

# Barriers to the Deployment of a 100 MW Tidal Energy Array in the UK

Stuart R.J. Walker

Department of Mechanical Engineering, University of Sheffield,  
South Yorkshire, UK  
s.r.walker@sheffield.ac.uk

**Abstract-** The UK is an internationally important area for tidal energy, with half of the extractable European tidal resource estimated to be in UK territorial waters [1]. Marine (wave and tidal) energy resources are said to have the potential to supply up to 20% of national electricity demand [2], and now is a critical time in the development of tidal energy, with a wide range of devices at the design and testing stage, some in the water, and a few generating meaningful amounts of electricity. The recent announcement of an increase in financial support for tidal devices is also a very positive development [3]. Many people believe that the UK tidal energy industry is currently in a similar position to the wind energy industry in the mid-1980s, and lies at the bottom of a very steep and exciting development curve.

Numerous companies have developed tidal energy machines, and the vast majority are designed to be operated in arrays, or “farms” of multiple devices, similar to those used in the on- and off-shore wind industry. No such tidal farms currently exist, although some are being developed [4]. This paper discusses the challenges the UK tidal industry is expected to face during the design, building, installation and operation of an array of tidal devices rated at 100 MW. A meeting was held during the RenewableUK conference in October 2011 to discuss the future of the industry, and notes from this meeting were drawn on during the writing of this paper. The author would like to thank everyone who contributed to this event.

The conclusion of this paper is that there are many challenges standing between the current position of the industry and deployment of a 100 MW array. It is very easy to focus, as is the case in mainstream media, on the development of the turbine devices themselves, however many of the challenges lie in other areas, such as installation, cabling and connection. Nonetheless, these challenges are not insurmountable, and by taking a holistic approach to the design of a tidal array and working together these challenges will be solved.

**Keywords-** Renewable Energy; Marine Energy; Tidal Energy; Tidal Energy Converters; Tidal Array; Tidal Farm

## I. INTRODUCTION

Anthropogenic climate change is now a generally accepted reality, and this has driven the need for low carbon forms of energy generation. In the UK and across the world, work is ongoing to reduce harmful emissions from conventional power generation, as well as to develop renewable energy sources and gradually de-carbonise the UK electrical supply network (the grid). A number of renewable energy sources are well developed and already contribute to the grid, such as photovoltaic panels and wind turbines. Tidal energy devices do not currently contribute to the grid, but in 2006 the Carbon Trust estimated that a contribution of up to 20% of the UK's energy requirement could be achieved from tidal energy [1].

Tidal power has a distinct advantage over many other forms of renewable energy, namely the predictability of its output. Whereas solar radiation, wind speed and wave height are all unpredictable with any accuracy beyond single day timescales, tides are known years in advance. This offers the tantalising prospect that in the future tidal power could provide part of the UK's energy “base load”, currently provided by coal and gas-fired power stations. However, before this possibility can even be considered, the scale of output required must be considered. For example, the UK's largest base load power station is the coal-fired Drax plant in North Yorkshire [5], which produces 4,000 MW (7% of the UK's demand) of base load. The current total installed tidal generation capacity in the UK is a quarter of a percent of this, at 10 MW in 2011 [6].



Fig. 1 Drax – the UK's largest emitter of CO<sub>2</sub>, but provider of 4000MW of base load [7]

This paper discusses the challenges which must be overcome in order to install a 100 MW array in the UK, which is seen as

a positive step towards a thriving and viable tidal energy industry, and to a reduction in reliance on high-carbon energy sources for UK base load.

## II. RESOURCE

In order for the required scale-up of the UK's tidal energy capacity to take place, a number of requirements must be satisfied. Firstly, a tidal resource with the potential to provide sufficient output is needed. In the case of the current generation of machines which are installed individually, this resource is required only over a relatively small area; however in the case of a tidal array a relatively large area is required.

A tidal resource can be defined by a number of variables. Important defining environmental variables include water depth; tidal stream velocity; relative spring and neap tide velocities; symmetry of tides; and site wave conditions. There are also numerous non-environmental issues which may make a resource viable (technically or economically) or not, such as the local grid connection potential; proximity to a town or port; and the current or future use of the proposed installation area.

### A. The UK Tidal Resource

The UK's incoming tides have an average raw power of 250 GW [8]. Areas of high tidal flow velocity are found throughout the country, with particularly high concentrations on the Scottish and South western coasts. Certain areas have become ubiquitous with tidal energy, such as the Bristol Channel (due to the repeatedly proposed and scrapped Severn Barrage [9]), and the Pentland Firth between Orkney and the Scottish mainland. The latter is the location of EMEC, the European Marine Energy Centre, which has device testing and monitoring capability, and is where many of the current first generation devices are located [15].

### B. Potential Array Sites

As well as the two locations highlighted in Section 2.1, there are a number of other areas with the potential for tidal array installation. Using the DECC Atlas of UK Marine Renewable Energy Resources [10], areas with average tidal velocities above 1 and 2 m/s can be shown, as illustrated in Figure 2. Approximately 1 m/s is the minimum exploitable tidal resource identified by developers.

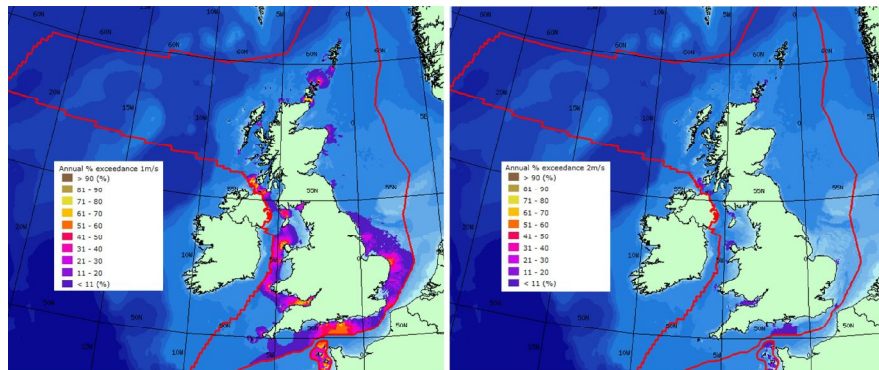


Fig. 2 UK Tidal map highlighting average velocities above 1 m/s and 2 m/s (left and right) [10]

Although there is clearly much more involved in selecting a site for a tidal array than the above diagrams (as will be discussed in Section 3), these maps highlight a number of potential areas of relatively high tidal stream velocity in UK waters, in addition to the Pentland Firth and Bristol channel: The Channel Islands; Isle of Wight; Norfolk; Western Isles and Hebrides; Isle of Man; Anglesey and Welsh coasts all offer potential.

Data such as that in [10] confirm that the UK is a suitable location for large scale tidal array installation. Subsequent sections of this work will detail the challenges which exist in the development of such an array.

## III. PRE-DESIGN WORK

This stage of work describes the selection and study of a potential tidal array site and the preparation of the array including site monitoring and assessment, community engagement, legal frameworks and environmental impact studies are also included in this stage.

### A. Site Selection

As discussed in Section 2, there is a wide range of criteria which must be satisfied before a site can be considered for a tidal array installation. A number of such criteria are detailed in the table below, along with the specific value which must be met (based on information from tidal array developers), and a method of determining whether or not a site meets the criteria.

TABLE I TIDAL ARRAY SITE REQUIRED CRITERIA

Criteria to be met	Limiting value / parameter	Method of assessment
Tidal stream velocity	Min. 1 m/s [21]	Tidal atlas; Local knowledge; Boat monitoring; ADCP (See Section 3.1.2)
Water depth	30 – 80m [20]	Digital mapping; ADCP
Relative spring / neap velocity	Minimise difference	Tidal atlas; Local knowledge; Boat monitoring; ADCP
Tidal symmetry	Maximise symmetry	Tidal atlas; Local knowledge
Wave conditions	Minimise waves	Historical information; WaveBouy; Radar
Seabed type	Minimise challenging surface (eg. Large rocks)	Local knowledge; Radar
Local grid system	33kV or 11kV [20]	National Grid
Distance to port	Minimise	Measurement

Assessment of these criteria is described in more detail in the following sections.

### 1) Initial Site Investigation:

Initial site investigation is conducted to determine whether a site may broadly be suitable for tidal energy. This process may be carried out at a number of locations before a suitable one is found, so the cost and time requirements of site assessment should be minimised whilst maintaining a rigorous approach.

Initial site investigations can be carried out by visiting the site, studying satellite photography of the area, or by using a tidal atlas. A tidal atlas is a map of a marine area, overlaid with arrows indicating the direction and strength of the tide for each hour of the 12-hour cycle.

If analysis of a tidal atlas suggests that the site may offer potential for energy extraction, the next step is to visit the site and conduct monitoring to further understand the resource.

### 2) Site Monitoring:

Site monitoring is often carried out using a system known as ADCP (Acoustic Doppler Current Profiler). This system involves placing a device either on the ocean floor, on the bottom of a boat, or suspending it in the tidal stream. The system uses rebounded sound waves to measure the velocity of the flow. ADCP systems vary in physical size from devices which can be handled by one person to larger machines which may require the use of an ROV (remotely operated vehicle) to deploy.



Fig. 3 Surface mounted (l) and bottom mounted (r) ADCP devices

ADCP produces useful high-quality data, but does have limitations. In particularly clear water the sound pulses may not bounce back to the device, and insufficient data would be gathered to achieve good results. Furthermore, areas with turbulent flows or regular movement of fish or other marine life may yield distorted results. ADCP is, however, a well-understood and relatively cheap technique for generating an accurate picture of the flow field in most potential tidal energy areas.

### 3) Computational Modelling:

Computational modelling of tidal sites can be a very useful technique for resource assessment. However, experimental data is required in order to construct an accurate model, which may mean ADCP studies are required before computational modelling can be conducted. This may therefore prove an expensive exercise; however it does allow a wide range of tidal or weather conditions (eg. storms) to be modelled without the expense and difficulty of having ADCP equipment installed on site throughout the year.

## B. Community Engagement

Sites suitable for tidal energy extraction tend to be located close to relatively small coastal communities. Industries in these areas are likely to be maritime-based, such as fishing and tourism, and in some cases oil and gas extraction or shipping.

All developers agree that community engagement must be an integral part of the site selection process. The wind industry provides many examples of schemes which have failed due to poor community engagement, and can teach us useful lessons

[26]. Members of coastal communities are likely to have detailed knowledge of the intricacies of the site that ADCP and computational modelling may be unable to reproduce, and making use of these skills is likely to benefit the project both technically and commercially. If the community can be “on-board” from an early stage, a project is much less likely to run into problems later. When work begins on a site, the use of local labour makes economic sense, especially as members of the community from maritime industries are likely to have relevant skills.

Through positive community engagement, a feeling of “outsiders coming and making lots of money from our sea” can be avoided, and the tidal energy extraction system can become a benefit to the community on many levels.



Fig. 4 Good community engagement should help promote positive attitudes

### C. Existing Habitat

Due to their high tidal stream velocities, potential array sites are likely to represent unique habitats, supporting marine life not found in areas with lower tidal velocities. However carefully the installation of a tidal energy extraction system is conducted, the existing maritime habitat will inevitably be modified. It is up to the array designers to minimise these effects, and to ensure that no species are permanently displaced.

#### 1) Marine Life (Flora):

Marine flora (plant life) in the region of a tidal energy farm can vary widely, especially when considering the global deployment of tidal power generation technology. Even within the UK, large climatic and geological differences exist between, for example, the Orkney and Devon coasts. These differences aside, it is inevitable that a tidal farm will have an impact on the flora of the seabed. Seabed environments are defined by the Marine Habitat Classification for Britain and Ireland [11], as shown in Figure 5. High speed tidal currents particularly affect the circalittoral region, leading to an increase in species richness relative to low tidal velocity areas.

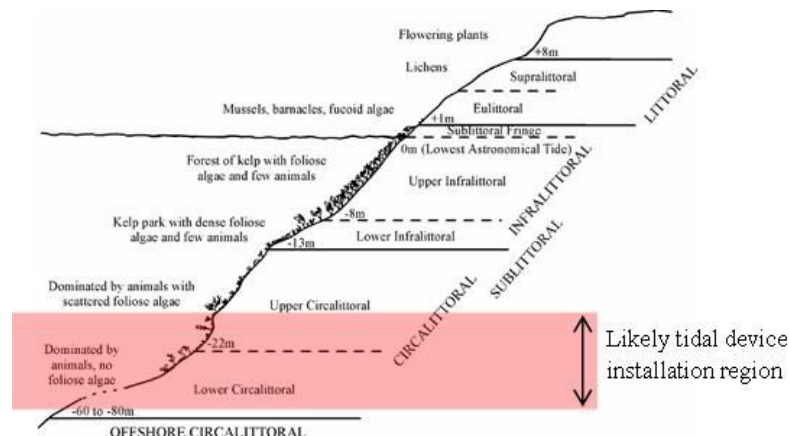


Fig. 5 Marine habitat areas defined by the Marine Habitat Classification for Britain and Ireland

As shown in Figure 5, the circalittoral region includes the area in which tidal device foundations are likely to be installed, so there is potential for damaging a valuable habitat during device installation. It is therefore imperative that, during site selection, this habitat is monitored so that specific species can be relocated if necessary. Although environmental monitoring for tidal turbine projects is, in theory, relatively simple [12], the cost of this monitoring can be significant and should be included when budgeting for installation.

#### 2) Marine Life (Fauna):

Studies into the effect of tidal turbine farms on marine species [13-14] conclude that the effects of the devices on fish and small creatures are minor due to the relatively low rotational velocity of the turbine blades. However, the effect of farms on larger marine species such as seals or cetaceans is currently unknown, and could be potentially problematic.

#### D. Securing the Site

Following the visiting, studying, monitoring and modelling of a number of sites, the final site will eventually be selected for the tidal array project and the focus of the developer can move from site selection to securing the site.

##### 1) Licensing and Leasing:

The UK seabed up to 12 nautical miles offshore is owned by the Crown Estate [27]. As of September 2010, tidal energy developers can apply for 10 MW leases to last 25 years. Developers must apply for a site lease before any work on site can take place, and leases will only be awarded following assessment of the proposed project. This means projects must be well planned and designed, and have sufficient funding in place. In addition to a lease agreement, licensing is also required. This is currently awarded in Scotland by Marine Scotland, and in England and Wales by the Marine Management Organisation. Licenses in Northern Ireland are awarded by the Departments of Enterprise, Trade and Investment and of the Environment. New licensing processes are designed to encourage engagement with all stakeholders, and to speed up the process of licensing. However, licensing and leasing remain considerable hurdles in the development of an array, and time and money must be allocated to these processes.

#### IV. ARRAY DESIGN

Following the selection of a site, the tidal energy array to be installed at the site must be designed. In reality, array design and site selection should be conducted simultaneously as decisions in each area clearly affect the other. Array design details are also likely to be required in order to achieve site leases, as well as to secure funding and supply agreements.

This section discusses the types of devices available, and the design and layout of arrays, cabling and connections.

##### A. Device Selection

A range of device types for tidal energy extraction have been proposed, and within each type a number of specific devices exist. There are four broad device types, as identified by EMEC [15]:

- Horizontal axis turbines (HAWT or HAT)
- Vertical axis turbines (VAWT or VAT)
- Oscillating hydrofoil
- Venturi

These devices are illustrated in the following figure.

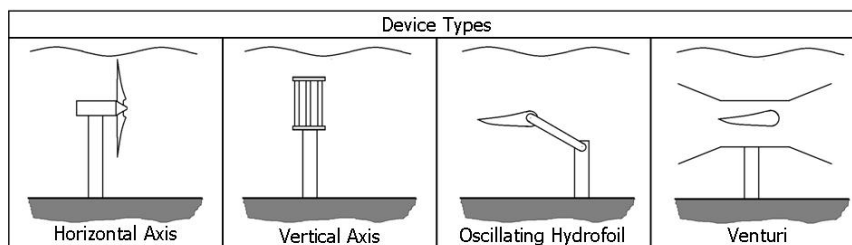


Fig. 6 Tidal energy device types

Horizontal axis devices are currently the most popular device type, and appear to be the most likely device type for the first large scale farm installations. Horizontal axis devices designed by OpenHydro are to be used in the small tidal array proposed at Brehat [4]. The OpenHydro turbine is a ducted design. A number of three-bladed turbine designs have been proposed and are relatively well-developed, with most having already undergone some form of test installation, such as those by Tidal Generation Ltd. [21] and Marine Current Turbines [28]. However, a range of turbine designs still exist, and it is likely that for a 100 MW installation a device would be specifically designed, or at least modified in order to operate most effectively on site. Modifications may also be carried out to allow for efficient installation and maintenance, as will be discussed later.

##### 1) Foundation Type:

Aside from the design of the turbine above the seabed, device manufacturers and installers use a range of foundation designs. The following main designs are used, again as defined by EMEC:

- Gravity base
- Pile mounted
- Hydrofoil downforce
- Floating (with Flexible, rigid or floating mooring)



These foundation types are illustrated in Figure 7. Each design has its own inherent advantages and disadvantages. Hydrofoil and floating designs are seen on relatively few design proposals, and are not believed to have been used on any installations to date. Gravity base and pile mounted foundations are by far the most popular designs, and are theoretically well understood, being employed by the offshore wind and oil industries.

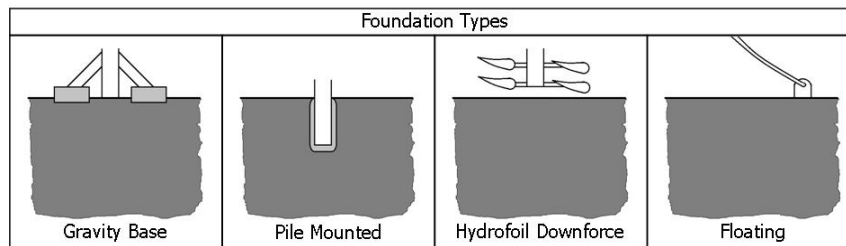


Fig. 7 Tidal energy foundation types

Gravity base foundations rely on an object of large mass fixed to the base of the tidal energy device, meaning that the device is not permanently attached to the seabed. Clearly the mass used must be of sufficient weight to ensure that the device does not move, even under extreme storm conditions. Due to the large mass required to achieve this, the gravity base method of foundation can lead to installation difficulties.

The installation of piles is a well-understood foundation method, and is regularly used in land and subsea applications. However, there are potential issues related to scour and erosion around the base of pile mounted devices in high speed tidal streams [29]. This is an area the author is currently researching, and hopes to publish work in the near future. However, piled foundations are still the most likely type to be used on a 100 MW tidal array installation.

### B. Array Design

Having chosen and agreed a site for the tidal array and decided upon a device and foundation design, the array itself must be designed. For the purposes of calculations during this section, the DeepGen turbine designed by Tidal Generation Limited (TGL) is used. This is a relatively well-developed three bladed HAWT turbine. The turbine planned for use in arrays is a 1 MWe design, of the horizontal axis type, and uses a three pile foundation design. The turbine is shown in Figure 8.

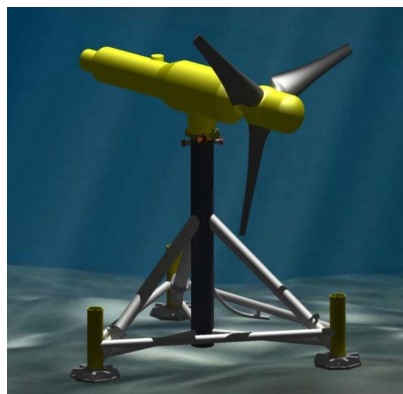


Fig. 8 TGL DeepGen Turbine

#### 1) Array Size and Layout:

A 100 MW array using the DeepGen turbine discussed previously would require 100 turbine units. How these would be laid out, and over what area, is a question of some debate. Careful placement of devices is imperative to ensure that the turbines do not affect each other sufficiently as to reduce output. Work has been carried out in this area [16-17], but is currently limited to the effect of a single upstream turbine on a downstream one. Wake effects within tidal arrays are another of the authors' areas of research.

There are similarities between tidal and wind farms, but research [18] suggests that, due to the interaction of the seabed and sea surface, which amplify the wake behind a tidal device, these devices must be spaced further apart than turbines in a wind farm. Tidal farm spacing has been estimated based on wind farm spacing guidelines of 10 rotor diameters [19] in all directions. However, since tidal flow directions are fixed, tidal turbines can be spaced closer together in the lateral direction. Following discussion with experts [20], tidal array spacing has therefore been estimated, for the purposes of this study, at 15 rotor diameters in the streamwise direction and 5 rotor diameters cross-stream. An approximate image is shown below.

Clearly the layout shown above is not the only option, and does not consider any topographical features which may affect layout. However as an approximate minimum area calculation, Figure 9 illustrates that a 100 MW array might require an area in the region of 2.4 km<sup>2</sup>.

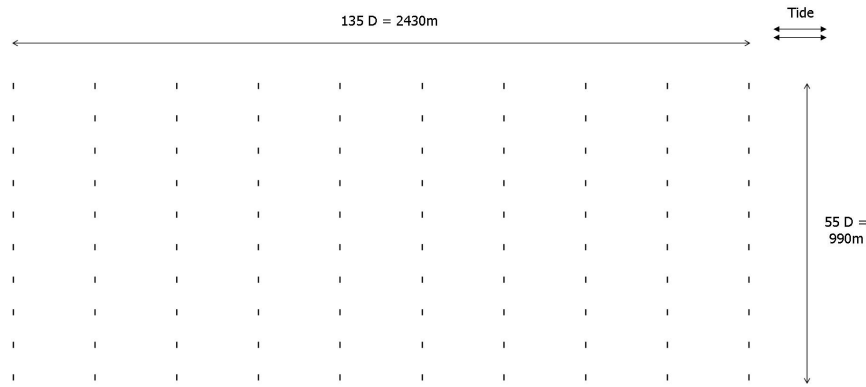


Fig. 9 Potential tidal farm size

### C. Cabling

To an external observer, cabling may appear to be a minor part of the installation of a tidal array. However, it is an area which holds many potential pitfalls. Expert cabling contactors and installers [20] highlight this part of the array design and installation procedure as one of the most likely to lead to delays in deployment. Over 70% of insurance claims in the offshore wind industry are cable-related, despite cables only representing around 7% of total installation cost in this industry [23].

During array design, cable layout must be considered in parallel with the positioning of tidal devices, as these factors directly influence each other. Furthermore, connections between the device and cables must be considered during the process of device selection.

#### 1) Cable Layout:

There are a number of suggested cable layouts for tidal arrays in the 100 MW region. The three most likely solutions are shown in Figure 10, and are (l-r):

- Individual
- Central Hub
- Central Rail

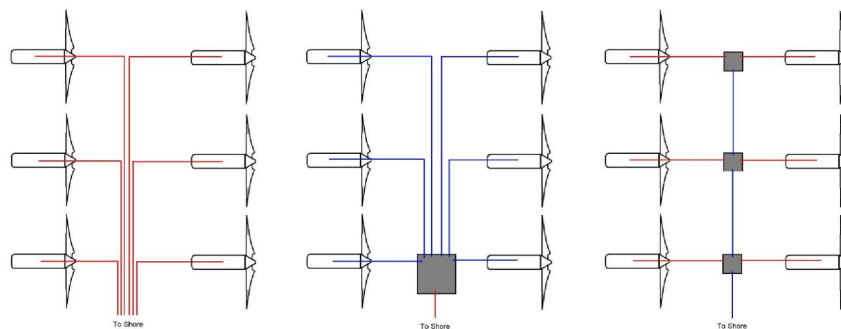


Fig. 10 Tidal array cabling options: Individual, hub, and rail (left-right)

Of the three options illustrated in Figure 10, the hub and rail designs aim to minimise the total length of cabling required between the array and shore power systems, thus reducing installation difficulty and cost. By requiring only a single cable from the array to the shore, these designs should allow simpler installation. However, additional complications are introduced by the increase in the number of connections required, as well as the requirement for larger cables. Individual cabling for array scale installations is not considered viable due to the volume of cabling this would result in.

#### 2) Connections:

Connecting the devices to the cabling system is another potentially difficult part of an array installation. The timing of the installation must be considered, for example whether the devices or cables are to be installed first. Similarly, it must be borne in mind whether the devices are likely to be removed at any stage in the future, as this will preclude certain connection types.

Two types of connection are possible, namely “Wet mate” and “Dry mate”. Wet mate connectors are used when the connection of the device to the cable system takes place under the sea, whereas dry mate connections generally take place on board an installation vessel, before the device and cables are installed together. The primary advantage of a wet mate system is the ability to remove the cable or device independently, should there be a problem with either. However, making the connection with a wet mate system requires subsea work, most likely using ROVs, which increases cost. Dry mate connections

avoid this requirement, but any problem with cabling or device would require the recovery of the entire system. Considering this limitation, a 100 MW array using entirely dry connections begins to appear impractical. Hybrid systems are also being considered, where devices connected in groups using dry mate connections are then connected to the array using wet mate connections.

Aside from the overall type of connection, the actual connection and holding mechanism of the connector must be designed. To ensure that the connection remains closed and sealed, the mass of the device can be used, or a mechanical or hydraulic closure mechanism applied. This mechanism must be able to survive a dynamic, saline, high pressure environment for the lifetime of the array, so represents a significant engineering challenge.

### 3) Cable Damage:

Due to its relative fragility, the cable part of a tidal array is highly vulnerable. Damage to cabling can occur during transport to the site, installation, or during use. Transport damage is likely to take the form of cable twisting or squashing, but the likelihood of this should be reduced over time, as the experience of the industry increases. Industries with similar experience, such as telecommunications and wind energy, are also likely to provide useful knowledge [22].

Cable installation presents both a potentially damaging time as well as the opportunity to protect the cable from damage during use. Cable threats during installation include:

- Loading (hanging, supporting its own weight)
- Twisting or squashing
- Damage during connection

The process of cable installation and the required machinery is discussed further in Section 5. During use, if the cable is well routed and adequately protected it should be relatively safe from damage. However, cable threats during use include damage from fishing, other marine activity (eg. anchors), activities such as dredging, or even marine wildlife.

A wide range of cable protection measures are available to protect the installed cable. An illustration of these measures is given in Figure 11.

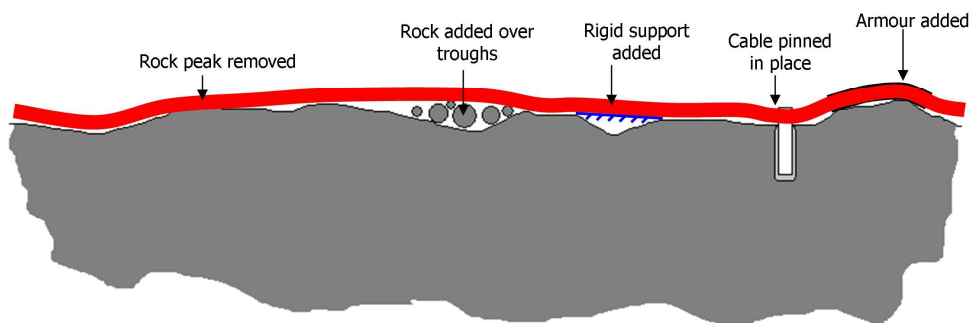


Fig. 11 Examples of seabed cable protection and routing options

By using these methods it is possible to suitably protect a cable from the rigours of the marine environment, but these works are not trivial in complexity or cost, and must be considered from the very early stages of a tidal array project [30].

### D. Power Transmission

It is important to consider the transmission of power from each tidal energy device to the shore, and eventually to the national grid. This incorporates a number of stages, some of which have been described previously. Power transmission stages can broadly be illustrated thus:

Device – Connector – Hub or Rail – Low Voltage Cable – Shoreline – Local Grid – National Grid

Not all cases will require all stages, for example devices which are connected individually (as discussed in Section 4.3.1) would not require connection to the hub or rail. Similarly, some devices do not use an intermediate low voltage transmission stage.

A tidal array will connect to the national grid via a lower voltage network and substations. The voltage of these networks varies around the UK coast, so consultation with local grid operators during the planning of the network is imperative in order to ensure that compatible equipment is selected. Electrical protection systems; fault ride-through capability, and voltage and power factor correction will also be required before any connection can be established. For a 100 MW tidal array these are complex and expensive systems.



## V. INSTALLATION

The installation of a 100 MW tidal array will present many challenges, not least due to uncontrollable variables, such as weather. The installation process can broadly be divided into three stages: transport, installation, and connection.

### A. Device Transport

Before any installation processes can begin, parts must be transported to the site. Transport and installation may be undertaken using the same vessel, as unlike; for example, the onshore wind industry, there is no capacity for storage of parts on site. Even if the transport vessel is not itself used for installation, it may remain present during the installation. It is clear that the choice of vessel for transport and installation is critical to the success of the array.

#### 1) Vessel Selection:

For the purposes of transport, a critical aspect of a vessel's performance is its carrying capacity. A single fully assembled tidal turbine will weigh in the region of 140 tonnes [21]. For the purposes of installation, perhaps the most important consideration is the maneuverability of the vessel, and its ability to remain static (known as "station keeping") in a moving tidal stream.

Large vessels with the ability to hold station within sufficient tolerances do exist and are used by other installers of seabed devices, such as the oil and gas industry, but are very expensive to hire. Such vessels are shown in Figure 12.



Fig. 12 Station-keeping vessels

These are large vessels; the Skandia Arctic (Figure 12, left) is 160 m long and has accommodation on board for 140 people. Station keeping vessels do so using a Dynamic Positioning (DP) system, which maintains the vessel's position in three translational planes of movement:

- Surge (forward / astern)
- Sway (starboard / port)
- Heave (up / down)

Using a computer-controlled system such as GPS to first ascertain the vessel's precise position, the vessels movements are then controlled as required, in order to maintain a static position. There are three classes of DP vessel, which are defined based on the conditions in which the vessel is able to continue to maintain its position.

- Class 1 vessels may move from position if a fault on the vessel occurs, and should be used when the loss of position would not result in human injury, significant damage, or any more than minimal pollution.
- Class 2 vessels may move from position if faults with certain equipment occur, but are able to withstand a single fault. They should be used if a loss of position would result in human injury, significant pollution, or large economic consequences.
- Class 3 vessels should be able to withstand failure of any equipment, or a fire or flood within the vessel. They should be used if a loss of position would result in large human injury, very significant pollution or very large economic consequences.

Due to the increased complexity of the vessel and control system, the cost of a Class 3 vessel is higher than that of a Class 2 vessel, and significantly higher than that of a Class 1 vessel. Tidal energy device installations which have taken place to date have been small scale, with the majority only installing a single device. For this reason, installation vessels have been hired, typically from the oil and gas industry. This is an expensive procedure, and places constraints on the availability of the vessels.

As the number of devices in arrays increases, it becomes more viable to construct or modify vessels specifically for the installation of the devices. The OpenHydro turbine device is expected to be installed in a small test array in the near future [4], and the company have developed an installation barge for this purpose. The barge is towed out to the installation site, and used as an installation platform. This method is believed to dramatically reduce the cost of an installation compared to the hiring of a DP vessel. The installation barge is shown in Figure 13.



Fig. 13 OpenHydro Installer

Further options for reducing this cost exist, such as breaking the device down into smaller parts and installing these separately. Vessel design is also continually moving forward, with developments such as Voith Schneider propeller systems, which allow DP vessels to hold station with high accuracy and lower fuel consumption than traditional systems. Due to the complexity of device installation, it is imperative to consider the design of the installation system simultaneously with that of the device, rather than designing the device and then designing an installation procedure.

## 2) Weather Windows:

The weather is perhaps the most unpredictable and potentially limiting variable in the installation procedure. DP vessels are only able to operate in relatively calm conditions, and if an installation requires the use of ROVs or divers, these are also highly weather-limited. Installers may have to wait a long time for a weather window of the required duration (i.e. a sufficiently long period of expected calm), which can be very expensive if hired installation vessels or equipment are held. Large amounts of money can therefore be saved by the development of vessels with the ability to work in less calm conditions, or devices which can be installed in shorter weather windows.

## B. Cabling Installation

Cable installation has; in many cases, very similar constraints to those discussed for device installation. However, the installation of cables requires its own specialist equipment, and is normally carried out using ROVs and other specific cable-laying equipment. Cable layouts, as discussed in Section 4.3, have many permutations and depend on many other aspects of the array. Due to the complexity of cable installation and requirement for expensive specialised equipment, it seems sensible to reduce the amount of cable installation to a minimum, by combining individual devices' cables as soon as possible.

## VI. OPERATION

Alongside the design and installation, the successful operation of a 100MW tidal energy array also presents challenges. The array must generate as much energy as possible through weather conditions from calm to extreme, be maintained when necessary, and be monitored continually.

### A. Monitoring

The first 100MW tidal array is likely to be extensively monitored, in order to analyse its performance and ensure maintenance is carried out when required [12]. Alongside monitoring of the performance of the devices, environmental conditions such as tidal stream velocity, wave conditions and wind speed are also likely to be monitored. Furthermore, it is likely that some monitoring of marine life will be required, in order to allow “before-and-after” comparisons of habitat conditions. These three distinct areas of monitoring will be carried out simultaneously but independently. Potential methods of monitoring a range of variables are given in Table 2, some of which are the same as those suggested in Table 1, for monitoring prior to site selection.

TABLE II MONITORING OF TIDAL ARRAY PERFORMANCE IN OPERATION

Item to measure	Method of assessment
Array power output	Electronic instrumentation (onshore)
Device power output	Electronic instrumentation (on device)
Tidal stream velocity	ADCP
Wave conditions	WaveBouy
Wind speed	Anemometer
Marine life (small)	Observation / camera
Marine life (large)	Observation

### B. Maintenance

During the lifetime of a tidal array, which is likely to be in the region of 20 – 30 years [28], it is inevitable that some maintenance will be necessary. Individual devices will require routine maintenance, and potentially emergency maintenance. It is estimated that devices might require routine maintenance every 2 years, and major maintenance every ten [21].

Routine maintenance is likely to require the lifting of the device, or at least a part thereof. As discussed previously, this is likely to be a much simpler process if a wet-mate connection has been used, as in this case cabling would not need to be raised. In a farm of many devices, the time taken to carry out maintenance must be considered when designing device maintenance schedules. For example, the time lapse between the maintenance of the first and last devices in a 100 device array may be large, due to the time taken to wait for suitable weather, and to maintain 98 other devices.

#### 1) Safety:

Maintenance will require some degree of human involvement, whether through the use of ROVs or directly using divers. Safety is therefore an imperative during maintenance, and as much danger as possible must be removed at the design stage. This can be achieved firstly by the reduction of direct human involvement wherever possible, for example through the use of comprehensive remote monitoring to enable the remote diagnosis of device problems.

There are currently a limited number of single tidal installations which have reached the operation stage, and no arrays at this stage, so the maintenance requirements of a large tidal array are currently not well understood. The first arrays installed are likely to require more maintenance than those which will be installed later, but the requirements remain the same. Maintenance must be minimised through intelligent monitoring, and devices and arrays must be designed so that it can be carried out as quickly as possible. This will also minimise energy generation downtime and help to improve the economic performance of the array.

### VII. SUMMARY OF KEY CHALLENGES

Previous sections of this report have studied the key challenges in each stage during the phases of a tidal array's lifetime, from proposal to operation. Those issues identified as the most difficult in each case are summarised below.

During pre-design work, the main challenges are likely to relate to community engagement. As discussed in Section 3.2, it is crucial that the local community are positively engaged in the proposed tidal farm, and that resources are directed to this engagement at the very beginning of the project. Failure to do this is likely to result in resistance from the community; which, among other problems, will make the acquisition of leases and licenses for the array more difficult to achieve.

A number of engineering challenges exist during the array design phase, most of which go hand-in-hand with challenges expected during the installation of the array. Two main areas which this work has highlighted are:

- The design and installation of foundations which will remain solid and able to withstand extreme weather for the design lifetime of a tidal array.
- The installation of reliable subsea cabling, with connections to allow the maintenance of the devices.

Installation challenges relating to vessels are also expected to be some of the most difficult to solve. Currently available DP vessels are expensive and weather-limited, making the cost of device installation difficult to predict accurately. The use of specifically-designed barges or vessels may offer a viable alternative.

Similarly, maintenance presents its own issues. If emergency maintenance is required, it may not be possible to wait for a weather window. In this case, a method of making the device safe remotely will be needed.

### VIII. ARRAY DEVELOPMENT TIMELINE

As a final part of this project, it was felt that it would be beneficial to estimate the time required for each of the main processes required to develop a 100MW tidal array from inception to generation.

Due to the infancy of the industry as a whole, and especially in the development of tidal arrays, it was difficult to estimate the required time for each process. Although analogous work in other industries[15, 22-23] was used, the timescales indicated in the figure below should be considered as educated guesswork. However, the chart aims to illustrate the importance of simultaneous work, as well as highlighting the number of processes which must be carried out before any work on site takes place. Unforeseen time requirements are not included, such as time when installation vessels are unavailable, or delays due to weather.

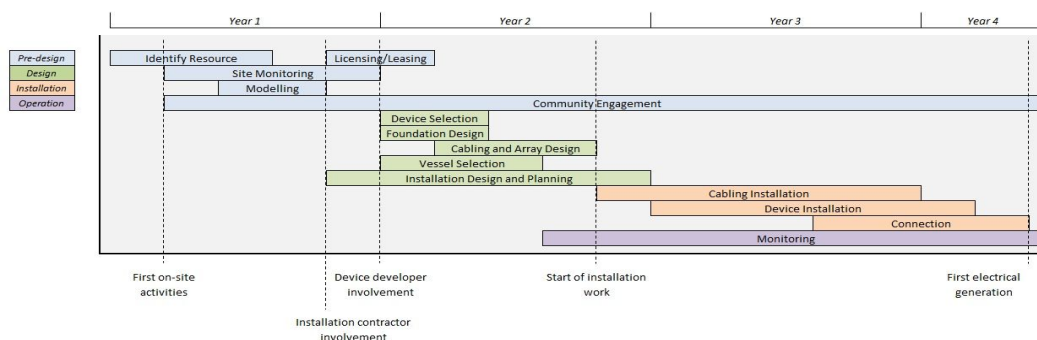


Fig. 14 100MW tidal array development timeline

## IX. CONCLUSIONS

This paper has studied potential barriers to the implementation of a 100 MW tidal array in UK waters. At the RenewableUK conference in October 2011, it was suggested that the UK tidal energy industry is currently demonstrating its potential, prior to the roll-out of the first tidal arrays. That potential is large, being estimated at over 10 GW [1], and the UK is currently leading the world in the development of tidal energy devices and technology.

However, if the UK is to cultivate a viable tidal energy industry, challenges in the scaling-up of the current resource must be addressed. These challenges have been identified in this paper, and range from community engagement, to the arrangement of leases and licensing, to engineering challenges like cable installation and device maintenance in extreme weather.

In many ways, the UK tidal energy industry is heading into the unknown, but none of these challenges are insurmountable. With knowledge from within the industry and from other related technologies, it is likely that all can be solved. Success is much more likely if all parties work together and take a holistic approach to the design of an array. Tidal power offers a viable future energy source, and a particularly useful one due to its predictability. As a result the author believes that the industry is very capable of solving these challenges and delivering a 100 MW tidal array by the end of this decade.

## ACKNOWLEDGMENT

The author would like to thank all who attended the “Tidal Array in a Day” event during the 2011 RenewableUK conference, especially Abbie Badcock and David Stoddart-Scott, who assisted with and encouraged this work after the conference.

The author would also like to thank research group members who read drafts of this work and suggested improvements, particularly Jon Leary and Louis Angelo M. Danao, as well as the author’s PhD supervisors, Dr. Robert Howell and Dr. Wernher Brevis.

## REFERENCES

- [1] E., D. and A. B., Phase II UK Tidal Stream Energy Resource Assessment. Carbon Trust, 2005.
- [2] Carbon Trust - Future Marine Energy. 2006.
- [3] Boettcher, D., Tidal power in line for more funding, in BBC News. 2011.
- [4] Pham, C. and V. Martin, Tidal current turbine demonstration farm in Paimpol-Brehat. 2009.
- [5] Drax Group - About our Business. 9/12/2011; Available from: <http://www.draxgroup.plc.uk/aboutus/ourbusiness/>.
- [6] RenewableUK, Wave and Tidal Energy in the UK. State of the industry report. 2011.
- [7] Matthews, C., Drax Power Station (Creative Commons Attribution Share-alike license 2.0). 2009.
- [8] MacKay, D., Sustainable Energy - Without the Hot Air. 2008.
- [9] BBC, Severn barrage tidal energy scheme scrapped by Huhne, in BBC News. 2010.
- [10] DECC. Atlas of UK Marine Renewable Energy Resources.
- [11] CONNOR, D.W., et al., THE MARINE HABITAT CLASSIFICATION FOR BRITAIN AND IRELAND VERSION 04.05. 2004.
- [12] Erwin, D., Presentation - Environmental monitoring, liaison and consultation concerning the MCT Strangford Lough Turbine. 2007.
- [13] Scottish Natural Heritage Scientific Advisory Committee - Tidal Turbines and Natura 2000. 2000.
- [14] Henry, B., et al., Marine life interaction with tidal turbines. 2007, University of Strathclyde.
- [15] European Marine Energy Centre. 19/12/2011; Available from: [www.emec.org.uk](http://www.emec.org.uk).
- [16] Akwensivie, F., IN THE WAKE OF A MARINE CURRENT TURBINE. 2006.
- [17] MacLeod, A.J., et al., Wake effects in tidal current turbine farms. IMarEST, 2002.
- [18] Bahaj, A.S., Generating electricity from the oceans. Renewable and Sustainable Energy Reviews, 2011.
- [19] Meyers, J. and C. Meneveau, Optimal turbine spacing in fully developed wind farm boundary layers. Wind Energy.
- [20] Badcock, A., et al. Tidal Array in a Day. 2011.
- [21] TGL DeepGen Brochure, Tidal Generation Limited.
- [22] Global Marine Systems, Norddeutsche Seekabelwerke GmbH and Global Marine Systems Ltd. to supply and install the infield cabling of the Global Tech I Wind Farm in the North Sea. 2008.
- [23] How to install and construct farshore, deepwater wind farms on time and cost efficiently. Wind Energy Update - Offshore Wind Construction & Installation Report. 2011.
- [24] J. Padhye, V. Firoiu, and D. Towsley, A stochastic model of TCP Reno congestion avoidance and control, Univ. of Massachusetts, Amherst, MA, CMPSCI Tech. Rep. 99-02, 2008.
- [25] J. Breckling, Ed., The Analysis of Directional Time Series: Applications to Wind Speed and Direction, ser. Lecture Notes in Statistics. Berlin, Germany: Springer, 2008, vol. 61.
- [26] P. Devine-Wright, Beyond NIMBYism: towards an Integrated Framework for Understanding Public Perceptions of Wind Energy, Wind Energy, 8:125–139, 2005.
- [27] The Crown Estate. 06/03/2013; Available from: [www.crownestate.co.uk](http://www.crownestate.co.uk)

- [28] The Seagen Turbine, Marine Current Turbines. 2008.
- [29] Scour Regime and Scour Depth around a Pile in Waves, S. Umeda, Journal of Coastal Research, Proceedings of the 11th International Coastal Symposium. 2011.
- [30] Submarine cables and the oceans: connecting the world, International Cable Protection Committee. ISBN: 978-0-9563387-2-3. 2009.



**Stuart R.J. Walker**, born in North Yorkshire, England, May 1985, studied at Stokesley School, Stokesley 6<sup>th</sup> Form College, and The University of Sheffield and graduated 2007, MEng Mechanical Engineering, Dept. of Engineering, University of Sheffield, South Yorkshire, UK. After graduation, he worked in AECOM's Advanced Design Group in Leeds, Yorkshire, UK. He is currently working as a PhD researcher at the University of Sheffield E-Futures Doctoral Training Centre. His PhD title is "Optimising the Spatial Layout of a Farm of Tidal Turbines". He has previously published work in the IMechE Journal of Engineering for the Maritime Environment and the Journal of Applied Psychology. Mr. Walker is a full member of the Institute of Mechanical Engineers, and a Graduate member of the Institute of Energy. Mr. Walker is very grateful to the EPSRC for supporting his research through the E-Futures DTC program.