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Edition 1.0 2013-05

TECHNICAL SPECIFICATION

colour inside

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

IEC/TS 62600-200:2013(E)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 200: Electricity producing tidal energy converters – Power performance assessment

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

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

IEC 62600-200, which is a technical specification, has been prepared by IEC technical committee TC 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
114/93/DTS	114/101A/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 of 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 web site 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- withdrawn,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.

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

Part 200: Electricity producing tidal energy converters – Power performance assessment

1 Scope

This Technical Specification provides:

- a systematic methodology for evaluating the power performance of tidal current energy converters (TECs) that produce electricity for utility scale and localized grids;
- a definition of TEC rated power and rated water velocity;
- a methodology for the production of the power curves for the TECs in consideration;
- a framework for the reporting of results.

Exclusions from the scope of this Technical Specification are as follows:

- tidal energy converters (TECs) that provide forms of energy other than electrical energy unless the other form is an intermediary step that is converted into electricity by the TEC;
- resource assessment. This will be carried out in the tidal energy resource characterization and assessment Technical Specification (future IEC/TS 62600-201);
- scaling of any measured or derived results;
- power quality issues;
- any type of performance other than power and energy performance;
- the combined effect of multiple TEC arrays.

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 60688:2012, *Electrical measuring transducers for converting AC and DC electrical quantities to analogue or digital signals*

IEC 61400-12-1:2005, *Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines*

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

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

International Hydrographic Organisation: 2008, *IHO standards for hydrographic surveys, Special publication No. 44. 5th edition* (http://www.iho-ohi.net/iho_pubs/standard/S-44_5E.pdf)

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. General terms and definitions regarding marine energy found in IEC 62600-1 also apply.

3.1
acoustic current profiler
an instrument that produces a record of water current velocities for specified depth and time intervals over a pre-determined distance through the water column

Note 1 to entry: Current profilers can be configured in many ways: downward facing, mounted on boats or moorings, installed on the seabed facing upwards, or mounted on a TEC oriented in any direction desired for tidal current and wave studies. Detailed specifications for the use of acoustic current profilers are provided in this technical specification.

3.2
averaging period
the period of time, in minutes, over which data samples are averaged to calculate a data point

3.3
current profiler bin
a distance interval, typically vertically on the order of 1 m or less, that is used to group data samples and data points for calculation of certain parameters according to their corresponding distance above the seabed or below the surface

Note 1 to entry: Mean current velocity, $\overline{Ushear}_{i,k,n}$, is an example of a parameter that is grouped by current profiler bins.

3.4
cut-in water velocity
water speed during the accelerating part of the tidal cycle, above which there is power production

3.5
cut-out water velocity
the maximum flow speed above which the TEC cannot continue operation

3.6
data point
a single measurement used to populate bins and obtained from averaging instantaneous data samples over the specified averaging period

Note 1 to entry: $U_{i,n}$, $P_{i,n}$ and $Q_{i,n}$ are all examples of data points.

3.7
data sample
a single measurement obtained at a minimum sampling frequency of 1 Hz used in the subsequent calculation of a data point

Note 1 to entry: $U_{i,j,k,n}$, $P_{i,j,n}$ and $Q_{i,j,n}$ are all examples of data samples. A data sample may consist of one or multiple current profiler 'pings' depending on the setting of the device.

3.8
data set
the collection of data points calculated during a specific portion of the test period, and is a subset of the test data

Note 1 to entry: For example, all data points collected during a flood tide would be considered a data set.

3.9
energy extraction plane
the plane that is perpendicular to the principal axis of energy capture where device rotation or energy conversion nominally occurs

Note 1 to entry: Refer to Figures 2 and 3 for a simplified illustration of the energy extraction plane. For devices with multiple extraction planes, an appropriate upstream energy extraction plane on both ebb and flood tides should be identified.

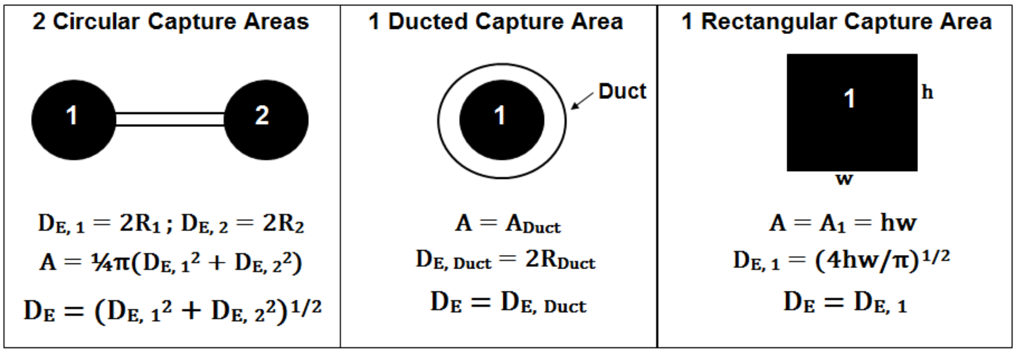
3.10
equivalent diameter
a common method used to transform a TEC that is non-circular in cross-section, where the cross-section is parallel to the energy extraction plane, into an equivalent device with a circular cross-section

$$D_E = \sqrt{\frac{4A}{p}}$$

where:

A is the projected capture area

Note 1 to entry: Examples of the calculation of equivalent diameter for various TEC projected capture areas are provided in Figure 1.



IEC 975/13

Figure 1 – Equivalent diameter calculations for various TEC projected capture areas

3.11
free-stream condition
boundary condition description for a TEC operating in a sufficiently large channel and without external influence such that its performance is equivalent to a TEC operating in a channel having a cross-section of infinite width and depth

3.12
hub height
distance from the centroid of the TEC projected capture area to the sea floor

3.13
low cut-out water velocity
water velocity during the decelerating part of the tidal cycle below which a TEC does not produce power

3.14
method of bins
a method of data reduction that groups test data for a certain parameter into sub-sets typified by an independent underlying variable that can be applied both spatially (current profiler bins) and by tidal current speed (velocity bins)

3.15
net electrical power output
the net active power at the output terminals, excluding any power generated by on-board ancillary generators or imported via separate cables

Note 1 to entry: Additional information on this term is provided in 8.8.4.

3.16
power weighted velocity
mean velocity derived with a power weighted (velocity cubed weighted) function to ensure that it is representative of the value of the incident power across the projected capture area as a standard mean of the velocity would underestimate the incident power

Note 1 to entry: A more specific definition can be found in formula (1).

3.17
principal axis of energy capture
an axis parallel to the design orientation or heading of a TEC passing through the centroid of the projected capture area

Note 1 to entry: Refer to Figure 2 for a simplified example of the principal axis of energy capture.

3.18
principal flow direction
the primary orientation or heading of the tidal current

Note 1 to entry: The primary flow directions for flood and ebb tides are nominally 180° apart; however, the exact difference between these two directions is determined by site specific factors, such as bathymetry.

Note 2 to entry: Refer to Figure 2 for a simplified example of the principal flow directions.

3.19
projected capture area
the frontal area of the TEC, or swept area in the case of an oscillating TEC, including the duct or other structures which contribute to the power extracted by the device perpendicular to the principal axis of energy capture

Note 1 to entry: If the upstream and downstream areas of the device are different, the larger area should be used in the calculation of $\eta_{System,i}$.

Note 2 to entry: The definition of projected capture area is further clarified in Figure 7.

3.20
rated water velocity
the lowest mean flow speed at which the TEC rated power is delivered to its output terminals

Note 1 to entry: Different rated water velocities may result for ebb and flood conditions depending on device design.

3.21
r.m.s. fluctuating velocity
the root-mean square of the current speed variations in each current profiler bin

Note 1 to entry: Additional details can be found in 9.5.

3.22
shear profile
the vertical variation of the mean current velocity across all measured current profiler bins

3.23
TEC annual energy production
an estimate of the total energy production of a TEC during a one-year period obtained by applying the measured flood and ebb power curves to a set of tidal current predictions, at a stated test availability

3.24
TEC footprint
the area described by the intersection of the energy extraction plane and the principal axis of energy capture for a floating TEC that is free to move on a compliant mooring

Note 1 to entry: Refer to Figure 6 for further details and an illustration on TEC footprint.

3.25
TEC output terminals
the node of a TEC power generation circuit where the output is available as an AC signal at the grid network frequency

Note 1 to entry: In the case of a DC output TEC, the output terminals are defined as the node where output power is available for battery charging or connection directly to the load.

Note 2 to entry: A full description of output terminal for both AC and DC cases is provided in 8.8.1.

3.26
TEC overall efficiency
ratio of the net power produced by the TEC at its output terminals to the power of an undisturbed flow of water with the same projected capture area as the TEC

3.27
TEC rated power
the maximum continuous electrical power measured at the TEC output terminals which the TEC is designed to achieve under normal operating conditions

3.28
TEC test site
the location of the TEC under test and the surrounding area

Note 1 to entry: A full description of TEC test site requirements is provided in Clause 5.

3.29
test availability
the ratio of the total number of hours during a test period where all test conditions are met, to the total number of hours of the test period

3.30
test data
all data points collected during the test period

3.31
test period
the period between first data collection and last data collection, for the purpose of TEC power performance assessment

Note 1 to entry: Refer to 8.3 for additional information.

3.32
tidal ellipse
a graphical representation of a tidal current in which the velocity of the current at different hours of the tidal cycle is represented by radial vectors and angles

Note 1 to entry: A line joining the extremities of the vectors will form a curve roughly approximating an ellipse.

3.33
tidal energy converter
any device which transforms the kinetic energy of tidal currents into electrical energy

3.34
velocity bin
a velocity magnitude interval, typically in the order of 0,1 m/s or less, that is used to group data samples and data points for calculation of certain parameters according to their corresponding velocity value

Note 1 to entry: Total instantaneous active electrical power, $P_{i,j,n,}$ is an example of a parameter that is grouped by velocity bins.

4 Symbols, units and abbreviations

NOTE SI units are assumed for all terms in this technical specification unless otherwise noted.

4.1 Symbols and units

A	Projected capture area of the TEC	[m^2]
A_k	Area of current profiler bin k across the projected capture area	[m^2]
D_E	Equivalent diameter	[m]
η_{System}	TEC overall efficiency	
$\eta_{System,i}$	TEC overall efficiency in velocity bin i	
h	Vertical dimension of the projected capture area	[m]
i	Index number defining the velocity bin	
j	Index number of the time instant at which the measurement is performed	
k	Index number of the current profiler bin across the projected capture area	
L	Number of samples in the defined averaging period which produces data point n	
n	Index number defining an individual data point in a velocity bin	
N_B	Number of measurement data bins	
N_i	Number of data points in velocity bin i	
N_k	Number of data points in current profiler bin k	
$\overline{P}_i$	Mean recorded TEC active power in velocity bin i	[W]
$\overline{P}_{i,n}$	Mean recorded TEC active power in velocity bin i for data point n	[W]
$P_{i,j,n}$	Magnitude of the total instantaneous active electrical power from the TEC	[W]
$\overline{Q}_i$	Mean recorded TEC reactive power in velocity bin i	[VAr]
$\overline{Q}_{i,n}$	Mean recorded TEC reactive power in velocity bin i for data point n	[VAr]
$Q_{i,j,n}$	Magnitude of the total instantaneous reactive electrical power from the TEC	[VAr]

R	Radius	[m]
S	Total number of current profiler bins across the projected capture area, normal to the principal axis of energy capture	
T	Time zone shift relative to UTC	[h]
$\overline{U}_i$	Mean power weighted tidal current velocity in velocity bin i	[m/s]
$\overline{U}_{i,n}$	Mean power weighted tidal current velocity in velocity bin i for data point n	[m/s]
$\widehat{U}_{i,j,n}$	Instantaneous power weighted tidal current velocity across the projected capture area	[m/s]
$U_{i,j,k,n}$	Magnitude of instantaneous tidal current velocity, time j, at current profiler bin k, in velocity bin i, for data point n	[m/s]
$\overline{Uellipse}_{i,k,n}$	Mean tidal current velocity in velocity bin i, for current profiler bin k at hub-height, for data point n	[m/s]
$Urms_{i,k}$	RMS fluctuating tidal current velocity in velocity bin i at current profiler bin k	[m/s]
$Urms_{i,k,n}$	RMS fluctuating tidal current velocity in velocity bin i, at current profiler bin k, for data point n	[m/s]
$\overline{Ushear}_{i,k}$	Mean tidal current velocity in velocity bin i at current profiler bin k	[m/s]
$\overline{Ushear}_{i,k,n}$	Mean tidal current velocity in velocity bin i, at current profiler bin k, for data point n	[m/s]
w	Horizontal dimension of the projected capture area	[m]
ρ	Density of water	[kg/m^3]
$\bar{\theta}_{i,k,n}$	Mean tidal current direction in velocity bin i, at current profiler bin k, for data point n	[deg]
$\theta_{i,j,k,n}$	Magnitude of the instantaneous tidal current direction, time j, at current profiler bin k, in velocity bin i, for data point n	[deg]

4.2 Abbreviations

AC	Alternating Current
AEP	Annual Energy Production
CD	Committee Draft
CT	Current Transformer
DAQ	Data Acquisition System
DC	Direct Current
EXT	Extrapolated
GPS	Global Positioning System
HAT	Highest Astronomical Tide
HV	High Voltage
IEC	International Electrotechnical Commission
IHO	International Hydrographic Organisation (Monaco)
INT	Interpolated
ISO	International Standards Organization
LAT	Lowest Astronomical Tide
LV	Low Voltage
MHW	Mean High Water
MLW	Mean Low Water

PPT	Parts per Thousand
RMS	Root Mean Square
SI	International System of Units
TC	Technical Committee
TEC(s)	Tidal Energy Converter(s)
TEOS-10	The Thermodynamic Equation of Seawater – 2010
TS	Technical Specification
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VT	Voltage Transformer
WGS84	World Geodetic System 1984

5 Site and test conditions

5.1 General

The TEC test site should be characterized in detail and reported prior to any assessment of power performance. Specifically, the bathymetry and flow conditions should be clearly identified. Guidance for satisfying the reporting requirements specified in 10.3 are described in this clause.

5.2 Bathymetry

The bathymetry of the TEC test site should be surveyed to ensure that it is free from obstacles and topography that could affect the performance of the TEC or the local quality of the tidal currents. A portion of the TEC test site, 10 equivalent diameters upstream and downstream of, and 5 equivalent diameters on either side of, the TEC location (an area with dimensions 20 × 10 equivalent diameters), should be surveyed in accordance with IHO Order 1a hydrographic survey standard. This survey is described in Chapter 1, and summarized in Table 1, of the IHO Standards for Hydrographic Surveys: 2008.

An analysis of the bathymetric survey of the aforementioned portion of the TEC test site should be conducted to clearly identify features of the local topography. Any significant variation in the local bathymetry should be clearly identified and characterized. There should be no local bathymetric disturbances present that could lead to a serious local variation in the quality and reliability of the incident resource, and thus, a misrepresentation of the TEC power performance.

5.3 Flow conditions

It is necessary to categorize the flow conditions at the TEC test site before any power performance assessment can be made. Guidance is provided here for the assessment of specific ambient flow conditions, i.e. principal flow directions, and this assessment should be completed in accordance with the description outlined below. The following parameters should be reported:

- tidal ellipse at the energy extraction plane centreline;
- predominant direction of flood tide streamlines (i.e. principal flood flow direction);
- predominant direction of ebb tide streamlines (i.e. principal ebb flow direction).

Procedures for calculating the predominant ebb and flood streamline directions are provided in 9.6 and a sample reporting diagram is provided in Figure 8 in 10.3. To position current profilers appropriately, the average principal ebb and flood flow directions should be calculated by the method of least squares.

The principal flow direction should be determined using one of the following methods; all measurements should take place over at least one full flood tide and one full ebb tide:

- a prediction of the flow direction at the TEC location from resource assessment modelling. This should be corroborated by the current profiler measurements taken during the test period or another of the methods detailed herein;
- a deployment of a bottom mounted current profiler at the TEC location, preferably prior to the deployment of the TEC for power performance assessment. The flow direction should be corroborated by the current profiler measurements taken during the test period or another of the methods detailed herein;
- a boat or bottom mounted current profiler deployment at the TEC location, preferably prior to the deployment of the TEC for power performance assessment, using a calibrated gyroscope as a heading input;
- should the TEC device be in position before these tests then measurements should take place on the upstream side of the TEC on both ebb and flood tides. Measurements should take place over at least one full ebb tide and one full flood tide.

Great care should be taken when measuring flow direction from bottom mounted current profilers using internal flux gate compasses as the heading input. The following precautions should be taken during calibration and deployment:

- it is advisable to use non-ferrous mounting frames and fittings;
- the compass calibration should take place in the deployment frame away from all magnetic influence;
- the calibration of the compass should include a cross-check of the heading of the current profiler against a known magnetic north;
- if divers are used to deploy the current profiler then they should measure the orientation of the current profiler once on the seabed with a precision compass.

NOTE None of these precautions guard against additional magnetic influences at the deployed location, the use of a calibrated gyroscope input avoids these magnetic effects.

Corroboration of resource assessment model predictions with measured quantities should not be done using data that was collected to develop, validate or tune the resource model.

5.4 TEC test site constraints

TEC performance assessment may be affected by a variety of external influences which need to be mitigated. The TEC test site, therefore, should be representative of the final deployment environment and bathymetry, with the following constraints:

- the TEC test site should be free from any performance enhancing features (i.e. objects or terrain that deflect flow to create local increases in the incident resource) which are not representative of typical operating conditions and/or deployment site(s);
- unrepresentative TEC performance may be observed when the size of the TEC relative to the cross-sectional area of the TEC test site prevents flow from diverting around the device as would naturally occur in free-stream conditions. The TEC test site cross-sectional area should therefore be representative of a typical deployment site. A diagram illustrating the proportion of channel cross-sectional area consumed by the projected area of the TEC and supporting structure (including foundations) onto the plane perpendicular to the principal flow direction should be provided (example provided in Figure 9 in 10.3). Data should be provided for both MLW and MHW, or LAT and HAT, conditions. Dimensions should be provided for the hub height distance above the seabed and below the free surface, and the proximity to any fixed boundaries should be reported. In instances where the principal flow direction varies on the ebb and flood tide, and as a result the projected area, a diagram for each direction should be provided.

NOTE In the event the TEC is located in a very large channel or open waterway, a suitable upper limit of channel cross-sectional area presented in the diagram is 200 times the combined projected area of the TEC capture area and supporting structure at low tide conditions.

5.5 External constraints

Additional external constraints may further affect the appropriate performance assessment of a TEC. Continuous operation of a TEC during the test period is strongly preferred and any external constraints that may prevent TEC operation should be identified during test planning and reported clearly. It is also necessary to enumerate the external constraints that may limit the ability to satisfy the data collection requirements, as given in 8.3. Additional constraints should be addressed and summarized as appropriate given the individual TEC test site. Potential constraints may include, but are not limited to:

- regulatory limitations;
- electric grid conditions;
- permitting limitations;
- adverse sea state;
- inclement weather.

6 Tidal energy converter (TEC) description

6.1 General

A general description and diagram of the TEC is required. Specifically, a description of the system, including components, subsystems and a method of operation for the TEC, as well as a description of the expected operating envelope are required. Procedures for satisfying the reporting requirements specified in 10.2 are described in 6.2.

6.2 Operational parameters

As well as a detailed description of the device system and operation method, given in 10.2, the following parameters should be reported:

- rated TEC output power;
- rated water velocity;
- equivalent diameter;
- cut-in water velocity to begin power production;
- low cut-out water velocity to end power production (if different than the cut-in water velocity);
- cut-out water velocity (maximum water velocity for TEC operation);
- rotational speed range or period for an oscillating device.

7 Test equipment

7.1 Electric power measurement

The net electric power of the TEC should be measured using a power measurement device such as a transducer and should be based upon measurements of current and voltage on all three phases for an AC TEC (measurement of current on only 2 phases is permitted where it is demonstrated that there can be no neutral current), and the measurement of the voltage and current for a DC TEC.

Electrical transducers and the data recording device used in the electrical measurements should be accuracy class 0.5 or better, should be calibrated (where relevant) to recognized and traceable standards and should meet the requirements of the following standards:

Power transducers: IEC 60688

Instrument transformers used in the measurement of electrical power should meet the following standards:

Current transformers (CTs): IEC 61869-2

Voltage transformers (VTs): IEC 61869-3

The operating range of the power transducer should be sufficient to include all positive peaks corresponding to net generation and all negative peaks corresponding to net imported power. As a guide the full-scale working range of the power measurement device and transducers should be at least:

Export: 5 % to 200 % of TEC rated power

Import: –5 % to –50 % of TEC rated power

If the working range of the transducers and the recording device allow for class 0.5 measurements within the power range less than ±5 % of the device’s rated capacity, the values within the working range should be recorded at their measured values. All measured values less than the lower working range of the transducers and the recording device should be recorded as zero.

In the case of an AC TEC, the method of calculation of the active and reactive power from the voltages and currents should be clearly documented.

Local power consumption during periods of non-power production should be measured by a separate measurement system where they are too small to be accurately measured using the main export power measurement setup. The measurement setup should be specified to measure the house load with a minimum of class 0.5 accuracy.

NOTE It is important that CTs are specified correctly because they become non-linear for low currents; roughly ≤5 % of the specified range. To improve accuracy at low current, class 0.5S CTs can be used with a known accuracy down to 1 % of rated current.

7.2 Tidal current measurement

The inflow tidal current to the TEC should be measured with an acoustic current profiler (current profiler) during the assessment of power performance. The following subclause describes the minimum data collection requirements for a current profiler that are to be adopted. As such, any instrument chosen for data collection should be able to:

- record a continuous time series of tidal current speed and tidal current direction;
- measure with sampling levels, at a minimum, the entire height of the TEC projected capture area;
- measure a vertical profile with a maximum vertical distance between sampling levels of 1 m across the TEC projected capture area;
- record data with a minimum number of 10 vertical sampling levels across the TEC projected capture area;
- record data with a minimum sampling frequency of 1 Hz;
- record time-stamped data;
- record a continuous time series of pitch and roll of the current profiler.

Any measurements collected should adhere to the following:

- the recording velocity range should be capable of covering the maximum and minimum current speeds identified at the Tidal Resource Assessment stage and with a resolution better than ±0,05 m/s;

- the geographic position during deployment should be measured using a system with accuracy equal to or better than a Differential GPS to identify the final current profiler placement location accurately. If the current profiler is deployed from a vessel, the measurement system should be positioned directly above the davit arm or block and the wire angle should be monitored during deployment. The final current profiler placement should adhere to the geographic tolerances described in 8.9.1.

Additionally, any available information on the following should be summarised and reported:

- the inherent Doppler noise for a given current profiler data collection scheme;
- the estimated and/or measured time stamp drift over the entire test period duration;
- details on current profiler pre-deployment calibration;
- current profiler blanking distance;
- the number of beams and beam spreading angle.

7.3 Data acquisition

A data acquisition system should be used to gather measurements and to store pre-processed data. End-to-end checking of any installed data acquisition system should be performed for each signal and/or channel. The uncertainty introduced by the data acquisition system should be demonstrated as being at least one order of magnitude lower than that of other sensors.

8 Measurement procedures

8.1 General

The objective of the measurement procedure is to collect data that meet a set of clearly defined criteria. This ensures that the data is of sufficient quantity and quality to accurately determine the power performance characteristics of the TEC.

The specific test conditions related to the power performance measurement of the TEC should be well defined and documented in the test report, as detailed in Clause 10. The test report should be sufficient to allow every procedural step to be reviewed, and if necessary, repeated.

The accuracy of the measurements should be expressed in terms of measurement uncertainty, as described in Annexes A and B.

The time used for data acquisition and all other test reporting should be UTC ± T hours. T should not alter for the test period and the time used should be clearly stated in the test report.

8.2 Operational status

During the measurement period, the TEC should be in normal operation as prescribed in the TEC operations manual. The machine configuration should not be changed during the test period. The control algorithm should not be changed during the test, and key parameters that control the performance of the machine should be those that are planned for normal operation, rather than for the test period alone.

At least one parameter indicating the operational status of the TEC should be monitored so that the test availability during the test period can be calculated.

A test log should be kept during the test period which details:

- times when the machine became unavailable or partially unavailable and the cause;
- the periods of data collection;

- any recordings of measured quantities that are not logged on the data-acquisition devices, i.e. time drift, sea level depth;
- any other unusual circumstances.

Normal maintenance of the turbine may be carried out throughout the test period, but such work should be noted in the test log. In particular any special maintenance actions which may ensure good performance during the test, such as blade washing, should be noted. Such special maintenance actions should by default not be made, unless agreed by contractual parties prior to commencement of the test.

8.3 Data collection

The test should take place over a minimum of a spring-neap cycle (15 days) so that the requirements of 8.7 should be met; it is likely that that the test will exceed 15 days to ensure sufficient data is recorded. The test availability should exceed 80 % during this 15 day test period. It is acceptable to record data on subsequent days with a maximum duration of the test period of 90 days.

Incident resource and power measurements should be collected at a sampling rate of 1 Hz or higher.

The data acquisition systems should store raw sampled data. This includes the current profiler data acquisition system where the data from each ping should be recorded.

No filtering, other than anti-aliasing filtering, may be used prior to data acquisition.

8.4 Instrument calibration

Instruments should be calibrated where required by an organisation complying with the requirements of ISO/IEC 17025:2005.

For power measurement transducers (CTs, VTs and power transducers) it is acceptable to rely on the certificate of conformity to the relevant standard as proof of its accuracy. Where there is no certificate of conformity, i.e. for a power meter, then a calibration should be performed.

Where the current profiling sensors on current profiler devices can be calibrated, a current calibration certificate should be provided. Otherwise a certificate of conformity is required and there should be evidence that the current profiler is in a serviceable state (an auditable self-test). The internal compass should be calibrated before deployment using the procedure given by the manufacturer, taking care to avoid the effects of external magnetism. A final check against the known magnetic north is a sensible precaution. Any pressure gauge should have a current calibration certificate.

8.5 Data processing

The power curve should be derived using data obtained during normal operation of the TEC device as prescribed in the TEC operations manual. The exclusion of data sets should be allowed under the following circumstances to ensure that data during abnormal operations or corrupt data is not included in the derivations:

- the TEC is manually shut down or in test or maintenance mode;
- the TEC is unable to operate due to a failure condition. The TEC is fully or partially unavailable;
- external conditions other than current speed are out of the operating range of the TEC;
- there is a failure or degradation of the test equipment or any downstream electrical equipment that would affect the measured results;

- the TEC is operating in a limiting mode due to an external factor, i.e. network limitations.

Any exclusion criteria, including those listed above, should be fully reported and substantiated. Individual outliers should not be removed unless they meet one of the general exclusion criteria.

Filtering the data during the data processing operation is not permitted.

8.6 Averaging

Selected data points and resulting data sets should be based on 10 min averaging periods derived from continuous measured data samples, and this averaging period should remain constant for the entirety of the test period.

An optional additional data set may be processed and reported at an averaging period less than 10 min but greater than or equal to 2 min. A suitable integer divisor of 10 min, or 600 s, should be used.

A data set should be discarded if less than 90 % of the data points are valid due to measurements falling outside of data acquisition limits. Criteria for excluding data sets are discussed in 9.2.2 and detailed in 8.5.

Where separate data acquisition systems are used, a method of associating the same averaging periods should be devised. A method for monitoring the drift of all acquisition devices' time stamp relative to UTC ± T hours should be devised and the data repair technique reported.

8.7 Test data properties

The test data should contain two data sets, one data set associated with flood operation and one data set associated with ebb operation. The selected data sets should be sorted using the method of bins procedure (see 9.3.1). The selected data sets should at a minimum cover a current speed range extending from:

- 50 % of cut-in velocity to 120 % of the current speed at TEC rated power.

OR

- 50 % of cut-in velocity to 80 % of the maximum current speed predicted at the site, to include the current speed at the TEC rated power.

A flood or ebb data set should be considered complete when it has met the following criteria:

- each velocity bin includes a minimum of 30 min of sampled data;
- each data set includes a minimum of 180 h of sampled data.

If there is an incomplete velocity bin preventing completion of the test then that velocity bin value can be estimated by linear interpolation from two directly adjacent complete bins. 90 % of the bins across the power curve range should be complete.

The data sets should be presented in the test report as detailed in 10.7.

8.8 Electric power measurement

8.8.1 Output terminals of the TEC

In the case of an AC TEC, its output terminals should be at the point where the output power is in the form of AC at the network frequency.

This point may be on either the LV side or the HV side of the TEC step-up transformer. Where the AC TEC is not grid connected this point should be where the frequency is stable and at a commonly used network frequency of 50 Hz or 60 Hz.

In the case of a DC TEC, its output terminals should be at the point where the power is in suitable DC form for battery charging or connecting directly to the DC load.

In both AC and DC cases, the output terminals should also be located at the point of the net electrical power output of the TEC (see 8.8.4).

Results obtained for DC applications are not valid for AC applications. In the event of a DC TEC being adapted for AC use it should be separately tested. The same should apply when adapting a TEC from AC to DC use.

8.8.2 The power measurement location

The power measurement location should be at the output terminals of the TEC.

Where this is impracticable or infeasible, losses due to cables and other components between the measurement point and the TEC's output terminals should be calculated and the power output should be adjusted accordingly. The methodology for these corrections should be fully detailed, explained and accompanied with supporting documentation as necessary.

The power measurement location should be stated with justifications when it is not the output terminals. The measured output should be adjusted as specified above and stated for the output terminals of the TEC.

8.8.3 Remote TEC sub-systems

Some TEC technologies have remote sub-systems that are external to the primary energy extraction equipment itself, such as power converters that are located ashore, but should be considered as a part of the complete system for the purposes of performance assessment. In these situations, the TEC power should be measured at the output terminals of the TEC (i.e. at the output of the onshore power converter). Losses due to cables and other components between the main TEC system and the remote sub-systems that are site specific should be calculated and the power output should be adjusted accordingly. The methodology for these corrections should be fully detailed and explained and accompanied by supporting documentation as necessary.

8.8.4 Power measurements

The net electrical power output should be the net active power at the output terminals (i.e. reduced by auxiliary power requirements), excluding any power generated by on-board ancillary generators or imported via separate cables. For AC TECs, the reactive power at this point should also be recorded. The power (or voltages and currents) measurements should be digitized at a minimum of 1 Hz.

8.9 Incident resource measurement

8.9.1 Current profiler placement relative to TEC

Measuring instruments should be installed at appropriate positions close to the actual TEC location to provide an acceptably accurate measurement of tidal current (magnitude and direction) conditions experienced during operation. The measurement instruments should be capable of recording the temporal variation in tidal velocity, in three orthogonal components, vertically throughout the water column across the projected capture area of the TEC energy extraction plane. The distance from the sea floor at the current profiler deployment location to the centre of each current profiler bin should be reported.

The positioning of the measuring instruments should be such that they capture the ambient current behaviour without modification due to the proximity of the TEC, but sufficiently close to the TEC to be representative of the local current regime. The difference in total water depth between the sampling location and the TEC location should be within ±10 % of the water depth relative to a known chart datum. Maximum and minimum distances between the recording device and the TEC should be based on the appropriate equivalent diameter for a given TEC and allowable ranges are given in Figures 2 to 5. These instruments should be deployed in one of two orientations, A (in-line) or B (adjacent); however, orientation A is strongly preferred due to potential blockage effects, horizontal shear and variations in bathymetry. Substantial justification should be provided if orientation B is chosen:

A – In-line (Figure 2): Two measuring instruments should be placed in-line with the TEC, one upstream of the TEC extraction plane on the flood tide and the other upstream on the ebb tide. These instruments should be placed such that the distance from the nearest external surface of the measuring volume (Figure 3) to the projected capture area of the TEC extraction plane is always greater than 2 equivalent diameters and less than 5 equivalent diameters. These instruments should be placed within ½ equivalent diameter of the principal ebb and flood direction streamlines coincident with the TEC extraction plane vertical centreline.

Or

B – Adjacent (Figure 4): Two measuring instruments should be placed adjacent to the TEC, one starboard and one port of the TEC extraction plane. These instruments should be placed such that the distance from the nearest external surface of the measuring volume (Figure 5) to the TEC extraction plane lateral extent is always greater than 1 equivalent diameter and less than 2 equivalent diameters. These instruments should be placed within ½ equivalent diameter of the TEC extraction plane lateral centreline. The linear average should be taken between any two measured values at equivalent water depths with identical measurement bin heights. The variation in measured axial velocity should be less than 10 % between the two measuring instruments for the linear average to be considered a valid approximation of the flow at the energy extraction plane.

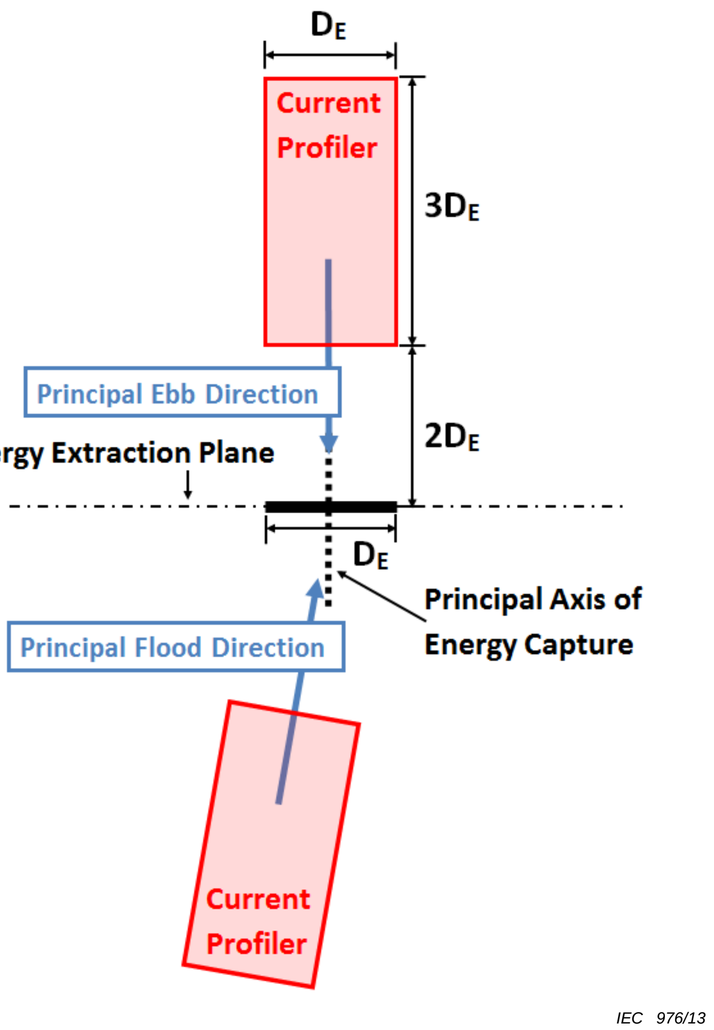


Figure 2 – Orientation A for current profiler deployment (plan view)

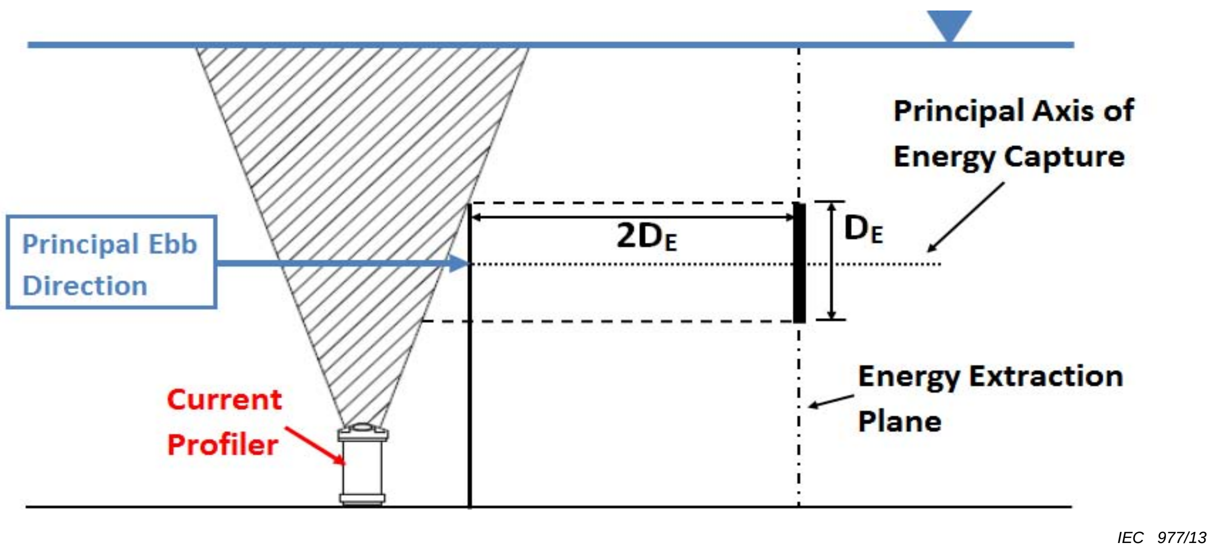


Figure 3 – Orientation A for current profiler deployment (section view)

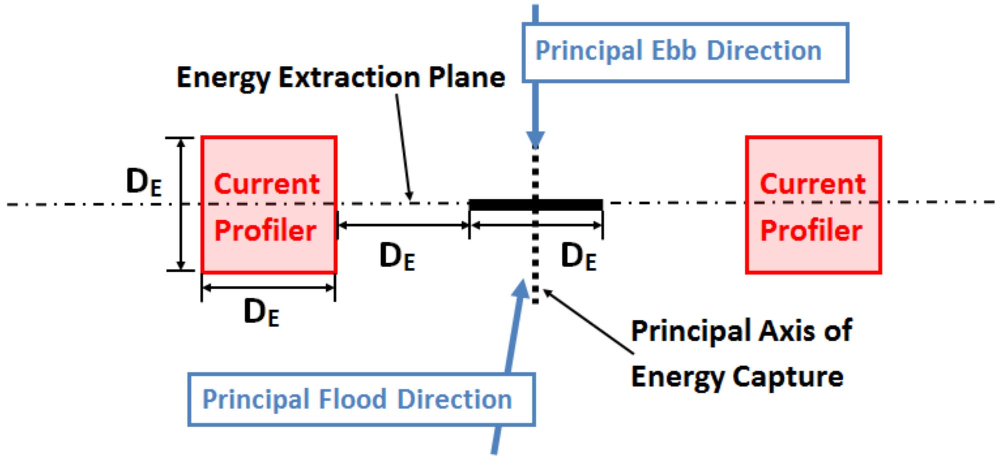


Figure 4 – Orientation B for current profiler deployment (plan view)

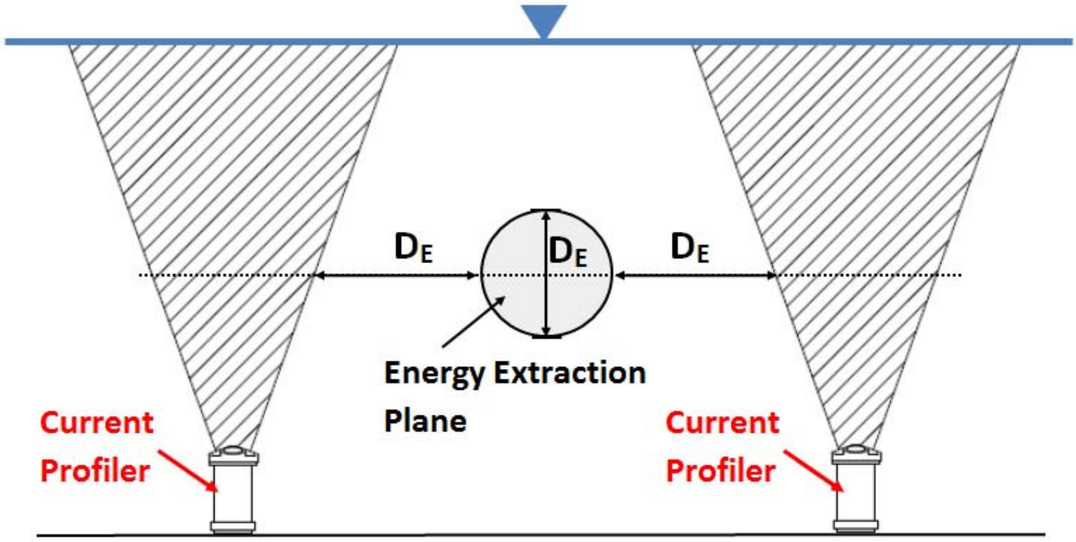


Figure 5 – Orientation B for current profiler deployment (section view)

A floating TEC that is free to move on a compliant mooring should use current profiler(s) positioned in one of the following ways:

- a current profiler mounted on the TEC itself that complies with orientations A or B, shown in Figures 2 through 5;
- a bottom mounted current profiler on both ebb and flood tides positioned in such a way that the footprint (the area described by the intersection of the energy extraction plane and the principal axis of energy capture) does not exceed the dimensions detailed in Figure 6;
- if none of these deployment orientations are achievable, an array of bottom mounted current profilers may be used, and a correction methodology developed and justified, such that the ambient current behaviour without modification due to the proximity of the TEC is measured. One method of justifying a methodology would be to perform a site calibration.

For any current profiler orientation, a device should monitor and record the position of the floating TEC itself.

Redeployment of a current profiler during the test period should be avoided. Where this is impracticable the current profiler should ideally be redeployed to the same position (leaving the seabed frame in place and retrieving the current profiler only). A redeployed current profiler should comply with the orientations outlined.

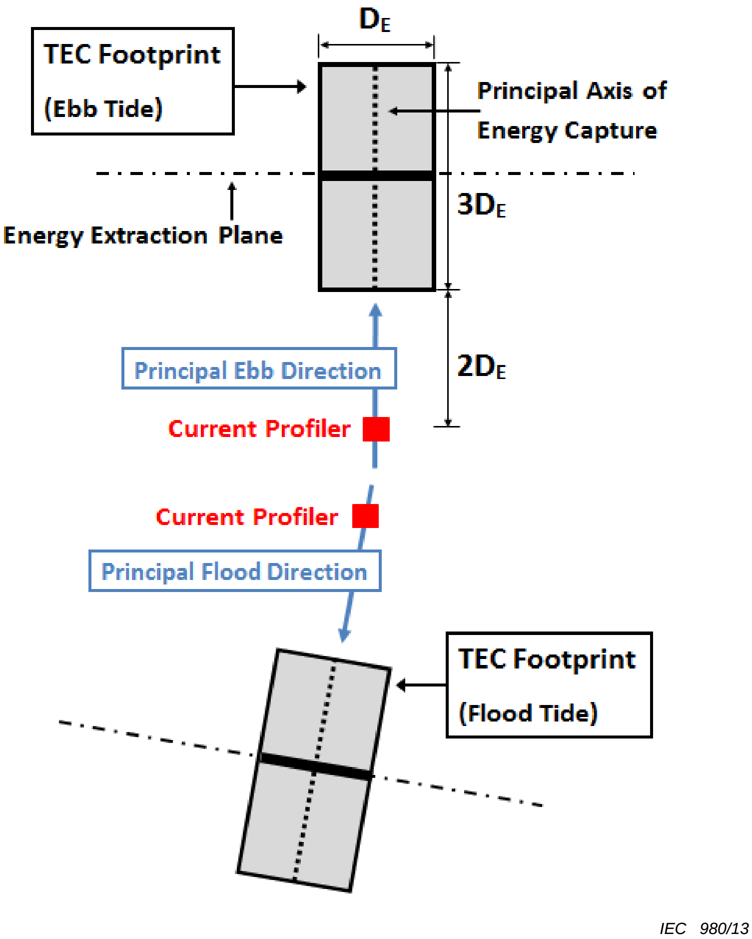


Figure 6 – Orientation for floating TEC current profiler deployment (plan view)

8.9.2 Contribution from turbulence

While there is a potentially significant influence on TEC power performance due to turbulence inherent in the tidal flow, no corrections for the effect of turbulence should be performed in the reported assessment of power performance. Future efforts will be made to quantify this influence; however, this issue is not covered at this stage of the Technical Specification development.

8.9.3 Contribution from waves

While there is a potentially significant influence on TEC power performance due to wave interaction with the tidal flow, no corrections for the effect of waves should be performed in the reported assessment of power performance. Future efforts will be made to quantify this influence; however, this issue is not covered at this stage of the Technical Specification development.

Measurement and reporting of the wave climate is strongly recommended if there is a significant wave climate at the TEC test site during the test period. Refer to informative Annex D for wave climate measurement guidance.

9 Derived results

9.1 General

9.1.1 Introductory remarks

The performance of the TEC device should be described by a representative power curve for each of the flood and ebb tide. Though not included as a normative part of this Technical Specification, the TEC annual energy production (TEC AEP) estimate can be calculated using the method recommended in informative Annex C using the measured in-situ data and a frequency distribution of the tidal currents for the site.

The effects of flow misalignment on TEC performance are not addressed in this Technical Specification at this time. The user of this information should be aware that tidal sites with large flow misalignment may result in significant performance variations.

9.1.2 Water density

A representative value for the density of seawater at 15 °C and 35 PPT salinity (ρ = 1 025 kg/m^3) should be used for all calculations. If applicable, an alternative density may be used to account for the influence of freshwater at the TEC deployment site, assuming reasonable convergence of the measured mean water density over time. Detailed measurements of the water temperature and salinity, as well as the formula used to derive density, should be included to justify any variation from the representative value. The Thermodynamic Equation Of Seawater – 2010 (TEOS-10) should be used for seawater density calculations in this situation.

9.2 Data processing

9.2.1 Filtering

Filtering of the data is only permitted during the data collection phase as per 8.3.

9.2.2 Exclusion

The power curve should be derived using data sets obtained during normal operation of the TEC device.

Data sets should be discarded in the following instances:

- if less than 90 % of the data points are valid due to measurements falling outside of data acquisition limits.
- if the current profiler is not able to resolve the flow over 90 % of the current profiler bins in the projected capture area.

The exclusion of data sets is only allowed under the circumstances defined in 8.5. All data series should be traceable and any reasons for exclusion of data in the data derivation process should be fully reported and substantiated.

9.2.3 Correction

All data corrections required during the derivation of results should be fully reported and substantiated.

9.3 Calculation of the power curve

9.3.1 Method of bins

The power curve constitutes a plot of the power production (*y*-axis) against the incident tidal current resource (*x*-axis). This curve is derived using the method of bins approach to calculate the mean values of the power output and the tidal current velocity for each bin. The method of bins is summarized as follows:

- calculate the instantaneous power weighted velocity from each current profiler bin averaged across the projected capture area;
- calculate the temporal (10 min) power weighted average value of these velocity data samples;
- calculate the average value of the active and reactive power data samples to produce active and reactive power data points;
- bin the velocity data points according to their corresponding velocity bin value. The active and reactive power data are also binned according to their corresponding velocity bin value;
- calculate an average velocity data point and power data points using all of the data points in the velocity bin. Plot this average velocity data point with the corresponding average active and reactive power data points.

9.3.2 Detailed description of method of bins

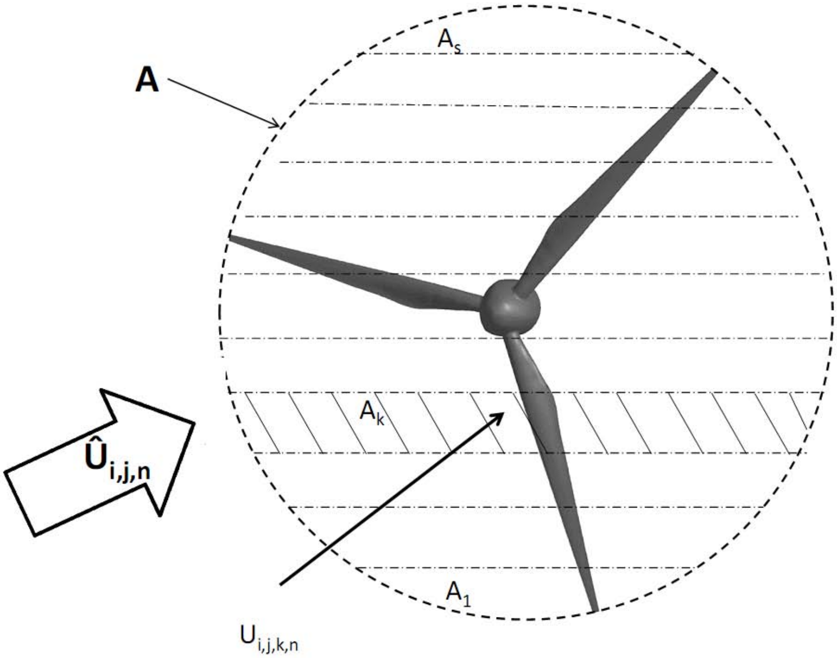
It should be assumed that the tidal current velocity data sample at any elevation above the seabed is representative of the tidal current velocity across the entire width of the projected capture area at that elevation. The vertical variation of the tidal current velocity at each time sampling interval (data sample $U_{i,j,k,n}$) should be integrated across the projected capture area, to provide a power weighted current velocity, $\widehat{U}_{i,j,n}$, based upon the following formula (1) and illustrated in Figure 7 for additional clarity:

$$\widehat{U}_{i,j,n} = \left[\frac{1}{A} \cdot \sum_{k=1}^{S} U_{i,j,k,n}^{3} \cdot A_k\right]^{1/3} \quad (1)$$

$$A = \sum_{k=1}^{S} A_k \quad (2)$$

where:

A	is the projected capture area of the TEC [m^2];
A_k	is the area of current profiler bin k across the projected capture area [m^2];
i	is the index number defining the velocity bin;
j	is the index number of the time instant at which the measurement is performed;
k	is the index number of the current profiler bin across the projected capture area;
n	is the index number defining an individual data point in a velocity bin;
S	is the total number of current profiler bins across the projected capture area normal to the principal axis of energy capture;
$\widehat{U}_{i,j,n}$	is the instantaneous power weighted tidal current velocity across the projected capture area [m/s];
$U_{i,j,k,n}$	is the magnitude of the instantaneous tidal current velocity, time j, at current profiler bin k, in velocity bin i, for data point n [m/s].



IEC 981/13

Figure 7 – The vertical variation of tidal current across the projected capture area

Whether the TEC is fixed, having no yaw capability, or capable of orientating to the dominant tidal current direction, the recorded velocity magnitude should be used for data sample $U_{i,j,k,n}$.

The instantaneous power weighted tidal current velocity calculated in formula (1) should be averaged over the period defined in 8.6 (typically 10 min). Formula (3), by taking the temporal averaging of $\hat{U}_{i,j,n}$, will produce a mean power weighted tidal current velocity, $\overline{U}_{i,n}$, which will form a data point in the data set of a specific current velocity bin, i. A corresponding averaged active power and reactive power output for that specific velocity bin should also be calculated over the period defined in 8.6 as given in formulae (4) and (5).

NOTE As an example, assuming i = 1 suggests the current velocity bin of 0,5 m/s. As such, the bin will contain all current velocities data points between $\overline{U}_{1,n}$ = 0,45 m/s and $\overline{U}_{1,n}$ < 0,55 m/s. The corresponding $\overline{P}_{1,n}$ and $\overline{Q}_{1,n}$ data points are also associated with the 0,5 m/s current velocity bin. Similarly, i = 2 suggests a current velocity bin of 0,6 m/s where 0,55 m/s ≤ $\overline{U}_{2,n}$ < 0,65 m/s for all data points n.

$$\overline{U}_{i,n} = \left[\frac{1}{L}\sum_{j=1}^{L}\hat{U}_{i,j,n}{}^{3}\right]^{1/3} \tag{3}$$

$$\overline{P}_{i,n} = \frac{1}{L}\sum_{j=1}^{L}P_{i,j,n} \tag{4}$$

$$\overline{Q}_{i,n} = \frac{1}{L}\sum_{j=1}^{L}Q_{i,j,n} \tag{5}$$

where:

i	is the index number defining the velocity bin;
j	is the index number of the time instant at which the measurement is performed;
L	is the number of samples in the defined averaging period which produces data point n;
n	is the index number defining an individual data point in a velocity bin;
$\overline{P}_{i,n}$	is the mean recorded TEC active power in velocity bin i for data point n [W];

$P_{i,j,n}$ is the magnitude of the total instantaneous active electrical power from the TEC [W];

$\overline{Q}_{i,n}$ is the mean recorded TEC reactive power in velocity bin i for data point n [VAr];

$Q_{i,j,n}$ is the magnitude of the total instantaneous reactive electrical power from the TEC [VAr];

$\overline{U}_{i,n}$ is the mean power weighted tidal current velocity in velocity bin i for data point n [m/s];

$\widehat{U}_{i,j,n}$ is the instantaneous power weighted tidal current velocity across the projected capture area [m/s].

The measured active power curve is to be calculated by binning the current velocity data using a maximum velocity bin increment of 0,10 m/s. If a velocity bin increment smaller than 0,10 m/s is chosen, it should be an increment that is an integer divisor of 0,10 m/s. A separate power curve is required for each of the flood and ebb data set as per the calculation in formulae (6) and (7):

$$\overline{U}_i = \frac{1}{N_i}\sum_{n=1}^{N_i}\overline{U}_{i,n} \quad (6)$$

$$\overline{P}_i = \frac{1}{N_i}\sum_{n=1}^{N_i}\overline{P}_{i,n} \quad (7)$$

where:

i is the index number defining the velocity bin;

n is the index number defining an individual data point in a velocity bin;

N_i is the number of data points in velocity bin i;

$\overline{P}_i$ is the mean recorded TEC active power in velocity bin i [W];

$\overline{P}_{i,n}$ is the mean recorded TEC active power in velocity bin i for data point n [W];

$\overline{U}_i$ is the mean power weighted tidal current velocity in velocity bin i [m/s];

$\overline{U}_{i,n}$ is the mean power weighted tidal current velocity in velocity bin i for data point n [m/s].

The active power curve for the flood and ebb data sets should be presented in graphical and in tabular format as defined in 10.8.

For TECs that produce AC power, the reactive power should also be measured in a similar manner as described for active power, formula (7), as shown by formula (8):

$$\overline{Q}_i = \frac{1}{N_i}\sum_{n=1}^{N_i}\overline{Q}_{i,n} \quad (8)$$

where:

i is the index number defining the velocity bin;

n is the index number defining an individual data point in a velocity bin;

N_i is the number of data points in velocity bin i;

$\overline{Q}_i$ is the mean recorded TEC reactive power in velocity bin i [VAr];

$\overline{Q}_{i,n}$ is the mean recorded TEC reactive power in velocity bin i for data point n [VAr].

The reactive power for the flood and ebb data sets should be presented in tabular format as defined in 10.8.

9.3.3 Interpolation

If the number of data points in a velocity bin is insufficient (i.e. less than 30 min of data as specified in 8.7) and is preventing the completion of the test program, the value in that velocity bin can be estimated by linear interpolation from the two adjacent completed bins. This process can be repeated for multiple velocity bins as long as no more than 10 % of the total number of velocity bins is interpolated. It is not permissible to interpolate a velocity bin with an incomplete adjacent velocity bin.

9.3.4 Extrapolation

Extrapolation of the data during the data processing operation is not permitted.

9.3.5 Uncertainty calculation

The graphical representation of the power curve should display the mean recorded TEC active power as a function of the mean power weighted tidal current velocity. The value of power for each velocity bin is a mean, or expected value, based upon an average of the collected data points in that bin. Consequently, there should be a distribution of data points scattered randomly around the mean value, with a standard deviation attached to that distribution. The standard deviation on each bin in the power curve should provide one of the levels of uncertainty associated with the behaviour of the device at the site. The derivation of overall system performance uncertainty should also account for the contributions made by the bias of the measuring instruments and other sources of uncertainty (i.e. current profiler position).

Additional details on the estimation of the uncertainty in measurement of the power curve are described in Annexes A and B.

The power curve data points for each velocity bin are expected to have a normal distribution around the mean value of each velocity bin. The user is recommended to use higher order metrics such as skewness and kurtosis to confirm this assumption.

9.4 Mean tidal current velocity vertical shear profile

The mean tidal current velocity vertical shear profile should be calculated over the full tidal current velocity range from cut-in to cut-out water velocity at 0,5 m/s increments using the mean current velocity at the hub height current profiler bin as the reference. When the mean current velocity at the hub height is within ± 0,05 m/s of one of the specified increments, the average current velocity corresponding to each current profiler bin should be calculated using the data samples measured during the defined averaging period. These average current velocities will produce a vertical shear profile for a given reference tidal current velocity. It should be noted that the tidal current data points are binned according to their corresponding current profiler bin, k, for this procedure.

The shear profile should be computed separately for both the flood and ebb tides. The procedure is summarized as follows:

At each period when the hub height average velocity is within ±0,05 m/s of the targeted velocity value, the average current velocity at each current profiler bin should be calculated as shown in formula (9):

$$\overline{\mathrm{Ushear}}_{i,k,n} = \frac{1}{L}\sum_{j=1}^{L} U_{i,j,k,n} \qquad (9)$$

where:

i	is the index number defining the velocity bin;
j	is the index number of the time instant at which the measurement is performed;
k	is the index number of the current profiler bin across the projected capture area;

n is the index number defining an individual data point in a velocity bin;

L is the number of data samples in the defined averaging period which produces data point n;

$U_{i,j,k,n}$ is the magnitude of the instantaneous tidal current velocity, time j, at current profiler bin k, in velocity bin i, for data point n [m/s];

$\overline{Ushear}_{i,k,n}$ is the mean tidal current velocity in velocity bin i, at current profiler bin k, for data point n [m/s].

The current profiler bin including the TEC hub height should be used. If the hub height is situated on the boundary of two current profiler bins, the use of either current profiler bin adjacent to the hub height is acceptable. Formula (9) is repeated for all values of k from 1 to S to calculate the average current velocity in each current profiler bin. (S is the total number of current profiler bins normal to the principal axis of energy capture across the projected capture area).

All of the data points in each current profiler bin are then averaged using formula (10):

$$\overline{Ushear}_{i,k} = \frac{1}{N_k} \sum_{n=1}^{N_k} \overline{Ushear}_{i,k,n} \tag{10}$$

where:

i is the index number defining the velocity bin;

k is the index number of the current profiler bin across the projected capture area;

n is the index number defining an individual data point in a velocity bin;

N_k is the number of data points in current profiler bin k;

$\overline{Ushear}_{i,k}$ is the mean tidal current velocity in velocity bin i at current profiler bin k;

$\overline{Ushear}_{i,k,n}$ is the mean tidal current velocity in velocity bin i, at current profiler bin k, for data point n [m/s].

The mean tidal current velocity vertical shear profile, $\overline{Ushear}_{i,k}$, for the flood and ebb data sets should be presented for velocity bins, i, in 0,5 m/s increments from cut-in to cut-out water velocity in graphical and in tabular format as defined in 10.7.

9.5 RMS fluctuating tidal current velocity

The RMS fluctuating velocity and corresponding standard deviation at the current profiler bin corresponding to the TEC hub height, should be reported at velocity bins from cut-in to cut-out velocity in 0,5 m/s increments (i.e. 1,0, 1,5, 2,0, 2,5 m/s).

At each period when the average hub height velocity is within ±0,05 m/s of the targeted velocity bin increment, the RMS fluctuating current velocity should be calculated as shown in formula (11):

$$Urms_{i,k,n} = \sqrt{\frac{1}{L} \sum_{j=1}^{L} (U_{i,j,k,n} - \overline{Ushear}_{i,k,n})^2} \tag{11}$$

where:

i is the index number defining the velocity bin;

j is the index number of the time instant at which the measurement is performed;

k is the index number of the current profiler bin across the projected capture area;

n is the index number defining an individual data point in a velocity bin;

L	is the number of data samples in the defined averaging period which produces data point n;
$U_{i,j,k,n}$	is the magnitude of the instantaneous tidal current velocity, time j, at current profiler bin k, in velocity bin i, for data point n [m/s];
$Urms_{i,k,n}$	is the RMS fluctuating tidal current velocity in velocity bin i, at current profiler bin k, for data point n [m/s];
$\overline{Ushear}_{i,k,n}$	is the mean tidal current velocity in velocity bin i, at current profiler bin k, for data point n [m/s].

All of the data points for the hub height current profiler bin are then averaged using formula (12):

$$Urms_{i,k} = \frac{1}{N_k} \sum_{n=1}^{N_k} Urms_{i,k,n} \tag{12}$$

where:

i	is the index number defining the velocity bin;
k	is the index number of the current profiler bin across the projected capture area;
n	is the index number defining an individual data point in a velocity bin;
N_k	is the number of data points in current profiler bin k;
$Urms_{i,k}$	is the RMS fluctuating tidal current velocity in velocity bin i at current profiler bin k [m/s];
$Urms_{i,k,n}$	is the RMS fluctuating tidal current velocity in velocity bin i, at current profiler bin k, for data point n [m/s].

The RMS fluctuating tidal current velocity, $Urms_{i,k}$, for the flood and ebb data sets should be presented for velocity bins, i, in 0,5 m/s increments from cut-in to cut-out water velocity, in tabular format as defined in 10.7.

9.6 Tidal ellipse at hub height

The tidal ellipse at hub height should be calculated for the full tidal current velocity range from cut-in to cut-out water velocity using average tidal current magnitude and direction data points. The average tidal current magnitude is calculated using formula (13). This calculation should only be performed for the value of k, corresponding to the current profiler bin that contains, or is adjacent to, hub height.

$$\overline{Uellipse}_{i,k,n} = \frac{1}{L} \sum_{j=1}^{L} U_{i,j,k,n} \tag{13}$$

where:

i	is the index number defining the velocity bin;
j	is the index number of the time instant at which the measurement is performed;
k	is the index number of the current profiler bin across the projected capture area;
n	is the index number defining an individual data point in a velocity bin;
L	is the number of data samples in the defined averaging period which produces data point n;
$U_{i,j,k,n}$	is the magnitude of the instantaneous tidal current velocity, time j, at current profiler bin k, in velocity bin i, for data point n [m/s];
$\overline{Uellipse}_{i,k,n}$	is the mean tidal current velocity in velocity bin i, for current profiler bin k at hub-height, for data point n [m/s].

In a similar manner, the corresponding average tidal current direction should be calculated using formula (14).

$$\bar{\theta}_{i,k,n} = \frac{1}{L}\sum_{j=1}^{L}\theta_{i,j,k,n} \qquad (14)$$

where:

i	is the index number defining the velocity bin;
j	is the index number of the time instant at which the measurement is performed;
k	is the index number of the current profiler bin across the projected capture area;
n	is the index number defining an individual data point in a velocity bin;
L	is the number of data samples in the defined averaging period which produces data point n;
$\bar{\theta}_{i,k,n}$	is the mean tidal current direction, in velocity bin i, at current profiler bin k, for data point n [deg];
$\theta_{i,j,k,n}$	is the magnitude of the instantaneous tidal current direction, time j, at of current profiler bin k, in velocity bin i, for data point n [deg].

For angles that cross 360°/0°, care should be taken to ensure the correct averaging of the tidal current direction. Formula (15) provides a suggested method.

$$\bar{\theta}_{i,k,n} = \arctan\left[\frac{\sum_{j=1}^{L}\sin(\theta_{i,j,k,n})}{\sum_{j=1}^{L}\cos(\theta_{i,j,k,n})}\right] \qquad (15)$$

All of the resulting average tidal current magnitude and corresponding direction data points should be displayed on a polar plot.

A line displaying the measured principal flow directions, as determined in 5.3, of both the flood and ebb tides during the test period should be plotted through the tidal ellipse data points using the method of least squares. Both flood and ebb data should be plotted on the same graph to allow easier comparison of the relative difference from one tide to the other. An example plot is provided in Figure 8 in 10.3.

9.7 Calculation of the TEC overall efficiency

The TEC overall efficiency at its output terminals should be added to the test results and presented as detailed in 10.9. The TEC overall efficiency for each velocity bin i should be derived from the measured flood and ebb power curves according to formula (16):

$$\eta_{System,i} = \frac{\bar{P}_i}{\frac{1}{2}.\rho.A.\bar{U}_i^3} \qquad (16)$$

where:

A	is the projected capture area of the TEC [m^2];
$\bar{P}_i$	is the mean recorded TEC active power in velocity bin i [W];
$\bar{U}_i$	is the mean tidal current velocity in velocity bin i [m/s];
$\eta_{System,i}$	is the TEC overall efficiency in velocity bin i;
ρ	is the density of water, as defined in 9.1.2 [kg/m^3].

9.8 TEC annual energy production (TEC AEP)

The calculation of the TEC AEP is not included in this Technical Specification at this time because an appropriate published resource assessment Technical Specification is not yet available. A normative reference for the assessment and calculation of the TEC AEP will be added when such a resource assessment specification becomes available. In the interim, a recommended methodology for the calculation of TEC AEP has been included in Annex C for reference.

10 Reporting format

10.1 General

Reporting requirements are described below. All work performed should adhere to the requirements in this Technical Specification, and any deviations should be documented as described in 10.11 below.

10.2 TEC report

The TEC under evaluation should be described in full. As a minimum, the following parameters should be provided:

- TEC make, type, serial number, production year;
- type of energy capture technology employed and standard dimensions of the TEC. This should incorporate the use of a diagram, and include projected capture area, supporting foundation/platform/mooring system, and distance above the seabed for a bottom-mounted device or below the surface for a floating device;
- device equivalent diameter;
- location of the energy extraction plane;
- description of the control system (device and software version);
- TEC power rating and operational parameters, as described in 6.2, including:
  - rated TEC output power;
  - rated water velocity;
  - equivalent diameter;
  - cut-in water velocity to begin power production;
  - low cut-out water velocity to end power production (if different than the cut-in water velocity);
  - cut-out water velocity (maximum water velocity for TEC operation);
  - rotational speed range or period for an oscillating device.
- description of the power take-off system up to the power measurement location. This should include the rated voltage, current and frequency rating (where applicable) of all components including the generator, converter, and any other equipment used to condition, transfer, or store power. A diagram detailing the power take-off system and location of the power measurement location should also be provided. Where applicable, calculations to account for cable losses as described in 8.8.2 and 8.8.3 should be provided in detail.

10.3 TEC test site report

The TEC test site should be well defined in accordance with the details in Clause 5. This should include:

- a minimum of one hydrographical/navigational chart of the test area that is of suitable scale to demonstrate the following information:
  - TEC location (expressed in Latitude/Longitude or UTM in WGS84); for moored devices, typical TEC location at slack tide, flood tide, ebb tide and an illustration of the watch circle / TEC footprint experienced during the tests;
  - illustration of the TEC footprint (fixed device) or anchor location(s) (floating device);

  - TEC angular orientation relative to True North (where applicable for a fixed device);
  - electrical cable route and length (if applicable);
  - shoreline profile;
  - water depth and tidal range in terms of MLW and MHW, or LAT and HAT, including the reference datum;
  - any nearby tidal gauges or environmental monitoring stations;
  - any other notable features or infrastructure in proximity to the device;
  - identification of the current measurement locations used during the tidal resource assessment.
- reporting of the bathymetry in accordance with the survey prescribed in 5.2, including clear identification of any unique features;
- reporting of the current profiler positions including a figure illustrating that the requirements of 8.9 are satisfied;
- reporting of the vertical dimension, and centre position above the seabed, of the energy extraction plane current profiler bins;
- reporting of the tidal ellipse and principal flow directions relative to the TEC as described in 5.3 and 9.6 (see example Figure 8);
- reporting (with diagram) of the cross-sectional area of the testing location consumed by the TEC and foundation as described in 5.4 (see example Figure 9);
- reporting of external constraints affecting or having the potential to affect typical device performance or operational periods as discussed in 5.5;
- reporting of any variation from the representative water density if used for the calculations as discussed in 9.1.2;
- reporting of the wave climate where applicable as described in 8.9.3.

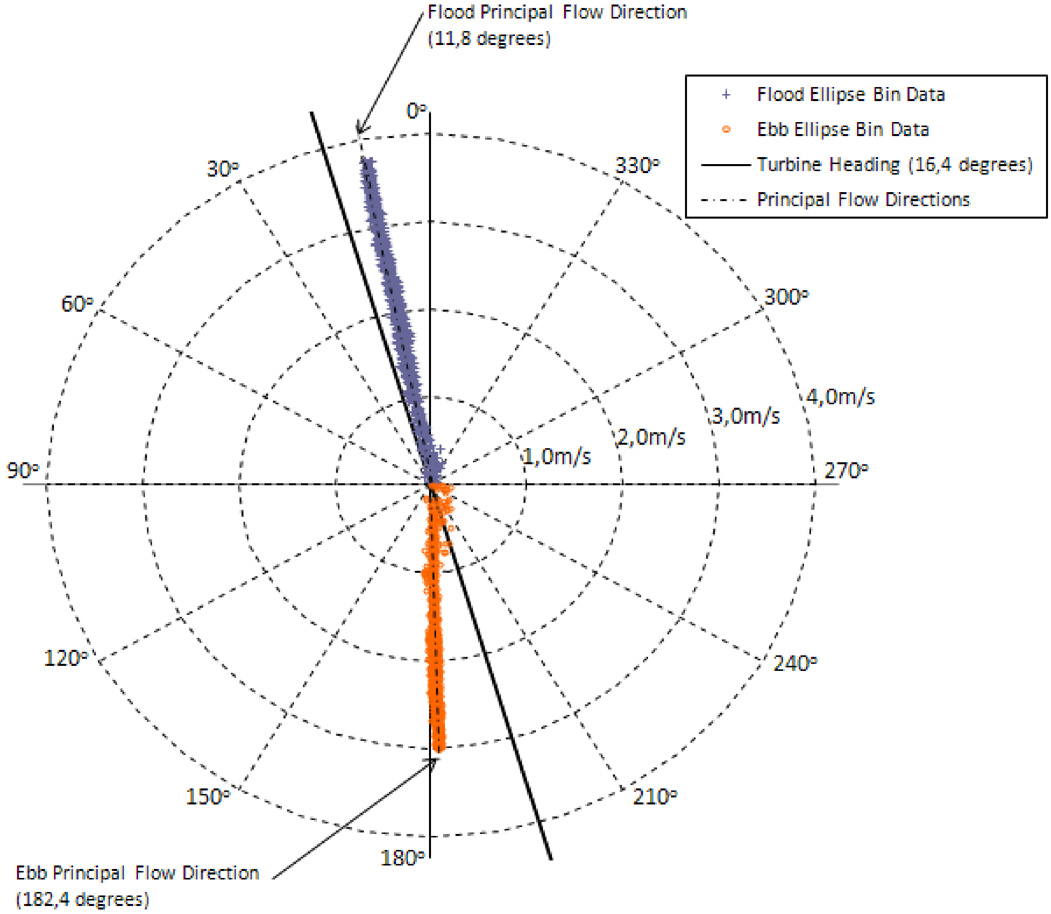


Figure 8 – Example tidal ellipse plot identifying principal ebb and flood directions

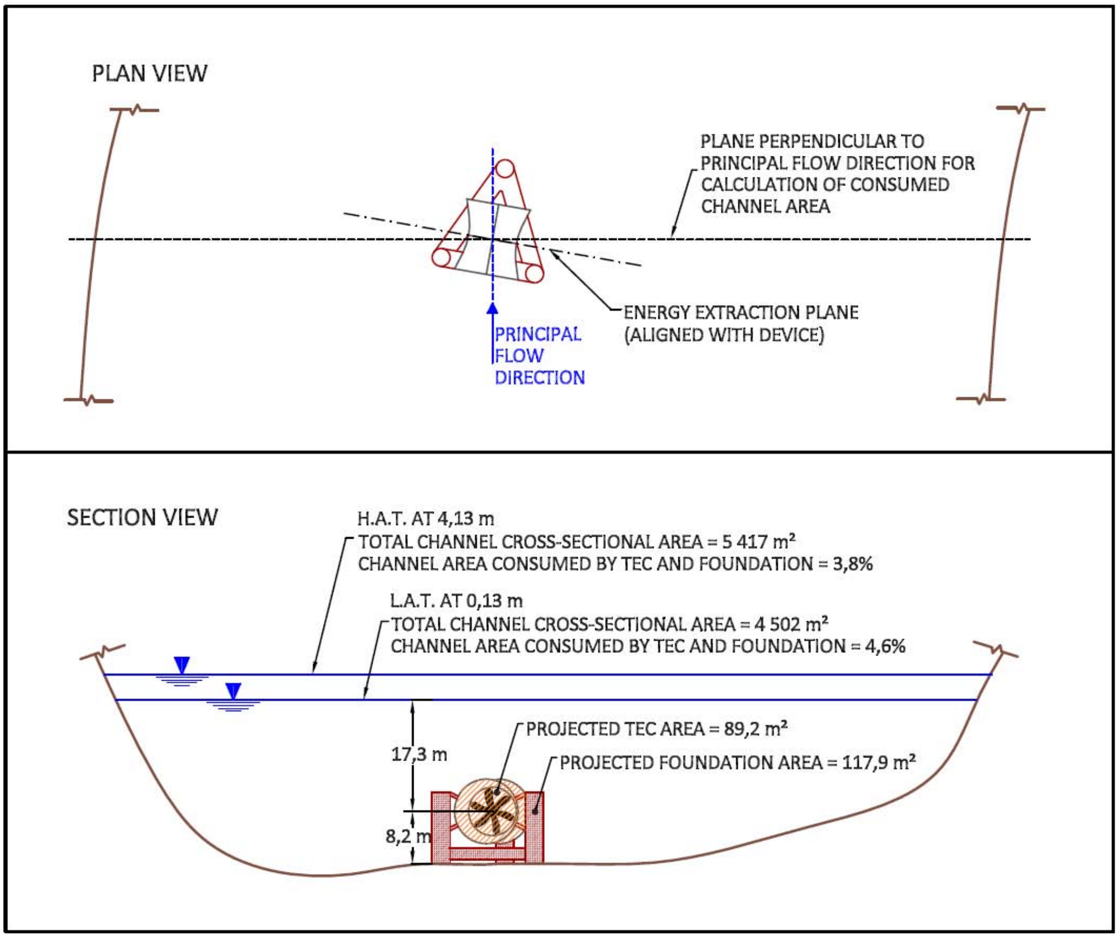


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Figure 9 – Example plot of the channel cross-sectional area consumed by the TEC on plane perpendicular to principal flow direction (plan and section view)

10.4 Electrical grid and load report

Grid parameters including voltage, frequency, and permitted tolerances should be provided. Any prevailing grid conditions limiting or having the potential to limit the power output during the testing period should be reported.

For devices not connected to a utility grid (i.e. used to charge battery powered systems) a detailed description of the electrical load, to be representative of the load for which the TEC is designed, should be provided. Where applicable, this should include specification of the batteries, charge controller and dump load used to dissipate energy from the system.

10.5 Test equipment report

A description of all test equipment including sensors, DAQ, current profiler, and power take-off components should be provided. For each component, this should include:

- name, model number, and general description;
- specification sheet demonstrating ability to meet requirements defined in Clause 7;
- reporting of all user-defined settings;
- calibration documentation or certificate of conformance, as well as documentation of compliance to manufacturer-recommended procedures;
- current profiler settings as prescribed in 7.2.

The method and results of DAQ end-to-end testing, in accordance with 7.3, should be reported.

10.6 Measurement procedure report

A description of the measurement procedure, in accordance with Clause 8, should be provided. This includes:

- reporting of the time used for data acquisition (UTC ± T hours), procedural steps, test conditions, sampling rate, time-drift considerations as per 8.6, and averaging time for each data set;
- a log book containing details as prescribed in 8.2 should be appended to the report.

10.7 Presentation of measured data

Information detailing the measured data used to populate the velocity bins should be provided in a scatter plot for each of the flood and ebb datasets. In each plot, mean recorded power ($\overline{P}_{i,n}$), the maximum and minimum values, and the standard deviation should be plotted against the mean recorded current velocity ($\overline{U}_{i,n}$) for each data point during the testing period.

Velocity vertical shear profile and RMS fluctuating velocity, calculated as described in 9.4 and 9.5, should also be reported for both the ebb and flood tide datasets.

An example of the scatter plot is provided in Figure 10. Table 1 provides an example for reporting of the velocity shear as a function of the current profiler bin across the energy extraction plane, with a sample plot provided in Figure 11. Table 2 provides an example for reporting the RMS fluctuating velocity at hub height.

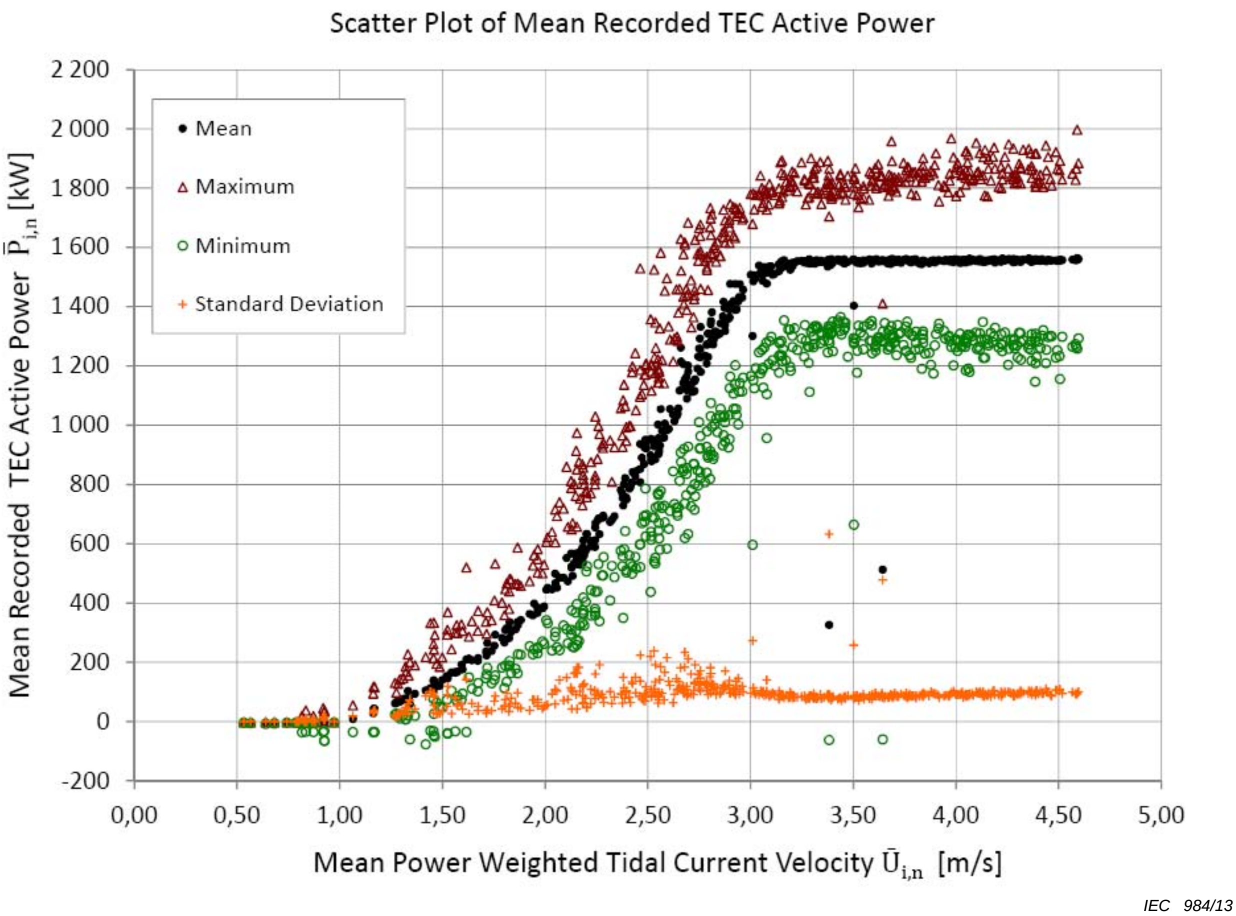

Figure 10 – Example scatter plot of performance data

Table 1 – Example presentation of the mean tidal current velocity vertical shear (mean velocity shear) data

		Hub Height Velocity = 1,0 m/s
Current Profiler Bin, k	Current Profiler Bin Vertical Extents [m]	Mean Velocity Shear $\overline{Ushear}_{i,k}$ [m/s]
1	0,00 - 0,45	0,996
2	0,45 - 0,91	1,004
3	0,91 - 1,36	1,003
4	1,36 - 1,82	1,011
5	1,82 - 2,27	1,015
6	2,27 - 2,73 (Hub Height)	1,023
7	2,73 - 3,18	1,021
8	3,18 - 3,64	1,026
9	3,64 - 4,09	1,029
10	4,09 - 4,55	1,029
11	4,55 - 5,00	1,028
		Hub Height Velocity = 1,5 m/s
:	:	:

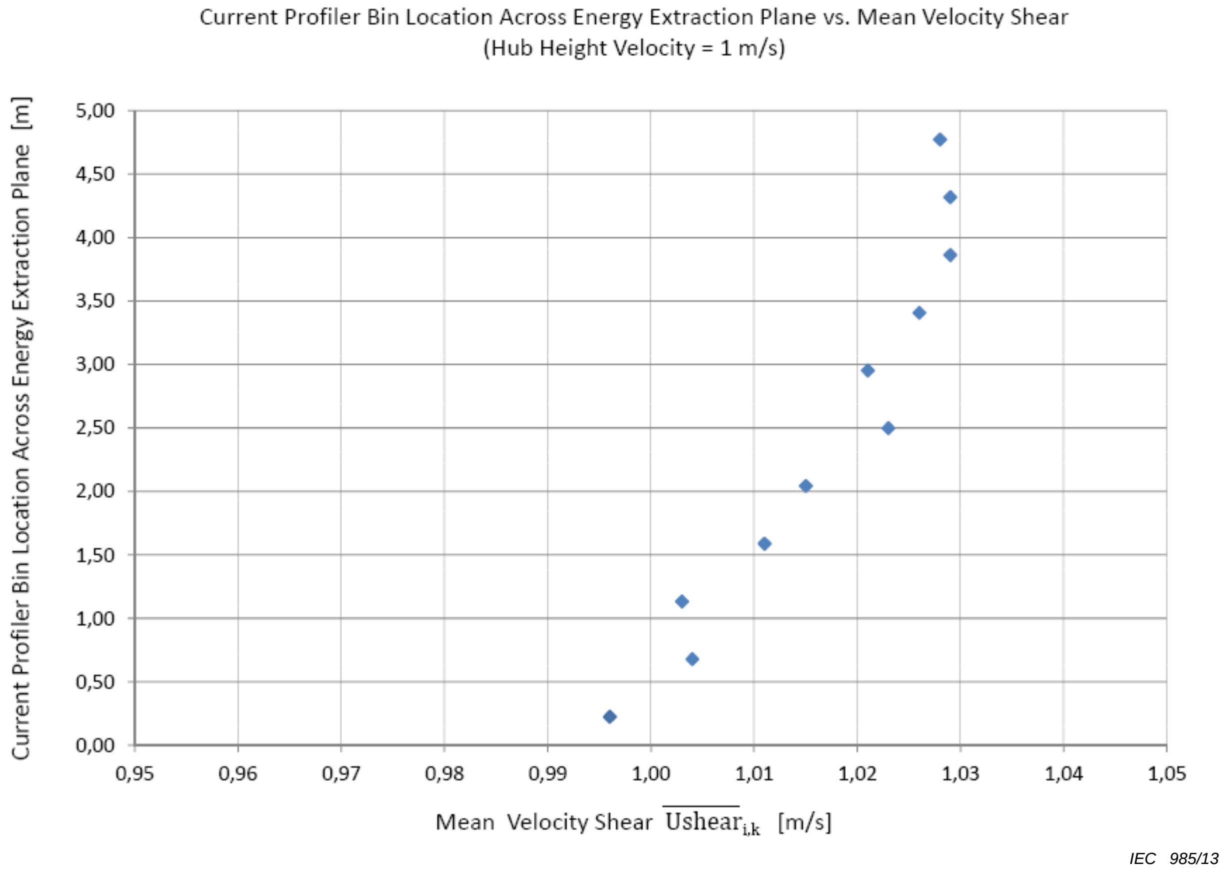

Figure 11 – Example plot of the mean tidal current velocity vertical shear (mean velocity shear) profile

Table 2 – Example presentation of the RMS fluctuating tidal current velocity at hub height

Hub Height Velocity [m/s]	RMS Fluctuating Velocity at Hub Height $Urms_{i,k}$ [m/s]
1,0	0,082
1,5	0,097
:	:

10.8 Presentation of the power curve

The power curve, calculated as per 9.3, should be presented in the report in both tabular and graphical format as follows:

- a table detailing each of the flood and ebb tide data set bins containing the following information should be provided:
  - bin number;
  - bin current velocity range;
  - bin mean current velocity ($\overline{U}_i$);
  - bin mean recorded TEC power output ($\overline{P}_i$);
  - selected bin duration and number of data sets in each bin;
  - category A, B, and combined standard uncertainty.
- a plot of mean recorded TEC active power ($\overline{P}_i$) vs. mean power weighted tidal current velocity ($\overline{U}_i$), containing a data set for each of the flood and ebb tides, should be provided. Uncertainties should be excluded from this plot;
- a plot of mean recorded TEC active power ($\overline{P}_i$) vs. mean power weighted tidal current velocity ($\overline{U}_i$) including standard uncertainty bars calculated as per Annexes A and B, and containing a data set for each of the flood and ebb tides, should be provided;
- a plot of mean recorded TEC active power ($\overline{P}_i$) vs. mean power weighted tidal current velocity ($\overline{U}_i$) including data points excluded as per 8.5 or 9.2.2, and containing a data set for each of the flood and ebb tides, should be provided. Justification of any criteria used to exclude data points should also be provided;
- plots of daily power curves should be provided in an appendix to facilitate data review.

Interpolated data points, as described in 8.7 and 9.3.3 should be designated with an “INT” next to the bin number in the table and corresponding table rows and plotted points should be formatted in an alternative colour. Table 3 provides an example format.

Figures 12, 13, and 14 provide examples of the required plots.

Table 3 – Example presentation of the power curve data

Velocity Bin Number i	Bin Velocity Range [m/s]	Mean Power Weighted Tidal Current Velocity $\bar{U}_i$ [m/s]	Mean Recorded TEC Active Power $\bar{P}_i$ [kW]	Mean Recorded TEC Reactive Power $\bar{Q}_i$ [kVAr]	Number of Data Points (10 minute bin duration)	Power Output Standard Uncertainty		
						Category A [kW]	Category B [kW]	Combined [kW]
1	0,500 - 0,549	0,523	-2,95	0,00	8	0,041	4,10	4,10
2	0,550 - 0,599	0,569	-2,74	0,00	6	0,030	4,10	4,10
3	0,600 - 0,649	0,644	-2,88	0,00	7	0,099	4,10	4,10
4	0,650 - 0,699	0,686	-2,56	0,00	6	0,652	4,10	4,10
5	0,700 - 0,749	0,719	-2,55	0,00	8	0,713	4,10	4,10
6	0,750 - 0,799	0,760	-2,69	0,00	7	0,301	4,10	4,10
7	0,800 - 0,849	0,836	-2,73	0,00	9	0,107	4,10	4,10
8	0,850 - 0,899	0,865	-3,00	0,00	11	0,073	4,10	4,10
9	0,900 - 0,949	0,933	-2,42	0,00	9	0,009	4,10	4,10
10	0,950 - 0,999	0,975	-2,37	0,00	6	0,058	4,10	4,10
11	1,000 - 1,049	1,023	5,57	62,07	8	0,113	4,37	4,37
12	1,050 - 1,099	1,074	2,55	62,14	6	0,049	4,51	4,51
13	1,100 - 1,149	1,126	12,64	62,06	10	0,194	5,93	5,93
14 INT	1,150 - 1,199	1,170	19,13	62,17	2			
15	1,200 - 1,249	1,230	25,62	62,33	7	0,257	6,60	6,60
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
63	3,600 - 3,649	3,623	1 556,55	62,26	11	0,624	17,94	17,95
64	3,650 - 3,699	3,690	1 556,01	62,24	6	0,656	17,81	17,82
65	3,700 - 3,749	3,730	1 557,42	62,30	8	0,360	17,66	17,67
66	3,750 - 3,799	3,765	1 560,07	62,40	7	0,376	17,69	17,69

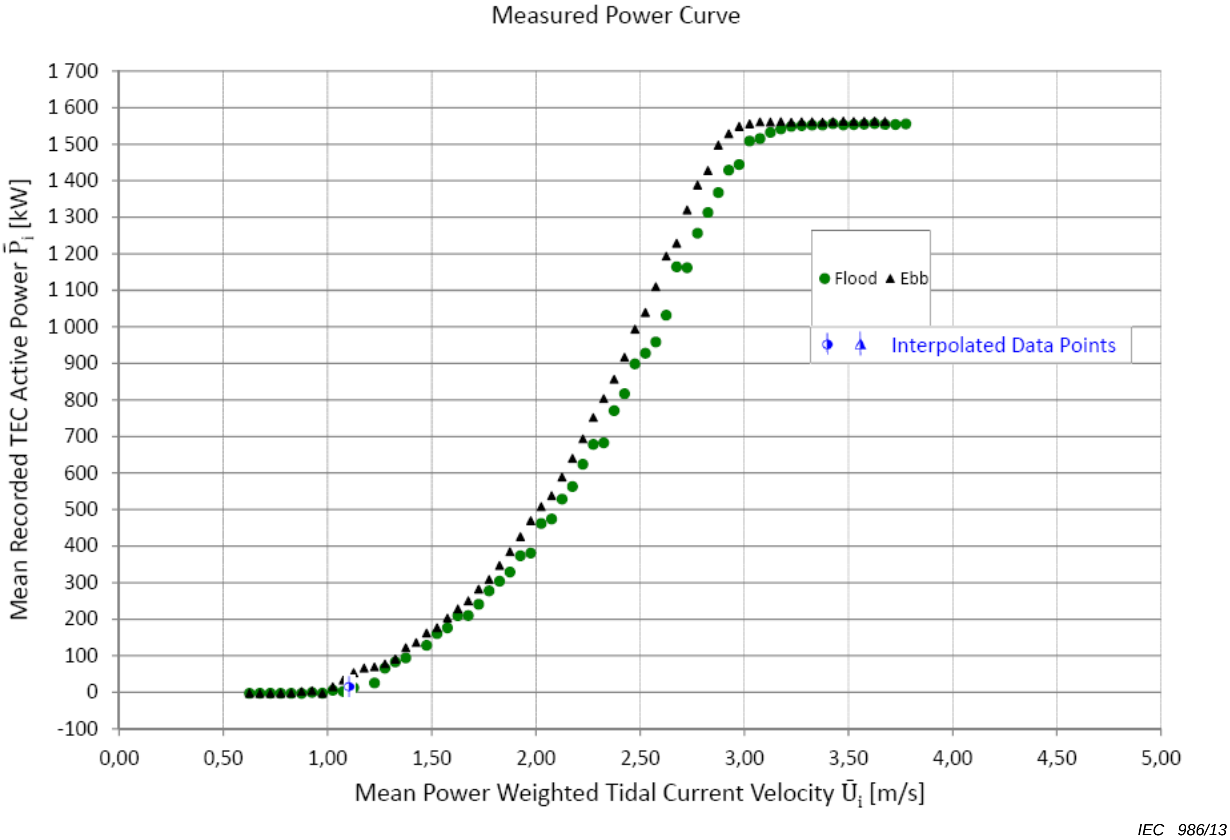

Figure 12 – Example presentation of the power curve

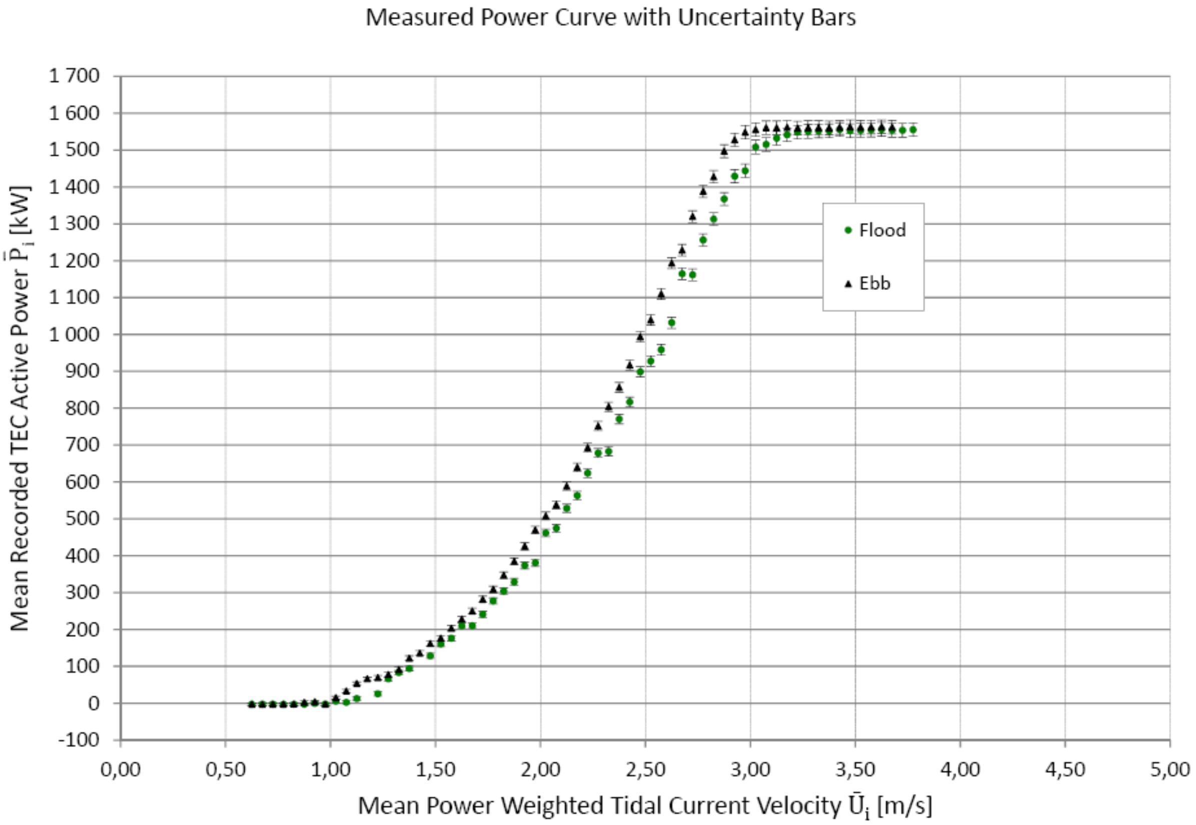

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Figure 13 – Example presentation of the power curve with uncertainty bars

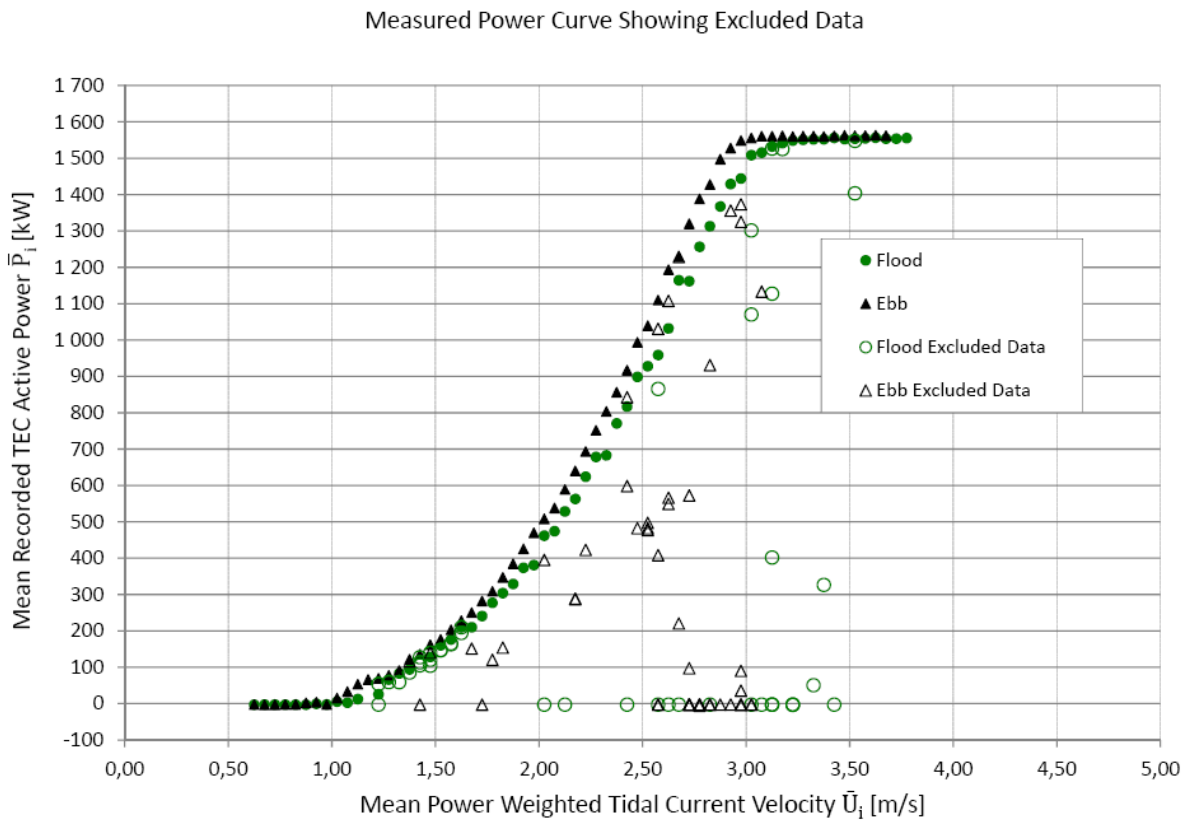

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Figure 14 – Example presentation of the power curve showing excluded data points

10.9 Presentation of the TEC overall efficiency

The TEC overall efficiency, $\eta_{system,i}$, calculated as per 9.7, should be presented in both tabular and graphical format for each of the ebb and flood tide data sets. Values calculated using interpolated power curve data points should be designated with an "INT" next to the bin number in the table, and corresponding table rows and plotted points should be formatted in an alternative colour.

Table 4 and Figure 15 provide sample formats for the presentation of these results.

Table 4 – Example presentation of the TEC overall efficiency

Velocity Bin Number i	Bin Velocity Range [m/s]	TEC Overall Efficiency $\eta_{system,i}$
1	0,500 - 0,549	-0,067
2	0,550 - 0,599	-0,062
3	0,600 - 0,649	-0,057
4	0,650 - 0,699	-0,040
5	0,700 - 0,749	-0,032
6	0,750 - 0,799	-0,028
7	0,800 - 0,849	-0,024
8	0,850 - 0,899	-0,022
9	0,900 - 0,949	-0,003
10	0,950 - 0,999	-0,012
11	1,000 - 1.049	0,025
12	1,050 - 1,099	0,010
13	1,100 - 1,149	0,043
14 INT	1,150 - 1,199	0,055
15	1,200 - 1,249	0,068
16	1,250 - 1,299	0,155
17	1,300 - 1,349	0,173
⋮	⋮	⋮
63	3,600 - 3,649	0,158
64	3,650 - 3,699	0,152
65	3,700 - 3,749	0,146
66	3,750 - 3,799	0,140

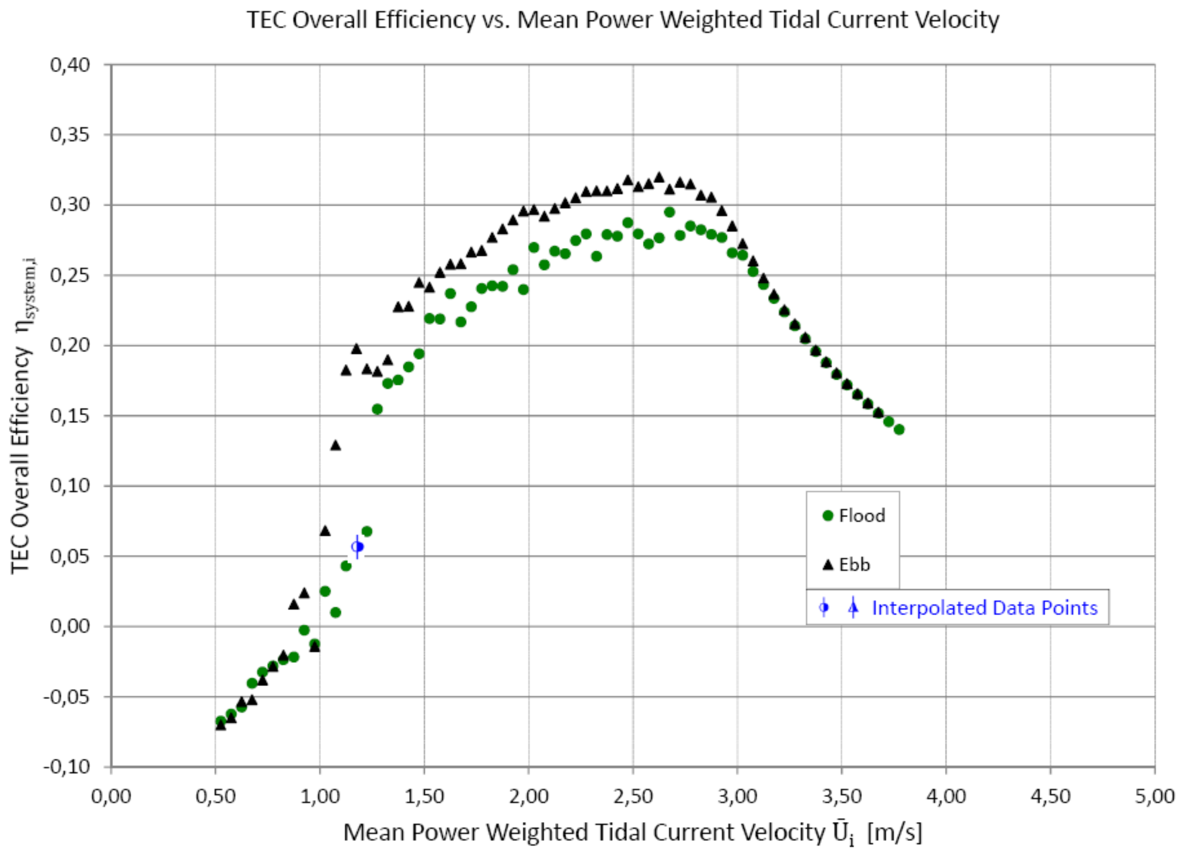

Figure 15 – Example presentation of the TEC overall efficiency curve

10.10 Uncertainty assumptions

Uncertainty assumptions on all uncertainty components should be provided as described in 9.3.5 as well as Annexes A and B.

10.11 Deviations from the procedure

Any deviations from the requirements of this Technical Specification should be clearly documented in a separate clause. Each deviation should be supported with the technical rationale and an estimate of its effect on test results.

Annex A
(normative)

Categories of error

This annex addresses the requirements for the determination of uncertainty in measurement. The theoretical basis for determining the uncertainty using the method of bins, with a worked example of estimating uncertainties, can be found in Annex B.

The measured power curve should be supplemented with an estimate of the uncertainty of the measurement. The estimate should be based on ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement* (GUM:1995).

Following ISO/IEC Guide 98-3, there are two types of uncertainties: category A, the magnitude of which can be deduced from measurements, and category B, which are estimated by other means. In both categories, uncertainties are expressed as standard deviations and are denoted standard uncertainties.

- The quantities intended to be measured are:

  The power curve, determined by the measured and normalized bin values of electric power and current speed, and the estimated annual energy production. Uncertainties in the measurements are converted to uncertainties in the quantities intended to be measured by means of sensitivity factors.

- Uncertainty components:

  Table A.1 provides a minimum list of uncertainty parameters that should be included in the uncertainty analysis.

Table A.1 – List of uncertainty parameters to be included in the uncertainty analysis

Measured parameter	Uncertainty component	Uncertainty category
Electric power	Current transformers	B
	Voltage transformers	B
	Power transducer or power measurement device	B
	Variability of electric power	A
Current speed	Current profiler accuracy	B
	Depth measurement relative to performance surface	B
	Misalignment of performance surface with principal flow direction	B
Data acquisition	Signal transmission	B
	System accuracy	B
	Signal conditioning	B

NOTE The implicit assumption of the method of this standard is that the 10 min mean power yield from a tidal turbine is fully explained by the simultaneous 10 min mean current speed measured across the performance surface.

This is not the case. Other flow variables affect power yield and thus identical tidal turbines should yield different power at different sites even if the current speed and water density are the same. These other variables include turbulence fluctuations of current speed (in three directions), the inclination of the flow vector relative to horizontal and vertical planes and the scale of turbulence, among others. Analytical tools offer little help in identification of the impact of these variables and experimental methods encounter equally serious difficulties.

The result is that the power curve should vary from one site to the next, but since the other influential variables are not measured and taken into account, the variation in the power curve should appear as uncertainty. This apparent uncertainty stems from differences in observed power yield under different bathymetric and wave conditions, i.e. when comparing an AEP-measured in homogeneous terrain with an AEP-measured at a non-homogeneous tidal farm site.

Quantification of this apparent uncertainty is difficult. Depending on site conditions and sea conditions, the uncertainty may amount to several percent. In general terms, the uncertainty may be expected to increase with increasing complexity of bathymetry and with increasing frequency of non-neutral sea conditions.

Annex B
(informative)

Uncertainty case study

As this Technical Specification is utilized and moves towards developing into a full standard, it is planned that a case study specific to the performance assessment of tidal energy converters should be produced and presented in this annex. During this period, refer to Annex E of IEC 61400-12-1:2005.

Annex C
(informative)

Calculation of TEC annual energy production

C.1 General

This annex lays out the recommended method for calculating the TEC annual energy production. It is not a normative element of this Technical Specification but it is considered to be the preferred method of carrying out this calculation.

The reporting period for TEC availability should be at least one year, but in any event the reporting period over which the value is calculated should be clearly indicated. The reporting period should be continuous and one or more gaps in the reporting period are not permitted.

C.2 TEC annual energy production (TEC AEP)

The mean annual energy production in kWh for a tidal energy device with a defined power curve for ebb and flood data sets should be obtained by combining each of the power curves described in 9.3 with the tidal energy resource data for an 'average' year for the specific site.

The tidal resource assessment will provide a velocity distribution (or exceedance curve) as well as a vertical velocity profile which should be used to calculate the mean current velocity, $\overline{U}_i$, in a similar manner to formulae (1), (2) and (3), throughout the 'average' year.

The TEC annual energy production should be derived according to formula (C.1):

$$\mathrm{TEC\ AEP} = N_h \cdot \mathrm{TECA} \cdot \sum_{i=1}^{N_B} \overline{P}_i \cdot f_i(\overline{U}_i) \cdot 1\,000 \qquad \text{(C.1)}$$

where:

$f_i(\overline{U}_i)$ is the proportion of time during an average year for which the mean current velocity occupies a value within velocity bin i;

i is the index number defining the velocity bin;

N_B is the total number of velocity bins in the device power curve;

N_h is the number of hours in one year (8 760);

$\overline{P}_i$ is the mean recorded TEC power in velocity bin i [W];

$\mathrm{TEC\ AEP}$ is the expected annual energy production [kWh];

TECA is the TEC availability;

$\overline{U}_i$ is the mean tidal current velocity in velocity bin i [m/s].

For the purpose of these calculations, the availability, TECA, is assumed to be 100 %. This test availability should not be confused with a commercial availability which is demonstrated through operational experience over a period of years.

C.3 Extrapolation

Extrapolation of the data during this calculation is only permitted under the following circumstances:

- for devices with a constant power characteristic at all current velocities above the rated water velocity, it is permissible to use a constant value power curve at all current velocities above the maximum measured current velocity up to the cut-out water velocity;
- for devices for which the power drops off after their rated water velocity, this trend should be reflected in all current velocities above the maximum measured current velocity up to the cut-out water velocity;
- under no circumstance should the power curve be increased above the maximum measured power value;
- the behaviour of the power curve above the maximum measured current velocity should be fully reported and substantiated. All extrapolated data should be clearly identified and differentiated from measured data.

C.4 AEP-measured and AEP-predicted

The $\mathrm{TEC\ AEP}$ should be calculated in two ways, one designated ‘AEP-measured’ and the other ‘AEP-predicted’. If the measured power curve does not include data up to the rated water velocity, the power curve from the maximum measured current velocity up to the rated water velocity should be predicted based on Clause C.3.

AEP-measured should be obtained from the measured flood and ebb power curve data sets by assuming zero power for all current velocities above and below the range of the measured power curves.

AEP-predicted should be obtained from the measured power curves by assuming zero power for all current velocities below the lowest current velocity in the measured power curve and a power level determined using the extrapolation guidelines in Clause C.3 for all current velocities between the highest measured current velocity in the measured power curve and the cut-out water velocity.

Generally it may be expected that the $\mathrm{TEC\ AEP}$ can be estimated for another site provided that the set of $\mathrm{f_i}(\overline{\mathrm{U}}_\mathrm{i})$, from formula (C.1), is known. Care should be exercised when performing this estimation as variations in site bathymetry and flow characteristics (turbulence levels and directional variability) can have a significant impact on $\mathrm{TEC\ AEP}$ estimates.

The uncertainties in the $\mathrm{TEC\ AEP}$ only consider those factors from the power performance test and not the uncertainties arising from other important effects. These other factors should be reported if allowances need to be made and/or caveats provided in the test report.

Practical AEP forecasting should account for other uncertainties and include availability of the TEC due to environmental effects associated with storm damage and other influences.

C.5 Presentation of the TEC AEP

In instances where extrapolated data points are required for the calculation of AEP-predicted, the table used to present the measured power curve (10.8) should be provided as part of the presentation of the AEP with the extrapolated data points clearly identified. These points should be designated with an “EXT” next to the bin number in the table, and the corresponding table rows should be formatted in an alternative colour.

A table, for each bin value, should present AEP-measured, the standard uncertainty for AEP-measured and AEP-predicted where applicable. In the event that AEP-measured is less than 95 % of the AEP-predicted, the $\mathrm{TEC\ AEP}$ table should be clearly labelled as “incomplete”. Table C.1 provides an example format for presentation of the $\mathrm{TEC\ AEP}$.

Table C.1 – Example presentation of annual energy production (flood tide shown)

Velocity Bin Number i	Nominal Bin Mean Current Velocity [m/s]	AEP-measured [MWh]	Standard Uncertainty in AEP [MWh]	Standard Uncertainty in AEP %	AEP-predicted [MWh]
1	0,525	-0,39	0,06	15,4	-0,39
2	0,575	-0,36	0,06	15,4	-0,36
3	0,625	-0,38	0,06	14,9	-0,38
4	0,675	-0,33	0,05	14,6	-0,33
5	0,725	-0,33	0,05	14,0	-0,33
6	0,775	-0,35	0,05	13,4	-0,35
7	0,825	-0,36	0,04	11,6	-0,36
8	0,875	-0,39	0,05	11,8	-0,39
9	0,925	-0,06	0,01	9,5	-0,06
10	0,975	-0,31	0,02	6,4	-0,31
11	1,025	0,73	0,03	4,3	0,73
12	1,075	0,33	0,02	4,6	0,33
13	1,125	1,65	0,07	4,1	1,65
14	1,175	2,50	0,08	3,2	2,50
⋮	⋮	⋮	⋮	⋮	⋮
64	3,675	203,63	4,89	2,4	203,63
65	3,725	203,97	5,30	2,6	203,97
66	3,775	198,4	4,96	2,5	198,4
67 EXT	3,825		6,47	4,8	134,80
68 EXT	3,875		6,03	4,8	125,60
	Total AEP-measured:	**5 875**		**Total AEP-predicted:**	**6 136**

NOTE Data shown in Table C.1 are representative values used only to demonstrate reporting requirements.

Annex D
(informative)

Wave measurement

D.1 General

If there is a wave regime at the test location that significantly influences the measurement of the incident resource and the power output of the TEC, this regime should be measured and reported during the test.

D.2 Procedure

If the TEC test site experiences waves which produce orbital velocities averaged over the performance area that exceed 20 % of the rated current speed, or where the TEC should shut down due to particular wave conditions, then the significant wave height, associated wave period and direction should be measured and reported.

Due to the difficulties of deploying a wave buoy in a tidal race, it is recommended that measurements be taken using the existing current profiler equipment deployed to measure the incident resource, or a separate bottom mounted current profiler within the TEC test site.

The measurement period should be uniform across the test but not necessarily at the same reporting period as the power curve data.

There should be a description of the measurement procedure, the device used and its accuracy.

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch