



DPC: 25/30510480 DC

BSI Group Headquarters

389 Chiswick High Road London W4 4AL

Tel: +44 (0)20 8996 9000

Fax: +44 (0)20 8996 7400

www.bsigroup.com

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Please notify admin.start@bsigroup.com if you are aware of any keywords that might assist in clarifying or identifying the standard or of the content of this standard:

- i) has any issues related to 3rd party IPR, patent or copyright
- ii) affects other national standard(s)
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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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UK Vote

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



114/597/CD

COMMITTEE DRAFT (CD)

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114/456/RR

IEC TC 114 : MARINE ENERGY - WAVE, TIDAL AND OTHER WATER CURRENT CONVERTERS

SECRETARIAT:

United Kingdom

SECRETARY:

Mr Danny Peacock

OF INTEREST TO THE FOLLOWING COMMITTEES:

TC 82

ASPECTS CONCERNED:

This document is still under study and subject to change. It should not be used for reference purposes.

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TITLE:

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

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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 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.

This document is a Technical Specification that has been prepared by IEC technical committee 114: Marine energy – Wave, tidal and other water current converters.

- a) The first edition published in 2016 was based on design methodologies developed by TC88.
- b) The second edition published in 2019 set forth design conditions unique to marine energy converters.

- c) This third edition streamlines the flow of the document and addresses specific considerations for MEC variants, including hybrid systems that include mooring in the power take off (PTO) and considerations for small MEC designs.

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 IEC Technical Committee (TC) 114 suite of Technical Specifications published under the general title *Marine energy conversion systems*, 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.

NOTE 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 document outlines minimum design requirements for marine energy converters (MECs) and is not intended for use as a complete design specification.

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. MECs have many variants including wave (WEC), tidal (TEC), ocean current (OCEC), river current (REC), and Ocean Thermal Energy Conversion (OTEC).

Any of the requirements of this document may be deviated if it can be demonstrated that the overall safety and performance of the marine energy converter is not compromised. Compliance with this document shall be done in observance of applicable regional regulations. Per ISO/IEC Directives Part 2, the Normative References listed in Clause 2 are for information. How these references apply are found in the place where they are cited, as applicable to the MEC being designed.

An essential element for any published Technical Specification or International Standard is to allow an opportunity to provide feedback on its contents to the appropriate TC 114 Working Group. TC 114 utilizes a standard methodology to allow this. To submit feedback such as proposed changes, corrections and/or improvements to this document, please send an email to the TC 114 Chair using the **Contact TC 114 Officers** feature on the IEC TC 114 Dashboard, accessible at www.iec.ch/tc114. On the right side of the Dashboard under Further information select the link to contact the TC 114 Officers. On the subsequent page find and select the Send Email link for the Chair to access the email tool. Complete all the required elements within the email pop-up. For the Subject field please include the document title and edition you are providing feedback for (ex: Feedback for TS 62600-2 ED2). In the Message field, include text which summarizes your feedback and note if further information can be made available (note attachments are not allowed). The Chair may request added information as needed before forwarding the submission to the remaining TC 114 Officers for review and then to the appropriate Working Group for their consideration.

1 Scope

This document provides design requirements to ensure the engineering integrity, safety, and performance of marine energy conversion systems. The primary focus will be on Marine Energy Converters (MECs), to include the wide range of use cases and sizes of MECs using wave, tidal, ocean current, and river current and the wide range of outputs such as electrical or mechanical energy. Note that general guidance on design of an Ocean Thermal Energy Conversion (OTEC) is covered in IEC TS 62600-20. This document does not pertain to hydroelectric impoundments and barrages and salinity gradient systems.

The purpose of this document is to provide an *appropriate level of protection* against damage from the most likely hazards that may lead to catastrophic failure of the MEC structural, mechanical, electrical or control systems. The document is applicable to MECs at the preliminary design stage as well as those MECs that have progressed to advanced prototypes and commercial deployment. It is anticipated that this document will be used in certification schemes for design conformity.

Figure 1 illustrates the scope of this document and critical interfaces with other elements of a marine energy conversion system, which include the 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 specification of requirements applies to the design, manufacture, transportation, installation, commissioning, operation, maintenance, and decommissioning of MECs.

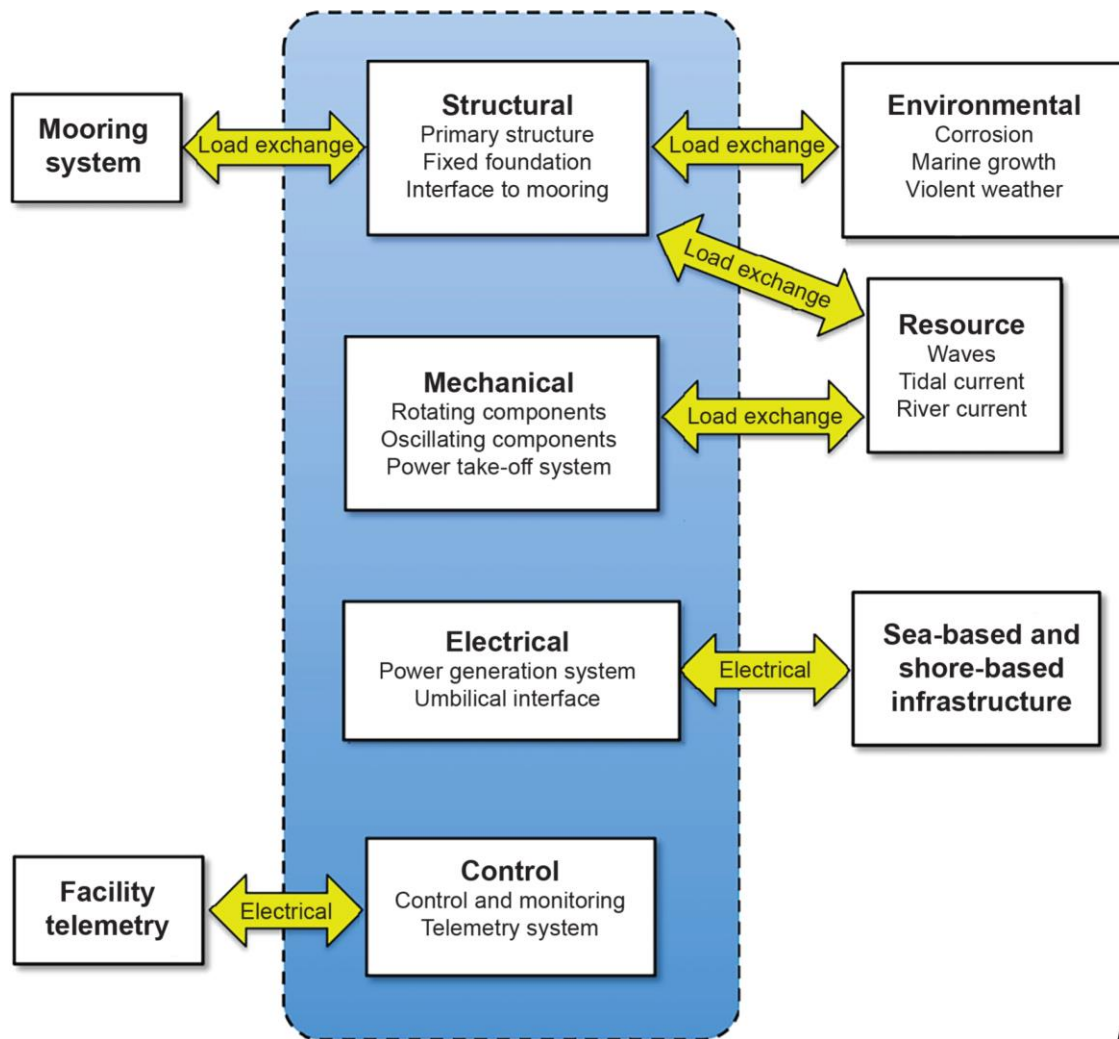


Figure 1 – Marine energy converter system boundary for this document and interfaces to boundary systems.

This document uses a limit state design methodology with partial safety factors for loads and materials to ensure MEC reliability as per the general principles discussed in [ISO 2394 \[1\]](#).

Several different parties may be responsible for undertaking the various elements of the design, manufacture, transportation, installation, commissioning, operation, maintenance, and decommissioning of MECs. 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.

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, or power quality. The designer shall analyze the MEC system requirements, including connected systems, to ensure that the outputs of MECs are useful for the intended purpose of the marine energy conversion system.

MECs are still in their relative infancy and so innovations are happening all the time. The IEC Maintenance Team responsible for this document is working hard to ensure the technical specifications are appropriate for the sector, and the recommendations provide the correct balance between ensuring consistency in approach and allowing innovation where required. This Technical Specification needs to be tried and tested in more operational situations, and

then revised, to ensure the MECs are fit for purpose. The Maintenance Team actively encourages end users to provide feedback on the contents and recommendations. If you wish to contact the Maintenance Team directly with feedback on this TS, wishing to know more about the TS development process or to get involved yourself, please follow the instructions in the Introduction.

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.

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:*

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

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*

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 60204-11:2018, *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 62600-10, *Marine energy - Wave, tidal and other water current converters - Part 10: Assessment of mooring system for marine energy converters (MECs)*

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

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

3 Terms and definitions

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

d	water depth
ESS	Extreme sea state
f	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
I_{ref}	reference value of turbulence intensity corresponding to 50% quantile at 1.5 m/s
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	mean water current velocity (~5 minute mean typical)
U_1	mean water current velocity with a 1-year return period
U_5	mean water current velocity with a 5-year return period
U_{50}	mean water current velocity with a 50-year return period
U_{bw}	breaking wave mean current velocity
U_{in}	cut-in mean velocity for a TEC
U_{rated}	device rated mean current velocity
U_{out}	cut-out mean velocity for a TEC
U_{ss}	sub-surface mean current velocity
U_w	wind-generated mean current velocity
U_{ref}	reference mean 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 associated with wave length

5 Principal elements

5.1 General

Figure 2 shows the design process specified by this document, which is intended to be iterative. The blocks in Figure 2 are described in further detail in the subsequent clauses. 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. Verification of the adequacy of the design shall be made by calculation, numerical simulation, and/or experimental testing.

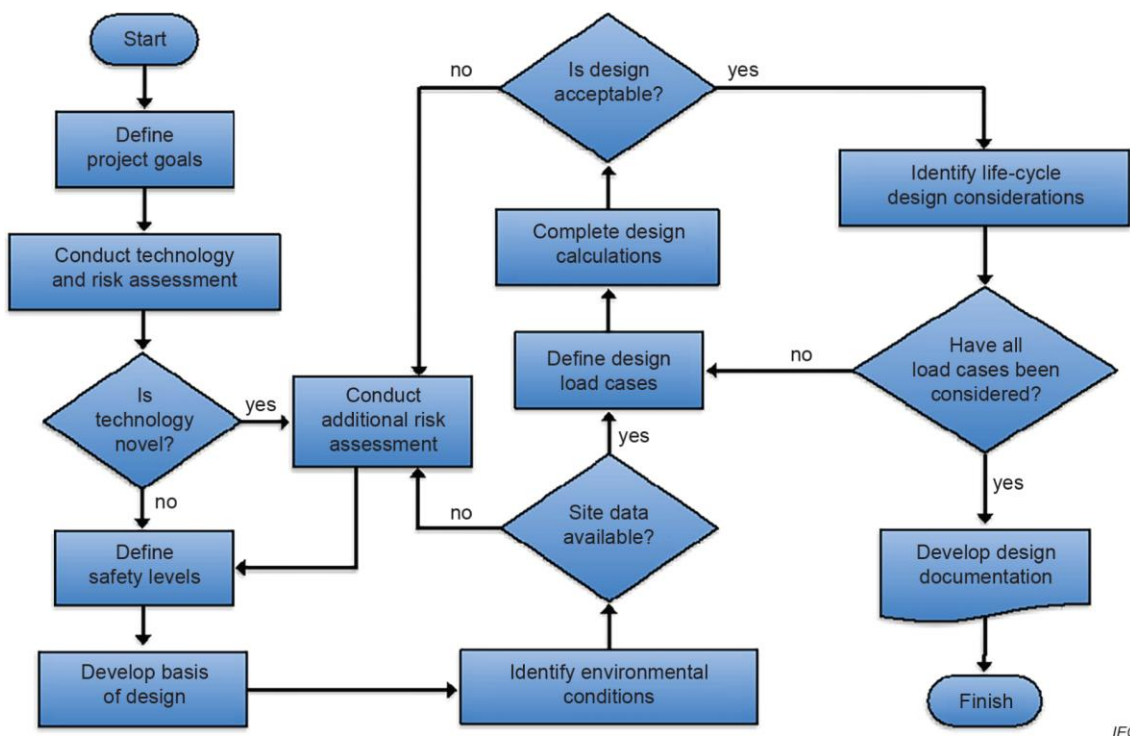


Figure 2 – Design process for a MEC

5.2 Design requirements

Design requirements shall be established to outline the design targets and project goals. They may include safety, integrity, environmental impact, functionality, operability, efficiency, reliability, lifecycle and availability targets. These requirements should take into account the needs of all MEC stakeholders. The design requirements shall analyze all phases of the project,

including design, manufacture, transportation, installation, commissioning, operation, maintenance, and decommissioning of MECs.

5.3 Consideration of the wide range of sizes, scales, end uses (use cases), and life cycles for marine energy conversion systems

The sizes, scales, and end uses (use cases) for marine energy converters (MECs) in a marine energy conversion system project shall be analyzed early in the design process so that the end result is fit for use. The designer should consider how to adapt the design process for the wide range of sizes for marine energy converters. This consideration applies to all MEC variants, ie, wave, tidal, ocean current, river current, and compound/hybrid WECs that incorporate mooring into the power take off (PTO). Some MEC projects may represent a range of operational life cycles, for example short term test deployments versus longer term commercial deployments, and the associated range of risk. All MEC projects may share requirements associated with site location authorities, regulatory and permitting requirements, and risk management. It is important to note that any deviation from the guidance of this document can be done with justification. Accordingly, the concept for the MEC may justify adjustments in the design process within the intent of this document. Of note, where most MECs are sited in locations regulated by state/province or national authorities and subject to public scrutiny, a MEC failure resulting in sinking or human/environmental damage can impact the emerging industry.

5.4 Technology assessment/qualification

As a part of MEC technology development, a technology assessment shall be carried out per IEC TS 62600-4 Technology Qualification. 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.

5.5 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, and the level of acceptance of the risks, should be compatible with the phase of technology development and requirements from authorities and other stakeholders. For example, short-term test deployments versus longer-term commercial deployments may have different risks and mitigations;
- identify, where possible, relevant standards for components and sub-systems;
- assess maintenance, condition monitoring and possible design alterations to reduce the risks to an acceptable level;

- define risks and consequences that are in line with phases of development and the range of events and failures for the technology; and
- in lieu of data obtained from the specific application or scale model testing of the technology, the probability of the event / failure to be used during the risk assessment may be derived from relevant data from other industries as appropriate considering the marine application.

As mentioned , and shown in Figure 2, additional risk assessments shall be carried out towards developing design basis for all phases of a MEC project. Risk assessments are also central to maintaining integrity of a marine energy conversion system through out its entire life cycle (as discussed in Clause 5.8 for the require integrity/safety management for the asset).

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 \[2\]](#);
- hazard identification study (HAZID) and hazard and operability study (HAZOP) – guidance on HAZID and HAZOP can be found in [ISO 17776 \[3\]](#) and [IEC 61882 \[4\]](#), respectively; and
- structured what if technique (SWIFT), which is described in [IEC 31010 \[5\]](#).

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.

Risk assessments shall inform achieved reliability and safety level of the technology, design basis for a project at different stages, considering various uncertainties.

5.6 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 analyze:

- 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 1](#) along with associated target probabilities of failure.

Table 1 – 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

Safety level	Definition	Target probability of failure
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. 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.

Safety levels shall be analyzed 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.

5.7 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 5.4). Typically, a basis of design would include the following information:

- governing project description, general requirements, deployment duration, goals 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.

5.8 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 during all phases of deployment including load changes when it is being towed, installed, operated, or removed.

5.9 Life cycle considerations

This section covers MEC design conditions that may be experienced over the life of the device beyond normal operations, which are covered in [Clause 7](#).

The designer shall consider the entire life cycle of the MEC and the effects of both frequent and infrequent operation. Fabrication, transportation, installation, inspection and maintenance, and decommissioning phases for MECs are significantly different than the operational phase. Each of these phases can impose loads that can affect the engineering integrity of the MEC. Careful

planning is required to provide an appropriate level of protection against damage from all hazards that may lead to failure of the MEC, injury to personnel or damage to the environment. National and international regulations on personnel safety and protection of the environment shall govern marine operations. Refer to ISO 19901-6 for guidance on marine operations.

Specific load cases that the designer shall analyze include safe lifting and handling of the MEC, including testing of lift padeyes and equipment; stability; watertight integrity; inspection and maintenance operations; and metocean limits for life cycle operations.

5.9.1 Planning

The assembly, transportation, installation, and removal of MECs and associated equipment shall be planned in order for the work to be carried out safely. As appropriate, the planning shall include:

- detailed drawings and specifications of the work and a quality assurance plan;
- procedures for safe execution of activities that have to do with foundation and underwater construction (for example pile driving, laying of scour protection and cable laying) especially taking into consideration local weather conditions, time of year, ocean and tidal currents, wind condition and seasonal storm situations;
- procedures for installation of anchors and moorings lines;
- health, safety and environmental rules for offshore work, including safety rules for diving and work in enclosed spaces; and
- evacuation procedures, including procedures for monitoring of wind conditions and sea states to determine when evacuation is required.

5.9.2 Bouyancy, stability and watertight integrity

During the life of a MEC, the device may be floating, submerged or semi-submerged. It is critical that the stability and watertight integrity of the device be maintained during all these conditions. Refer to [6] for additional for guidance on stability and watertight integrity.

An allowance shall be included in the stability calculations to account for uncertainty in mass, buoyancy, location of centre of gravity, density of ballast and ballast water, and density of seawater. Allowance for ice accumulation on exposed structures should also be taken into account if there is a potential for air temperature to be below 0 °C.

If motion responses in various floating stages (such as construction afloat, towing and installation) can cause loss of freeboard, stability or station keeping, model tests and CFD simulations may be warranted in combination with dynamic analyses. Changes in buoyancy and stability from floating, to neutrally bouyant, to submerged, and bottomed shall be analyzed and calculated.

The number of openings in watertight boundaries shall be kept to a minimum. Weathertight hatches, which can be submerged or exposed to slamming or sloshing, should be designed for such actions and suitably verified as fit for purpose. Type and securing of seals and gaskets should be carefully considered. The placement and positioning of watertight hatches shall be done in such manner that during opening and accessing there is no risk of down flooding including from rogue waves.

5.9.3 Cranes, hoists and lifting equipment

Cranes, hoists, slings, cables, hooks and other lifting apparatus shall be adequate for safe lifting and handling. Manufacturer's instructions and documentation with respect to installation and handling shall provide information on expected loads and safe lifting points for components and assemblies. All hoisting equipment shall be periodically tested and certified for the rated safe load. Special attention shall be paid to ensure that cranes are not exercised beyond their rated radius for a given load.

5.9.4 Transportation

Transportation can result in abnormal conditions beyond those considered for normal operation. A plan to minimize the risk of damage to the MEC, personnel or the environment during transportation shall include:

- weather windows for transportation and installation
- damage control contingencies and monitoring systems;
- lashing and sea fastening for inertial loads;
- modularity and assembly at sea;
- freeboard of hatches, maintenance openings and risk of down-flooding;
- role of independent surveyors, harbour and coastal pilots;
- launch considerations, including dynamics and irreversible/unstoppable launching procedures;
- clearance of submerged and overhead hazards;
- transitions in centre of gravity and centre of buoyancy and associated risks of capsizing:
 - physics of floating device;
 - physics of submerged device;
 - physics of bottomed device;
 - transitions between states;
 - limbering of tanks to facilitate drainage and enhance stability;
 - abnormal hydrostatic pressures;
 - lifts at sea:
- snap loads; and
- entrained mass of water;
 - tensioning the mooring; and
 - power cable connections.

5.9.5 Installation and commissioning

Installation procedures shall provide pre-planned methods to be used that at any point, if necessary, to curtail all work and secure all items and equipment without causing danger to personnel or unacceptable loads on the MEC. In the case of a MEC that changes orientation from horizontal to vertical and/or changes state from floating to submerged or bottomed, appropriate measures shall be taken to control buoyancy and stability and prevent dramatic change of centre of gravity/buoyancy. Critical ballasting and stability control precaution measures shall be included in the installation manual.

The site of a marine energy conversion facility shall be prepared, maintained, operated and managed so that work can be performed in a safe and efficient manner in accordance with appropriate regulations and permitted requirements. This may include:

- marking of individual structures, or fields of structures;
- installation of power cables between individual MECs, transformer stations, and shore;
- monitoring of the facility by the operator;
- procedures to prevent unauthorized access, where appropriate; and
- contingency plans to address:
 - the possibility of MEC units breaking loose and becoming floating, submerged, or beached hazards;
 - retrieval of lost or loose components;

- loss of vessel control;
- loss of electrical power;
- fire;
- collision (or allision) that may include leakage and pollution;
- structural failure;
- mooring line failure;
- man overboard;
- personnel accidents or medical emergencies, including medical evacuation from remote locations;
- grounding; and
- unexpected water depth limitations or sea floor hazards.

Metocean conditions may constrain installation. It can be impractical and/or uneconomical to plan to transport or commission a MEC in extreme environmental conditions. Consequently, there is a need to establish weather windows of minimum duration with specified limits on the metocean parameters during which the marine operations can be performed. Setting the limits too high can lead to unacceptable risk, whereas setting the limits too low can lead to excessive waiting times.

A set of limiting metocean criteria based on the specific MEC transportation and commissioning requirements shall be established. Such criteria shall include, but not be limited to:

- wind speed and direction;
- wave height, direction, and period;
- current speed and direction; and
- swell height and direction.

Other factors and combinations of factors that may need to be considered include:

- combinations of wind, wave and current;
- water level, including tide and surge;
- restricted visibility;
- sea ice, icebergs, snow and ice accretion on topsides and structure, exceptionally low temperatures; and
- tropical storms and local squalls.

5.9.6 Operations, inspection and maintenance strategy

The operations, inspections and maintenance strategy of MECs includes key considerations for developing and implementing an appropriate Asset integrity Management program for MECS, covering all phases of the life cycle. The owner of MECS shall be responsible for ensuring that an appropriate Asset Integrity Management (AIM) program is implemented (see Clause 5.9.6.3 and refer to ISO 19901-9), including monitoring, inspection, maintenance and repair, is in place for maintaining integrity of MECS throughout its life cycle and to achieve the intended target safety level, as per the Clause 5.5. Owners' operation and maintenance strategy for MECS shall satisfy the appropriate local and national codes and regulations.

The requirements for a robust inspection strategy will vary according to the type of MEC and the offshore environment in which it is working. Given the harsh environmental conditions that MECs typically experience, access for inspection and in-situ working may be difficult to achieve in a safe manner, hence it may be necessary to recover and transport the MEC back to shore or harbour for inspection.

The owner may consider any of the following paths for establishing relevant asset inspection, maintenance and repair strategy:

- For floating MECs, use Class rules for both the hull structure and topsides, with demonstration that the application of Class rules for topsides meets the safety objectives of the Clause 5.5.
- Develop an owner's Asset Integrity Management program for the entire MECs that satisfies the Safety Objectives of the Clause 5.5. covering entire life cycle, from design, construction, installation, operation and decommissioning phases for the project.

The safety of personnel engaged in operations, inspection, and maintenance is paramount. Appropriate risk assessments to eliminate or limit the need to expose personnel to dangerous working environments shall be analyzed during the design stage. However, since specific guidance on human safety is outside the scope of this document, designers should refer directly to local and national regulations.

Structural integrity monitoring and other diagnostic systems to provide a remote continuous assessment of MEC structural integrity and functionality are encouraged.

Evaluation of coating condition is primarily performed by visual inspection to determine the need for recoating. A close visual examination will also disclose any areas where coating degradation has allowed corrosion to develop to a degree requiring repair or replacement of structural components.

The MEC design should anticipate the need for diver inspection and therefore not include features that may be hazardous to diving personnel. Designers should also anticipate the use of remotely operated vehicles (ROVs) for underwater inspection.

Inspection of cathodic protection systems may include visual examination of anodes and measurements of structure-to-seawater potentials and anode-to-sea water potentials. Safety regulations for diver activities when impressed current (IC) systems are in operation shall be developed.

5.9.6.1 Operations, inspection, and maintenance planning

The requirements for a robust maintenance planning will vary according to the type of MEC and the offshore environment where it is deployed. The manner in which a MEC is operated and maintained will have a significant impact on its integrity and functionality throughout the intended design life. In order for any maintenance plan to be effective, it shall be analyzed in a holistic manner throughout the design, construction, commissioning and operation of the MEC.

The designer shall analyze the overall MEC System life cycle, as well as the individual subsystems and components that may have a much reduced design life compared to the overall MEC system. Maintenance strategies to consider include:

- time-based or schedule-based maintenance – where maintenance intervals are prescribed for the MEC system, subsystems, equipment and components. For example: some MECs may require periodical cleaning to control marine growth or periodic component replacement.
- condition-based maintenance – this involves monitoring the operational condition and alerts of the MEC system, subsystems, equipment and components. Maintenance is scheduled when certain conditions are met; and
- risk/reliability based maintenance – where maintenance intervals are determined based on the risk to and reliability of the MEC system, subsystems, equipment or components.

MEC design shall analyze the need to remove components requiring maintenance, while ensuring that elements located on the seabed require little or no maintenance during their service life. Where electrical, hydraulic or other fixed connections exist between the device and shore, due consideration should be given to how this connection will be made and broken safely

and reliably during the operational life if it is intended to remove the device for maintenance. Electrical connections shall be isolated while maintenance is undertaken.

Maintenance activities can expose workers to a number of potential hazards. The planning stage of maintenance activities shall identify all potential hazards and identify means of reducing or eliminating exposure to these hazards. The maintenance strategy shall identify all local and national health, safety and environmental requirements that may apply to ensure the proposed activities comply.

5.9.6.2 Operations, inspection, and maintenance execution

All maintenance activities shall be developed as part of the design, documented in a Operations and Maintenance (O&M) manual, and performed by personnel suitably trained or instructed in this activity. Access for maintenance of a MEC shall be a key design decision during the design stage with particular attention to transferring personnel to and from the MEC in a range of sea conditions. Because of the nature of MECs and the harsh environment, it might be necessary to recover the MEC to shore for periodic maintenance. Where on-site maintenance is a design option, consideration should be given to provision of refuge areas for personnel on the MEC. An appropriate risk assessment, or similar, shall be undertaken to determine safe methods of undertaking maintenance work.

An emergency procedure plan shall be developed during design as part of the O&M manual and practiced prior to deployments. The plan shall analyze the risk to personnel during emergency escape, such as when there is a fire, loss of stability, or apparent risk of structural damage to the MEC or its components.

A strategy for inspection and possible removal of marine growth shall be planned as part of the MEC design. Inspection frequency, inspection method and growth removal criteria shall be based on the impact of marine growth on the structural reliability and performance of the MEC and the extent of marine growth for the site-specific conditions.

Issues surrounding the growth type and any environmental impact of the removal of the growth, for example protected species, will require compliance with local regulations.

5.9.6.3 Asset Integrity Management Program

An Asset Integrity Management (AIM) Program for the hull structure, mechanical, electrical, and control subsystems, seakeeping/mooring systems, shall include systematic process(es) for (a) identifying different hazards (refer to IEC 63366, IEC 61882, and ISO 17776 for further guidance) during all phases of the life cycle & then assessing risk (refer to ISO 31010 for further guidance) considering structural, mechanical, material and electrical integrity, and (b) managing assessed risks during installation (commissioning), operational and decommissioning stages, through monitoring, inspection, maintenance, evaluation, and repair.

As part of the risk management process within the AIM program, appropriate inspection, maintenance and repair methods and actions shall be identified, planned, executed and evaluated according to relevant industry practices/standards wherever applicable. For details on principles, framework and core component of risk management, ISO 31010 can be referred. Target safety level can be used as part of the risk mitigation and management strategy.

An AIM shall include the following key elements and processes:

- Measurable objectives and targets and performance indicators related to asset integrity and need to be updated through a management review process and to be part of a continual improvement process.
- A suitable organizational structure with well-defined responsibilities and authorities for supporting effective implementation of the AIM program.
- A process for managing integrity-related data between phases, such as, design phase, to manufacture, operational and maintenance phases.

- Management of Resources, including a process for determining competency requirements and enabling training of employees and contractors responsible for administrating and executing asset integrity related activities.
- A documented process for hazard identification and risk assessment to identify and assess consequence and to carry out risk assessment for controlling hazards that have potential to impact integrity of MECs sub-systems, sea-based and shore-based facilities and equipment.
- A documented process outlining approaches for managing assessed risks through monitoring, inspection and maintenance, and/or through mitigation involving engineering and administrative solutions.
- A documented process for planning, executing and evaluating monitoring, inspection and mitigation activities.
- A documented process for learning from incidents for continual improvement to the AIM Program
- A documented process for control of non-conformance, defining responsibility and authority for handling non-conformance and taking action on initiating and completing corrective actions.

An implemented effective AIM Program will ensure a MEC will perform its required function while protecting safety, and structural & environmental integrity during its design life.

5.9.7 Removal and decommissioning

Removal procedures shall be defined during the design of the MEC. Any removal aids that are integrated into the MEC should be installed at the time of construction, with a design service life exceeding the maximum foreseen operational life of the MEC itself.

Selection of a removal option depends on several environmental, technical and economical parameters, Including:

- effect of removal and/or disposal on marine life, navigation and fishing activities;
- regulatory requirements
- technical feasibility and risks; and
- risk to personnel.

5.10 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;
- –normal design situations and extreme environmental conditions.
- fault design situations when the MEC is operating with a single major system failure and appropriate environmental conditions; and

[Clause 7](#) also defines MEC design limit states and loading partial safety factors.

5.11 Limit state design

The adequacy 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](#).

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)

5.12 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.

For SL2, 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 analysis 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 fall, i.e. corresponds to the target annual probability of failure defined in [clause 5.6](#). Annex C defines a methodology for calibration of load and material factors of a limit state design equation to reach a desired safety level.

Model testing and prototype tests may also be used to support analytical design methods, as specified in [ISO 2394 \[1\]](#).

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.

5.13 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. ISO 19902 applies to bottom fixed structures and ISO 19904-1 applies to floating structures. 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. For applicable structural design equations, see [Clause 9](#).

6 Environmental conditions

The environmental conditions described in this clause shall be analyzed in the modelling, analysis and prediction of environmental loads on MECs. While not a requirement, the upper limits on environmental conditions for different MEC system (environmental load) classes, as defined in Informative Annex D, is recommended to facilitate robust MEC system designs that can operate reliably at different sites. The subsequent clauses provide guidance for determining design load conditions waves ([6.1](#)), currents ([6.2](#)), and water level ([6.3](#)) along with other secondary conditions, such as wind, ice, earthquake, soil conditions, temperature, and marine growth. In estimating all design load conditions, historical measurements should be used if available. Alternatively, hindcast data can be used if historical measurements are unavailable.

Each design load condition is categorized as follows:

- Operational: most likely to occur (i.e., the median condition)
- Extreme: largest likely event for a given return period (e.g., 1-, 5, or 50-years)

6.1 Waves

Sea states should be characterized by significant wave height (H_{m0}), a peak period (T_p) or energy period (T_e), wave direction, and a spectral shape when possible. Where available, regional or site-specific data shall be used to specify spectral shape and directional distributions. 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.

6.1.1 Operational sea state

The Operational Sea State (OSS) shall be defined as the sea states most likely to occur within a 1-year period.

6.1.2 Extreme sea state (ESS)

The designer shall analyze extreme stochastic sea states for 50- (ESS₅₀), 5- (ESS₅), and 1-year (ESS₁) return periods. The return period is the average period between occurrences of a particular value being exceeded. Two approaches available for determining the ESS are:

- (Preferred): The spectral parameters (H_{m0} , T_p , etc.) should be determined via a contour (multivariate) approach (see, e.g., [DNV-RP-C205 \[7\]](#))
- A univariate extreme value analysis on H_{m0} , followed by an empirical determination for realistic values of T_p using

$$3,54\sqrt{H_{m0}} \leq T_p \leq 4,56\sqrt{H_{m0}} \quad (3)$$

Both a contour and univariate approach, will produce a set of sea states. Design calculations shall be based on the sea states that result in the most onerous loads acting on the MEC.

6.1.3 Extreme wave height (EWH)

The extreme wave height (H_{EW}) is the largest single wave height for a given return period. As with the ESS, EWH shall be analyzed for 1, 5, and 50-year return periods. The values of H_1 , H_5 , and H_{50} 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.

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

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 analyzed in design calculations for the range of deepwater waves periods given in formula (3).

The extreme wave heights H_1 , H_5 , H_{50} 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_1 , H_5 and H_{50} shall be assumed equal to the breaking wave height if the breaking wave height is less than the values of H_1 , H_5 and H_{50} determined from the Rayleigh distribution given by formulae (3) and (4).

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 Ocean currents

The most common categories of ocean 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.

6.2.1 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 depth below SWL, z :

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

The 1, 5, 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.

6.2.2 Wind-generated near-surface currents

The wind-generated current velocity 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:

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

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:

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

where $V_{1-hour}(z = 10 m)$ 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 $V_{1-hour}(z = 10 m)$ may be determined from analysis of site measurements.

6.2.3 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).

6.2.4 Operational current model (OCM)

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

6.2.5 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.

6.2.6 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 analyzed 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 and are randomly distributed about the expected value at the 50% quantile value. 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: