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TECHNICAL SPECIFICATION

colour inside

Marine energy – Wave, tidal and other water current converters –
Part 201: Tidal energy resource assessment and characterization

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

IEC TS 62600-201, 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
114/142/DTS	114/151A/RVC

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

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

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

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

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- withdrawn,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

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

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

INTRODUCTION

This Technical Specification is for use by appropriately qualified and competent persons. The development of the tidal power industry is at an early stage and the significance of particular tidal energy resource characteristics is not well understood. This Technical Specification is intended to be updated as understanding of the resource and its response to power extraction becomes better understood. It is noted that it is presently particularly difficult to derive the uncertainty (within specified confidence limits) of the resource, given lack of field and model data for a statistically significant number of sites.

The purpose of this Technical Specification is to provide a uniform methodology that will ensure consistency and accuracy in the estimation, measurement, characterization and analysis of the theoretical tidal current resource at sites that could be suitable for the installation of an array of Tidal Energy Converters (TECs), together with defining a standardised methodology with which this resource can be described and reported. Application of the estimation, measurement and analysis techniques recommended in this Technical Specification will ensure that resource assessment is undertaken in a consistent and accurate manner. This Technical Specification presents techniques that are expected to provide fair and suitably accurate results that can be replicated by others.

The overall goal of the methodology is to enable calculation of the Annual Energy Production (AEP) for the proposed array of TECs at each TEC location in conjunction with IEC 62600-200.

In this Technical Specification, the theoretical tidal energy resource (undisturbed or disturbed by power extraction) is defined as the velocity probability distribution $f(U_i)$. For projects over c. 10 MW (circa 10 MW), the velocity probability distribution is calculated using hydrodynamic models that have been appropriately verified using measured data. The methodology for measuring the required data is also defined. For individual TECs within small projects of less than c. 10 MW, an alternative method which uses measured data at each TEC location may also be used to define the resource.

This Technical Specification describes only the aspects of the resource required to calculate AEP; e.g., it does not describe aspects of the resource required to evaluate design loads or to satisfy environmental regulations. Furthermore, this Technical Specification is not intended to cover every eventuality that may be relevant for any particular project. Therefore, this Technical Specification assumes that the user has access to, and reviews, other relevant IEC documentation before undertaking work (e.g., surveys and modelling) which could also satisfy other requirements.

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

Part 201: Tidal energy resource assessment and characterization

1 Scope

This part of IEC 62600 establishes a system for analysing and reporting, through estimation or direct measurement, the theoretical tidal current energy resource in oceanic areas including estuaries (to the limit of tidal influence) that may be suitable for the installation of arrays of TECs.

It is intended to be applied at various stages of project lifecycle to provide suitably accurate estimates of the tidal resource to enable the arrays' projected annual energy production to be calculated at each TEC location in conjunction with IEC 62600-200.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61400-12-1, *Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*

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

IEC TS 62600-200, *Marine energy – Wave, tidal and other water current converters – Part 200: Electricity producing tidal energy converters – Power performance assessment*

IHO (International Hydrographic Organisation), 2008, *Standards for Hydrographic Surveys. Special Publication No. 44. 5th Edition*

ICES, 2006, *Guidelines for Multibeam Echosounder Data*

3 Terms and definitions

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

4 Symbols, units and abbreviations

4.1 Symbols and units

$f(U_i)$ Time occurrence likelihood of a velocity in each magnitude bin (%)

$f(U_i, \theta_k)$ Time occurrence likelihood of a velocity in each magnitude and direction bin (%)

I Turbulence intensity

i Index for velocity magnitude bin numbers

j	Index for number of time intervals
k	Index for direction bin numbers
K	Turbulent kinetic energy (m^2/s^2)
N	Number of time intervals
N_B	Number of velocity bins
u'	Root-mean-square of the turbulent velocity fluctuations (m/s)
$\overline{U}$	Mean velocity magnitude (m/s)
U_i	Central value velocity magnitude in the i^{th} bin (m/s)
U_j	Central value velocity magnitude of time step j (m/s)
θ_k	Direction for the k^{th} bin (deg)
V_{rmc}	Root Mean Cubed Velocity (m/s)
ρ	Density of the water (kg/m^3)

4.2 Abbreviations

AEP	Annual Energy Production
ADV	Acoustic Doppler Velocimeter
APD	Average Power Density (kW/m^2)
CTD	Conductivity, Temperature, Depth
CFD	Computational Fluid Dynamics
EEP	Energy Extraction Plane
GPS	Global Positioning System
IEC	International Electrotechnical Commission
NOAA	National Oceanic and Atmospheric Administration
PCA	Projected Capture Area
RTK	Real Time Kinematics
SAR	Synthetic Aperture Radar
TEC	Tidal Energy Converter
UTC	Coordinated Universal Time

5 Methodology overview

5.1 Project definition

5.1.1 General

This Technical Specification should be applied at various stages of the resource assessment process to provide velocity probability distributions for computing Annual Energy Production (AEP) with increasing accuracy or lower levels of uncertainty. This specification assumes that a region of interest has already been identified. Aspects of the methodology to be followed when undertaking a tidal resource assessment depend on the scope of the analysis and its objectives. Two distinct types of studies, feasibility and layout design, are defined as indicated in Table 1. The feasibility study generally has a focus on the whole estuary or channel with a medium level of uncertainty. The layout design study is expected to focus on the particular sites chosen through the feasibility studies.

Table 1 – Resource assessment stages

Stage	Aim	Area	Level of uncertainty
Stage 1	Feasibility	Whole estuary, channel, etc.	Medium
Stage 2	Layout design	Development site.	Low

The expected decrease in uncertainty as the resource assessment stages progress can result from:

- measurements and/or modelling over longer durations / periods;
- availability of additional, and/or higher quality measurements;
- use of more capable models, as outlined in 7.3;
- finer discretisation in space and time;
- use of improved boundary conditions;
- improvements in modelling techniques during the project's evolution.

5.1.2 Stage 1: Feasibility study

A Stage 1 study is focused on investigating the scale and attributes of the energy resource within a particular study area. The results of a Stage 1 resource assessment can be used to help assess the feasibility of constructing tidal energy arrays at sites within the study area by estimating the undisturbed site resource.

5.1.3 Stage 2: Layout design study

A Stage 2 study is focused on generating detailed and accurate information on the tidal energy resource in a specific area to determine AEP, through supporting the layout design of a tidal array, and may incorporate energy extraction impacts depending upon the project scale. The Stage 2 study should consider the technology to be installed and locations of TEC deployments in order to estimate AEP with lower uncertainty.

5.2 Methodology

The resource assessment requirements are defined depending on the scale of the project as well as the objective of the assessment (feasibility or design layout). The AEP (calculated using the method outlined in Annex A) may be assessed based on data from either direct measurements or from hydrodynamic modelling.

For projects where the total power output is expected to be less than c. 10 MW, or those where the proposed energy extraction is less than 2 % of the theoretical undisturbed tidal energy resource (see Note) and therefore there is expected to be little if any impact on the underlying hydrodynamics of the site, AEP may be estimated from direct resource measurements using static current profiler measurements and harmonic analysis as defined in 8.2.3. In order to use this method, measurements shall be made at each individual turbine location. Such projects may also use the hydrodynamic modelling required for larger projects. If the data collection indicates that the TECs should be deployed in different locations to where static current profiler data has been collected, then either additional data gathering at the new location or the modelling approach is required.

NOTE Understanding of the potential impact of energy extraction from TEC arrays is evolving; existing useful references include: Black & Veatch/Carbon Trust (2011); Garrett et al. (2004); Garrett et al. (2005); Sutherland et al. (2007); Polagye et al. (2008); Karsten et al. (2008); Draper et al. (2009); Vennell (2010); Vennell (2011); Polagye et al. (2011), Defne et al. (2011), Walters et al (2013).

For projects larger than c. 10 MW or 2 % of the theoretical undisturbed resource, AEP shall be assessed by hydrodynamic modelling, with appropriate verification by measurements. The first step in this process is to define the required model inputs, as described in 7.2. Subclause 7.3 describes the choice of numerical model. The next step is to assemble the information required to implement the model. If sufficient data does not exist for the model inputs, additional data shall be collected as described in Clause 6. The accuracy of the model may then be assessed as per 7.4. For feasibility studies, the model output may be used to produce the velocity probability distribution for AEP calculation. For layout design studies, if the level of energy extraction is to be small relative to the existing resource (see 7.6), the model data may be used directly. Otherwise, the model should be run with energy extraction to accurately specify velocity probability distributions for AEP estimation.

Many of the external constraints that determine the assessment of the practical resource, such as acceptable environmental impacts, are beyond the scope of this Technical Specification. However, the modelling methodologies described within this Technical Specification may be used to assess some of the impacts of TEC deployments, including changes in tidal regime, tidal currents and bottom sediment movements, and may also provide data required for environmental studies. External constraints to be considered in determining the tidal resource should be determined in consultation with the appropriate regulators.

Table 2 should be used to help determine the appropriate model and survey requirements to estimate the tidal energy resource at any particular resource assessment Stage. Where appropriate, Table 2 references the relevant clause in this Technical Specification where the detailed information related to that activity is contained. These recommendations consider the practicalities of gathering the data to satisfy these requirements.

Table 2 – Model and field survey recommendations (Overview)

		Stage 1	Stage 2
Modelling	Minimum number of harmonic constituents for modelling driving boundary (tidal amplitude)	4-8	8-12
	Grid resolution at the area(s) of interest	< 500 m or > 10 grid cells across a channel section	< 50 m
	Period of run	> 35 days	> 35 days
	Other model characteristics	7.2 and 7.3	Shall include energy extraction impacts as needed 7.6
Physical data requirement	Bathymetry	6.2	6.2
	Tidal height	6.3.3	6.3.3
	Wave characteristics	6.5	6.5
	Meteorological data	6.4	6.4
	Flow structure / Eddies / Turbulence	6.6	6.6
	Stratification, seawater density and sediment measurement	6.7	6.7
	Tidal currents – Mobile survey	6.3.4	6.3.4
	Tidal currents – Stationary survey	6.3.5	6.3.5
Data analysis	Harmonic analysis on available current data (minimum no. of constituents)	20	20

6 Data collection

6.1 Introduction

For projects using hydrodynamic models for providing velocity distributions to support AEP calculations, field measurements are required to calibrate and validate numerical models of the tidal currents. This includes measurements of harmonic tidal currents, as well as non-tidal low frequency processes that may impact tidal resource assessment such as storm surge, residual flows and stratification, and high frequency processes such as turbulence. For projects smaller than c. 10 MW, the field measurements may be used to provide the velocity distributions to directly calculate AEP for individual turbines. Guidelines for current profiler measurements are provided in Annex B.

6.2 Bathymetry

The required resolution of the bathymetry data to feed into a hydrodynamic model is described in 7.2.1.

The bathymetric data already available shall be reviewed, e.g. contact with the oceanographic centres responsible for the region concerned is recommended. If existing data is to be used, then the collection techniques for the original data and their appropriateness shall be reviewed, e.g. by comparison to modern techniques. Such data should be used with an element of caution. If a bathymetric survey is required to complement and expand the available existing data in the specific region of interest, the survey should be conducted in accordance with the IHO *Standards for Hydrographic Surveys*:2008. Reporting of bathymetric survey activities shall be completed to the standard of the ICES *Guidelines for Multibeam Echosounder Data*:2006.

A map should be provided for all undertaken surveys for which data is available. The following information should be provided on each survey:

- date of survey;
- survey methods used;
- uncertainty of data;
- coordinate system and transformation used to convert to/from another coordinate system, as appropriate, for later use;
- method for accounting for stage of tide throughout survey and tidal reference (measurement or prediction) used;
- chart/tidal datum applied;
- calibrations applied;
- availability of data in electronic form.

There is no accepted world standard definition of tidal datum or chart datum used for navigation charts and tidal height graphs. Many nations have developed their own definitions. It is particularly important for numerical modelling purposes to have bathymetric depths referenced to a fixed geodetically determined datum, which can be referenced to true local mean sea level. Tidal or chart datum used on all worldwide navigation charts is not a fixed datum but may change from chart to chart and should be defined.

If new survey data is used in conjunction with existing data, the new data should overlap the existing data to allow for validation between the two datasets.

6.3 Tidal characteristics

6.3.1 General

The tidal height and tidal current (both depth-averaged and depth varying) characteristics at the site shall be identified and reported. As a minimum this should include graphs of typical daily, monthly and annual tidal height, current speed and direction. These graphs may be generated directly from measured data or predictions may be calculated from tidal harmonic constituents derived from measured data using harmonic analysis software, according to the Stage of the investigation.

The usage of 'typical' is intended to convey the general conditions to be expected on site, for example a 'typical' daily cycle for a semi-diurnal or diurnal site will show the repetition in the expected pattern of high and low tides. A 'typical' daily cycle for a site with mixed tides may require several daily graphs to capture clearly the lower high water and higher low water cycles. A 'typical' monthly cycle should be selected for a 29 day period when solar semi-annual and annual constituents have minimal influence. A 'typical' annual cycle should be presented in the context of the longer term 18,6 year lunar-solar cycle.

Existing long-term data sets and tidal constituent data maintained by the national hydrographic office or oceanographic data centre responsible for the region should be accessed where available. Tidal characteristics from all tidal height stations and tidal current stations in the area of interest shall be determined. Further tidal height data including tidal constituents may also be obtained from appropriate satellite databases. If additional location specific tidal height data is required, an appropriate survey should be conducted (see 6.3.3). These approaches to obtaining data require use of appropriate methodologies, and an appropriate assessment of the uncertainty in the data should be reported.

NOTE 1 A standard text on the theory of tides and tidal currents, including what constitutes a typical spring tidal cycle, and tidal harmonic analyses and prediction may be consulted before any substantive work is completed on this tidal resource analysis. Several good references are freely available including the straightforward Forrester (1983), and the more mathematically complex Foreman (2004). The latter manual includes freely available tidal height and current prediction and analysis software. Alternative analysis and prediction software is available, e.g. T-Tide, (Pawlowicz et al., 2002) (http://www.eos.ubc.ca/~rich/) or UTide (Codiga 2011).

NOTE 2 Tidal height and tidal current constituent data can be obtained from a number of sources. These are freely available in the USA and many other localities but some countries, including the UK, protect the raw constituent data and only make them available for a fee.

NOTE 3 Examples of appropriate satellite databases include TOPEX/POSEIDON, and ERS-1. For those unfamiliar with satellite imagery the following references may be useful: http://sealevel.jpl.nasa.gov, http://podaac.jpl.nasa.gov/OceanSurfaceTopography.

NOTE 4 Preliminary tidal characteristics such as the spatial structure of persistent tidal eddies may be evaluated for a project site through the use of surface drifters.

6.3.2 Assessment of data quality

Ideally, an overall assessment of tidal current data quality would be conducted according to the standardised approach presented in ISO/IEC Guide 98-3:2008. However, application of this method to current profiler non-steady (turbulent) flow data is itself subject to debate. Current profiler manufacturers can prescribe a given uncertainty in measurement for the selected instrument configuration, but this value is applicable only for homogeneous flow across layers of constant depth. Hence, this prescribed uncertainty value does not account for the error caused when separate beams detect spatially varying flow, yet transform the data into a velocity vector at a single point. The ISO/IEC Guide 98-3 provides a method for characterizing measurement uncertainty using the standard deviation of multiple measurements. However, this method relies upon the measurement of fluctuations from an observed steady mean value. At many sites, the approximately 12 h period of the tidal cycle, in combination with large-scale eddies with time scales of just a few minutes and small-scale turbulence with timescales of a few seconds, precludes an averaging period over which the underlying velocity can be considered a truly steady value. Thus it is generally not possible to rigorously conduct propagation of uncertainty for values dependent on the tidal velocities