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TIDAL CURRENT ENERGY DEVICE PERFORMANCE PROTOCOL

Response to feedback from 19th July workshop and consultation

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Tidal Current Energy: Device Performance Protocol – Response to feedback from 19th July Workshop and consultation

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The Department of Trade and Industry (DTI) commissioned this protocol in April 2006. A draft submission for consultation was released in July 2006 and discussed with key stakeholders at a Workshop held on the 19th July. The preliminary stage of the document was completed in August 2006. This accompanying report reflects the input and impact on the protocol of the consultation exercise. This updated version of the preliminary document is in response to comments received from the client and stakeholders, submitted in February 2007. This report has been prepared by Dr. Scott J. Couch and Henry Jeffrey of The University of Edinburgh.

Disclaimer

This report is submitted in good faith only. The University of Edinburgh will not accept responsibility or liability for third party use or interpretation of the findings.

Workshop participants

The following individuals and organisations participated in the Workshop and consultation addressing the draft version of the 'Tidal Current Energy: Device Performance Protocol'. Their contribution and comments were very helpful and most welcome, and have assisted greatly in shaping the updated protocol documentation.

Individuals	Organisation
Gary Shanahan	Department of Trade and Industry
Neil Kermode	European Marine Energy Centre
Phil Michael	Future Energy Solutions
Kelso Riddell	iXSurvey
Peter Wilks	iXSurvey
John Griffiths	JWG Consulting
Simon Meade	Lunar Energy
David Ainsworth	Marine Current Turbines
Jeremy Thake	Marine Current Turbines
Emma Robertson	Open Hydro
Ralph Manchester	SMD Hydrovision
Alan Owen	The Robert Gordon University
George Gibberd	Tidal Generation
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Scott Couch	University of Edinburgh
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Introduction

On 2nd August 2004 the Secretary of State for Trade and Industry announced a new 'Marine Renewables Deployment Fund' worth £50 million. At the core of this program is a 'Wave and Tidal Stream Energy Demonstration Scheme' (the Scheme) taking up to £42 million of the total fund. Within the requirements of the Scheme a monitoring and reporting program is mandated. In April 2006 the Department of Trade and Industry (DTI) commissioned the production of a 'Tidal Current Energy Device Performance Assessment Protocol (the Protocol) by the University of Edinburgh to provide a framework within which the monitoring and reporting program would be prescribed.

The approach taken by the University of Edinburgh to producing the Protocol involved the production of a draft Protocol obtaining input from specific key stakeholders where deemed appropriate, holding a Workshop with, and inviting written responses from key stakeholders to discuss the draft Protocol, leading to the production of a preliminary Protocol document to be deliver to the DTI.

A total of 30 stakeholders were consulted during the production of the preliminary Protocol, including 15 participants at the Workshop. The response to the Protocol document elicited thus far has given broad support. In light of discussions during the Workshop, and written responses received a number of amendments have been made to the original draft version of the Protocol. While not changing the fundamental nature of the protocol, these amendments seek to improve the 'fit-for-purpose' intent of the Protocol procedure and reporting format. Fit-for-purpose in this context is defined as obtaining an effective balance between quality and quantity of data collection, processing and delivery and operational achievability without being overly burdensome on the Scheme participants.

This document provides an explanation of the changes that have been made to the Protocol, our arguments against some of the suggestions put forward or discussion points that was raised by stakeholders and response to further queries or requests for clarification by the client.

In parallel with this document we have also produced the finalised preliminary version of the Protocol (version 1.3).

We would like to thank all the participants in the Workshop and written respondents for the feedback we have received. In particular the lively discussion, openness and willingess to share experience observed at the Workshop have been very valuable both in advocating the framework underlying the draft Protocol and in the continued development of the preliminary Protocol.

Understanding this document

The generic approach of the "Response to comments received on proposals for the £50M 'Marine Renewables Deployment Fund'" document published by the DTI in May 2005 has been adopted for providing a narrative description of the consultation exercise.

Section 1 of this document discusses issues raised relating to the methodology under-pinning the Protocol which potentially impact throughout the Protocol.

Section 2 of the document follows the order of the draft Protocol indicating where significant alteration has taken place relating to a specific individual issue as opposed to the wider issues discussed in section 1. Responses and conclusions in both sections are presented in **bold print**.

Section 3 of the document summarises in the key knowledge gaps which have been identified throughout development of the Protocol, through the Workshop event and individual stakeholder interaction. These knowledge gaps are introduced as 'research questions' in sections 1 and 2 of the document, numerically cross-referenced to the content in section 3 where a synopsis of the relevant issues is provided.

All terminology referred to in this document refers to the definitions provided in the preliminary Protocol.

We acknowledge that this document does not capture every single point raised during the Workshop and consultation, but believe that it does capture and respond to the substantive issues raised.

Overview of responses

There was broad and strong support for the requirement for a defined Protocol, and the underlying methodology behind the Protocol, i.e. (i) the production of a pre-development site survey and resource monitoring, analysis and prediction program in order to characterise the site and resource potential, (ii) device performance characterisation using the concept of a power curve derived from parallel in-situ measurement of resource and power production from an individual device (similar to the approach of the wind industry standards), and (iii) monitoring and reporting of the operational status of individual devices and annual energy production from the eligible facility.

Discussion was raised that the International Standards Agency (ISO) is currently in the early stages of a scoping exercise considering the way ahead for an ISO tidal energy standard with the potential for advocating following a hydro model as opposed to a wind model during preliminary discussions of.

General consensus of the Workshop participants was that the wind analogy was the most appropriate model as the nature of the resource and similarities in the underlying physics provides a more representative match than the hydro analogy. University of Edinburgh (UoE) is in strong agreement with this consensus. This opinion is formed from a history of more than 10 years continuous research experience into the nature of the resource and its potential response to energy harvesting.

There were concerns voiced by the developer community regarding the volume of data that is being requested to be reported by the Protocol, and more specifically the intended usage of this data by the DTI.

It remains unresolved whether the preferred approach to conducting the field work, analysis and reporting or aspects of these duties will be the sole responsibility of the developer, developer partnered third-parties, independent third-parties, or one individual third-party organisation designated by the DTI.

The requirement for reporting to and potential dissemination of data by the DTI is out with the remit of the current project, and is believed to have been fully consulted on previously during the development of the Scheme.

There was strong agreement that an audit trail must be in place in association with the Protocol for obvious reasons. With the potential uncertainty of where responsibility lies for different aspects of the Protocol, at this preliminary stage it was deemed suitable to impose the most stringent envisaged requirement as the reporting format. When the preliminary Protocol has been through the final development stage it would be hoped that these aspects will have been resolved enabling the Protocol to be specified in a definitive framework reflecting where reporting responsibilities lie (e.g. with the developer or an independent third-party organisation).

Discussion was raised that there was no attempt within the draft Protocol to measure the larger scale impact on the underlying resource of Tidal Energy Converter (TEC) device operation.

The purpose of the protocol is the performance assessment of TEC device operation. The larger scale response of the system to energy harvesting therefore falls out with the remit of the Protocol. It is acknowledged that this is an important and significant research question[1] that needs to be addressed by the marine renewables community. However the question currently lies squarely on the shoulders of the academic community being at the research interface. Furthermore, the scale of a typically envisaged eligible facility within the Scheme is deemed to be an order of magnitude smaller than would currently be considered significant in terms of having a measurable large scale impact on the underlying resource. This does not deny the potential that smaller facilities can have a significant local *environmental* impact, which must be mitigated against within the planning procedures and processes currently in place.

In addition to the strong support for the concept of a TEC performance assessment protocol, it was also suggested that the protocol could also be adopted as the standard of data monitoring and reporting required to enter the Scheme (with reference to sections 6.1.2.4 and 6.1.2.5 of the "Wave and Tidal Energy Demonstration Scheme" document published May 2005).

As it stands, the Protocol is only addressing the requirements of Scheme participants once they have been accepted onto the Scheme and bears no relation to the requirements to apply for the Scheme. The idea does have merit, however it is deemed inappropriate to mandate at this stage as many potential Scheme participants may already have successfully monitored and analysed their particular device technology for part or all of the period required to meet the application criteria. To retroactively impose a specific protocol on the requirements of this data collection and analysis procedure would disadvantage developers in this position and is not the intention. There was however strong support from Future Energy Solutions (FES, acting as the Authority's Project Supervisor), that developers yet to embark on the full-scale testing necessary to meet the project eligibility criteria for accessing the Scheme would benefit from adopting at least the approach of the Protocol as it reflects the sort of standard of monitoring of device operation that is deemed appropriate for accessing the Scheme.

Section 1

This section of the document addresses issues which impact on the over-arching methodology under-pinning the Protocol which therefore impact in more than one part of the document.

The draft version of the protocol called for the production of a power curve for each device in the array on an annual basis, or when any 'significant change' had been introduced into device design or operation. There was concern expressed and lengthy discussion during the Workshop of various merits of aspects relating to this, including

- the operational achievability of this approach,
- the need for mandated annual reproduction of a power curve,
- the need to monitor every device in the array,
- difficulties monitoring the resource representatively across a potentially large array
- definition of 'a significant change'

A number of different scenarios were also postulated around the table and discussed.

These discussions have been taken on board. Alteration to the Protocol reflects the change in approach that has resulted from this stakeholder input. The Protocol now only requires the production of a power curve for one device within the array. In terms of characterising device performance using a power curve, the advantage of producing multiple curves for identical devices from a similar resource is limited.

Furthermore, the directive requiring annual production of a power curve is now removed. Instead, a power curve is required to be submitted in accordance with the procedure laid out in section four of the Protocol within the first 18 months of the commissioning date of the eligible project facility. Following the initial submission, the Scheme participant is able to submit an updated power curve following the same procedure as and when they see fit. The most recently submitted power curve will be that accepted by the DTI as being representative of the device performance of that Scheme participant's device. The onus therefore lies with the Scheme participant to update the accepted power curve when an improvement in performance has been achieved. There is now no longer any need for reference to 'a significant change'. We believe that these alterations meet the needs of the DTI and wider community in still being able to reliably assess and compare device performance, but are less burdensome on the Scheme participants, thereby more than adequately addressing the 'fit-for-purpose' intent of the Protocol.

Concerns were raised that there is no attempt within the Protocol to measure the impact of wave action on device performance, particularly with respect to wave-current interactions. However, existing understanding of wave-current interactions lie at the research interface[2], and in terms of the potential impact on TEC device performance, beyond even the research interface. There was therefore no consensus opinion arising at the Workshop as to how to suitably measure and then incorporate wave-current interaction at suitable temporal resolution into the Protocol. One option with merit which was put forward was to reject data from production of the power curve when the wave height was above a mandated limit (1 metre was discussed), the power curve therefore being representative of device performance during the 'regular' or 'dominant' sea-state.

The aspect of wave induced currents and wave-current interaction impact throughout the Protocol. The first order impact of wave forces on TEC devices relates to survivability issues. The tendency is therefore to consider locating TEC devices in sheltered locations or regions that are typically not exposed to high wave climates. However, a further impact is the potential for wave-current interactions to influence device performance. The action of wave orbitals superimposed on a strong current is reasonably well understood. Given the near surface clearance depth typically specified for a TEC device, the impact of wave orbitals should already be significantly diminished at the depth of the device. Nonetheless, it is important to consider the influence not only of wave induced currents, but wind induced and density induced currents all acting in concert with the dominant tidal currents. This is a major reason why the proposed Protocol adopts the approach of integrating the measured current (which will capture all the dynamics discussed, not just tidal currents) over the performance surface of the device. This is a departure from the wind energy industry approach, which typically measures and analyses a hub height wind record. Assuming a 1/10th power law variation, the difference between integrating across the performance surface and using a hub height (or equivalent) record to determine the kinetic energy flux introduces an error of between 0.5% and 4% dependent upon the percentage of the water column the device occupies. However, in the shallow water environment where TEC devices will typically be sited, it is not necessarily representative to assume that the vertical variation of

horizontal currents can be simply assumed to follow power law dynamics, particularly as sites selected for development are subject to such extreme currents which are not in themselves particularly well understood or much studied. This is particularly the case where we introduce wind, wave and density induced currents, which have the effect of altering the vertical variation of the horizontal current profile, particularly nearer the surface. These are significant different to the experience of a typical wind energy capture device, hence the slightly different approach. Integrating across the performance surface offers a number of advantages that therefore go some way towards incorporating the different dynamical forcing creating the current that the TEC device then interacts with. The difficulty remains in adequately resolving the different timescales of interaction with the device. Tidal, wind and density driven currents are typically fairly slowly varying phenomena, in comparison with wave induced currents, and are well captured by the measurement programme mandated in the Protocol, as are any drift effects associated with wave-induced currents. The rapid cyclical nature of wave induced currents (observed as wave orbitals) are not however captured. This is a necessary compromise, which it is acknowledged may lead to underestimation of the incident kinetic energy flux acting on the TEC device performance surface. In order to adequately resolve the time scales involved in wave-induced current variation, it would be necessary to operate a measurement program using AD device at frequencies of sub-1Hz. It is not clear that this length of record produces statistically relevant output from the range of AD devices currently available on the market. This remains a research question[3]. An alternative approach would be to attempt to monitor the surface wave variation using a Waverider buoy or similar, and then attempt to incorporate the influence of wave induced currents through analytical techniques. The reliability of this method would be unclear as it would be extremely difficult to attempt to remove the already captured wave effects from the existing AD record before applying the analytical correction. Furthermore the analytical methodology required for doing so would produce a further research question. Attempts to monitor and incorporate wave induced currents beyond what is already prescribed in the Protocol is consequently deemed to fall outside the 'fit-for-purpose' remit of the Protocol in the opinion of UoE. The suggestion raised at the Workshop to reject data from production of the TEC device power curve in section four of the protocol when the wave height exceeds a certain prescribed limit has been considered. It is our opinion that although this proposal has merit, and may well offer an approach to be adopted when developing a standard for TEC device performance assessment, it is beyond the needs of the Protocol as defined within the Scheme. If this approach was taken, a suitably accurate and reliable wave measurement device such as a Waverider buoy would have to be deployed in tandem with the AD device, *and the two records would have to be synchronized in time*. This is not as trivial a task as it may appear. UoE does not deem the extra operational and cost burden imposed on Protocol implementation by this extension to the existing Protocol a positive return. This suggestion has therefore been rejected. In our opinion, the prescription of a 15-day continuous measurement period should ensure that an arbitrarily representative set of sea state conditions occur and are captured by the data monitoring equipment. The method of binning data captured in producing the end-product power curve should assist in smoothing any significant weather/wave induced outliers in the record.

Similar concerns were raised that there is no attempt within the Protocol to measure the impact of turbulence on device performance.

The potential impact of various and varying levels of turbulence on TEC device performance is a significant research question[4]. As yet it remains unclear how to parameterise the impact (if significant) and how it influences TEC device performance. This remains a significant unanswered question[5]. Furthermore, gathering accurate turbulence data requires specialist bespoke equipment such as Oregon State University's Marlin towed microstructure profiler. This equipment is not readily available as it requires specialist design and manufacture. We contend that given the existing lack of understanding of the impact of turbulence on TEC device performance and difficulty in actually obtaining accurate turbulence data, that incorporating consideration of turbulence in the Protocol does not meet the 'fit-for-purpose' remit.

No attempt is made within the draft Protocol to explicitly detail how to characterise 'good' (acceptable) and 'bad' (rejected) data from the various resource and power output measurements mandated in the document. Concerns were raised as how to deal with this aspect of data analysis. As this sort of analysis involves human intervention the general (but not universal) consensus of the Workshop participants was that there would be potential benefit from the appointment of a single company/organisation/individual to conduct the data analysis required by the Protocol for all Scheme participants. This would ensure that the human intervention required when analysing data was subject to the same process for each of the Scheme participants.

The aspect of data 'quality' and how to characterise and deal with 'good' and 'bad' data had been consciously avoided during writing of the draft Protocol. The UoE project team had long discussions addressing this issue prior to submitting the draft document. As appears to have been the consensus of the Workshop participants, how to prescribe the 'quality' and 'acceptability' of different data is very much a knowledge gap and potential avenue for further research[6]. The current industry standard approach is very much reliant on human intervention. This tends to be in the form of an experienced data processor who has their own 'feel' for the particular data stream built upon past experience, which is part science part art form as it blends understanding of the physics relating to the particular data set being examined, the instrumentation used to gather that data and to an extent gut instinct. Hence there is no obvious standard procedure that we can suggest is adopted. The suggestion raised at the Workshop that the analysis required by the Protocol in fulfilment of the Scheme requirements is conducted by one organisation or individual for all the Scheme participants therefore has obvious merits and receives the endorsement of the UoE project team. Prescription of this aspect of the Protocol however is outside the remit of UoE and is a decision for the DTI to make.

Certain developers expressed concern that prescription of a statutory 15-minute ensemble recording period for data collection is sections 3 and 4 of the document would limit the collection of data for their own specific project development purposes. Further, MCT indicated that there at sea experience and analysis had

indicated that a 10-minute ensemble recording period was most appropriate for filtering out high frequency noise from the record while maintaining the essential features of the tidal record. This was noted as being similar to analysis conducted by the wind industry.

This point is acknowledged. The updated Protocol requires that "The AD device recording period should be set as a minimum resolution of 10-minute time-stamped ensemble average data (i.e. 10 minute ensemble average or less)". Similarly prescription of the resolution between samples has been relaxed to being a *minimum* of 20 seconds as opposed to fixed at 20 seconds. In order to ensure that interpretation of the data is not skewed by selection of a particular time-period, the ensemble average data must be a suitable multiple of 10 minutes, and for analysis purposes be manipulated to produce an equivalent 10-minute resolution data-set. Specification of the most appropriate recording period resolution and sampling rates remains at the research interface[3]. What is proposed is the best fit to the requirements of the Protocol that can be provided given the existing understanding of the technology deployed and underlying physics that are relevant and of interest.

Clarification of the role of the project monitoring officer was requested.

The project monitoring officer is envisaged as the arbiter when a specific situation lies outside the guidance given in the performance protocol, ensuring that any alteration necessary to the protocol procedures neither advantages nor disadvantages the relevant Scheme participant.

Section 2

Section 2 follows the procedure of section 1 but addresses issues which relate to a specific aspect of the Protocol document rather than impacting on the over-arching methodology as the issues discussed in section 1 dealt with. The alterations to the document from the draft to preliminary stage are dealt with sequentially below.

Acknowledgments

Workshop participants and additional consultees since the draft document was released have been added to the acknowledgements section.

Definitions

Requests for clarification relating to some of the definitions applied in the document were raised.

The definitions as provided relate specifically to the definition as adopted by the Protocol. Some of the terminology employed can have a variety of meanings dependent upon context of use. This is why a specific definition is provided that relates to the definition adopted in the Protocol. Some minor alterations have been incorporated in the existing terminology to aid understanding. Additionally a number of new definitions have been provided which relate to the alterations made

to the body of the document. There is significant cross over between the language adopted by the Scheme and the Protocol. Within the Protocol we have therefore used definitions as prescribed in the "Wave_Tidal grant template 17Mar06 draft issue 1" (http://www.dti.gov.uk/files/file27060.pdf) when there is obvious benefit from adopting similar language.

Normative References

An additional normative reference has been proposed during consultation and after suitable assessment has been adopted with reference to site survey requirements (IHO S44: 1998, IHO Standards for Hydrographic Surveys, 4th edition).

Procedure to characterise the local resource

The stipulation of a minimum 30-day recording period and subsequent analysis of the record drew some comment. The suitability of this length of record in terms of accurately representing the tidal resource through harmonic analysis was queried.

The initial specification of a 30-day minimum recording period was directly linked to the subsequent harmonic analysis to be carried out. The length of record stipulated is considered to be most representative of 'fit-for-purpose' as deemed appropriate for the protocol. In the oceanographic community, the acknowledged recording periods that are typically adopted for generating a record for harmonic analysis are 15, 30, 180 and 365 days. An 18.6 year record is required to fully resolve all 175 typically recognised tidal constituents. A much smaller number of constituents characterise the majority (typically 95% +) of the variation in a tidal record. A 30-day record enables accurate resolution of a minimum of 23 tidal constituents, incorporating the statistically dominat constituents when ranked in standard order. This is 8 more guaranteed resolved constituents than for a 15-day record, and 6 less than for a 180-day record. After outlining this background data, the consensus of the Workshop participants was that a minimum specification of a 30-day recording period was appropriate for the purposes of the Protocol. Although a longer (particularly 180-day or 365-day) record would be desirable to improve accuracy of the subsequent harmonic analysis, the necessity to conduct the measurement and survey program in section three of the protocol prior to development of the site would adversely impact on the Scheme participants project development considering the time constraints and larger goals of the MRDF framework.

Prescription of the requirements for survey of the test-site were identified as an area of the Protocol where further work was required, as the initial draft proposal was too limited and limiting in terms of operational achievability.

Acknowledging these deficiencies, a re-working of the requirements for surveying of the test-site has been proposed. The IHO Standards for Hydrographic Surveys have been adopted as a new normative reference. This is an internationally recognised standard which the UK survey industry will be familiar working to. The classification of survey requirements deemed appropriate for this application under the IHO Standard is 'Order 1'. This relates to the accuracy requirements and operational

boundaries within which the survey must be conducted. The requirements of section 4.1 and 4.3 of the IHO Standard are deemed inappropriate for application in the Protocol and are therefore not mandated. Section 4.1 provides no insight into potential device performance (although would be of obvious benefit to the project developer), and section 4.3 requires a less rigorous observation of the local variation of tidal currents than is already prescribed in section 3.2.2 of the Protocol.

Concern was raised that the phrase "located at the centroid of the array" with reference to location of the AD device was overly prescriptive. It was suggested that this could potentially mandate against the developer altering the exact location of their particular TEC devices within the array in response to the characterisation of the local resource exercise, as this would alter the position of the 'centroid of the array'.

In order to avoid needlessly penalising slight alteration of the location of the array and devices within the array the wording has been altered to provide more flexibility. However, in order to ensure that a representative data-set is produced, an additional requirement of the location of the AD device with respect to the depth of water that the TEC devices will be operating in has been inserted.

Developers suggested that 0.01 m/s was a more realistic specification of the minimum resolution produced by the AD device as opposed to 0.002 m/s as originally proposed.

This has been accepted and altered to suit both in section 3 and 4 of the Protocol document.

During data analysis, more precise description of the orientation of the analysis has now been prescribed: "The data should be analysed to determine the principal current direction. The data set should then be processed along the principal current direction ...". Conversion of the analysed resource velocity data to the kinetic energy flux available to a device no longer considers only the component of velocity perpendicular to the performance surface. The available resource is obviously independent of device design. If the device is able to orientate to capture the predominant flow direction that is a design advantage provided by that device over a static device that is achieved at an extra monetary cost. Conversely many potential sites lend themselves to static devices as the flow is predominatly rectilinear, and therefore the potential advantages of a rotating device are negated.

Prescription of longitudes and latitudes was not fully prescribed and clarification was requested.

World Geodetic System 84 (WGS 84) is now prescribed throughout the protocol. WGS 84 is the reference system currently utilised by Global Positioning Systems. WGS 84 is geocentric and is globally consistent to within ± 1 metre.

An additional reporting requirement has been prescribed: "Specification of the AD device deployed and the user defined settings employed.".

If the AD device is capable of returning data pertaining to the quality of a particular measured record, then such information should be supplied (e.g. signal-to noise ratio and standard deviation are typical).

Procedure to characterise the TEC device performance envelope

Strong cases were put forward at the Workshop for various configurations of AD device deployment in order to satisfy the requirements of incident resource measurement.

This is an area which received considerable attention during development of the Protocol framework. Five potential scenarios were identified and considered. A Force Field Analysis enabled iteration towards the solution that UoE adjudged most appropriate within the guiding philosophy of 'fit-for-purpose'. This was the solution promoted in the draft Protocol. This elicited significant discussion during the Workshop where alternate approaches were put forward by the participants, all of which coincided with one or other of the five scenarios that had already been researched and considered during development of the draft under discussion. Further interaction with relevant stakeholders, discussions with survey companies and supporting evidence provided has led to a more flexible approach being adopted, incorporating the initially proposed methodology, and a second alternate approach from which the Scheme participants are enabled to select the approach they feel best fits their individual requirements. As mandated in the Protocol, the relevant passage is:

"The project developer has two options for AD device placement as follows:

1. **One AD device should be deployed at the TEC to be monitored. The AD device should be deployed perpendicular to the TEC along the minor principal axis of the tidal resource (as reported in clause 3.2.5). The AD device should be positioned no more than 60 metres away from the centre-line of the TEC device. The difference in depth between the TEC and AD device positions must be established from the pre-installation site survey data to be less than ± 15% of the depth to chart datum.**
2. **Two AD devices should be deployed at the TEC to be monitored. The AD devices should be deployed immediately up- and down-stream of the TEC along the major principal axis of the tidal resource (as reported in clause 3.2.5). The AD devices should be positioned no less than 3 performance surface widths (e.g. 3 diameters in the case of a horizontal axis turbine) from the TEC device, and no more than 120 metres from the TEC device. The difference in depth between the TEC and AD device positions must be established from the pre-installation site survey to be less than ± 15% of the depth to chart datum.**

Any deviation from this methodology must be agreed in writing with the project monitoring officer prior to the inception of data collection."

A valid point was raised that potentially two separate cables may well be utilised on the monitored device, one for import of electricity, and one for export.

Taking this eventuality into account required some re-writing of the relevant section as included below:
"The accuracy of the power measurement device, if it is a power transducer, shall meet the requirements of IEC 60688 with a minimum accuracy class of 0,5. If the power measurement device is not a power transducer then the accuracy should be equivalent to class 0,5 power transducers. The operating range of the power measurement device shall be set to measure all positive and negative instantaneous power peaks generated by the TEC device. The power transducer shall be calibrated to traceable standards. The power measurement device shall be mounted between the TEC device and the electrical connection to ensure that only the net active electric power (i.e. reduced by self-consumption) is measured. If a separate cable is used for importing of electricity, this also needs to be monitored to the same standard. It shall be stated whether the measurement devices are located on the TEC device side or the network side of the transformer."

Another issue which would potentially disadvantage certain developers who may wish to utilise a common grid connection point such as at the EMEC test centre is the requirement: "To facilitate the auditing of this power production the TEC operator shall also provide copies of the accredited meter operator, contiguous 30-minute sampled data record over the same 15-day period."

It is important that the Protocol does not mandate unnecessarily against existing infrastructure when it is deemed of a suitable quality. Therefore additional text has been inserted at the appropriate point in the document to address this eventuality:
"In the situation where multiple eligible facilities utilise a common grid connection point, metering meeting the relevant COP standard must be installed at a point before the facilities output combines in order to produce the same standard of data specific to each eligible facility."

When analysing the data gathered to produce a power curve, the component of velocity vector magnitude operated upon depends upon whether the TEC device has the ability to orientate itself to face the dominant incident flow direction or is mounted statically. This was not fully developed within the original draft. Further thought and discussion has led to some alteration to the wording of the analysis section of the document as shown below:

"In the case of a fixed TEC device, only the component of velocity perpendicular to the performance surface should be considered. For a TEC device capable of orientating the performance surface into the principal current direction, the recorded velocity vector magnitude irrespective of direction is to be analysed."
A fixed TEC device will operate most efficiently in a tidal regime dominated by rectilinear flow assuming that it is installed orientated in such a way as to take best advantage of the flow conditions. In a rotary dominated tidal regime the ability to orientate may be beneficial in terms of potentially 'capturing' a larger resource in terms of presenting the performance surface to the largest available incident flow velocity throughout the tidal cycle.

Reporting of the output from the Procedure to characterise the TEC device performance envelope to be provided to the project monitoring officer has been altered to reflect the knock-on effect of the alterations to the Protocol discussed above.

Section 3

Section 3 of the document brings the knowledge gaps and associated research questions identified during the development of the Protocol and introduced in sections 1 and 2 together. Further background to each issue is provided via a quick synopsis of the pertinent points.

1. Large scale impact on the resource

The larger scale impact on the underlying resource of Tidal Energy Converter (TEC) operation is an ongoing research question. The EPSRC funded Supergen Marine program has begun to address this issue and has made significant progress using analysis from first-principles, numerical modelling and physical modelling. However a definitive all-encompassing answer to this research question has yet to be produced. Further work is therefore obviously required; in particular data from the field to corroborate the existing research findings and then enable the existing work to be taken forward. However, these larger scale aspects of the tidal current energy field fall out with the scope of the Protocol as currently defined by the DTI and therefore do not impact on the methodology advocated.

2. Wave-current interaction

The impact of wave-current interaction on TEC device performance is a potentially significant knowledge gap which has as yet received very limited consideration and therefore is not well understood. In large part, this is because understanding of wave-current interaction itself is a developing area of oceanography. Therefore the underlying science is not fully formed or ready to be applied to the emerging field of tidal current energy. There is potential that this knowledge gap could impact significantly on the proposed Protocol, but without the necessary science to inform an appropriate response, the current proposal best matches the 'fit-for-purpose' requirements of the Protocol in the opinion of UoE.

3. AD device sampling and recording periods

Prescription of the recording and sampling period of AD devices and the impact this may have on potentially omitting significant data or biasing the results towards a particular generic TEC device or site topology was carefully considered. The experience of the developer community and survey companies was sought without a definitive answer being produced. Although consensus was arrived at on the approach advocated in the preliminary Protocol, it was agreed that enhanced understanding of these issues gained during the early stages of the Scheme operation can be used to underpin the approach taken, or inform a more appropriate methodology to be adopted for later application within the framework of the Protocol if such a procedure therefore presents itself.

4. The impact of turbulence on TEC device performance

It remains unclear whether turbulence will have a significant impact on device performance. This therefore presents an obvious knowledge gap and research question. It is important to recognise that turbulence is not in itself a fully understood concept, although significant work has been undertaken to measure, parameterise and model turbulence and turbulent flow phenomena. It is also important to recognise that the use of the generic term turbulence is often used as a catch-all for fluid motions at a range of scales which are not well understood. Part of the research question must therefore be to determine the impact of small scale turbulence, larger scale turbulent motions and cohesive eddies up to the extent of 1-2 turbine diameters before assessing which phenomena are of any, greater or lesser significance to TEC device performance and daily operation.

5. Appropriate methods for gathering data to inform the impact of turbulence on TEC device performance

In order to inform research question 4, particularly with regards to small scale turbulence, appropriate data has to be gathered. How best to achieve this is also a research question in itself. It is possible to obtain varying levels of accuracy of turbulence data using simple technologies such as recording current meters or simple pressure sensors like a pitot tube, using more complex systems like an appropriately designed and set-up AD device or to produce the best accuracy currently available a bespoke piece of kit typically incorporating a minituarised three-dimensional pressure sensor. Which level of technology is most appropriate for this particular scientific problem remains unclear as yet, or whether an even higher degree of accuracy would be desirable.

6. Data rejection and quality measures

Prescription of the 'quality' and 'acceptability' of in-situ oceanographic data is a continuing research theme. AD devices are long established as the industry standard for measuring current velocities benefitting from the non-invasive (on the measured parameter) remote-sensing operation, and accuracy of the technology. However individual pieces of data within a record can be of unacceptable or 'bad' quality due to a myriad of possible factors such as not enough back-scattering of the acoustic signal. When then analysing the data, particularly when manipulating the complete record, 'bad' data can adversely influence the analysis and therefore tends to be rejected. The existing procedure is to leave interpretation of 'bad' data to the intervention of an experienced user. Improving upon this procedure is an obvious research question. In terms of the Protocol, data processing will be a potentially significant issue. A further concern is the inability to independently calibrate AD devices which forms a related knowledge gap,

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