



BSI Standards Publication

Marine energy – Wave, tidal and other water current converters

Part 2: Marine energy systems – Design requirements

National foreword

This Published Document is the UK implementation of IEC TS 62600-2:2019. It supersedes PD IEC/TS 62600-2:2016, which is withdrawn.

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 committee manager.

Attention is drawn to the fact that during the development of this Technical Specification, the UK committee voted against its approval.

The UK committee submitted a negative vote due to its opinion that this document does not provide extensive technical requirements for wave energy converter (WEC) or tidal energy converter (TEC) systems.

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TECHNICAL SPECIFICATION



Marine energy – Wave, tidal and other water current converters – Part 2: Marine energy systems – Design requirements

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**MARINE ENERGY –
WAVE, TIDAL AND OTHER WATER CURRENT CONVERTERS –****Part 2: Marine energy systems – Design requirements**

FOREWORD

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- 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 future 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 62600-2, which is a Technical Specification, has been prepared by IEC technical committee 114: Marine energy – Wave, tidal and other water current converters.

This second edition cancels and replaces the first edition published in 2016. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) The first edition published in 2016 was based on design methodologies developed by TC88. The second edition sets forth design conditions unique to marine energy converters.

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

Enquiry draft	Report on voting
114/306/DTS	114/322/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 publication 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 publication will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- transformed into an International Standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 62600 outlines minimum design requirements for marine energy converters (MECs) and is not intended for use as a complete design specification.

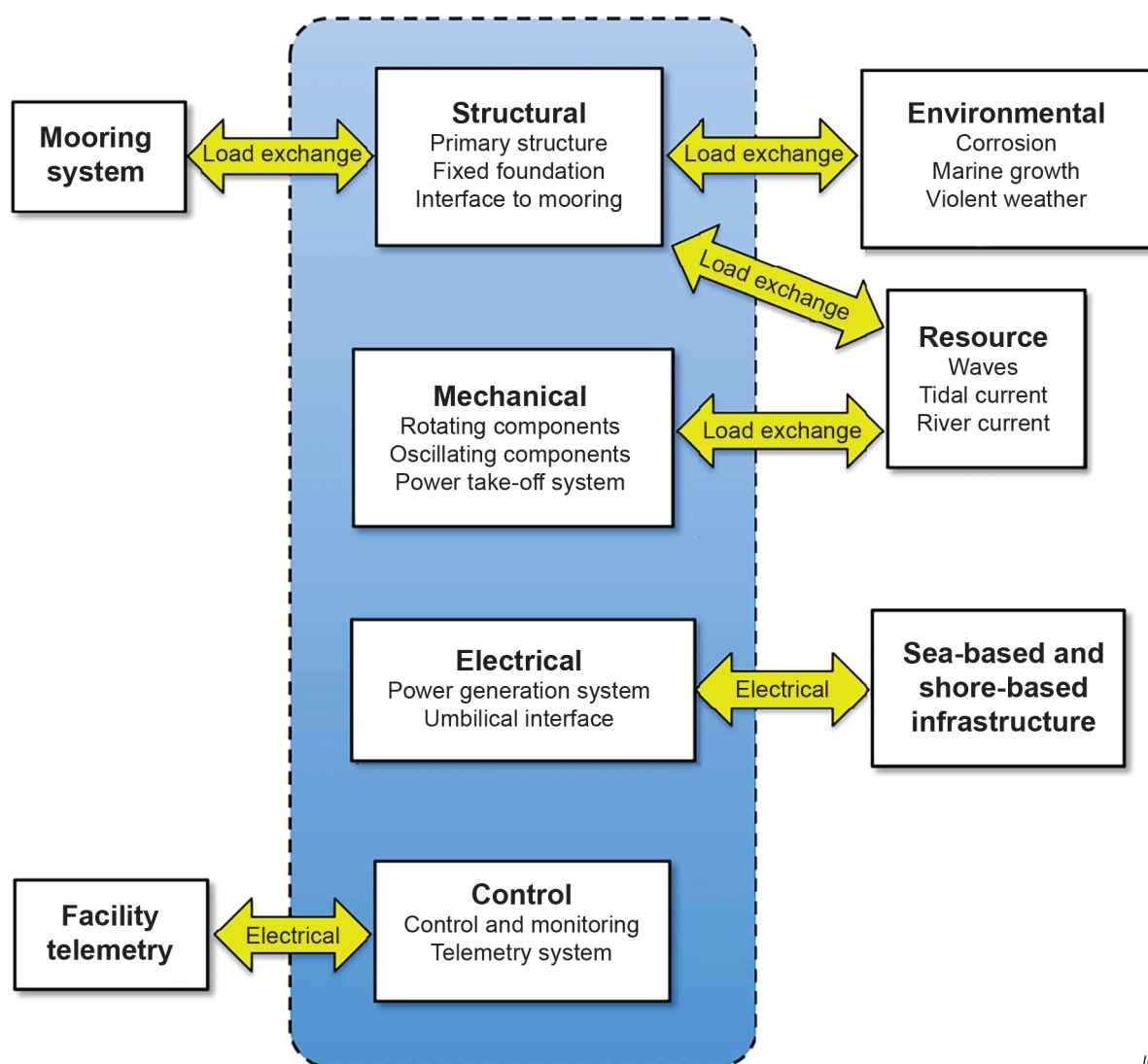
Any of the requirements of this document may be altered if it can be demonstrated that the overall safety of the marine energy converter is not compromised. Compliance with this document shall be done in observance of applicable regional regulations.

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

Part 2: Marine energy systems – Design requirements

1 Scope

This document provides design requirements to ensure the engineering integrity of wave, ocean, tidal and river current energy converters, collectively referred to as marine energy converters. Its purpose is to provide an appropriate level of protection against damage from all hazards that may lead to catastrophic failure of the MEC structural, mechanical, electrical or control systems. Figure 1 illustrates the scope of this document and critical interfaces with other elements of a marine energy converter installation.



IEC

Figure 1 – Marine energy converter system boundary for IEC TS 62600-2 and interfaces

This document provides requirements for MEC main structure, appendages, seabed interface, mechanical systems and electrical systems as they pertain to the viability of the device under site-specific environmental conditions. This document applies to MECs that are either floating or fixed to the seafloor or shore and are unmanned during operational periods.

NOTE Refer to IEC 62600-10 for guidance on the design of moorings for floating MECs.

In addition to environmental conditions, this document addresses design conditions (normal operation, operation with fault, parked, etc.); design categories (normal, extreme, abnormal and transport); and limit states (serviceability, ultimate, fatigue and accidental) using a limit state design methodology.

Several different parties may be responsible for undertaking the various elements of the design, manufacture, assembly, installation, erection, commissioning, operation, maintenance and decommissioning of a marine energy converter and for ensuring that the requirements of this document are met. The division of responsibility between these parties is outside the scope of this document.

This document is used in conjunction with IEC and ISO standards cited as normative references, as well as regional regulations that have jurisdiction over the installation site.

This document is applicable to MEC systems designed to operate from ocean, tidal and river current energy sources, but not systems associated with hydroelectric impoundments or barrages. This document is also applicable to wave energy converters. It is not applicable to ocean thermal energy conversion (OTEC) systems or salinity gradient systems.

Although important to the overall objectives of the IEC 62600 series, this document does not address all aspects of the engineering process that are taken into account during the full system design of MECs. Specifically, this document does not address energy production, performance efficiency, environmental impacts, electric generation and transmission, ergonomics, or power quality.

This document takes precedence over existing applicable standards referred to for additional guidance. This document adheres to a limit state design approach utilizing partial safety factors for loads and materials to ensure MEC reliability in accordance with ISO 2394.

MECs designed to convert hydrokinetic energy from hydrodynamic forces into forms of usable energy, such as electrical, hydraulic, or pneumatic may be different from other types of marine systems. Many MECs are designed to operate in resonance or conditions close to resonance. Furthermore, MECs are hybrids between machines and marine structures. The control forces imposed by the power take-off (PTO) and possible forces from faults in the operation of the PTO distinguish MECs from other marine structures.

The document is applicable to MECs at the preliminary design stage to those that have progressed to advanced prototypes and commercial deployment. It is anticipated that this document will be used in certification schemes for design conformity.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60092-301, *Electrical installations in ships – Part 301: Equipment – Generators and motors*

IEC 60092-350, *Electrical installations in ships – Part 350: General construction and test methods of power, control and instrumentation cables for shipboard and offshore applications*

IEC 60204-1:2016, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60204-11:2018, *Safety of machinery – Electrical equipment of machines – Part 11: Requirements for equipment for voltages above 1 000 V AC or 1 500 V DC and not exceeding 36 kV*

IEC 60228, *Conductors of insulated cables*

IEC 60364-5-54, *Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors*

IEC 60812, *Failure modes and effects analysis (FMEA and FMECA)*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61643-11, *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems – Requirements and test methods*

IEC 61882, *Hazard and operability studies (HAZOP studies) – Application guide*

IEC 62305-3, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

IEC 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

IEC TS 62600-1, *Marine energy – Wave, tidal and other water current converters – Part 1: Terminology*

IEC TS 62600-201, *Marine energy – Wave, tidal and other water current converters – Part 201: Tidal energy resource assessment and characterization*

IEC TS 62600-10, *Marine energy – Wave, tidal and other water current converters – Part 10: Assessment of mooring system for marine energy converters (MECs)*

ISO 2394, *General principles on reliability for structures*

ISO 12473, *General principles of cathodic protection in sea water*

ISO 17776, *Petroleum and natural gas industries – Offshore production installations – Major accident hazard management during the design of new installations*

ISO 19900, *Petroleum and natural gas industries – General requirements for offshore structures*

ISO 19901-1: 2015, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 1: Metocean design and operating considerations*

ISO 19901-4, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 4: Geotechnical and foundation design considerations*

ISO 19901-6, *Petroleum and natural gas industries – Specific requirements for offshore structures – Part 6: Marine operations*

ISO 19902, *Petroleum and natural gas industries – Fixed steel offshore structures*

ISO 19903, *Petroleum and natural gas industries – Fixed concrete offshore structures*

ISO 31010, *Risk management – Risk assessment techniques*

DNVGL-OS-C301, *Stability and watertight integrity*

DNVGL-RP-C205, *Environmental conditions and environmental loads*

EUROCOMP, *Structural design of polymer composites*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 62600-1 as well as the following apply.

IEC and ISO maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

4 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in IEC TS 62600-1 as well as the following apply.

d	water depth
f	wave spectrum frequency
f_d	material property design value
f_k	material property characteristic value
f_P	wave spectrum peak frequency
f_E	elastic buckling stress
f_y	specified minimum yield stress
F_d	load design value
F_k	load characteristic value
g	gravitational acceleration
h	ice thickness with a 50-year return period
H_1	extreme wave height with a return period of 1 year
H_5	extreme wave height with a return period of 5 years
H_{50}	extreme wave height with a return period of 50 years
H_b	breaking wave height
H_{EWH}	extreme wave height
H_{OWH}	operational wave height
H_{rated}	device rated wave height
H_{m0}	significant wave height
$H_{m0, OSS}$	significant wave height of the operational sea state
H_{mn}	significant wave height with a return period of n years

I	turbulence intensity
K	turbulent kinetic energy
MEC	marine energy converter
REC	river energy converter
s	slope of beach floor
S	pseudo response spectrum
SWL	still water level
T	wave period
T_P	peak wave period
TEC	tidal energy converter
U_{bw}	breaking wave current velocity
U_{in}	cut-in velocity for a TEC
U_{rated}	device rated current velocity
U_{out}	cut-out velocity for a TEC
U_{ss}	sub-surface current velocity
U_w	wind-generated current velocity
V	10 min mean wind speed
V_{1-hour}	1 h mean value of wind speed at 10 m height above SWL
V_5	extreme wind speed with a return period of 5 years
WEC	wave energy converter
z	height above still water level
σ_c	ice crushing strength
σ_U	standard deviation of the current velocity
$\sigma_{U,c}$	characteristic standard deviation of mean current velocity at a specified probability distribution
γ	damping ratio
γ_f	partial load safety factor
γ_m	partial material safety factor
ω	angular frequency
λ	slenderness parameter; wave length

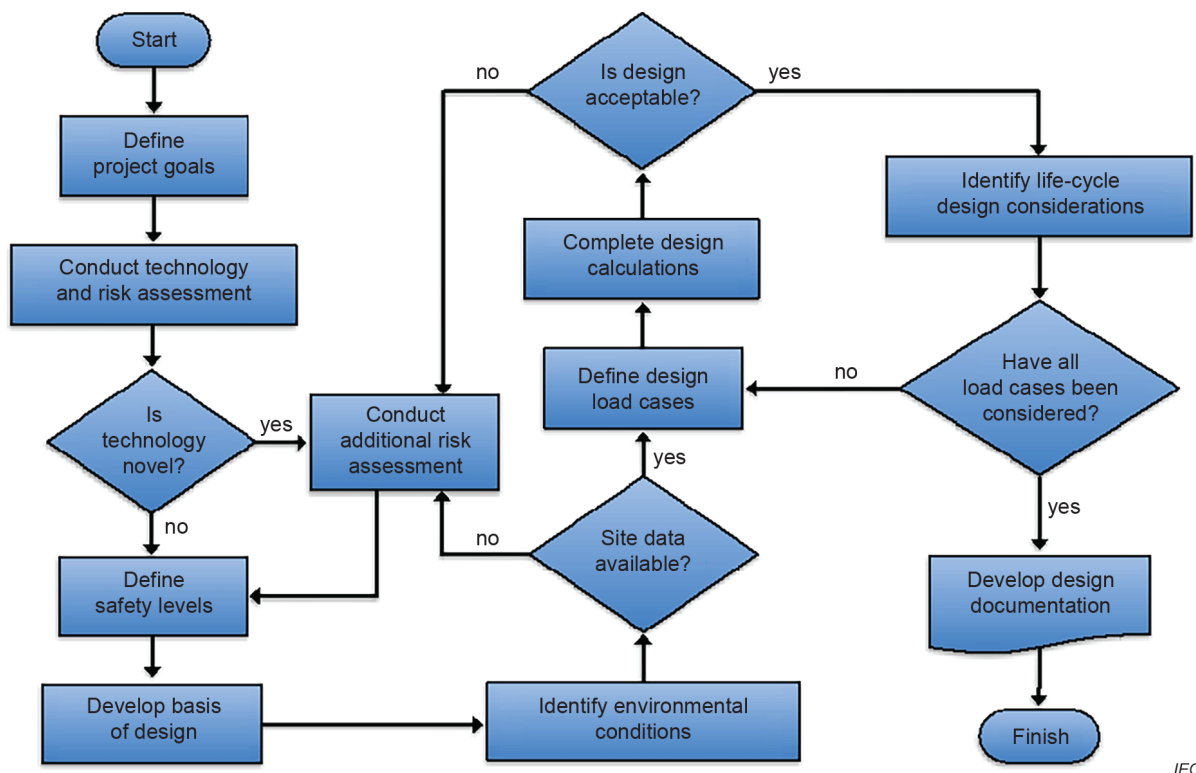
5 Principal elements

5.1 General

The engineering and technical requirements to ensure the integrity and safety of the structural, mechanical, electrical and control systems of a MEC are given in the following clauses. This specification of requirements applies to the design, manufacture, installation, operation and maintenance of MECs.

A common characteristic of all MEC devices that distinguishes them from other marine devices is the requirement to determine loading and response due to interaction with power take-off (PTO) and control systems.

The design process for MECs is illustrated in Figure 2. The process is iterative and shall incorporate load and load effect calculations for the complete MEC, including the support structure, foundation or moorings, mechanical and electrical elements. The structural design of a MEC shall be regarded as completed when its structural integrity has been verified based on the limit state analyses described in Clause 7.



IEC

Figure 2 – Design process for a MEC

Verification of the adequacy of the design shall be made by calculation and/or by testing. If test results are used in this verification, the environmental conditions during the test shall be shown to reflect the characteristic values and design situations defined in this document.

5.2 Design objectives

Design objectives shall be established to outline the design targets and project requirements. They may include safety, integrity, environmental impact, functionality, operability, efficiency, reliability, lifecycle and availability targets. These objectives should take into account the needs of all MEC stakeholders. The design objectives should consider all phases of the project, including manufacturing, transport, installation, operation, maintenance and decommissioning.

5.3 Technology assessment

As a part of MEC technology development, a technology assessment shall be carried out. The first stage of this will be to break down the MEC technology into distinct elements or components that can be individually assessed for their maturity. This system decomposition is achieved through a structural and/or functional breakdown of the overall system into subsystems, equipment and components down to the smallest element/sub-component that can be assessed. The technology will be then assessed for two aspects:

- degrees of novelty; and
- application area.

For degrees of novelty, it is necessary to decide for each element/sub-component which category it falls into:

- verified;
- limited field history; or
- new or unverified.

For the application area, it is necessary to decide for each element/sub-component which category it falls into:

- known; or
- new.

From this, the technology class can be established using Table 1.

Table 1 – Technology classes

Application area	Technology degree of novelty		
	Verified	Limited field history	New or unverified
Known	1	2	3
New	2	3	4

The technology classes indicate the following levels of maturity.

- a) No new technical uncertainties.
- b) New technical uncertainties.
- c) New technical challenges.
- d) Demanding new technical challenges.

Verified technology operating in a known application is considered technology classified as Class 1. No new technical uncertainties. Verified technology shall be documented in accordance with recommended practices and relevant international standards. All other classes reflect varying levels of technology novelty.

All systems and phases (from manufacturing to decommissioning) should be considered. New technologies (Classes 2-4) have increasing degree of technical uncertainty and shall be subject to qualification in addition to traditional certification processes. Verified technology covered in Class 1 can utilize traditional certification procedures in place with third-party classification entities. Class 2 items normally require only additional design studies to mitigate the added risk. Class 3 and 4 items normally require testing in addition to design studies.

5.4 Risk assessment

The purpose of a risk assessment is to provide further information regarding technology uncertainties to support the development of the technology. While performing the risk assessment the following shall be carried out:

- definition of risks reflecting the level of acceptance of the risks to success compatible with the phase of technology development and requirements from authorities and other stakeholders;
- identify, where possible, relevant standards for components and sub-systems;
- assess maintenance, condition monitoring and possible concept modifications to reduce the risks to an acceptable level;
- define consequences and technology classes that are in line with the range of events and failures for the technology; and

- in lieu of data obtained from the specific application or the technology, the probability of the event / failure to be used during the risk assessment can be derived from relevant data from other industries, provided that an assessment of the impact of the new application in the marine renewables sector is taken into account.

A risk assessment can be done using a number of techniques such as (but not limited to):

- failure mode effects and criticality analysis (FMECA) – guidance on FMECA can be found in IEC 60812;
- hazard identification study (HAZID) and hazard and operability study (HAZOP) – guidance on HAZID and HAZOP can be found in ISO 17776 and IEC 61882, respectively; and
- structured what if technique (SWIFT), which is described in ISO 31010.

The process shall be carried out based on (but not limited to) the following:

- design objectives;
- technology assessment;
- detailed drawings of items subject to review;
- drawings and descriptions of control and safety systems;
- material specifications;
- outline of fabrication procedures;
- outline of installation procedures; and
- outline of inspection and maintenance procedures.

5.5 Safety levels

The appropriate safety level shall be selected with due regard to possible consequences of failure.

The assessment of the consequences of failure shall cover all phases of MEC installation, operation, maintenance and decommissioning and shall consider:

- risk to life and injury;
- environmental impact, e.g. pollution due to fluid releases and risk to marine life;
- economic consequences, e.g. cost of repair, cost due to loss of power generation; and
- loss of public reputation and other political and societal consequences.

Three safety levels for MECs depending on the consequences of failure are defined in Table 2 along with associated target probabilities of failure.

Table 2 – Safety levels

Safety level	Definition	Target probability of failure
SL1	High risk to human life and/or injury, significant environmental impact and/or very high economic or political consequences	$< 10^{-5}$ per year
SL2	Risk of human injury, significant environmental impact and/or high economic or political consequences	$< 10^{-4}$ per year
SL3	Low risk of human injury and minor environmental and economic consequences	$< 10^{-3}$ per year

The requirements in this document, including partial safety factors for loads and materials, have been derived to comply with the target probability of failure for safety level 2 (SL2). Other safety levels may be appropriate depending on project particulars.

Safety levels shall be considered while defining redundancy or safety features for the equipment and systems. Different safety levels may be required for different sub-systems/components of the same MEC depending on consequences of their failure. Higher levels of safety might be required for critical sub-systems and components depending on their consequences of failure.

The safety level of a MEC shall satisfy local regulations where the device is designed to operate. To achieve this, SL1 may need to be selected for the MEC design.

When failure of a MEC does not imply risk of human injury and environmental impact and may only cause minor economic consequences, SL3 may be selected, subject to compliance with local regulations. Safety requirements for the MEC, including partial safety factors, shall be agreed upon between the manufacturer and the customer.

5.6 Basis of design

The basis of design defines the technical framework for a project, the intended operational environment for the MEC and the associated parameters to be adopted for design. The basis of design is also a key input to the technology qualification process (see 5.3). Typically, a basis of design would include the following information:

- governing project description, general requirements, deployment duration, targets and objectives;
- reference assumptions (e.g. datums, legislation and regulations);
- site definition (e.g. location, water depth);
- environmental conditions (e.g. water levels, currents, wave conditions, turbulence, wind); and
- seabed characterisation (e.g. geotechnical, bathymetry).

The basis of design shall be applicable to all stages of MEC development, subject to refinement as operational data becomes available. In addition to being a design governance document, a key objective of the basis of design is to promote consistency across design activities of a project and to manage updates in light of new information.

5.7 Environmental conditions

A MEC shall be designed to safely withstand the environmental conditions defined in the basis of design. The environmental conditions described in Clause 6 include waves, currents, water level, wind, sea ice, marine growth, seismic forces and seabed conditions. These conditions apply to the MEC when it is deployed.

5.8 Life cycle considerations

Clause 12 considers design conditions when the MEC is not operationally deployed. This includes inspection and maintenance operations, where it is anticipated that personnel will be required to work on the MEC. Other life cycle MEC phases include fabrication, transportation, installation and decommissioning.

Specific load cases addressed in Clause 12 include safe lifting and handling of the MEC; stability; watertight integrity; inspection and maintenance operations; and metocean limits for life cycle operations.

5.9 Load definition and load combinations

Clause 7 defines the load cases that MECs are expected to experience when deployed. Design load cases used to determine the structural integrity of the MEC shall be calculated from the following combinations:

- normal design situations and normal external conditions;

- fault design situations when the MEC is operating with a single major system failure and appropriate environmental conditions; and
- normal design situations and extreme environmental conditions.

Clause 7 also defines MEC design limit states and loading partial safety factors.

5.10 Limit state design

The performance of a MEC or part of it shall be designed with reference to a specified set of limit states beyond which the MEC no longer satisfies the design requirements. Ultimate, fatigue, serviceability and accidental limit states are defined in 7.3.4.

A MEC and its components shall be designed, constructed and maintained so that they are suited to their intended use for the design service life. In particular, the MEC and its components shall:

- withstand extreme actions likely to occur during construction and anticipated use (ULS requirement);
- perform adequately during normal operation (SLS requirement);
- not fail under repeated actions (FLS requirement); and
- provide an appropriate level of robustness to avoid accidental failure (ALS requirement)

5.11 Partial safety factors

This document applies partial safety factors for loads and materials to support limit state design. Limit states are the acceptable limits for the safety and serviceability requirements of the structure before failure occurs. The design of MECs by this method will ensure that they will not reach limit states and will not become unfit for the use for which they are intended.

Partial safety factors for loads are given in Clause 7 and for materials in Clause 9. Partial safety factors for loads and materials shall be calibrated in the same engineering model to ensure that appropriate values are derived for design calculations. To achieve design loads and material strength for design calculations, the characteristic load and material strength are modified by the partial safety factor for loads and materials, respectively. The characteristic load for a given limit state is defined as the value below which not more than a prescribed percentage of test results may be expected to fail.

Model testing and prototype tests may also be used to support analytical design methods, as specified in ISO 2394.

To ensure safe design values, the uncertainties and variability in loads and materials are taken into account by partial safety factors as defined in formulas (1) and (2).

$$F_d = \gamma_f F_k \quad (1)$$

where:

- F_d is the design value for loads acting on the MEC for the given design load case;
- γ_f is the partial safety factor for loads;
- F_k is the characteristic value for the load;

$$f_d = \frac{f_k}{\gamma_m} \quad (2)$$

where:

- f_d are the design values for material properties;
- γ_m are the partial safety factors for material properties;
- f_k are the characteristic values of material properties.

5.12 Structural modelling and analysis

Structural analysis is the process of determining the action effects in a structure, or part thereof, in response to a given set of actions. Action effects required for the design of MECs typically include the following:

- internal section forces, which shall not exceed the strength of the section;
- displacements and vibrations, which shall be within acceptable limits; and
- support reactions, from which the required foundation or mooring capacity can be determined.

The number, types and extent of analyses to be performed shall cover all stages of the lifetime of the MEC. However, if it can be demonstrated that particular stages in the design service life of a component of the MEC do not govern its design, such stages need not be analysed for that component. In general, refer to ISO 19902 for structural design equations.

6 Environmental conditions

6.1 General

The environmental conditions described in this clause shall be considered in the modelling, analysis and prediction of environmental loads on MECs. The most important environmental phenomena for most MECs, waves, currents, and water level, are discussed in 6.2. Other conditions, such as wind, ice, earthquake, soil conditions, temperature, and marine growth, are discussed in 6.3.

The marine conditions for load and safety considerations are divided into the normal marine conditions that are statistically expected to occur more frequently than once per year, and extreme marine conditions that are expected to occur less frequently than once per year i.e. defined as having return periods greater than one year. Load cases associated with normal and extreme conditions are prescribed in Clause 7. ISO 19901-1 provides additional guidance for the determination of environmental conditions and their relevant parameters.

6.2 Primary environmental conditions

6.2.1 General

Primary environmental conditions shall be used for the development of MEC modelling, unless site-specific secondary environmental conditions are more severe and likely to occur. The conditions defined in this section are used to compose the design load cases covered in Clause 7.

6.2.2 Waves

6.2.2.1 General

Waves are considered a primary influence on loading for WECs and some TECs. Characteristics of the site, including the combination of wave heights, periods and directions should be considered.

6.2.2.2 Operational sea state (OSS)

The Operational Sea State (OSS) is characterized by a significant wave height (H_{m0}), a peak period (T_p) and a wave direction. For use in DLCs, OSSs shall be defined as those sea states

likely to occur within a 1-year period. Where available, regional or site-specific data shall be used to specify spectral shape and directional distributions.

6.2.2.3 Operational wave height (OWH)

The Operational Wave Height (OWH), H_{OWH} , shall be derived from analysis of appropriate measurements and/or hindcast data for the site of deployment of the MEC and defined as the single most likely wave height. Consideration shall be given to the range of wave periods (T) appropriate to the operational wave height. Design calculations shall be based on values of the wave period within this range that result in the highest loads on the MEC.

The wave periods, T , in combination with the operational wave heights, H_{OWH} , may be assumed to be within the range given by:

$$11,1\sqrt{\frac{H_{m0,OSS}}{g}} \leq T \leq 14,3\sqrt{\frac{H_{m0,OSS}}{g}} \quad (3)$$

where:

$H_{m0,OSS}$ is the significant wave height of the operational sea state in metres;

g is gravitational acceleration in m/s²; and

T is the wave period in seconds.

Formula (3) is appropriate only for deepwater waves. Water is considered 'deep' for a wave, if the water depth is greater than one-half of the wavelength of the wave. See Annex D for more information on shallow water hydrodynamics and breaking waves. The full dispersion relation shall be solved for waves falling in the intermediate regime.

Short-term stationary irregular sea states shall be described by a wave spectrum that represents the power spectral density function of the vertical sea surface displacement. Where possible, site-specific spectra should be used. When site-specific-spectra are unavailable, idealized spectra can be used. The most frequently used spectra for wind-generated seas are Pierson-Moskowitz (PM) spectra for a fully developed sea, and the JONSWAP spectra for a developing sea. Standard wave spectrum formulations are given in Annex C. The Ochi-Hubble spectrum based on superposition of two modified PM spectra or the Torsethaugen double peak spectral model based on sea state and swell may also be appropriate. Information on swell spectra can be found in ISO 19901-1.

6.2.2.4 Extreme sea state (ESS)

The designer shall consider extreme stochastic sea states for 50-, 5-, and 1-year return periods. The return period is the average period between occurrences of a particular value being exceeded. When possible, the spectral parameters (H_{m0} , T_p , etc.) should be determined via a contour approach, where a plot of H_{m0} versus T_p for various return periods establishes contour lines (see DNV RP 205). Alternatively, the one-dimensional significant wave height distribution can be used to define three extreme significant wave heights (H_{m50} , H_{m5} , and H_{m1} , respectively). For both a contour and one-dimensional approach, historical measurements should be used if available. Alternatively, hindcast data can be used if historical measurements are unavailable. If a one-dimensional approach is taken, a wide range of the remaining spectra parameters can be based on empirical relations given in formula (3). Design calculations shall be based on values of peak spectral period that result in the most onerous loads acting on the MEC.

6.2.2.5 Extreme wave height (EWH)

The extreme wave height (H_{EWH}) is the largest single wave height for a given return period. As with the ESS, EWH shall be considered for 50-, 5-, and 1-year return periods. The values

of H_{50} , H_5 , H_1 and the associated wave periods may be determined from a one-dimensional probabilistic analysis of historical measurements or hindcast data. Alternatively, the designer may assume the following based on the Rayleigh distribution of wave heights assuming a three-hour storm.

$$H_n = 1,86 H_{mn} \quad (4)$$

Here, H_{mn} is the significant wave with a return period of n years. Thus, H_n is the corresponding extreme wave height. The general form of (4) for a period t and zero crossing period T_z is:

$$H_n = \frac{H_{mn}}{2} \sqrt{\ln(t/T_z)} \quad (5)$$

Extreme wave height shall be considered in design calculations for the range of deepwater waves periods given in formula (3).

The extreme wave heights H_{50} , H_5 , H_1 and the associated wave periods for shallow water sites shall be determined from analysis of appropriate site-specific measurements. In the absence of measurements, H_{50} , H_5 and H_1 shall be assumed equal to the breaking wave height if the breaking wave height is less than the values of H_{50} , H_5 and H_1 determined from the Rayleigh distribution given by formulae (3) and (4). See Annex D for more information on breaking waves.

The computations shall be based on values of the wave period within this range that result in the highest loads on the MEC.

6.2.3 Sea currents

6.2.3.1 General

The most common categories of sea currents are: wind generated currents, tidal currents, circulatory currents, loop and eddy currents, soliton currents, and longshore currents. The total current velocity is the vector sum of all components at a given position in the water column. The designer shall determine whether sea currents may be neglected for calculation of fatigue loads considering site characteristics and MEC geometry.

6.2.3.2 Sub-surface currents

In the absence of other data, the sub-surface current velocity, $U_{ss}(z)$, profile may be characterized by a simple power law over the water depth, d , as a function of height below SWL, z :

$$U_{ss}(z) = U_{ss}(0) \left\{ (z+d)/d \right\}^{\frac{1}{7}} \quad (6)$$

The 1-year, 5-year and 50-year return periods of the sub-surface velocity, $U_{ss}(0)$, may be determined from analysis of measurements of tidal, storm surge, wind generated and wave induced surf currents. If the current velocity is of significant importance to the design, current velocity measurements shall be carried out at the MEC deployment site.

6.2.3.3 Wind-generated near-surface currents

Wind-generated current may be characterized as a linear distribution of velocity, $U_w(z)$, reducing from the surface velocity $U_w(z)$ to zero at a depth of 20 metres (m) below the static water level SWL:

$$U_w(z) = U_w(0) \left\{ (1 + z) / 20 \right\} \quad (7)$$

The wind generated current velocity at the sea floor will be non-zero at sites where the water depth is less than 20 m. The wind generated sea surface current velocity may be assumed to be aligned with the wind direction and may be determined from:

$$U_w(0) = 0,01 V_{1-hour}(z = 10m) \quad (8)$$

where $V_{1-hour}(z = 10 \text{ m})$ is defined as the 1 hour (h) mean value of wind speed at 10 m height above SWL.

The 1-year, 5-year and 50-year return periods of $V_{1-hour}(z = 10 \text{ m})$ may be determined from analysis of site measurements.

6.2.3.4 Tidal currents

Tidal currents are often magnified by topographical features, such as headlands, inlets and straights, or by the shape of the seabed when water is forced through narrow channels. Strong tidal currents may exist in inlets and straits in coastal regions (see IEC 62600-201).

6.2.3.5 Operational current model (OCM)

The operational current model includes the appropriate site-specific combination of wind-generated currents and breaking wave surf induced currents, if any, associated with operational wave conditions.

6.2.3.6 Extreme current model (ECM)

The extreme current model is defined as the appropriate site-specific combination of sub-surface currents, wind generated currents and breaking wave surf induced currents, if any, associated with peak spring tides.

6.2.3.7 Turbulence

Marine tidal current turbulence generated by sea bed material, ripples, bed forms, changes in bathymetry, waves and swell, ambient environment, and vortices shed from the blades and support structure shall be considered in determining frictional drag, flow separation, thickness of boundary layers, extent of secondary flows, and the spreading of jets and wakes. Flow fluctuations caused by turbulence will vary with current velocity. The three vector components of the turbulent current velocity are defined as:

- streamwise: along the principal direction of the flow;
- transverse: horizontal and normal to the streamwise direction, and
- vertical: normal to both the longitudinal and transverse directions.

Turbulence intensity, I , a measure of current flow variability, is given as:

$$I = \frac{u'}{\bar{U}} \quad (9)$$

where:

u' is the standard deviation of the streamwise, transverse and vertical turbulent current velocity;

$\bar{U}$ is the mean current velocity over a set period of time, usually taken as 10 min.

For the normal turbulence model (NTM), the current velocity shall be defined as the 50 % percentile in the probability distribution of the standard deviation u' of the 10 min mean current velocity at a specific point in the water column. The 95 % percentile in the probability distribution of the standard deviation u' shall be used for the extreme turbulence model (ETM).

The turbulent kinetic energy, K , can be estimated by:

$$K = \frac{2}{3}(u')^2 \quad (10)$$

Site-specific spectral densities of the current speed data show how the energy of the current turbulence is distributed between different frequencies. Acoustic Doppler Current Profilers (ADCP) used to characterise the flow conditions of a tidal turbines sites generally give conservative estimates of turbulence. Acoustic Doppler Velocimeters (ADV) give more accurate speed readings but their location in the current stream is critical.

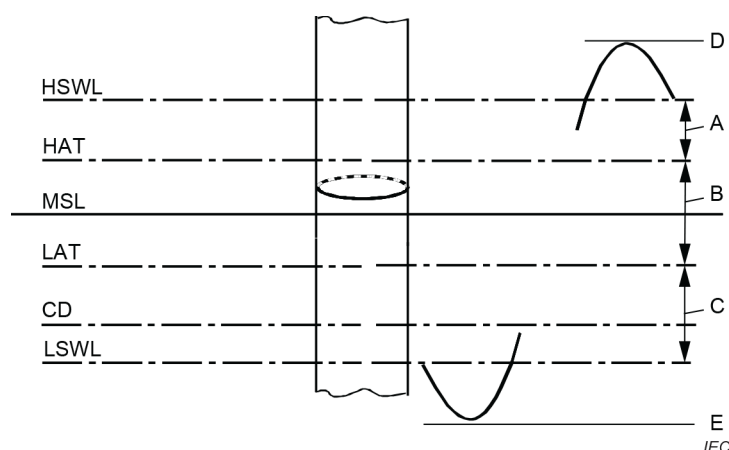
When measured current data are insufficient to establish site-specific spectral densities, turbulence models are to be used. The turbulence model shall include the effects of varying current speed, shears and direction and allow rotational sampling through varying shears. IEC 62600-201 provides guidance on use of turbulence modeling for power performance projection, which however, may be insufficient for determining the long-term spectral component of turbulence necessary to estimate TEC fatigue loading.

NOTE Modeling of turbulence intensity, I , and turbulent kinetic energy, K , in highly energetic current fields is an area of ongoing research, especially in regions affected by TEC operation. [Kilcher, et al., 2016, see Bibliography]

6.2.4 Water level

6.2.4.1 General

The variation in water level at the site shall be taken into account in the calculation of the hydrodynamic loading of MECs. The designer may assume a constant water level equal to the mean still water sea level (MSL) for ultimate load cases involving operational wave conditions (OSS and NWH). Different water levels are illustrated in Figure 3.



HSWL	highest still water level	A	positive storm surge
HAT	highest astronomical tide	B	tidal range
MSL	mean sea level	C	negative storm surge
LAT	lowest astronomical tide	D	maximum crest elevation
CD	chart datum (often equal to LAT)	E	minimum trough elevation
LSWL	lowest still water level		

Figure 3 – Definition of water levels

6.2.4.2 Normal water level range (NWLR)

The normal water level range shall be assumed equal to the variation in water level with a return period of 1 year. The normal water level range may be assumed to be equal to the variation between highest astronomical tide (HAT) and lowest astronomical tide (LAT) in the absence of site-specific data to characterize the long-term probability distribution of water levels.

6.2.4.3 Extreme water level range (EWLR)

The following extreme water level ranges shall be used if the long-term joint probability distribution of water level is not available:

- highest still water level (HSWL) with a return period of 50 years, based on an appropriate combination of highest astronomical tide and positive storm surge;
- lowest still water level (LSWL) with a return period of 50 years, based on an appropriate combination of lowest astronomical tide and negative storm surge; and
- water level associated with the maximum breaking wave load.

6.3 Secondary environmental conditions

6.3.1 General

Secondary environmental conditions shall be considered when the potential exists for significant MEC loading at the deployment site.

6.3.2 Breaking waves

A breaking wave is a wave whose amplitude reaches a critical level that causes large amounts of wave energy to be transformed into turbulent kinetic energy. The effect of breaking waves shall be assessed, if necessary, for a given site during the design of the MEC. Annex D provides guidance for modelling breaking waves based on site conditions and presents an empirical model of the distribution of wave heights for shallow water (see also DNV-RP-C205).