blade. The purpose of the tests is to confirm to an acceptable level of probability that the whole installed production of a blade type fulfils the design assumptions.

1.2 Subdivision of marine energy converter types

There is a wide variety of marine energy converter types, especially concerning wave energy converters (WECs). For tidal energy converters and other current energy converters (CECs) the working principle of a turbine comprising blades connected to a rotor shaft, is common, whether seabed mounted or mounted to floating structures. However, 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. This document aims to cover all types of hydrodynamic marine energy converters, being wave energy converters (WECs) and current energy converters (CECs). Therefore, this document provides requirements and recommendations for all wave energy converters and current energy converters. For wave energy converters and current energy converters 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.

For all wave and current energy converters a subdivision can be made between seabed (or shore) mounted devices (see Figure 1) and floating devices (see Figure 2). The seabed can also be a riverbed and the shore can also be a pier, a bridge girder, a canal lock gate or another artificial construction. The seabed (or shore) mounted devices generally consist of the following subsystems:

- prime mover;