Catapult Offshore Renewable Energy

Tidal Turbine Collision Detection

Requirements Report

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Disclaimer

Contents

List of Tables

Abbreviations

ADCP	Acoustic Doppler Current Profiler
DART	Drifting Acoustic Recording and Tracker
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EPS	European Protected Species
ER	Environmental Requirements
ETI	Energy Technologies Institute
FLOWBEC	Flow and Benthic Ecology 4D
FR	Functional Requirements
NERC	Natural Environment Research Council
ORJIP	Offshore Renewables Joint Industry Programme
PVA	Population Viability Analysis
ReDAPT	Reliable Data Acquisition Platform for Tidal
SAMS	Scottish Association for Marine Science
SMRU	Sea Mammals Research Unit
SNH	Scottish Natural Heritage
SPHLSM	Smooth particle hydrodynamics lattice spring method
TRL	Technology Readiness Level
TTCD	Tidal Turbine Collision Detection

1 Executive Summary

The need for marine mammal collision detection was identified as a priority by the Offshore Renewables Joint Industry Programme (ORJIP) Ocean Energy[1] for offshore marine energy array consenting to become a viable proposition at scale. Scientific evidence is required to reduce uncertainly around the probability and consequence of any marine mammal collisions with operating tidal turbines, to improve collision risk models and to inform the consenting process for proposed tidal energy developments. This will dictate future monitoring and turbine control strategy requirements and mitigate environmental effects. To date there is no known evidence of mammal collisions or injuries from any wave or tidal devices.

Significant efforts have resulted in progress in recent years in the development of approaches and technologies that detect and validate mammal collision events. However the technology readiness in some areas is still at best only at the proof of concept level. It is challenging to identify the relevant environmental parameters to measure and the technical requirements of an ideal sensor system that will operate reliably in high-energy tidal zones. Nonetheless, it is clear from the approaches identified in this study that any such solution must combine multiple techniques, including passive and active acoustics, optical, and electro-mechanical sensing methods. Key elements of these sensor requirements are summarised in this report. While acoustic techniques for tracking fine scale behaviour of marine mammals close to turbines have matured recently, other relevant technologies, such as tactile detection for instance, need to be explored and developed further in order to confirm a collision event.

A collaborative, cross-disciplinary approach is recommended to advance the technology readiness for marine mammal turbine impact detection systems. Work to date has covered a number of specific areas in the overall problem domain, based on readily available subject matter expertise. An integrated, systemic approach will provide additional benefits. Further knowledge sharing amongst tidal turbine developers, environmental scientists and sensor specialists is required for an overall system solution, allowing for impact sensing to be integrated into the turbine system design from initial development.

[1] http://www.orjip.org.uk/oceanenergy/about

2 Introduction

2.1 The Challenge

As tidal turbine technologies advance, understanding of their performance in tidal races is improving and on-device sensors to monitor machine condition are likely to play an essential part. At longer deployment durations, extreme loading of turbine blades from collisions with animals and other water-entrained objects could represent a substantial risk to the structural integrity of devices, as well as jeopardising environmental consenting requirements. From an environmental impact perspective, there is a need for developers to 'prove the negative' with respect to collisions between tidal turbines and animals, not only to meet consenting conditions, but also to maintain a 'social licence' for development, as the death of a charismatic mammal (rightly or wrongly) attributed to turbines could have a major impact on progress. The focus of this project is on the last metre of an interaction between animals and turbines, and aims to develop a standardised, cost effective collision detection system to detect whether a collision has actually occurred with a tidal turbine.

2.2 State of the Nation

Research is underway to understand the close range movements of animals around turbines (Scotland, Wales and the US) but these will not inform us of the interactions in the final metre, i.e. enumerate collisions themselves. Instrumentation is therefore needed to (i) detect a collision between a turbine blade and an object, and (ii) cue other instruments to determine what type of object it was. In many cases, progression of marine energy projects from demonstration scale to commercial scale may depend on such empirical measurements.

Numerous methods have been suggested but none has yet been demonstrated to actually work. Underwater cameras, for instance, are unable to document a collision in darkness or turbid water and may be used retrospectively in combination with sonar in determining what it was that made contact. Passive and active sonar techniques provide information about animals in proximity of a device, but cannot detect physical contact between animals and turbines. Blade mounted sensors may provide answers though how effective these would be has not yet been established.

2.3 This Project

This interim report captures the initial findings from the Tidal Turbine Collision Detection (TTCD) status review, which presents an update on the available reports by industry organisations.

This project is a feasibility activity that seeks to:

- summarise key regulatory consenting requirements and approaches to satisfy these;

- summarise recent research and development activities relevant to collision, proximity or condition monitoring sensors deployed in the turbine-based renewable energy sector;
- articulate key technical and environmental factors and constraints for sensors in this application against the identified detection needs of:
  - collision detection
  - collision/proximity warning
  - post-event condition monitoring
  - post-event object identification
- identify available and emerging sensor technologies that could be used in underwater turbine applications.

It is intended to use the findings of this project to recommend the priorities and focus areas for longer-term collaborative research and development projects that could potentially address knowledge or evidence gaps identified.

This interim report summarises initial findings against (i) key environmental consenting regulatory requirements, (ii) key related research and development activities, and (iii) key technical and environmental sensor requirements. Information has been collected from desk-based research and interviews with identified experts, in the UK and abroad, including regulators, advisors, developers, academics and researchers.[2]

[2] A list of the consultees is provided in Appendix 1 .

3 Regulatory Aspects of UK Tidal Energy Projects

3.1 Introduction

Tidal turbine renewable energy developments require an Environmental Impact Assessment (EIA) and also a Habitats Regulations Appraisal before a Marine Licence and Section 36 (if the project is >1MW) are granted. The UK consenting bodies responsible for enforcing national and European regulatory requirements and their scientific advisors are:

Area	**Consenting Body**	**Scientific Advisor**
England	Marine Management Organisation	Natural England
Northern Ireland	Department of Environment	Department of Environment
Scotland	Marine Scotland	Scottish Natural Heritage
Wales	Natural Resources Wales (*)	Natural Resources Wales (*)

Table 1: Marine Consenting Bodies and Scientific Advisors

** Note: NRW operates separate licensing and advisory organisations.*

3.2 Applicable Legislation

The applicable UK legislation acts for protection of marine mammals and fish in the context of tidal turbine deployment are:

- Marine Works (Environmental Impact Assessment) (Amendment) Regulations 2015,
- The Conservation of Habitats and Species Regulations 2010,
- The Offshore Marine Conservation (Natural Habitats, and c.) Regulations 2007,
- Conservation of Seals Act 1970,
- The Conservation (Natural Habitats, and c.) Regulations 1994
- Offshore Marine Regulations 2007
- Marine (Scotland) Act 2010
- Marine and Coastal Access Act 2009,
- Wildlife and Natural Environment (Scotland) Act 2011

These regulations are derived from directives including, the EU Environmental Impact Assessment and Habitats Directives. If a development has the potential to injure or disturb a European Protected Species (EPS), then an EPS Licence would also be required under The Conservation (Natural Habitats, &c.) Regulations 1994. Examples of protected species include sea mammals (e.g. seals and porpoises), diving birds (e.g. guillemots) and fish (e.g. sturgeon).[3]

Beyond obtaining a Marine Licence and Section 36 (if the project is >1MW), developers must also obtain a Development Consent Order (DCO) from the Department of Energy and Climate Change (DECC). The local marine consenting body (e.g. Marine Scotland) is responsible for enforcing, post-consent monitoring, varying, suspending and revoking any marine license(s) granted as part of the DCO. (An outline flow chart of marine power project development process steps is available on the European Marine Energy Centre (EMEC) website[4].).

3.3 Regulatory Requirements and the Scottish Context

3.3.1 Introduction

Developers must satisfy a number of conditions with respect to site surveying, deployment monitoring and operational monitoring of their tidal turbines. These requirements vary with size, type and location of the development. The Marine Scotland "Licensing and Consents Manual" summarises the processes and roles and responsibilities of organisations involved in consenting and licence awards in Scotland. The information covered, however, provides general reference and guidance more widely applicable.[5] The key aspects of the regulatory requirements are summarised below.

3.3.2 Baseline Survey and Impact Assessment

Baseline site characterisation surveys are required (typically lasting 12-24 months) to establish which animal species are present in the vicinity of proposed site, their abundance, distribution and also their behavioural characteristics. Regulators are particularly interested in the presence of any protected endangered species. The survey findings are captured within the EIA, where the potential impact or disturbance by the turbine structure construction, installation and operation is identified, with possible mitigation and monitoring strategies identified.

3.3.3 Deployment Monitoring

The regulatory approach adopted for tidal turbine deployment is "Survey-Deploy-Monitor". Preparation of the site and the deployment of tidal turbines often involve noisy operations and disturbances due to installation vessels. Hence, monitoring is required to observe and record the actual effects on animals, allowing for operations to be halted if the potential risk of harm to wildlife becomes significant. Given the varied nature of the deployment sites, there are a range of specific approaches used. These include deployment of sensor

[3] Thompson D., Culloch R., Milne R., Current state of knowledge of the extent, causes and population effects of unusual mortality events in Scottish seals, Marine Mammal Scientific Support Research Programme MMSS/001/11, Sea Mammal Research Unit Report to Scottish Government (2013).
[4] Figure 2, page 2, weblink: http://www.emec.org.uk/?wpfb_dl=43
[5] Draft Renewable Licensing Manual, The Marine Scotland, Govt. Scotland. Weblink: http://www.gov.scot/Topics/marine/Licensing/marine/LicensingManual

equipment, human observers stationed on boats, and a managed gradual increase in machinery noise.

3.3.4 Operational Monitoring

A primary concern with tidal turbines is the risk of mammal collision, however there is a lack of clear evidence to illustrate how the animals interact with the turbines and to what degree this represents a real risk. Monitoring requirements vary from site to site, but could include:

- animal behaviour around turbine structures (e.g. can they detect turbines, do they avoid them, can they escape tidal stream, etc.),
- quantification of number of collisions and near misses (accuracy of assumed or modelled impact),
- outcome of animal collisions (injury/damage to animal, without evidence each collision assumed to be fatal),
- identification of object/species types (vs. behaviour and impact).

Given the low number of deployments and therefore the small evidence base in this specific area, the regulators are keen to obtain evidence in order to assess the risk and also inform future consent/monitoring approaches. The developers are working with the regulators to develop a pragmatic approach – the developers are seeking to provide evidence that can demonstrate that deployed turbines do not injure species of concern or unacceptably affect their habitat. Guidance on survey and monitoring in relation to marine energy renewables is available from Scottish Natural Heritage (SNH).[6] Particular guidance regarding the monitoring of cetaceans and basking sharks is available from Marine Scotland.[7] [8]

3.4 Current Options Meeting Regulatory Requirements

It is acknowledged that there is a significant knowledge gap in branches of science and technology related to different aspects of collision detection in particular, and tidal energy development in general, amongst regulators[9], developers and academics.[10] [11] The environmental setting for the tidal turbine structures also provides a significant challenge to the monitoring of mammal-turbine interactions (e.g. energetic tidal flow and bio-fouling).

[6] Guidance on Survey and Monitoring in Relation to Marine Renewables Deployments in Scotland, Vol. 1-5, Scottish National Heritage. Weblink: http://www.snh.gov.uk/docs/B925810.pdf

[7] Macleod, K., Lacey, C., Quick, N., Hastie, G. and Wilson J. (2011). Guidance on survey and monitoring in relation to marine renewables deployments in Scotland. Volume 2. Cetaceans and Basking Sharks. Unpublished draft report to Scottish Natural Heritage and Marine Scotland.

[8] Macleod, K., Lacey, C., Quick, N., Hastie, G. and Wilson J. (2011). Guidance on survey and monitoring in relation to marine renewables deployments in Scotland. Volume 2. Cetaceans and Basking Sharks. Unpublished draft report to Scottish Natural Heritage and Marine Scotland.

[9] Thompson, D., Hall, A.J., Lonergan, M., McConnell, B. and Northridge, S. (2013) Current status of knowledge of effects of offshore renewable energy generation devices on marine mammals and research requirements. Edinburgh: Scottish Government (and the references therein). Weblink: http://www.smru.st-and.ac.uk/documents/1321.pdf

[10] Mammals: Sparling, C. E., Coram, A. J., McConnell, B., Thompson, D., Hawkins K. R. and Northridge, S. P. (2013) Marine Mammal Impacts - Wave and Tidal Consenting Position Paper Series, Natural Environment Research Council, UK (and the references therein).

[11] Wave and tidal energy enabling actions report (2013/14) Aquatera Ltd. (not available in public domain)

However, there is precedence in some successful licence applications, for the acceptability of such approaches as:

- *Turbine Design*: involving stakeholders in assessing different turbine design specifications to identify optimal designs to minimise risk to mammals.
- *Risk Modelling*: marine mammals experts advise developers on modelling the environmental risks, based on predictions which can be validated with operational monitoring,
- *Risk Mitigation*: seasonal restrictions of installation during the migratory period and turbine shutdown during period of increased risk of collision.
- *Trials with New Sensor Technologies*: monitoring with a range of sensor technologies (e.g. active sonar, passive acoustics and camera).

3.5 Future Approaches to Meet Regulatory Requirements

3.5.1 Introduction

Most developers acknowledge the knowledge/evidence gap in this area and are actively seeking improvements to their monitoring capabilities in order to improve understanding. Some have planned to progress their own solutions, whilst others are willing to establish a collaborative approach with other organisations in order to share knowledge and funding. Others were cautious of sharing their turbine and sensor design technology/IP. Recently, a market deployment strategy for Europe was prepared, which also covered suggestions for new approaches to consenting.[12]

3.5.2 Current Activities Informing the Evidence Base

- *Modelling*: developers already create collision risk models to identify probability of mammal-turbine collision. In a collaborative project (X-MED - described later), collision events between a tidal turbine and a whale were modelled.
- *Experimental Evidence Collection[13]*: impact studies using seal carcasses are planned by Sea Mammals Research Unit (SMRU).[14]
- *Tracking Live Animal Behaviour*: for example, tagging has been used to record the behaviour of Atlantic salmon and found that they spent 70-80% of time at 0m to 5m depth.[15]

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[12] Wave and Tidal Energy Market Deployment Strategy for Europe (2014), SI Ocean report to EU. Weblink: http://www.oceanenergy-europe.eu/images/OEF/140037-SI_Ocean_-_Market_Deployment_Strategy.pdf
[13] Collision Damage Assessment, a recently SNH funded project to be carried out by SMRU. See weblink: section (6.1) http://www.gov.scot/Publications/2013/09/5811/7
[14] Collision Damage Assessment, a recently SNH funded project to be carried out by SMRU. See weblink: section (6.1) http://www.gov.scot/Publications/2013/09/5811/7
[15] GodfreyJ.D., Stewart D.C., Middlemas S.J. and Armstrong J.D. (2014) Depth use and movements of homing Atlantic salmon (Salmo salar) in Scottish coastal waters in relation to marine renewable energy development, Scottish Marine and Freshwater Science Vol 05 No 18. Weblink: http://www.gov.scot/Resource/0046/00466487.pdf

- *'Noiseless' Acoustic Designs*: a leading academic research unit has been working with various synthetic noise signatures for tidal turbine designs in order to monitor the response of mammals.[16]

3.5.3 Existing Challenges in Development of Collision Monitoring Solution

- *Bio-fouling*: can grow over the sensor devices, resulting movement can degrade signal to noise performance, which causes difficulty in identifying the signal of interest.
- *Imaging:* available light levels, water turbidity and bio-fouling all present significant challenges to the use of imaging techniques.
- *Sensor Technology Maturity*: related subsea impact monitoring technology appears to be at a low maturity due to the environmental challenges and the limited opportunity to trial in a representative setting.
- *Lack of Behavioural Confinement of Mammals*: only a negligible fraction of the mammal population can be tagged, and in open water the tagged population may not visit the site of interest. Further behavioural studies are desirable.
- *Underwater Tracking*: tagging works well above water and can provide valuable data, but the signal is often lost underwater.

In addition to the above technical and scientific challenges, organisational barriers have also slowed development. There exists an opportunity to create a collaborative and interdisciplinary approach, with interested parties pooling knowledge, resources and experience to accelerate technology development and evidence gathering. However, there remains the challenge of managing and protecting commercially sensitive information. Most of the developers and institutions consulted recognised the need for an initiative, led by a competent body, to collate the existing information and promote development of a solution by engaging with regulators, funding bodies or the government.

[16] Personal communication; documentary references can be available in future.

4 Project Activities and Technology Development

4.1 Project Activities

4.1.1 Introduction

Activities within collaborative research and development projects and also consented tidal marine energy projects have been considered.

4.1.2 Collaborative Research and Development Projects

Error! Reference source not found. identifies a number of key projects relevant to ammal-turbine collision detection (listed in chronological order of the start date).

Project Name	Participating Research Organisation/Lead	Funding	Project Duration
SMRU Long-term measurement of marine mammal population structure, dynamics and trophic interactions	*Sea Mammal Research Unit	confidential	Apr06 / Mar09
SAMS Marine Renewables	*Scottish Association for Marine Science	confidential	Apr07/Mar15
ReDAPT, Reliable Data Acquisition Platform for Tidal	Energy Technologies Institute (ETI) (*EMEC), Tidal General Ltd/Alstom (now GE)	£12,600,000	2010 / 2014
FLOWBEC, Flow and Benthic Ecology, 4D	National Oceanographic Centre	confidential	Jan 2011 - 2014
Intelligent acoustic deterrence of marine mammals to reduce risk during offshore construction	Subacoustech Environmental Limited	£100,000	Oct12/Jun14
X-MED: Extreme Loading of Marine Energy Devices due to Waves, Current, Flotsam and Mammal Impact	*University of Manchester	£901,377	Feb12 / Jul15
Tracking small cetaceans under water to inform collision risk: developing a tool for industry.	University of St. Andrews	£98,508	Jan14/June15
Marine mammal behavioural monitoring using acoustic technology at DeltaStream Demonstration, Ramsey Sound.	Swansea University	£17,335	Mar14 / Jul14
To improve marine mammal mitigation and to provide 3D/4D visualisation of cetacean movements in response to seismic survey activity.	University of Bath Seiche Measurements Ltd	£188,585	May15/Apr17

Project Name	Participating Research Organisation/Lead	Funding	Project Duration
Scottish Government Demonstration Strategy	SMRU	Confidential	2014/2016

Table 2: Identified Collaborative Research and Development Projects

** Shows coverage in terms of partner organisations or individuals consulted. (Further information including publicly available final reports may be collected from the respective)*

As conveyed in Table 2 above, discussions have highlighted the following key activities:

X-MED Project, University of Manchester

This project is of relevance as its scope includes the turbine-animal interaction. A sophisticated model (SPHLSM - smooth particle hydrodynamics lattice spring method) has been developed to investigate impact. Qualitative information on structures simulating large marine vertebrates impinging on a blade is available. Studies include a series of dry tests with a device that acts like a turbine blade, creating impact of a known force onto simulated animal targets. The targets have different mechanical properties such as mass, hardness, coatings and ballistic gel to represent characteristics of marine animals (i.e. muscle, bone, skin and blubber). Further tests are now planned underwater to understand how the body (representing a marine animal for example) is forced to move before the blade impacts on it, changing its relative velocity, reducing load and how that is then slowed down or given extra inertia by the surrounding flow.

Multiple Projects, SMRU

SMRU has significant knowledge relevant to the scope of mammal collision and is the only body in the UK with a licence to tag seals. It has been active in the 3D tracking of animals, including around tidal turbines and is engaged in projects to develop tracking systems using active multi-beam sonar. It is also adding passive acoustics to these systems for species detection. Currently, it believes these systems are mature enough to track species around turbines, but lack the ability to identify collisions.

Other relevant projects include investigations of tidal turbine operational noise impact on wild seals' behaviour and an assessment of collision impact and resulting damage on seal carcasses. Such studies add to a growing scientific evidence base required for the consenting process.

Multiple Projects, Scottish Association for Marine Science (SAMS)

Researchers at SAMS measured and modelled noise in tidal environments and found that there are 'quiet' zones between periodic noise zones. However, if these zones are dynamic, as one would expect in a turbine array environment, then it may in fact present a larger threat of animal collision with turbines. They are also working on models to predict the possible location of seal mortality events by collecting and analysing information about the site locations where seal carcases are found. This could be helpful in indicating whether seal mortality was due to turbine collision or other reasons.

ReDAPT, ETI

An underwater environmental monitoring pod was developed under this project. The first version of this pod, sited on a seabed template, contains an active sonar device and bidirectional hydrophones to record operational noise, and sensors to record conductivity, temperature and density data of the tidal water It also contained a video camera looking at the pod and a wired acoustic Doppler current profiler (ADCP) unit for real time tidal current data. The second and most recent version of the pod contains improved versions of the devices, a pair of video cameras configured to point at each other, a bio-fouling assessment lander, and a Drifting Acoustic Recording and Tracker (DART) device, also known as 'drifting ears' (drifting hydrophones). The pods are powered from the shore by a dedicated feed cable. In the future versions of the pod, installation of different improved sensors is expected.

FLOWBEC, National Oceanographic Centre

The project aims to understand how currents, waves and turbulence at tide and wave energy sites may influence the behavior of marine wildlife and how important collision risks might be. It is also intended to explore how tide and wave energy devices might alter the behavior of wildlife as different device types are tested as single devices are scaled up to arrays. Further information and key technical information related to FLOWBEC project is available in a recently published paper.[17] In the future work, investigators will integrate passive acoustics and video, with the development of triggering algorithms. This may be implemented with MeyGen in their future commercial deployment of turbines (with cabled connections) and/or in the battery-powered existing FLOWBEC platform.

Offshore Renewables Joint Industry Program (ORJIP) Ocean Energy

ORJIP has four priority projects, the first and second being of particular relevance, adding to the scientific base of interest

- Project 1: Bird collision risk and avoidance rate monitoring.
- Project 2: Evidence gathering for a Population Consequences of Acoustic Disturbance (PCAD) model to predict impacts on marine mammals from underwater noise.
- Project 3: Underwater noise mitigation technologies for piled foundations in deeper water.
- Project 4: Improvements to standard underwater noise mitigation measures during piling.

[17] http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=7066984

4.1.3 Marine Tidal Turbine Projects

Full-scale wave and tidal devices installed or operating in UK waters are summarised in a Natural Environment Research Council (NERC) report published in 2013[18]. Marine tidal turbine projects, and their status at August 2015 is provided in Table 3[19, 20].

MeyGen, Inner Sound, Pentland Firth

For the MeyGen Inner Sound project 64 turbines have been consented. There is a requirement to collect data on collision detection to support the consenting assumptions. MeyGen, is engaged in the FLOWBEC and Scottish Government Demonstration Strategy projects and has internal research and development to support detection and monitoring requirements.

Marine Current Turbines, Strangford Lough[21]

A trial period of operation without shut down mitigation at Marine Current Turbines' SeaGen has been licensed. Monitoring is in place to measure encounter rates and record the behaviour of marine mammals around the operating device. There has already been one instance of the machine having to be shutdown to prevent collision.

DeltaStream Project, Ramsey Sound, Pembrokeshire

This is a significant project, with the consenting approach taken being a Population Viability Analysis (PVA). This involves calculating the number of allowable collisions (per species) without a long-term risk to the species population. On this basis, the number of possible species collisions is determined and the allowable collision thresholds set. The project requires a sensing system that can detect collisions and identify at the species level. The sensor solutions involve stress and accelerometers sensing within the blades for collisions and active sonar or passive acoustics (hydrophones) to enable species detection.

[18] Weblink: http://www.nerc.ac.uk/innovation/activities/infrastructure/offshore/marine-mammal-impacts/
[19] https://maps.espatial.com/maps/pages/map.jsp?geoMapId=19671&TENANT_ID=115744
[20] http://www.gov.scot/Topics/marine/Licensing/marine/scoping
[21] http://seageneration.co.uk/files/SeaGen-Environmental-Monitoring-Programme-Final-Report.pdf

Pre-Application	Application and Determination	Post-Determination
SCOTLAND		
Brims Tidal Array Ltd (OpenHydro & SSE Renewables) - Brims Tidal Array (200MW)	DP Marine Energy Ltd – West Islay Tidal Energy Park (30MW)	Argyll Tidal Ltd (Nautricity) – Argyll Tidal Demonstrator Project (0.5MW)
Scotrenewables Tidal Power Ltd - Lashy Sound Tidal Array (30MW)		*MeyGen Ltd – Inner Sound, Pentland Firth Phase 1 (86MW)
ScottishPower Renewables - Ness of Duncansby (95MW)		ScottishPower Renewables - Sound of Islay (2014) (10MW)
DP Marine Energy Ltd - Westray South Tidal Array (200MW)		Nova Innovations Ltd. – Shetland (2014) (30kW)
NORTHERN IRELAND		
Tidal Ventures Limited (OpenHydro & Brookfield Renewable) - Torr Head (100MW)		*Sea Generation Ltd (Marine Current Turbines) – Strangford Lough (1.2MW)
*Fair Head Tidal Energy Park Ltd (DP Marine Energy Ltd & Bluepower NV) – Torr Head (100MW)		Minesto UK Limited - Strangford Lough Demonstration (0.375MW)
ENGLAND		
*Atlantis Resources/Marine Current Turbines - Portland Bill (30MW)		

WALES		
Tidal Energy Developments South Wales Ltd – St Davids Head (10MW)		Atlantis Resources/Sea Generation (Wales) Ltd – Anglesea Skerries Tidal Array (10MW)
Minesto UK Ltd - Holyhead Deep (10MW)		*Tidal Energy Limited – Ramsey Sound (1.2MW)

Table 3: Marine Tidal Turbine Projects

**Shows coverage in terms of organisations or individuals consulted.*

4.2 Technology Development

4.2.1 Introduction

For marine tidal energy project environmental consenting it is clear that a system approach is required for sensing environmental impact, considering:

- collision detection;
- collision/proximity warning;
- post-event condition monitoring; and
- post-event object identification.

4.2.2 Simulation and Modelling

Current research aims to inform the scientific evidence base around the following areas:

- Impact of marine animals on turbines, to understand the likely signatures from impacts for detection and risk of injury to animals from impact.
- Interaction of marine animals with tidal turbine structures to understand how animals might avoid tidal structures and what factors may contribute to environmentally safe designs.
- Understanding tidal behaviour and local hydrodynamics to optimise turbine efficiencies and also predict object flows.
- Characterisation of noise in the marine environment and understanding its likely impact on marine animals.

Generally this research is in the early stages, technology readiness level (TRL) 2 to TRL 3, and requires demonstration or trials to validate the concepts.

4.2.3 Collision or impact detection

This area requires further research and development. Some projects have been identified where collision detection is planned to be incorporated into the turbine blades, however there appears to be no publically available sensor review or accessible knowledge base of the likely impact signatures for different species and different turbine designs.

4.2.4 Proximity (including behavioural response near site)

The technology around proximity detection appears relatively mature, TRL 6. Active acoustic systems have been developed, deployed and tested demonstrating the ability to track animals with resolutions of 1m to 2m. The extent of trials is insufficient to demonstrate animal behavioural response to marine structures. Research has shown that animal behavioural response may change over time; therefore longer-term studies over a period of a number of years may be required.

4.2.5 Post-event object identification

This area requires further investigation to clarify the technology readiness level. Generally active acoustics, passive-acoustics and camera technologies are likely to be required, along with some data fusion to identify objects. It is understood some algorithms have been developed; however greater understanding of the system solution and specific algorithms is required.

4.2.6 Post-impact condition monitoring

There are two areas for post-event condition monitoring, the tidal turbine condition and the effect of impact on the marine animal. For the first, stress sensors and accelerometers are in use, with significant changes in the data collected used to identify an issue/maintenance event. For animals, early research studies are underway to identify speeds, forces and potential damage to differing species. It is estimated that the turbine condition monitoring is relatively mature TRL 6, whilst the marine animal impact effects are at an early stage around TRL 2.

5 Impact Sensor - System Requirements

5.1 Introduction

It is likely that any system for animal-turbine impact detection will utilise and fuse a number of available sensing modalities including, active acoustics (sonar), passive acoustics (hydrophone), imaging (camera) and electro-mechanical (strain, accelerometers) devices.

An impact sensing system should commence with the following requirements, which are the high-level needs for its specification. Phase 2 of this study explores the second level, adding definition of detailed parameters and likely target values based on the accumulated knowledge from the organisation identified and discussed.

5.2 Functional Requirements

No.	System Area	Requirement
FR1.	Collision or impact detection	Measure force on turbine blade from object collision. It has been shown that additional vibration measurements can improve accuracy of detection
FR2.	Collision or impact detection	Determine area on turbine blade of object contact
FR3.	Collision or impact detection	Identify marine animal to species level or colliding object
FR4.	Proximity (including behavioural response)	Identify animal species within locality of turbine
FR5.	Proximity (including behavioural response)	Map movement of animals over time whilst within locality of turbine
FR6.	Proximity (including behavioural response)	Locate animals with resolution of (m – to be determined in phase 2 of this study)
FR7.	Post-event object identification	Map movement of animals post-collision over time within locality of turbine
FR8.	Post-event object identification	Obtain image of object post event (resolution and format – to be determined in phase 2 of this study)
FR9.	Post-event condition monitoring (turbine)	Identify critical changes to turbine performance (e.g. bearing load – to be determined in phase 2 of this study)
FR10.	Post-event condition monitoring (animal)	Identify if animals suffer immediate fatal injury

Table 4 Functional Requirements

5.3 Environmental Requirements

No.	Parameter	Requirement
ER1.	Ingress Protection	IP68, Submersible to depth of 100m

No.	Parameter	Requirement
ER2.	Operating Temperature	0C to +20C, (non-freezing)
ER3.	Storage Temperature	-20C to +30C
ER4.	Mechanical Shock	TBD, critical for application
ER5.	Vibration	TBD, critical for application
ER6.	Hydrostatic Pressure	Operates at twice submersible depth
ER7.	Corrosion	Seawater operation for 5 years. Evaluate via salt mist (to be determined in phase 2 of this study)
ER8.	Bio-fouling	Operation for at least 12 months without maintenance to remove bio-fouling
ER9	Maintenance	Minimum 12-month operation without preventative maintenance

Table 5 Environmental Requirements

6 Acknowledgements

This feasibility study was undertaken and completed with funding support from Scottish Natural Heritage and the Natural Environmental Research Council.

Appendix 1 List of Interviews Held

Date	Interviewee Name	Professional Role	Organisation	Org Type	Location	Medium
23/06/15	Jenny Norris	Research Director	EMEC	B, D2	UK	Face
23/06/15	Michael Butler	PhD Student Acoustic Engn.	EMEC	D2	UK	Face
24/06/15	Benjamin Williams	Acoustic Engn.	Aberdeen Uni	A, D2	UK	Face
25/06/15	Ben Wilson	Prof. – Mammalogy and Marine Renewables	SAMS	A, B	UK	Face
	Raeanne Miller	Marine Scientist	SAMS	A, B	UK	Face
29/06/15	Caroline Carter	Marine Mammal Advisor	SNH	C2	UK	Face
	Chris Eastham	Marine Renewable Energy Casework Advisor	SNH	C2	UK	Face
30/06/15	Kate Smith	Marine Renewable Energy Advisor	Natural Resources Wales	C1	UK	Phone
01/07/15	Tim Stallard	Professor – Mech. Aero. and Civil Eng.	U. Manchester	A	UK	Phone
02/07/15	Kate Brookes	Marine Mammal Scientist	Marine Scotland	C1	UK	Phone
06/07/15	Edward Rollings	Environment and Consents Manager	MeyGen	D1	UK	Face
08/07/15	Gordon Hastie	Marine Biologist	SMRU	A, D2	UK	Face
	Carole Sparling	Marine Scientist	SMRU	A, D2	UK	Face
	Douglas Gillespie	Marine Biologist	SMRU	A, B	UK	Face
08/07/15	Mark James	Operations Director	MASTS	A	UK	Face
09/07/15	Beth Scot	Prof - Ecologist	Aberdeen Uni	A	UK	Face
09/07/15	James Njuguna	Prof – Mech. and vibration Eng.	RGU	A	UK	Face
10/07/15	Chris Williams	Development Director	Tidal Energy	D1	UK	Phone
	Peter Bromley	Engineering Manager	Tidal Energy	D1	UK	Phone
10/07/15	Gavin McPherson	Development Engineer	Nova Innov.	D1	UK	Phone
10/07/15	Jeremy Thake	Head of Engineering	Atlantis	D1	UK	Phone
10/07/15	Claire Bowers	Wildlife Officer	MMO	C1	UK	Phone
14/07/15	Paul Morris	Commercial Director	Tocardo	D1	NL	Phone
15/07/15	Clodagh McGrath	Environmental Manager	DP Energy	D1	UK	Phone
17/07/15	Simon Harper	Mechanical Design Engineer	Alstom	D1	France	Phone
	Antonin Caillet	Project Engineer	Alstom	D1	France	Phone
29/07/15	Lindsey Booth-Huggins	Case Officer - Licensing	MMO	C1/2	UK	Phone

Organisation Type	Acronym	
A: Academic	EMEC	European Marine Energy Centre
B: Business Consultant	MASTS	Marine Alliance for Science and Technology for Scotland
C1: Consenting Authority	MMO	Marine Management Organisation
C2: Consenting Authority Advisor	NRW	Natural Resources Wales
D1: Developer (Turbine)	RGU	Robert Gordon University
D2: Developer (Sensor)	SAMS	Scottish Association for Marine Science
	SMRU	Sea Mammal Research Unit
	SNH	Scottish Natural Heritage

Appendix 2 Master List of Interview Questions

Section A: General Information Scope (open questions)

1(a): Is there any need to develop sensor solutions for tidal turbine, especially considering collision detection, monitoring and warning systems? How important and desired it is and why?

1(b): who are currently developing these sensors solutions? Are there sufficient developers and activities along the sensor supply chain to address the tidal-turbine industry needs?

1(c): Any current or previous Rand D activities or developments in (*) tidal turbines or (**) wind turbines regarding

(i) Collision or impact detection

(ii) Proximity (and object) detection and warning

(iii) Condition monitoring (of blades or complete system)

(iv) Post impact/proximity object identification

1(d): Possible sensor types, sensor technologies for each type, technical or environmental factors and constraints for sensors operating in underwater turbine environment.

1(e) is there any knowledge or technology gap not covered by current developers regarding tidal-turbine sensors development? What are the reasons or limitations? Is there any role for other agencies to push development activities to fill this gap?

2(a): Environmental consenting, regulatory requirements regarding tidal turbine setup and operation, will that also affect the sensors deployment?

2(b): Options for tidal/wind developers to achieve these

2(c): How developers intend to meet them

2(d): what has or hasn't worked in this regard

2(e): current or future approaches to meet the regulatory requirements in context of sensor development for tidal turbines

Section B: scenario specific questions for detailed understanding

Tidal Turbine Environment

- What is the standard mechanism of tidal turbine operation?
- What is the standard practice in tidal turbine management?

- What is the flow mechanism of tidal waves at the preferential sites of turbine (i) with and (ii) without turbines/arrays installed?
- What are the geometrical features of the tidal turbine sites? Such as size of the site, separation between turbines, turbine separation from rocks/walls, depth from the normal/tidal sea level etc.
- What are the typical and extreme (minimal/maximal) parameters of operation such as speed of tidal water flow at high and low tide conditions, rotation speed of blades, size of blades and turbine?
- Water turbidity and its dependence on tide? Need to measure it?
- Light levels near turbine and its influence on species presence in tide stream

Interaction Scenario

- What are the typical ecological changes introduced when the turbines are installed at the sites? (Influence on density of species, their activity etc.)
- What are the behavioural responses of species at the sites of interest (i) with and (ii) without turbines installed?
- Are there any references available to experimental/theoretical work to understand interactions between turbines and ecosystem around turbines done by stakeholders?
- Are there any specific academic/other references?
- Is there any information available regarding seawater chemistry and its interaction with turbines during the turbine lifetime?
- What are the species around turbine sites and their behaviour far from or near the turbines
- Influence of bio fouling and any preferential sites around turbines?
- If and how the bio fouling influences the sensors and sensing behaviour
- How a specific sensor will respond in normal/tidal flow conditions under Sea-waters at a certain depth when fixed installed or moving
- How a specific sensor will respond in presence of bio species and bio foul and whether any differences will be noted when the density of bio species/fouling changes with time

Sensing Information Required

- What are the typical sensor solutions being applied in ocean (in-water) applications? How do they differ from their in-air counterparts? Say in terms of packaging or sensing parameters (A case of temperature sensor)?

- What sensing, monitoring data/information will be needed for a smooth and prolonged turbine operation and in which form?
- What technical methods and commercial solutions are available or researched solutions are possible for communicating data from turbine sites to monitoring/management sites?

Scenario Specific Technical Details

Proximity: sensing

- What is the typical proximity range for detection of species?
- What is the (SAFE?) proximity length?
- How this safe distance is/can be determined?
- Does the safe distance differ for different species, turbine/blade designs?
- Does the safe distance differ with tidal situation?
- Proximity sensors need to be fixed next/near turbine or they can be distributed within a certain radius from turbine?
- What is the preferable mode of sensing data communication (wired/wireless/mixed?) and any example solutions

Proximity: warning

- Is it sufficient to sense the proximity along the axis of turbine, or, proximity in 3d is also important?
- What is the separation between species and turbine when the warning should be issued? How to determine this separation? Dependence on environmental variables?
- In which form this warning should be issued?
- Warning is issued to species as well in some way (acoustic) to keep them away?

Collision Detection and monitoring

- What are the collision detection requirements? Collision event? Collision strength? Collision duration? Frequency of collision?
- What are the geometrical requirements for collision detection? Is it important to record the collision point on the blades/turbine?
- What should be the visualization scheme to show the real time and historical data for useful interpretation and possible prevention steps

- Is it enough to identify colliding object as bio-species or just as a material mass?
- Is it important to differentiate and/or determine the “colliding species” or just registering a collision event is enough?

Post-Collision Turbine Blade Condition Monitoring

- Collision influence on blades (cracks?)
- Scattered deposit of collision hit species and their influence on turbine
- Post collision sensor health checks, required?
- Mode of sensor calibration (auto/human) and frequency (every few years)?

Sensor Specific Technical Details

- Sensor Operation Requirements for each type
- sensitivity
- selectivity
- lifetime
- power consumption

Sensing Environment Requirements (range)

- water turbidity / sediment / turbulence
- temperature
- depth and pressure
- flow speed

Impact Detection Requirements

- activate detection with how long object proximity?
- sensitivity : impact detection vs tidal movement (“background noise”) vs “clunk"
- in service life duration
- fixing locations
- power consumption
- Proximity along 3 axes?

- Rotation speed/force and blade dimensions
- collision frequency and magnitude,
- Communication requirements

Post Event Monitoring Requirements:

- light levels
- fixing (base of turbine looking upwards?)
- information from “numerous methods”
- communication requirements

Context

- tidal water movement, forces, acceleration…..
- depth, pressure, temperature,
- maintenance schedule
- update from “close range movements of animals around turbines”
- approximate size, material and movement of objects to be detected or determined (including other objects)
- information on existing condition monitoring sensors and deployment
- What are/could be the typical power requirements of the (i) existing sensors in ocean applications and (ii) future sensor solutions for proximity/collision detection/warning system [how often, size/rate/system/on-board or off-board data storage method]

Developers and Technologies

- Who are developing sensors for tidal turbines?
- What sensors solutions are already available?
- What technologies are in use already and what other are prospecting?
- What should be the cost range for the qualifying sensor solutions?

Regulatory requirements

- What consent/regulations are in place that affects the deployment of sensors at tidal turbine sites

- Regulations generally affecting tidal turbines development and deployment
- Any case studies available on the influence of regulatory requirements
- How developers intend to meet the requirements
- What approach or strategy has worked so far in meeting the requirements and still developing solutions

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