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Edition 1.0 2018-08

TECHNICAL SPECIFICATION

colour inside

Marine energy – Wave, tidal and other water current converters –
Part 30: Electrical power quality requirements

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

Part 30: Electrical power quality 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 62600-30, which is a technical specification, has been prepared by IEC technical committee 114: Marine energy – Wave, tidal and other water current converters.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
114/238/DTS	114/253A/RVDTS

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

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

A list of all parts of the IEC 62600 series, 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- withdrawn,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

Marine energy conversion systems, as viable electric power sources for utility and community-based applications, require close attention to the quality of the power produced. Poor power quality has negative impacts on both the electrical power source and the load. Therefore, guidance is needed for the manufacturer, developer and user on how to mitigate power quality issues during the design of the device. Electrical system planners also need to identify the requirements for grid integration of such variable and intermittent energy sources, while maintaining high reliability and power quality standards.

Conceptually, except for wave energy convertors, many marine energy converter unit devices operate in a manner similar to wind turbines. As power quality is a mature topic within other renewable and conventional power generation schemes, there are numerous standards, codes, and guidelines in existence. In contrast, there are no standards or technical specifications for marine power generation systems that deal with the power quality issues and the associated integration needs. Therefore, this knowledge-gap needs to be addressed through incremental, detailed and collaborative standards development.

This technical specification aims at:

- identifying power quality issues and parameters (non-device specific and non-prescriptive) for single/three-phase, grid-connected/off-grid (including micro-mini grid) marine wave, tidal and other water current converter-based power systems;
- establishing the measurement methods, application techniques and result-interpretation guidelines.

In addition to containing the associated definitions, normative references, symbols and units, forms, annexes, as well as other supporting material, the core of this technical specification would contain the following key items:

- identify characteristic parameters, define and specify the quantities required to characterize the power quality impacts of marine energy conversion devices,
- develop measurement procedures as pertains to marine energy devices,
- outline standardized procedures for measuring the characteristic parameters, including test and measurement conditions, and test equipment requirements.

It is expected that this technical specification will provide evaluation guidelines for device developers and applied researchers.

Assessment of power quality for utilities will be part of a separate, future technical specification that is currently being developed under IEC TC 8 SC 8A.

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

Part 30: Electrical power quality requirements

1 Scope

This part of IEC 62600 includes:

- definition and specification of the quantities to be determined for characterizing the power quality of a marine energy (wave, tidal and other water current) converter unit;
- measurement procedures for quantifying the characteristics of a marine energy (wave, tidal and other water current) converter.

The measurement procedures are valid for a single marine energy converter (MEC) unit (or farm) with three-phase grid or an off-grid connection. The measurement procedures are valid for any size of MEC unit, though this document only requires MEC unit types intended for PCC (Point of Common Coupling) at Medium Voltage (MV) or High Voltage (HV) to be tested and characterized. In addition, a simplified measurement and reporting procedure is outlined for MEC units connected at Low Voltage (LV) networks. MV–connected and LV-connected devices are defined as:

- MV connected units – typically multiple three-phase MEC units operating as a marine power farm and delivering power through a HV or MV network;
- LV connected units – typically single-phase or three-phase units deployed in isolated, hybrid or micro-grid type systems supplying small-scale loads.

Considering the nascent status of the marine energy sector, the following limitations of this document are to be recognized:

- voltage fluctuations under switching operation – the current revision only considers voltage fluctuations under continuous operation;
- resource classifications – to categorize the measured flicker quantities, various resource classes are suggested only as guidelines. The user is advised to use these resource classes judiciously.

The measurement procedures are designed to be as non-site-specific as possible so that power quality characteristics measured at a test site, for example, can be considered valid at other sites also providing the same MEC unit configuration and operation modes (for example control parameters). If the configuration or operation mode is changed in any way that might cause the MEC unit to behave differently with respect to power quality, the power quality measurement procedures must be repeated.

This document is for testing of wave, tidal and other water current energy converter units, though it contains information that may also be useful for testing of MEC farms. The cases described are not intended for Ocean Thermal Energy Conversion (OTEC) systems.

NOTE This document uses the following terms for system voltage:

– low voltage (LV) refers to U_n <= 1 kV;

– medium voltage (MV) refers to 1 kV < U_n <= 35 kV;

– high voltage (HV) refers to U_n > 35 kV.

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 TR 61000-3-6:2008*, Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*

IEC TR 61000-3-7:2008, *Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems*

IEC 61000-4-7:2002, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*
IEC 61000-4-7:2002/AMD1:2008

IEC 61000-4-15:2010, *Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications*

IEC 61400-21, *Wind turbines – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines*

IEC 61800-3:2017, *Adjustable speed electrical power drive systems – Part 3: EMC requirements and specific test methods*

IEC 61869-1:2007*, Instrument transformers – Part 1: General requirements*

IEC 61869-2:2012, *Instrument transformers – Part 2: Additional requirements for current transformers*

IEC 61869-3:2011*, Instrument transformers – Part 3: Additional requirements for inductive voltage transformers*

IEC 62008:2005, *Performance characteristics and calibration methods for digital data acquisition systems and relevant software*

IEC TS 62600-100:2012, *Marine energy – Wave, tidal and other water current converters – Part 100: Electricity producing wave energy converters – Power performance assessment*

IEC TS 62600-101:2015, *Marine energy – Wave, tidal and other water current converters – Part 101: Wave energy resource assessment and characterization*

IEC TS 62600-201:2015, *Marine energy – Wave, tidal and other water current converters – Part 201: Tidal energy resource assessment and characterization*

3 Terms and definitions

For purposes of this document, the following terms and definitions apply.

ISO and IEC 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

3.1
flicker
impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time

Note 1 to entry: Flicker is caused by rapid, regular changes to the voltage level of the electrical supply caused by devices connected to the electrical system. The voltage variations are caused by fluctuating power consumed or generated by a load or particularly renewable generator, more severely for reactive power fluctuations.

[SOURCE: IEC 60050-161:1990,161-08-13, modified – The note to entry has been added]

3.2
network impedance phase angle
phase angle of network short-circuit impedance:

$$\psi_k = \arctan(X_k / R_k)$$

where

X_k is the network short-circuit reactance;

R_k is the network short-circuit resistance.

3.3
point of common coupling
PCC
point in an electric power system, electrically nearest to a particular load, at which other loads are, or may be, connected

Note 1 to entry: These loads can be either devices, equipment or systems, or distinct network users' installations.

[SOURCE: IEC 60050-161:1990,161-07-15, modified – " Power supply network" has been replaced by "electric power system"; in note 1 to entry, "customer" has been replaced by "user" and note 2 to entry has been deleted]

3.4
total harmonic distortion
ratio of the RMS value of the harmonic content to the RMS value of the fundamental component or the reference fundamental component of an alternating quantity

[SOURCE: IEC 60050-551:1998,551-20-13, modified – Notes to entry have been deleted]

4 Symbols and units

α_o	is the electrical angle at t = 0
β	exponent with a numerical value to be selected to determine $I_{h\Sigma}$
$\alpha_m(t)$	electrical angle of the fundamental component of the measured voltage (°)
ψ_k	network impedance phase angle (°)
Δd_{dyn}	fractional change in voltage
$c(\psi_k)$	flicker coefficient for continuous operation
$c_i(\psi_k)$	flicker coefficient of an individual marine energy converter

$c(\psi_k)(t)$ time-series data of flicker coefficient (synthesized)

d relative voltage change (%)

E_{plti} long-term flicker emission limits for the PCC under consideration

E_{psti} short-term flicker emission limits for the PCC under consideration

f_g supply/grid frequency (Hz)

$f(t)$ time-varying frequency

$f(V_{MEC})$ device flicker characteristics (graphical, tabular/look-up or best-fit formula)

H_{m0} significant wave height (m)

I_h subgrouped RMS current harmonic of harmonic order h

$I_{h\Sigma}$ h^{th} order harmonic current distortion at the PCC

$I_{h,i}$ h^{th} order harmonic current distortion of the i^{th} converter

$i_m(t)$ measured instantaneous current (A)

I_r rated phase current (A)

L_{fic} inductance of fictitious grid (H)

n_i ratio of the transformer at the i^{th} converter

N_{mec} number of marine energy converters connected to the PCC

P_{600} 600 s average value of maximum measured active power of the marine energy converter

P_{60} 60 s average value of maximum measured active power of the marine energy converter

$P_{0,2}$ 0,2 s average value of maximum measured active power of the marine energy converter

P_{lt} long-term flicker disturbance factor

$P_{lt\Sigma}$ long-term flicker emission from the sum of marine energy converters

P_r rated active power of marine energy converter (W)

P_{st} short-term flicker disturbance factor

$P_{st,fic}$ flicker emission from the marine energy converter unit on the fictitious grid

$P_{st,i}$ flicker disturbance factor of an individual marine energy converter

$P_{st}(t)$ time-series data of flicker disturbance factor (synthesized)

$P_{st\Sigma}$ short-term flicker emission from the sum of marine energy converters

Q reactive power

Q_{max} maximum reactive power

Q_{min} minimum reactive power

R_{fic} resistance of fictitious grid (Ω)

R_k network short-circuit resistance (Ω)

S_k short-circuit apparent power of the grid under specified conditions (VA)

$S_{k,fic}$ short-circuit apparent power of the fictitious grid (VA)

S_r rated apparent power of the marine energy converter (VA)

$S_{r,i}$ rated apparent power of the individual marine energy converter unit of a farm (VA)

$T_{\_e}$ energy period (s)

$u_o(t)$ instantaneous phase-to-neutral voltage of an ideal voltage source (V)

$u_{fic}(t)$ instantaneous phase-to-neutral voltage simulated at fictitious grid (V)

$u_m(t)$ measured instantaneous voltage (V)

U_n nominal phase-to-phase voltage (V)

v_{ta} average tidal speed (m/s)

v_{wa} average water current velocity (m/s)

$V_{MEC}(t)$ time varying marine resource (typically synthesized or measured) for a given site

V_{MEC} marine resource (wave, tidal or water current)

X_k network short-circuit reactance (Ω)

X_{fic} reactance of fictitious grid (Ω)

5 Abbreviated terms

HV high voltage (> 35 kV)

LV low voltage (< 1 kV)

MV medium voltage (> 1 kV and < 35 kV)

PCC point of common coupling

RMS root mean square

MEC marine energy converter

SCR short circuit ratio

VD voltage drop

6 Marine energy converter power quality characteristic parameters

6.1 Overview

Clause 6 gives the quantities that shall be stated for characterizing the power quality of a MEC unit, i.e. MEC unit specifications (6.2), voltage fluctuations (6.3), harmonics (6.4), voltage drop response (6.5), and power control (6.6 to 6.7). A sample report format is given in Annex A.

Generator sign convention shall be used, i.e. the positive direction of the power flow is defined to be from the MEC unit to the grid. If the MEC unit is replaced with a resistor and an inductor, both active and reactive power will be negative.

6.2 Marine energy converter specification

The rated data of the MEC unit (referred to the MEC unit terminals) shall be specified, including P_r, S_r, and U_r.

NOTE The rated data are used only for normalizing purposes in this document.

6.3 Voltage fluctuations (continuous operations)

6.3.1 General

The voltage fluctuations caused by the MEC unit shall be characterised as described in 6.3.2 and 6.3.3 for continuous operations, (i.e. no switching voltage fluctuations) for MV and LV connected systems respectively.

6.3.2 Continuous operation: MV connected systems

The MEC unit flicker coefficient for continuous operation, $c(\psi_k)$, shall be stated as the 95th percentile[1] for the network impedance phase angles ψ_k = 30°, 50°, 70° and 85° in a table, preferably for three different resource levels. The flicker coefficient for continuous operation refers to the normalised measure of the flicker emission during continuous operation of the MEC unit:

$$c(\psi_k) = P_{st,fic} \times \frac{S_{k,fic}}{S_r}$$

where

$P_{st,fic}$ is the flicker emission from the MEC unit on the fictitious grid;

S_r is the rated apparent power of the MEC unit;

$S_{k,fic}$ is the short-circuit apparent power of the fictitious grid.

NOTE The flicker coefficient for continuous operation is the same for a short-term (10 min) and long-term period (2 h).

These resource levels should represent low, medium and high resource levels at the specific location. Sample low, medium and high resource levels are given for wave, tidal and water current converters in Table 1. These values are indicative only as it is acknowledged that the resources can vary from location to location. The following guidelines apply. For tidal and current devices, the three resource ranges should be between the cut-in and cut-out flow velocities. For wave energy devices, it should be ensured that the three sea states chosen reflect the full operating range of the wave energy device.

Measured flicker coefficients should be reported (in tabular, graphical and/or formula format) for the whole range of the MEC unit's operation, i.e. the high resource level selected should allow specified rated active power output of the MEC unit. Annex A contains a template of the report.

1 A flicker coefficient value below which 95 % of the observed values fall.

Table 1 – Marine energy – resource classification

Converter	Wave[2]	Tidal [3]	Water current
Definition	Scatter table/chart of the annual occurrence of the significant wave height H_{m0}, energy period T_{-10}	Annual average tidal speed (10 min average, v_{ta}) experienced at the rotor whether ducted/un-ducted, or uni/bi-directional	Flow speed information presented in duration curves, where 90 % probability that the flow velocity (annual data with 10 min average, v_{wa}) would exceed a given threshold
Low		v_{ta} ≤ 1,00 m/s	v_{wa} ≤ 1,00 m/s
Medium		1,00 m/s < v_{ta} <1,75 m/s	1,00 m/s < v_{wa} <1,75 m/s
High		1,25 m/s < v_{ta}	1,75 m/s < v_{wa}

The characteristics shall be stated for the MEC unit operating with reactive power as close as possible to zero, i.e. if applicable, the reactive set-point control shall be set to Q = 0. If any other operational mode is used, this shall be clearly stated.

6.3.3 Continuous operation: LV connected system

The MEC unit short term flicker disturbance factor for continuous operation, P_{st}, shall be stated as the 95th percentile for the measured condition in a table, preferably for three different resource levels, as before. Also measured flicker disturbance factor should be reported (in tabular, graphical and/or formula format) for the whole range of MEC unit's operation. Annex A contains a template of the report.

6.4 Current harmonics, interharmonics and higher frequency components

The emission of current harmonics, interharmonics and higher frequency components during continuous operation shall be measured and recorded. This document considers steady-state harmonic emissions only, i.e. fault free operation.

The values of the individual current components (harmonics, interharmonics and higher frequency components) and the total harmonic current distortion shall be given in tables in percentage of I_n and for operation of the MEC unit within the active power bins 0 %, 10 %, 20 %..., 100 % of P_r. 0 %, 5 %, 15 %, ..., 95 % are the bin midpoints.

The individual harmonic current components shall be specified as subgrouped values for frequencies up to 50 times the fundamental grid frequency, and the total harmonic current distortion shall be stated as derived from these.

The interharmonic current components shall be specified as subgrouped values for frequencies up to 2 kHz in accordance to Annex A of IEC 61000-4-7:2002/AMD1:2008.

The higher frequency current components shall be specified as subgrouped values for frequencies between 2 kHz and 9 kHz in accordance to Annex B of IEC 61000-4-7:2002/AMD1:2008.

The current harmonics, interharmonics and higher frequency components shall be stated for the MEC unit operating with reactive power as close as possible to zero, i.e. if applicable the

2 IEC TS 62600-101:2015, *Marine energy – Wave, tidal and other water current converters – Part 101: Wave energy resource assessment and characterization*

3 IEC TS 62600-201:2015, *Marine energy – Wave, tidal and other water current converters – Part 201: Tidal energy resource assessment and characterization*

reactive set-point control shall be set to Q = 0. If another operational mode is used, this shall be clearly stated.

6.5 Response to voltage drops

The response of the MEC unit to the voltage drops specified in Table 2 shall be stated for the MEC unit operating between 0,1 P_r and P_r. The stated response shall include results from 2 consecutive tests of each case (VD1-VD6) by time series of active power, reactive power, active current, reactive current and voltage at the MEC unit for the time shortly prior to the voltage drop and until the effect of the voltage drop has abated. The MEC operational mode shall be specified.

The test is for verifying the MEC unit response to voltage drops (due to grid faults) and providing a basis for the MEC numerical simulation model validation. Optional tests and measurements (for example pitch angle and rotational speed tests in the case of tidal turbines, or tests using different damping coefficients in the case of wave energy converters) may be carried out and reported for more detailed assessment of simulation models and compliance with specific grid code requirements.

Table 2 – Specification of per unit voltage drops (the specified magnitudes, duration and shape are for the voltage drop occurring as if the MEC under test is not connected, i.e. without contribution from the installation)

Case	Magnitude of voltage phase to phase (as a fraction of voltage immediately before the drop occurs)	Magnitude of positive sequence voltage (as a fraction of voltage immediately before the drop occurs)	Duration s	Shape
VD1 – symmetrical three-phase voltage drop	0,90 ± 0,05	0,90 ± 0,05	0,5 ± 0,02	¯¯|__|¯¯
VD2 – symmetrical three-phase voltage drop	0,50 ± 0,05	0,50 ± 0,05	0,5 ± 0,02	¯¯|__|¯¯
VD3 – symmetrical three-phase voltage drop	0,20 ± 0,05	0,20 ± 0,05	0,2 ± 0,02	¯¯|__|¯¯
VD4 – two-phase voltage drop	0,90 ± 0,05	0,95 ± 0,05	0,5 ± 0,02	¯¯|__|¯¯
VD5 – two-phase voltage drop	0,50 ± 0,05	0,75 ± 0,05	0,5 ± 0,02	¯¯|__|¯¯
VD6 – two-phase voltage drop	0,20 ± 0,05	0,60 ± 0,05	0,2 ± 0,02	¯¯|__|¯¯

A voltage drop may cause a MEC unit to cut-out for many reasons, not only related to the electrical drive train but also due to mechanical vibrations or ancillary system low voltage capabilities. It is therefore necessary to do the test on the complete MEC unit where possible rather than relying on drive train testing only.

NOTE The purpose of VD1 and VD4 is for testing of MEC units that have no capabilities to ride through any deep voltage drops, and the tests are generally relevant as basis for validation of numerical simulation models.

The measurements in 6.5 relate to characterizing a MEC unit's response to a voltage drop caused by a grid fault. Grid operators can have different requirements for low voltage ride through (LVRT). While these measurements go somewhat to characterizing an installation's LVRT capability they may not meet grid operators grid code compliance requirements. It is advised that consultation is undertaken with the relevant grid operator to ensure this test is to their requirements.

6.6 Active power

6.6.1 Maximum measured power

The maximum measured active power of the MEC unit shall be specified as a 600 s average value, P_{600}, a 60 s average value, P_{60} and as a 0,2 s average value, $P_{0,2}$. For each measurement, the input resource conditions shall be stated.

6.6.2 Ramp rate limitation

If available, the ability of the MEC unit to operate in ramp rate limitation control mode shall be characterised by test results presented in a graph. The graph shall show available and measured active power output during a ramping operation. The ramp rate value achievable by the MEC shall be presented as a percentage of rated power per minute for a test period of at least 10 min.

The test results shall be reported as 0,2 s average data.

6.6.3 Set-point control

If available, the ability of the MEC to operate in active power set-point control mode shall be characterized by test results presented in a graph. The graph shall show available (extrapolated from resource conditions) and measured active power output during operation at set point values being adjusted from 100 % down to 20 % of rated power in steps of 20 % with 2 min operation at each set-point value, i.e. according to Figure 1.

The test results shall be reported as 0,2 s average data.

NOTE The ability of a MEC to participate in an automatic frequency control scheme is closely linked to its ability to operate in active power set-point control mode. Participation in automatic frequency control can for instance be achieved through the SCADA system of a MEC farm that may continuously update the active power set-point of the individual MEC to achieve a requested frequency response.

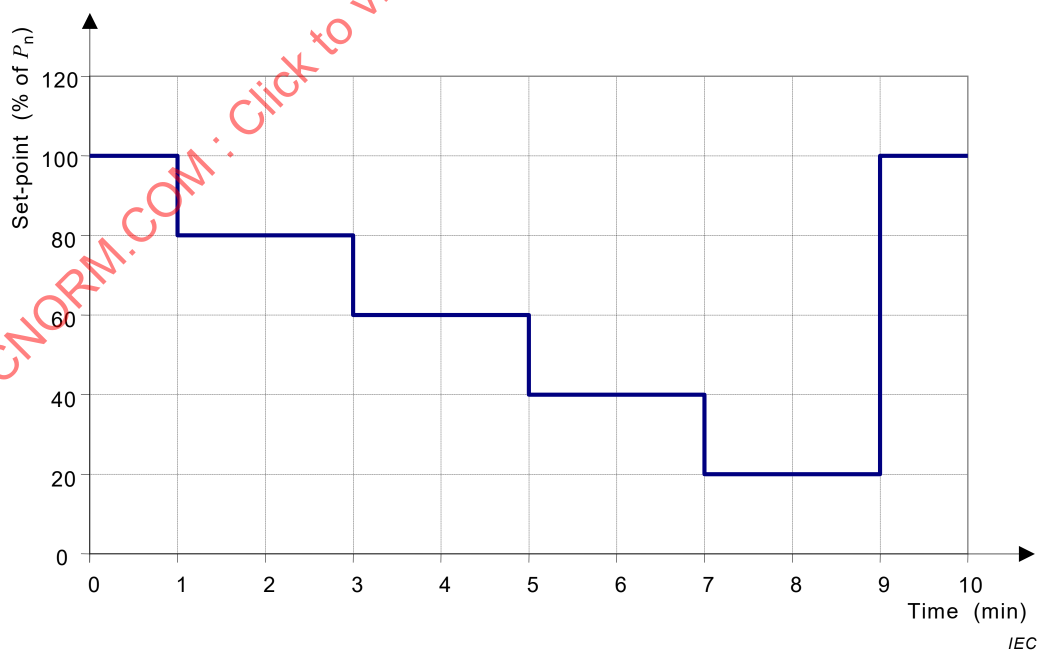


Figure 1 – Adjustment of active power set-point

6.7 Reactive power

6.7.1 Reactive power capability

The capability of the MEC unit concerning the maximum inductive reactive power and the maximum capacitive reactive power of the MEC shall be specified in a table as 1 min average values as a function of the 1 min average output active power for 0 %, 10 %, ... 90 %, 100 % of the rated power.

6.7.2 Set-point control

Where available, the reactive power set-point control shall be described by a table and a graph as follows.

The table shall show measured reactive power at reactive set point value = 0 for operation at 0 %, 10 %, 20 %, … 100 % active power output. The active and reactive power shall be 1 min average values.

The graph shall show measured reactive power during a step change of the reactive power set-point as specified in Figure 2. The step change shall be between Q_{max} and $-Q_{max}$ where Q_{max} and $-Q_{max}$ are the reactive power capability of the MEC at the active power output as shown according to 6.7.1. The active power output, measured as 1 min average values, shall be approximately 50 % of rated power. The reactive power shall be 0,2 s average data.

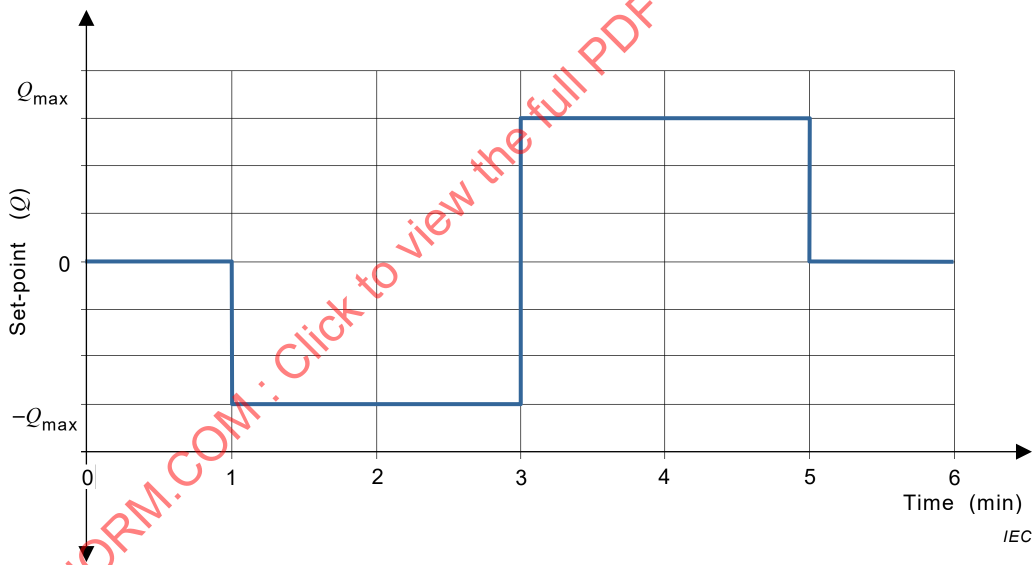


Figure 2 – Adjustment of reactive power set-point

NOTE The ability of a MEC unit to participate in an automatic voltage control scheme is closely linked to its ability to operate in reactive power set-point control mode. Participation in automatic voltage control can, for instance, be achieved through the SCADA system of the MEC farm that may continuously update the reactive power set-point of the individual MECs to achieve a requested voltage response.

7 Test procedures

7.1 General

7.1.1 Overview

Subclause 7.1 gives general information about the validity of the measurements, required test conditions and equipment.

The measurement procedures are valid for single MEC units with a three-phase grid connection. Similar procedure can be used for single-phase devices at the testers' discretion.

The measurements aim in general to verify the characteristic power quality parameters for the full operational range of the assessed MEC unit. Measurements are however not required for wave heights/periods, tidal velocities and water current velocities for the ranges given in Table 3, or alternatively conditions which occur less than 5 % of total time annually, i.e. rare occurrences. This is because requiring measurements at higher wave heights or tidal/river flow velocities would normally give a significantly longer measurement period due to the rare appearance of these conditions. If these conditions are not known, Table 3 can be used as a reference.

Table 3 – Measurement ranges to be excluded

MEC	Resource condition
Wave	Measurements are not required for sites if high energy seastate occurs for less than 5 % of the time.
Tidal	v_{ta} < 1 m/s and v_{ta} > 3,5 m/s
Water current	v_{wa} < 1 m/s and v_{wa} > 3 m/s

7.1.2 Test validity

The measured characteristics are valid for the specific configuration of the assessed MEC type only. Other configurations, including altered control parameters, that cause the MEC unit to behave differently with respect to power quality, require separate assessment. Such assessment can be made by simulation, where sufficient validation of simulation tools has been undertaken and presented.

In the situation that the MEC unit terminals are not easily accessible, the PCC shall be used as the measurement point. This should be clearly stated in the test report (Annex A), with full details of subsea cables as necessary. In addition, the specific configuration of the assessed MEC unit, including relevant control parameter settings, should also be specified.

7.1.3 Test conditions

The following test conditions are required, and shall be measured and reported as part of the test procedure. Any test data measured during periods not complying with the given test conditions shall be excluded.

- the total harmonic distortion (THD) of the voltage including all harmonics up to the order of 50 shall be less than a percentage, defined by the local system operator's code and standards measured as 10 min average data at the MEC terminals, or the PCC as appropriate while the MEC unit is not generating. Where no such codes or standards exist a value of 5 % shall be used. The total harmonic distortion of the voltage may be determined by measurement prior to testing the MEC unit;
- the grid frequency measured as 0,2 s average data shall be within a percentage of the nominal frequency, defined by the local system operator's code and standards. Where no such codes or standards exist a value of ± 1 % shall be used. The rate of change of the grid frequency measured as 0,2 s average data shall be less than that defined by the local system operator's code and standards. Where no such codes or standards exist, a value of 0,2 % of the nominal frequency per 0,2 s shall be applied. If the grid frequency is known to be very stable and well within the above requirements, which would commonly be the case in a large interconnected power system, this need not be assessed any further. Otherwise, the grid frequency shall be measured during the test;
- the voltage level shall be within a percentage of its nominal value, defined by the local system operator's code and standards, measured as 10 min average data at the MEC unit

terminals, or the PCC, as appropriate. Where no such codes or standards exist, a value of ± 10 % shall be used;

- the voltage unbalance factor shall be less than a value, defined by the local system operator's code and standards, measured as 10 min data at the MEC unit terminals, or PCC as appropriate. Where no such codes or standards exist, a value of 2 % shall be used. The voltage unbalance factor may be determined as described in IEC 61800-3:2017, Clause B.5. If the voltage unbalance factor is known to be well within the above requirement, it need not be assessed any further. Otherwise, the voltage unbalance factor shall be measured during the test;
- the environmental conditions shall comply with the manufacturer's requirements for the instruments and the MEC unit. Commonly, this does not call for any online measurements of the environmental conditions, though it is required that these are described in general terms as part of the measurement report;

Tests may be prepared at any turbulence intensity (for tidal and water current) and at any short-circuit ratio, but conditions (average turbulence intensity, short-circuit apparent power and network impedance angle) shall be stated as part of the test report/certificate. The turbulence intensity shall be stated based on sector-wise identification of obstacles and seabed variations or based on tidal velocity measurements.

The specified conditions are required to achieve reliable test results, and should not be interpreted as conditions for reliable grid connection and operation of MEC units.

7.1.4 Test equipment

7.1.4.1 General

The description of the measurements assumes application of a digital data acquisition system with elements as illustrated in Figure 3 and Figure 4 for MV and LV connected systems respectively.

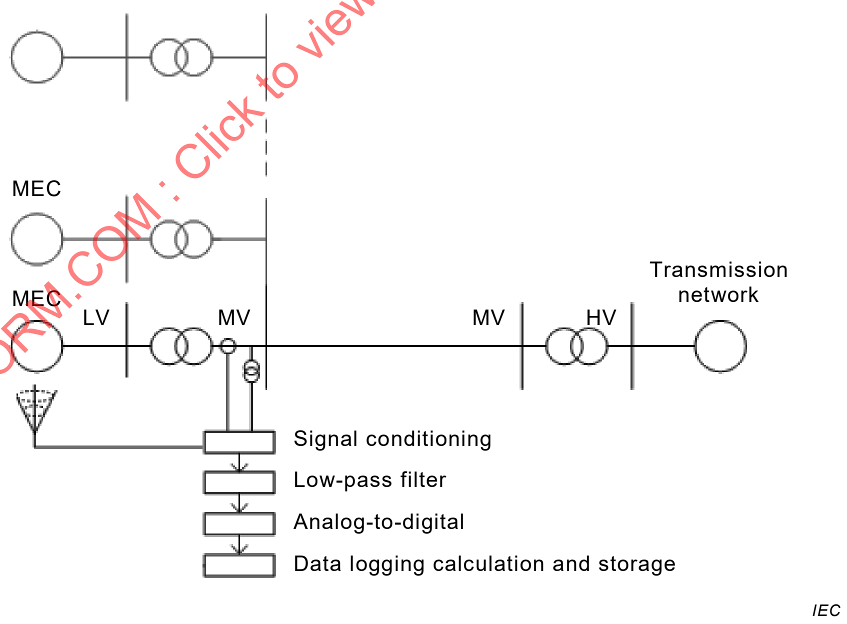


Figure 3 – Assumed elements of measurement system (MV-connected marine energy converter unit)

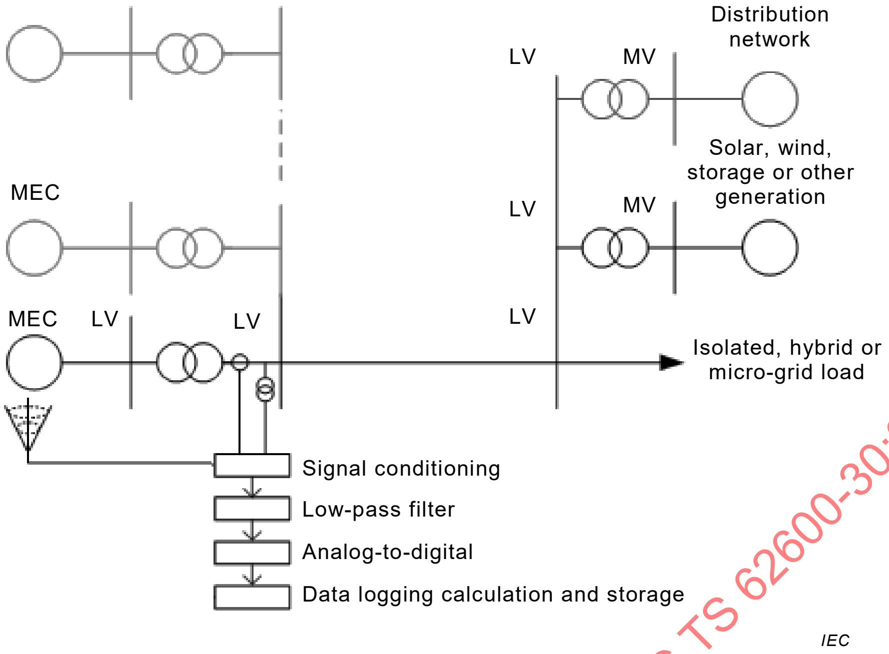


Figure 4 – Assumed elements of measurement system (LV-connected marine energy converter)

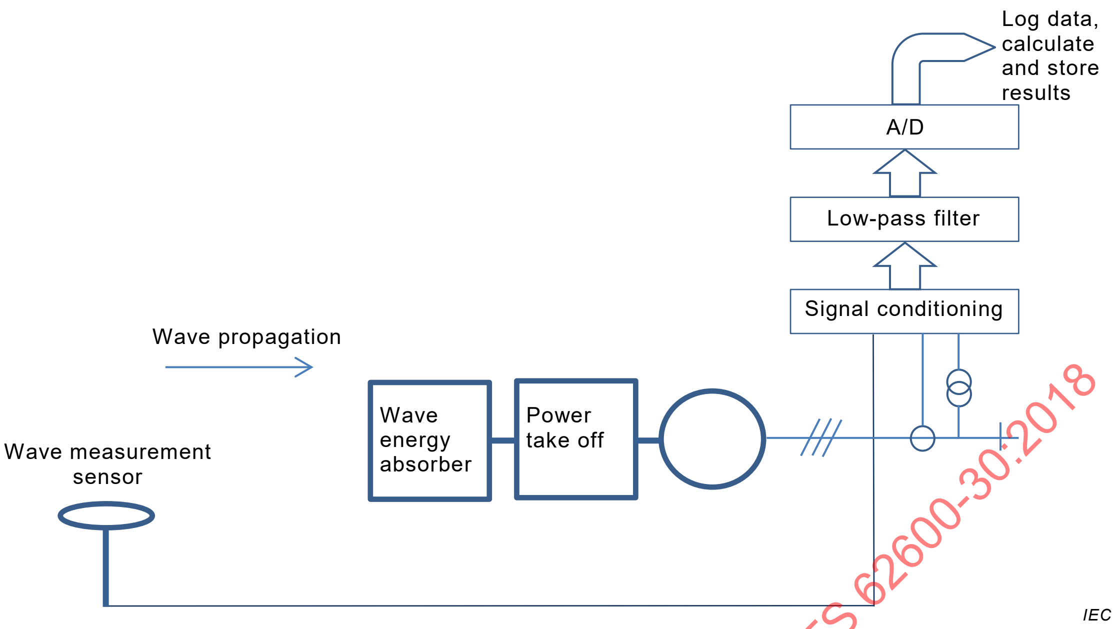
Table 4 – General specification of requirements for measurement equipment

Equipment	Required accuracy	Compliance with standard
Voltage transformers	Class 1,0	IEC 61869-1, IEC 61869-3
Current transformers	Class 1,0	IEC 61869-1, IEC 61869-2
Filter + A/D converter + data acquisition system	1 % of full scale	IEC 62008

7.1.4.2 Wave energy converters

The description of the measurements assumes application of a digital data acquisition system with elements as illustrated in Figure 5.

The wave resource measurement device (flow meter, acoustic Doppler current profiler (ADCP) or others), voltage transducers (transformers) and current transducers (transformers or other) are the required sensors of the measurement system. The signal conditioning is for connecting these to the low-pass filter which is required for anti-aliasing. The analogue to digital conversion (A/D) shall be of at least 12-bit resolution, i.e. to maintain the required measurement accuracy. See Table 4 and Table 5 for specification of equipment accuracy. In Figure 5, the power take-off point is as defined in IEC TS 62600-100.



Measurement sensor distances are not to scale.

Figure 5 – Assumed elements of wave energy converter power quality measurement system

Table 5 – Specification of requirements for wave measurement equipment

Equipment	Required accuracy	Compliance with standard
Wave measurement buoy / ADCP	IEC TS 62600-101 (as a guidance)	IEC TS 62600-101 (as a guidance)

The digital data acquisition system is assumed to log, calculate and store results as specified in the subsequent clauses. General guidance for calculation of RMS voltage, active and reactive power in a system as outlined in Figure 5 is given in Annex C. This requires a sample rate of at least 2 kHz per channel of the voltage and current signals. For measurement of harmonics (higher frequency components), the minimum sample rate shall be at least 20 kHz per channel.

The tidal flow velocity signal shall be sampled with at least 1 Hz resolution.

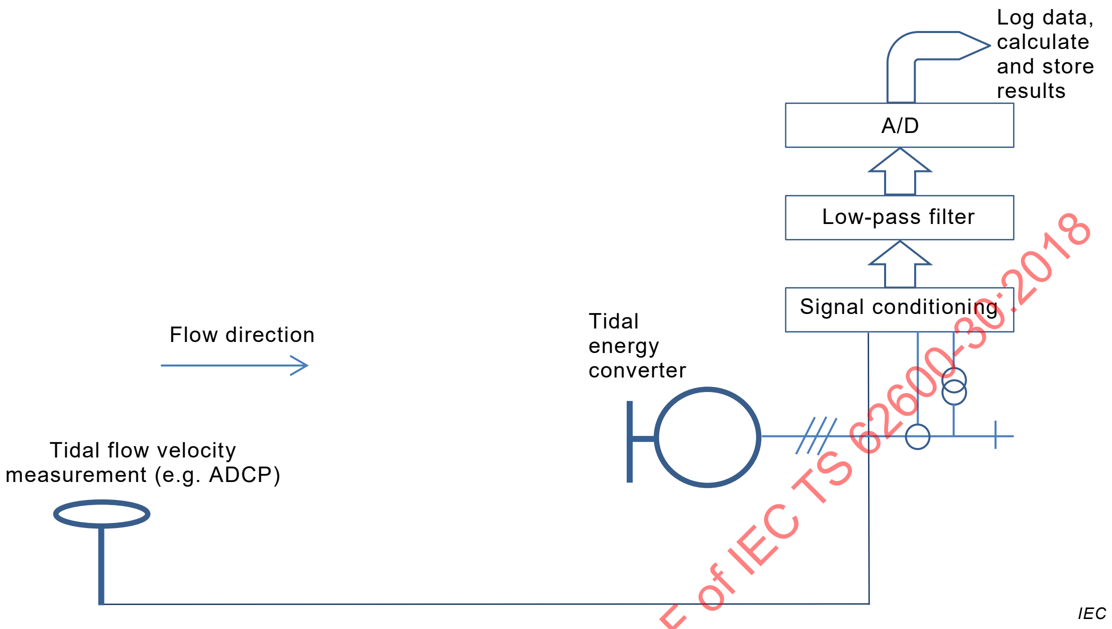
Ideally, the wave measurement will be taken as close as possible to the MEC unit. Alternatively, wave resource measurements can be estimated from local measurement or from corrected accelerometer measurements possibly in conjunction with power measurements and knowledge of the MEC unit response.

7.1.4.3 Tidal energy converters

The description of the measurements assumes application of a digital data acquisition system with elements as illustrated in Figure 6.

The tidal flow velocity measurement (e.g. ADCP, Acoustic Doppler velocimetry (ADV), propeller flow meters, etc.), voltage transducers (transformers) and current transducers (transformers) are the required sensors of the measurement system. The signal conditioning is for connecting these to the low-pass filter that are required for anti-aliasing. The analogue to digital conversion (A/D) shall be of at least 12-bit resolution, i.e. to maintain the required measurement accuracy. See Table 4 and Table 6 for specification of equipment accuracy.

In the situation where it is planned to measure the tidal flow velocity using alternative means than those recommended above (namely, the ADCP, Acoustic Doppler velocimetry (ADV), propeller flow meters, etc.), full details of the methodology should be provided in the test report, including an indication of accuracy.



Sensor distances are not to scale.

Figure 6 – Assumed elements of tidal energy converter unit power quality measurement system

Table 6 – Specification of requirements for tidal velocity measurement equipment

Equipment	**Required accuracy**	**Compliance with standard**
Tidal velocity measurement (e.g. ADCP)	1 % of the measured velocity	IEC TS 62600-201 (as a guidance)

The digital data acquisition system is assumed to log, calculate and store results as specified in the subsequent clauses. General guidance for calculation of RMS voltage, active and reactive power in a system as outlined in Figure 5 is given in Annex C. This requires a sample rate of at least 2 kHz per channel of the voltage and current signals. For measurement of harmonics (higher frequency components), the minimum sample rate shall be at least 20 kHz per channel.

In the situation where it is planned to measure the voltage and current using alternative means than those recommended in Table 4 (ensuring that sampling requirements are met), full details of the methodology should be provided in the test report, including an indication of accuracy.

Ideally, the tidal flow velocity measurement will be taken as close as possible to the MEC unit and in line with the direction of tidal flow. Alternatively, tidal energy flow velocities can be estimated from local measurement or from corrected turbine measurements possibly in conjunction with power measurements and knowledge of the MEC unit power curve.

7.2 Voltage fluctuations (continuous operation)

7.2.1 MV connected marine energy converters

The MV network will normally have other fluctuating loads that may cause significant voltage fluctuations at the MEC unit terminals, or the PCC, where the test measurements are taken. Moreover, the voltage fluctuations caused by the MEC unit will depend on the characteristics of the grid. The aim is, however, to achieve test results which are independent of the grid conditions at the test site. To accomplish this, this document defines a method that uses current and voltage time series measured at the MEC unit terminals, or the PCC as appropriate, to simulate the voltage fluctuations on a fictitious grid with no source of voltage fluctuations other than the MEC unit (see NOTE).

The application of the fictitious grid is further described below. The measurement procedures for voltage fluctuations are described only for continuous operation.

NOTE Although the specified method to simulate the voltage fluctuations on a fictitious grid avoids the direct influence of the real voltage fluctuations of the grid at the measurement point of flicker, there can be an influence of these voltage fluctuations, caused by other sources, on the measured current from the marine energy converter. This in turn can influence the simulated voltage fluctuations on the fictitious grid. However, this effect is relatively small and does not justify changing the procedure for determining the flicker coefficient.

7.2.2 Fictitious grid

The phase diagram of the fictitious grid is shown in Figure 7.

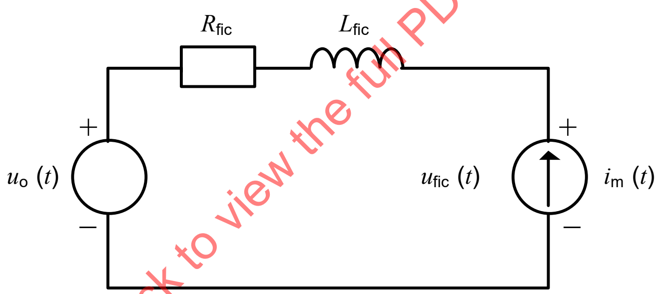


Figure 7 – Fictitious grid for simulation of fictitious voltage

The fictitious grid is represented by an ideal phase-to-neutral voltage source with the instantaneous value $u_0(t)$ and a grid equivalent impedance given as a resistance R_{fic} in series with an inductance L_{fic}. The MEC unit is represented by the current generator source $i_m(t)$ which is the measured instantaneous value of the line current. In some studies, an impedance in parallel with the current source can be assumed. This simple model gives a simulated voltage with the instantaneous value $u_{fic}(t)$ according to formula (1):

$$u_{fic}(t) = u_o(t) + R_{fic} \times i_m(t) + L_{fic} \times \frac{di_m(t)}{dt} \quad (1)$$

The ideal voltage source $u_0(t)$ can be generated in different ways. But two properties of the ideal voltage should be fulfilled:

a) the ideal voltage should be without any fluctuations, i.e. the flicker on the voltage should be zero;

b) $u_0(t)$ shall have the same electrical angle $\alpha_m(t)$ as the fundamental of the measured voltage. This ensures the phase angle between $u_{fic}(t)$ and $i_m(t)$ is correct, provided that $|u_{fic}(t) - u_o(t)| << |u_o(t)|$. To fulfil these properties, $u_0(t)$ is defined as:

$$u_{o}(t) = \sqrt{\frac{2}{3}} \times U_{n} \times \sin(\alpha_{m}(t)) \qquad (2)$$

where U_n is the RMS value of the nominal voltage of the grid.

The electrical angle of the fundamental of the measured voltage may be described by formulas (3) to (12).

$$\alpha_{m}(t) = 2\pi \times \int_{0}^{t} f(t)dt + \alpha_{o} \qquad (3)$$

where

$f(t)$ is the frequency (that may vary over time);

t is the time since the start of the time-series;

α_o is the electrical angle at $t = 0$.

R_{fic} and L_{fic} shall be selected to obtain the appropriate network impedance phase angle ψ_k applying formula (4) below:

$$\tan(\psi_{k}) = \frac{2\pi \times f_{g} \times L_{fic}}{R_{fic}} = \frac{X_{fic}}{R_{fic}} \qquad (4)$$

where f_g is the nominal grid frequency (50 Hz or 60 Hz).

The three-phase short-circuit apparent power of the fictitious grid is given by formula (5) below:

$$S_{k,fic} = \frac{U_{n}^{2}}{\sqrt{R_{fic}^{2} + X_{fic}^{2}}} \qquad (5)$$

A proper short-circuit ratio $S_{k,fic}/S_r$ shall be used to ensure that the applied flicker meter algorithm or instrument gives P_{st} values that are well within the measurement range required 787 in IEC 61000-4-15. A class F1 flicker meter for low measurement uncertainties shall be used. Due to the magnitude of the P_{st} values involved in the flicker characterization of the wind turbines, the flicker meter shall specify the working range in the performance testing (rectangular voltage changes and performance testing, Table 5 of IEC 61000-4-15:2010) as the lowest and highest k-value for which the corresponding value $P_{st,k}$ is within ± 5 % (disregarding the ± 0,05 p.u. tolerance). IEC 61400-21 suggests using the measurement range 0,05 ≤ k ≤ 5,0, though it is the responsibility of the assessor to select the appropriate short-circuit ratio $S_{k,fic}/S_r$ for the available measurement range. It shall be taken into account that, on the one hand, larger voltage fluctuations can be obtained by decreasing the short-circuit ratio. On the other hand, if the short-circuit ratio becomes too small, the mean RMS value of $u_{fic}(t)$ will deviate significantly from the RMS value of $u_0(t)$, which will influence the relative voltage changes because the absolute voltage changes are normalised with a different mean value. To obtain simulated voltage fluctuations within the flicker meter range, a short-circuit ratio $S_{k,fic}/S_r$ between 20 and 50 is recommended.

7.2.3 Continuous operation – MV connected marine energy converters

The flicker coefficient $c(\psi_k)$ shall be determined so it can be stated according to 6.3.2. This shall be done by measurement and simulation.

Subclause 7.2.3 gives the detailed procedure, whereas an informative outline is provided in Clause B.1.

The following measurements shall be performed (see also Note in 7.2.1):

a) the three instantaneous line currents and the three instantaneous phase-to-neutral voltages shall be measured at the MEC unit terminals, or the PCC as appropriate.

b) measurements shall be taken so that at least fifteen 10 min time-series of instantaneous voltage and current measurements (five tests and three phases) are collected for resource variations as outlined in 6.3;

c) the resource conditions shall be measured according to relevant IEC 62600 standards; switching operations (start-up or switching among generators) are excluded except for conditions such as switching of capacitors that occur during continuous operation of the MEC unit.

The voltage flicker during the test shall be reported. The voltage flicker shall be measured at the MEC unit's terminals, or PCC as appropriate, according to IEC 61000-4-15. The measurements shall be taken with a measurement set-up as specified in Figure 3 or Figure 4, and by applying voltage and current transformers and resource measurement devices with specifications according to Table 4 to Table 6. The cut-off frequency of the voltage and current measurements shall be at least 400 Hz.

The measurements shall be treated to determine the flicker coefficient of the MEC unit as a function of the network impedance phase angle and recorded resource variation conditions. This shall be done repeating the following procedure for each of the network impedance phase angles.

First, the flicker coefficient for each set of 10 min measured voltage and current time-series shall be determined. The procedure for this is given in steps 1) to 3) below:

1) the measured time-series shall be combined with formula (1) to give voltage time-series of $u_{\text{fic}}(t)$;

2) the voltage time-series of $u_{\text{fic}}(t)$ shall be input to the flicker algorithm in compliance with IEC 61000-4-15 to give one flicker emission value $P_{\text{st,fic}}$ on the fictitious grid for each 10 min time-series;

3) the flicker coefficient shall be determined for each of the calculated flicker emission values by applying formula (6):

$$c(\psi_k) = P_{\text{st,fic}} \times \frac{S_{k,fic}}{S_r} \tag{6}$$

where

S_r is the rated apparent power of the MEC unit;

$S_{k,\text{fic}}$ is the short-circuit apparent power of the fictitious grid.

These assessed quantities (resource conditions, flicker coefficients, etc.) are to be presented using a template similar to the one in Annex A.

The flicker algorithm described in IEC 61000-4-15 generates the RMS value of $u_{\text{fic}}(t)$, and then cuts off variations faster than 35 Hz. Still a minimum cut-off frequency of 400 Hz, corresponding to a minimum sampling frequency of 800 Hz, is required for flicker measurements of continuous operation in this document. Test calculations have shown that this sampling frequency is necessary to obtain consistent results. A lower sampling frequency will reduce the accuracy of the electrical angle of the fundamental of the measured voltage $\alpha_m(t)$.

7.2.4 Continuous operation – LV connected marine energy converters

For LV connected MEC units, a simplified measurement and direct reporting procedure is suggested. The following measurements shall be performed:

- single or three-phase instantaneous line currents and instantaneous phase-to-neutral voltages shall be measured at the MEC unit terminals or PCC as appropriate;
- measurements shall be taken so that at least fifteen 10 min time-series of instantaneous voltage and current measurements are collected for resource variations between cut-in to rated conditions;
- the resource conditions shall be measured according to relevant IEC 62600 standards;
- switching operations (start-up or switching among generators) are excluded except such as switching of capacitors that occur during continuous operation of the MEC unit.

Each set of measured instantaneous voltage time series $u_m(t)$ is then used as input to the voltage flicker algorithm described in IEC 61000-4-15 to generate the flicker disturbance factor P_{st}. The 95th percentile P_{st} of the disturbance factor is then reported in tabular format. In addition, the measured flicker disturbance factor is reported (in tabular, graphical and/or formula format) for the whole range of the MEC unit's operation.

7.3 Current harmonics, interharmonics and higher frequency components

The emission of current harmonics, interharmonics and higher frequency components from the MEC unit during continuous operation shall be measured so that these can be measured and recorded in accordance with 6.4.

The results shall be based on observation times of 10 min for each active power bin, (i.e. the bin midpoints 5 %, 15 %, 25 %, …, 95 % of P_r as stated in 6.4). Background harmonic distortion from the grid shall be measured and recorded at the PCC. It is desirable that the harmonic emissions from the MEC unit are measured with minimum distortion from the grid. The measurement procedure shall be suitable for MEC units, i.e. where the magnitude of the current harmonics produced can be expected to change rapidly, i.e. within seconds.

At least nine 10 min time-series of instantaneous current measurements (three tests and three phases) shall be collected for each 10 % power bin.

The measurements and grouping of the spectral components shall be performed according to IEC 61000-4-7. The choice of grouping method is made reflecting that measurements are made on a fluctuating source. The accuracy class I as defined in IEC 61000-4-7 shall be applied.

The 10-cycle window for 50 Hz and 12-cycle window for 60 Hz systems is recommended. The window size shall be stated in the test report (see Annex A).

Harmonic currents below 0,1 % of I_r for any of the harmonic orders need not be reported.

The DFT (Discrete Fourier Transform) is applied to each of measured currents with rectangular weighting, i.e. no special weighting function (Hanning, Hamming, etc.) shall be applied to measured time-series. The active power shall be evaluated over the same time window as the harmonics.

The harmonic current components for frequencies up to 50 times the fundamental grid frequency shall be subgrouped as given in 5.6 of IEC 61000-4-7:2002/AMD1:2008.

The total harmonic current distortion (THC) shall be calculated according to formula (7):

$$\mathrm{THC} = \frac{\sqrt{\sum_{h=2}^{50} I_h^2}}{I_r} \times 100 \tag{7}$$

where

I_h is the subgrouped RMS current harmonic of harmonic order h;

I_r is the rated current of the MEC unit.

The interharmonic current components below 2 kHz shall be subgrouped in accordance with Annex A of IEC 61000-4-7:2002/AMD1:2008 (formulas (A.3) and (A.4) for 50 Hz and 60 Hz systems respectively).

The higher frequency components, i.e. the 2 kHz to 9 kHz current components, shall be measured and grouped according to Annex B of IEC 61000-4-7:2002/AMD1:2008, (formula (B.1)). The output of raw DFT shall be grouped in bands of 200 Hz.

The 10 min averages of each frequency band (i.e. each subgrouped harmonic, interharmonic and higher frequency current component) shall be calculated for each 10 min time-series, and subsequently the maximum 10 min averages of each frequency band in each 10 % power bin shall be reported.

The voltage harmonics during the test shall be reported. The voltage harmonics shall be measured at the MEC unit terminals, or PCC as appropriate, and according to IEC 61000-4-7. As a minimum, the 10 min average values of the total harmonic distortion of the voltage shall be reported.

IEC 61000-4-7:2002/AMD1:2008, 5.6 is on voltage harmonics. This grouping procedure is still recommended for assessing the current harmonics of a fluctuating source like MEC units.

7.4 Response to temporary voltage drop

The response of the MEC unit to the temporary voltage drops shall be measured so that these can be stated in accordance with 6.5. The stated response shall include time series of active power, reactive power, active current, reactive current and voltage at the MEC unit terminals, or the PCC as appropriate, for the time shortly prior to the voltage drop and until the effect of the voltage drop has abated. The MEC unit operational mode and the sea state conditions (H_{m0}, T_{-10}) or tidal/water flow velocity (m/s) shall be specified.

The active power, reactive power, active current, reactive current and voltage shall be given for each phase (L1, L2, L3), and shall be measured as positive sequence fundamentals, see Annex C.

The test shall be carried out for the MEC unit operating between 0,1 P_r and P_r.

The test can be carried out using for instance a set-up such as the one outlined in Figure 8. The voltage drops are created by a short-circuit emulator that connects the three or two phases to ground via an impedance, or connecting the three or two phases together through an impedance. If access to the MEC unit terminals is not possible, the measurements can be carried out at the PCC, under the guidelines of the local grid operator.

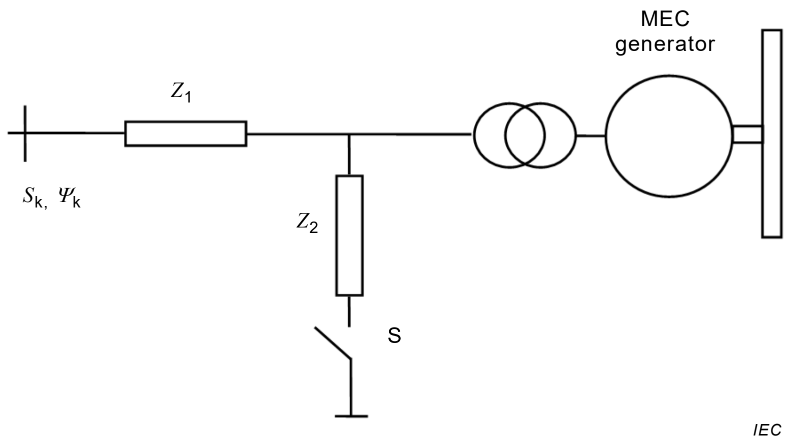


Figure 8 – System with short circuit emulator for testing MEC unit response to temporary voltage drop

The impedance Z_1 is for limiting the effect of the short-circuit on the up-stream grid. The size of the impedance should be selected so that the voltage drop testing is not causing an unacceptable situation at the upstream grid, and at the same time not significantly affecting the transient response of the MEC unit. A by-pass connection of Z_1 may be applied prior and after the drop.

The voltage drop is created by connecting the impedance Z_2 by the switch S. The size of Z_2 shall be adjusted to give the voltage magnitudes specified in Table 2 when the MEC unit is not connected.

The values of the impedances Z_1 and Z_2 used in the tests shall be stated in the description of the test equipment.

The switch S shall be able to accurately control the time between connection and disconnection of Z_2, and for all three or two phases. The switch can be for example a mechanical circuit breaker or a power electronic device.

The voltage magnitudes specified in Table 2 may be affected by the MEC unit operation, but are defined for the MEC unit not connected to the setup outlined in Figure 8. Without the MEC unit connected, the voltage drop shall be within the shape indicated in Figure 9. The duration of the drop shall be measured from closing to opening of the switch S. The time-tolerance is included as to account for tolerance in operation of the switch S and that the positive sequence voltage will not drop or rise instantly, but with a slope.

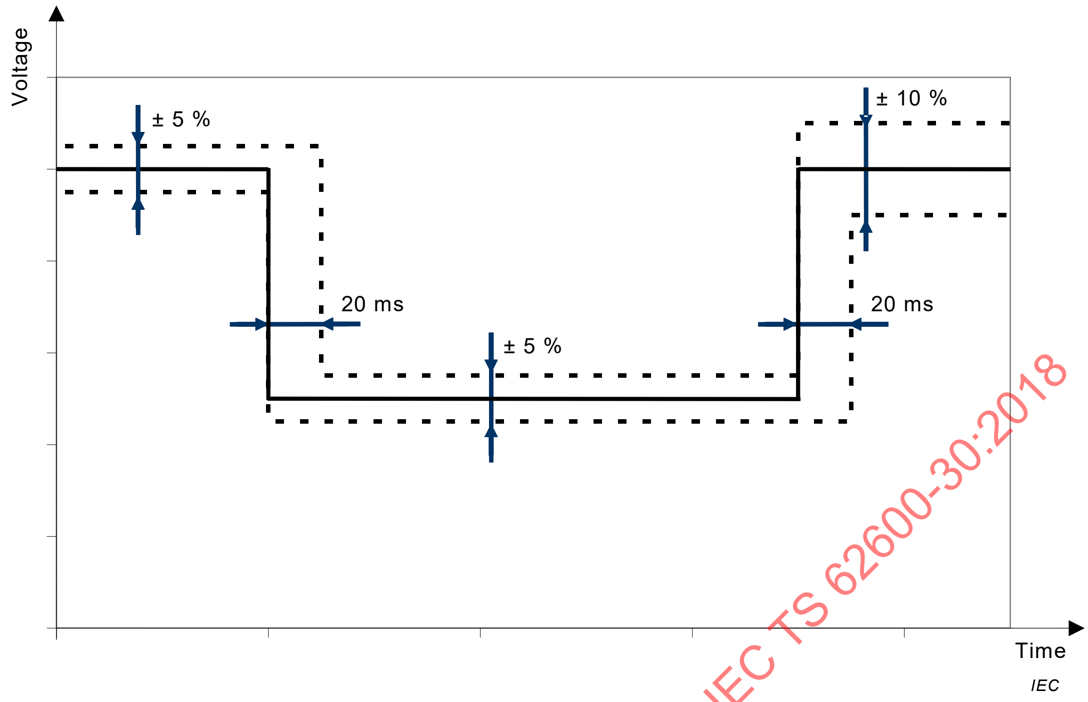


Figure 9 – Tolerance of voltage drop

7.5 Active power

7.5.1 General

For each subclause in 7.5, the measurements shall be taken with a measurement set-up as specified in Figure 5 (wave) or Figure 6 (tidal and water current), and by the current and voltage, and resource measurement guidelines outlined in 7.1.

The wave resource (H_{m0}, T_{-10}) or tidal flow velocity (m/s) shall be stated once for each test carried out.

As a guidance, the full-scale range for measuring the current may be two times the rated current of the MEC unit.

The available active power output shall be read from the control system of the MEC unit, or if the MEC unit control system does not facilitate this, an approximate value can be used based on measured resource (wave or tidal) combined with the power characteristic of the MEC unit.

7.5.2 Maximum measured power

The maximum measured active power shall be measured so that it can be specified in accordance with 6.6.1 as a 600 s average value, P_{600}, a 60 s average value, P_{60} and as a 0,2 s average value, $P_{0,2}$ applying the following procedure:

- measurements shall be sampled during continuous operation only;
- the active power shall be measured at the MEC unit terminals, or the PCC as appropriate;
- measurements shall be taken so that at least five 10 min time series of power are collected (at resource conditions where the active power output of the MEC would reach its full rated power output);
- the wave resource (H_{m0}, T_{-10}) or tidal/water flow velocity (m/s) is measured over 20 mins (17,5 min of data collection). This 20 min period overlaps with the measured power 10 min. range;

- the measured power shall be transferred to 0,2 s average data and 60 s average data by block averaging;
- $P_{0,2}$ shall be determined as the highest valid 0,2 s average value recorded during the measurement period;
- P_{60} shall be determined as the highest valid 60 s average value recorded during the measurement period;
- P_{600} shall be determined as the highest valid 600 s average value recorded during the measurement period.

7.5.3 Ramp rate limitation

Where available, the ramp rate limitation shall be tested so that it can be characterized according to 6.6.2. The following procedure shall be applied:

- the MEC unit shall be started from stand still/idle;
- the ramp rate shall be set to a stated percentage of rated power per minute;
- the test shall be carried out for at least 10 min after the MEC unit has connected to the grid;
- the available active power output shall be at least 50 % of rated power during the whole test;
- the active power shall be measured at the MEC unit terminals, or at the PCC as appropriate;
- the test results shall be reported as 0,2 s average data.

7.5.4 Set point control

If available, the active power set point control shall be tested so that it can be characterized according to 6.6.3. The following procedure shall be applied:

- the test shall be carried out during a test period of 10 min;
- ramp rate limitation shall be deactivated during the test to ensure fastest possible response;
- the set point signal shall be reduced from 100 % to 20 % in steps of 20 % with 2 min operation at each set point value, i.e. according to Figure 1;
- the available active power output shall during the whole test be at least 90 % of rated power;
- the active power shall be measured at the MEC unit terminals, or at the PCC as appropriate;
- the test results shall be reported as 0,2 s average data.

7.6 Reactive power

7.6.1 General

For each subclause in 7.6, the measurements shall be taken with a measurement set-up as specified in Figure 5 (wave) or Figure 6 (tidal and water current), and by the current and voltage, and resource measurement guidelines outlined in 7.1.

7.6.2 Reactive power capability

The maximum inductive reactive power and the maximum capacitive reactive power shall be measured so that it can be stated according to 6.7.1.

- For the measurement of the maximum inductive reactive power, the MEC unit shall be set to the operation mode which gives the maximum inductive reactive power in the whole power range.
- For the measurement of the maximum capacitive reactive power, the MEC unit shall be set to the operation mode which gives the maximum capacitive reactive power in the whole power range.

For each of the two setting modes, the following procedure shall be applied:

- measurements shall be sampled during continuous operation only;
- the active and reactive power shall be measured at the MEC unit terminals, or at the PCC as appropriate;
- measurements shall be taken so that at least ten 1 min time-series of active and reactive power are collected at each 10 % power bin;
- the sampled data shall be transferred to 1 min average data by applying block averaging for each 1 min period;
- the 1 min average data shall be sorted according to the method of bins so that the reactive power can be specified as average bin values in a table for 0 %, 10 %, ...90 %, 100 % of rated power. Here 5 %, 15 %, ...85 %, 95 % are the midpoints of active power bins.

7.6.3 Set point control

If available, the reactive power control by set point value shall be measured so that it can be stated according to 6.7.3.

For the measurement, at a set point of reactive power Q= 0, the following procedure shall be applied:

- measurements shall be sampled during continuous operation only;
- the active and reactive power shall be measured at the MEC unit terminals, or at the PCC as appropriate;
- measurements shall be taken so that at least ten 1 min time-series of active and reactive power are collected at each 10 % power bin;
- the sampled data shall be transferred to 1 min average data by applying block averaging for each 1 min period;
- the 1 min average data shall be sorted according to the method of bins so that the reactive power can be specified in a table for 0 %, 10 %, ...90 %, 100 % of rated power. Here 5 %, 15 %, ...85 %, 95 % are the midpoints of active power bins.

For the measurement during the step change of reactive power, the following procedure shall be applied:

- measurements shall be sampled during continuous operation only;
- the active and reactive power shall be measured at the MEC unit terminals, or at the PCC as appropriate;
- the active power output shall be at approximately 50 % of rated power;
- the sampled data for reactive power shall be 0,2 s average data;
- the set point of reactive power shall be varied according to Figure 2. The step change shall be between Q_{max} and $-Q_{max}$ where Q_{max} and $-Q_{max}$ are the reactive power capability of the MEC at the active power output as shown according to 7.6.2;
- the measured reactive power shall be shown in a graph as 0,2 s data together with the set point value of reactive power.

8 Determination of power quality

8.1 General

Clause 8 gives methods for estimating the flicker expected from a MEC unit or farms built from groups of MEC units when deployed at a specific site, and to allow the results to be compared to requirements in other IEC publications.

If electricity network operators and regulatory authorities apply their own requirements in place of or in addition to IEC standards, the principles of Clause 8 may still be used as a guideline.

8.2 Voltage fluctuations (continuous operation)

8.2.1 MV connected marine energy converter units

The methods for assessing compliance with power quality requirements are valid for MEC units with PCC at MV or HV in power systems with fixed frequency within ± 1 Hz, and sufficient active and reactive power regulation capabilities. In other cases, the principles for assessing compliance with flicker requirements may still be used as guideline.

The flicker emissions from a MEC unit shall be limited to comply with the flicker emission limits as specified in formula (8) and formula (9) below.

$$P_{\mathrm{st}} \leq E_{\mathrm{psti}} \tag{8}$$

$$P_{\mathrm{lt}} \leq E_{\mathrm{plti}} \tag{9}$$

where

P_{st} and P_{lt} are the short and long-term flicker emissions from the MEC unit respectively;

E_{psti} and E_{plti} are the short and long-term flicker emission limits for the relevant PCC respectively.

Furthermore, the relative voltage change due to a MEC unit shall be limited in accordance with formula (10) below.

$$d \leq \frac{\Delta d_{\mathrm{dyn}}}{U_{\mathrm{n}}} \tag{10}$$

where

d is the relative voltage change due to a switching operation (for example start-up) of a MEC unit;

Δd_{dyn} is the fractional change in voltage.

Recommended methods for assessing the flicker emission limits and the maximum permitted voltage change for installations at medium and high voltage levels are given in IEC TR 61000-3-7.

The 95th percentile flicker emission from the MEC unit during continuous operation shall be estimated applying formula (11) below.

$$P_{st} = P_{lt} = c(\psi_k) \times \frac{S_r}{S_k} \quad (11)$$

where

$c(\psi_k)$ is the flicker coefficient of the MEC unit for the given network impedance phase angle ψ_k at the PCC, and for the given annual average resource condition. (See Table A.6 in Annex A. This value may be found by applying linear interpolation or direct approximation from this data);

S_r is the rated apparent power of the MEC unit;

S_k is the short-circuit apparent power at the PCC.

If the flicker coefficient data for the measured site (i.e. the 95th percentile data in Annex A, Table A.6) does not correspond to the resource conditions for a given site, the 95th percentile of a time-series of synthesized data can be used using formula (12):

$$c(\psi_k)(t) = f(V_{MEC}) \times V_{MEC}(t) \quad (12)$$

where

$c(\psi_k)(t)$ is the time series data of flicker coefficient synthesized using a given MEC unit characteristics (flicker vs. resource) and resource data. (For wave, H_{mo} and T_{-10} should be stated once for each test);

$f(V_{MEC})$ is the MEC unit characteristics represented in graphical, tabular/look-up or best-fit formula format relating measured flicker index against the MEC unit's full range of operation as reported during the measurement, for a given network impedance angle;

$V_{MEC}(t)$ is the marine resource (typically synthesized or measured) for a given site for a given duration, where $V_{MEC} = \{H_{m0}, T_{-10}\}$ for wave, $V_{MEC} = \{v_{ta}\}$ for tidal, and $V_{MEC} = \{v_{wa}\}$ for water current.

In the case where a farm of MEC units is connected to the PCC, the flicker emission from the sum of them can be estimated from formula (13) below.

$$P_{st\Sigma} = P_{lt\Sigma} = \frac{1}{S_k} \times \sqrt{\sum_{i=1}^{N_{mec}} \left(c_i(\psi_k) \times S_{r,i}\right)^2} \quad (13)$$

where

$c_i(\psi_k)$ is the flicker coefficient of the individual MEC unit;

$S_{r,i}$ is the rated apparent power of the individual MEC unit;

N_{mec} is the number of MEC units connected to the PCC.

8.2.2 LV connected marine energy converter

If the flicker disturbance factor data for the measured site (i.e. the 95th percentile data in Annex A, Table A.6) corresponds to the resource conditions for a given site, this quantity can be used directly for a given site at the assessor's discretion. However, If the flicker disturbance factor data for the measured site (i.e. the 95th percentile data in Annex A, Table A.6) does not correspond to the resource conditions for a given site, the 95th percentile of a time series of synthesized data can be used using formula (14):

$$P_{st}(t) = f(V_{MEC}) \times V_{MEC}(t) \tag{14}$$

where

$P_{st}(t)$ is the time series data of flicker disturbance factor synthesized using a given MEC characteristics (flicker vs. resource) and resource data;

$f(V_{MEC})$ is the MEC unit characteristics represented in graphical, tabular/look-up or best-fit formula format relating measured flicker index against the MEC unit's full range of operation as reported during the measurement, for a given network impedance angle.

In case more MEC units are connected to a common point, the flicker emission from the sum of them can be estimated from formula (15) below.

$$P_{st\Sigma} = P_{lt\Sigma} = \sqrt{N_{mec}}\, P_{st,i} \tag{15}$$

where

$P_{st,i}$ is the flicker disturbance factor of an individual MEC unit;

N_{mec} is the number of MEC units connected to the PCC.

8.3 Current harmonics, interharmonics and higher frequency components

The harmonic currents shall be limited to the degree needed to avoid unacceptable harmonic voltages at the PCC. The applicable limits for emission of harmonics may be found by applying the guidance given in IEC TR 61000-3-6. However, these limits will be defined by the relevant authority in a given jurisdiction.

IEC TR 61000-3-6 gives guidance for summation of harmonic current distortion from loads. Applying this, the harmonic current at the PCC due to a MEC unit installation with a number of converters may be estimated applying formula (16) below:

$$I_{h\Sigma} = \sqrt[\beta]{\sum_{i=1}^{N_{mec}} \left(\frac{I_{h,i}}{n_i}\right)^{\beta}} \tag{16}$$

where

N_{mec} is the number of converters connected to the PCC;

$I_{h\Sigma}$ is the h'th order harmonic current distortion at the PCC;

n_i is the ratio of the transformer at the i'th converter;

$I_{h,i}$ is the h'th order harmonic current distortion of the i'th converter;

β is an exponent with a numerical value to be selected according to Table 7 and the points below.

Table 7 – Specification of exponents according to IEC TR 61000-3-6

Harmonic order	β
$h < 5$	1,0
$5 \le h \le 10$	1,4
$h > 10$	2,0

If the converters are equal and their power converters' line commutated, the harmonics are likely to be in phase and $\beta = 1$ shall be used for all harmonic orders.

Formula (16) does not take into account the use of transformers with different vector groups that may cancel out particular harmonics. If this is the case, adequate measures should be taken to include the effect of this.

Formula (16) can also be applied for current interharmonics and higher frequency components. As current interharmonics and higher frequency components are assumed to be uncorrelated, it is recommended to use $\beta = 2$ in formula (16) for summation of these.

Annex A
(informative)

Sample report format

A.1 General

This sample report format gives a suggested format for reporting the results of tests for characterizing the power quality parameters of a MEC unit. The assessor should fill in the empty tables and insert graphics at the figure captions.

REPORT ON RESULTS OF MARINE ENERGY CONVERTER POWER QUALITY TESTS

The reported characteristics are valid for the specific configuration of the assessed MEC unit type only. Other configurations, including altered control parameters, that cause the MEC unit to behave differently with respect to power quality, require separate assessment, see Tables A.1 and A.2.

Table A.1 – General marine energy converter information

Name of test organization	
Report number	
Marine energy converter type designation	
Marine energy converter manufacturer	
Serial number of marine energy converter tested	

The marine energy converter identified above has been tested in accordance with IEC TS 62600-30. General marine energy converter data are given below:

Table A.2 – Marine energy converter nameplate ratings

Marine energy converter type (wave, tidal, water current)	Wave ☐ Tidal ☐ Water current ☐
Mechanical conversion scheme (wave: heave, pitch, yaw, sway, surge; tidal and water current: horizontal, vertical; other – specify)	
Unit rating(s) (kW)	
Generator type (synchronous, induction, doubly-fed, full power frequency converter, other – specify)	
Frequency converter type and rating (kVA)	
Frequency converter firmware version	
Frequency converter software settings	
Reactive compensation type and rating (kVAr)	
Transformer ratio and rating (kVA)	
Identification of marine energy converter terminals, or PCC as appropriate	

This test report is accompanied by the documents specified below, see Tables A.3 to A.7.