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Best practice report – Operation and Maintenance requirements

Deliverable 3.6.3 from the MERiFIC Project

A report prepared as part of the MERiFIC Project "Marine Energy in Far Peripheral and Island Communities"

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Executive Summary

This report is a deliverable of MERiFIC Work Package 3.6: ‘Operation and Maintenance requirements’ and has been produced as a cross border collaboration between IFREMER and the University of Exeter. The report provides an overview of guidelines and recommendations for the management of O&M operations necessary for an optimal exploitation of Marine energy plants, with a focus on the specific areas of South West Cornwall, UK and Iroise sea, Brittany, France. An overview of the onshore infrastructures and ports possibly suitable for management of such O&M operations is also provided. Management of scheduled and unscheduled maintenance operations are discussed in their various aspects including site accessibility. It should be noted that this topic, including weather window assessment for operations is discussed in more details in the additional MERIFIC report *D3.6.2: Best Practice for installation procedures* [17].

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The MERiFIC Project

MERiFIC is an EU project linking Cornwall and Finistère through the ERDF INTERREG IVa France (Manche) England programme. The project seeks to advance the adoption of marine energy in Cornwall and Finistère, with particular focus on the island communities of the Parc naturel marin d'Iroise and the Isles of Scilly. Project partners include Cornwall Council, University of Exeter, University of Plymouth and Cornwall Marine Network from the UK, and Conseil général du Finistère, Pôle Mer Bretagne, Technôpole Brest Iroise, IFREMER and Bretagne Développement Innovation from France.

MERiFIC was launched on 13th September at the National Maritime Museum Cornwall and runs until June 2014. During this time, the partners aim to

- Develop and share a common understanding of existing marine energy resource assessment techniques and terminology;
- Identify significant marine energy resource 'hot spots' across the common area, focussing on the island communities of the Isles of Scilly and Parc Naturel Marin d'Iroise;
- Define infrastructure issues and requirements for the deployment of marine energy technologies between island and mainland communities;
- Identify, share and implement best practice policies to encourage and support the deployment of marine renewables;
- Identify best practice case studies and opportunities for businesses across the two regions to participate in supply chains for the marine energy sector;
- Share best practices and trial new methods of stakeholder engagement, in order to secure wider understanding and acceptance of the marine renewables agenda;
- Develop and deliver a range of case studies, tool kits and resources that will assist other regions.

To facilitate this, the project is broken down into a series of work packages:

WP1: Project Preparation
WP2: Project Management
WP3: Technology Support
WP4: Policy Issues
WP5: Sustainable Economic Development
WP6: Stakeholder Engagement
WP7: Communication and Dissemination

1 Introduction

A key requirement for the continued operation of a MRE device is to have in place the facilities, personnel and procedures to i) effectively carry out routine operation and maintenance (O&M) procedures and ii) rapidly respond to unscheduled maintenance requirements. Scheduled maintenance has to be carried out in order to keep the performance of components, assemblies and systems at the required level necessary for optimum power production over the lifetime of the device or arrays of devices. It also includes preventative measures to mitigate the risk of failure which are based on reliability analysis and measurements from condition monitoring systems. In addition, the flexibility to be able to adapt to rapidly changing circumstances is necessary (i.e. component or system faults, short-term weather variations and equipment or vessel availability). Failure to address these issues will inevitably lead to a loss of device availability and subsequent impact on the revenue that is generated. With onshore wind, a relatively mature technology, Walford [1] highlighted the influence of component reliability on O&M costs and ultimately the cost of energy.

The operation and maintenance of offshore equipment is not a new requirement and a substantial range of support vessels, trained personnel, equipment and procedures exist to fulfil necessary actions. Some, but not all of this expertise and facilities is transferable to the MRE industry, as has been the case of offshore wind (in which O&M costs are expected to increase to £1.2bn/year in the UK [2]). Due to the diversity of MRE designs either proposed, trialled or currently deployed, O&M requirements are likely to be highly device specific and long-term deployment experience is required before these requirements can be accurately defined. As array deployments increase the utilisation of offshore expertise, equipment and vessels will clearly put increased pressure on the existing offshore support industry, whilst creating new financial opportunities. Already low vessel availability has been reflected in the competing requirements for jack-up barges by the offshore wind and oil and gas industries[1]. To reduce operation bottlenecks, the industry has responded by commissioning vessels which have been designed for offshore wind turbine installations, such as DBB's *Wind Server*[2]. This trend has also been reflected by the emerging tidal energy industry (e.g. OpenHydro's installation barge[3] and the recent High Flow Installation Vessel , HF4 project[4]).

It may be necessary to carry out O&M actions year-round in a range of weather conditions. MRE devices tend to be located in energetic environments suitable for energy extraction (i.e. high tidal or wave energy resource locations). The sites may therefore be challenging to work in, potentially featuring extreme waves and wave loads. The safety of personnel has to be a priority and access may be limited if conditions for a required task dictate that it is not safe to work[5].

This report provides an overview of guidelines and recommendations for the management of O&M operations necessary for an optimal exploitation of Marine energy plants, with a focus on the specific areas of South West Cornwall, UK and Iroise sea, Brittany, France.

[1] http://www.offshore-technology.com/features/featureoperation-maintenance-offshore-wind-oil-gas-hydrocarbons-installed-capacity-wind-farm-specialised-resources-ship-boat-vessel-installation/ (accessed online 03/12/12)

[2] http://www.windpoweroffshore.com/article/1214101/specialised-vessels-cut-costs (accessed online 03/12/12)

[3] http://www.openhydro.com/news/OpenHydroPR-010911.pdf (accessed online 03/12/12)

[4] http://worldmaritimenews.com/archives/94136/mojo-maritime-high-flow-project-remains-on-schedule/ (accessed online 03/12/12)

[5] Weather windows for Marine Operations and access time assessment procedures which are of primary interest for the management of Operations and Maintenance were presented and discussed in the MERIFIC report *D3.6.2 Guidelines for Installation Operations*

Management of operations is briefly commented in Section 2. Recommendations for the management of O&M operations, whether they are scheduled or not are presented in Section 3 and include details on site accessibility for both geographical areas. The major ports equipped with facilities suitable for such O&M operations are presented in Section 4 and the specific case of the maintenance operations at SWMTF is provided as an example in Section 5. Finally recommendations are provided in Section 6 to help reducing O&M operations costs.

2 Operations

Defined as the management of the asset on a day-to-day basis, operations management includes; device monitoring, control and performance assessment, environmental monitoring and logistics management. The latter category could include; O&M scheduling (including organising personnel), responding to faults, as well as co-ordination with equipment manufacturers and suppliers, service providers, consenting bodies and harbour authorities. Integral functions also include the sale of generated electricity, co-ordination with utility companies and the distribution grid, marketing, administration, accounting, dealing with warranty issues and human resources management.

A vital part of operations management is the ability to determine how the device is performing at the deployment site and when support vessels are required to perform O&M activities. The latter requirement is clearly dependent on the vessel characteristics, vessel availability and environmental conditions. At a basic level, a developer will be interested in the level of power production for an array or farm of devices subjected to a given set of wave or current conditions (e.g. Figure 1). Based on these measurements, adjustment of the device, or array of devices, may be possible to optimise power production in response to the grid demand in real-time using active control [4,5]. It is likely that MRE farms will utilise Supervisory Control and Data Acquisition (SCADA) systems which have already been successfully used for wind turbines [6]. In addition, condition monitoring of critical components provides an early warning of premature failure which necessitates a preventative maintenance action [7]. Several example monitoring activities are listed in Table 1, although not all of these may be economically feasible or relevant to the application. The project stage will also determine the level of monitoring required (i.e. if it is a prototype at an instrumented test site or mature technology [8-10]).

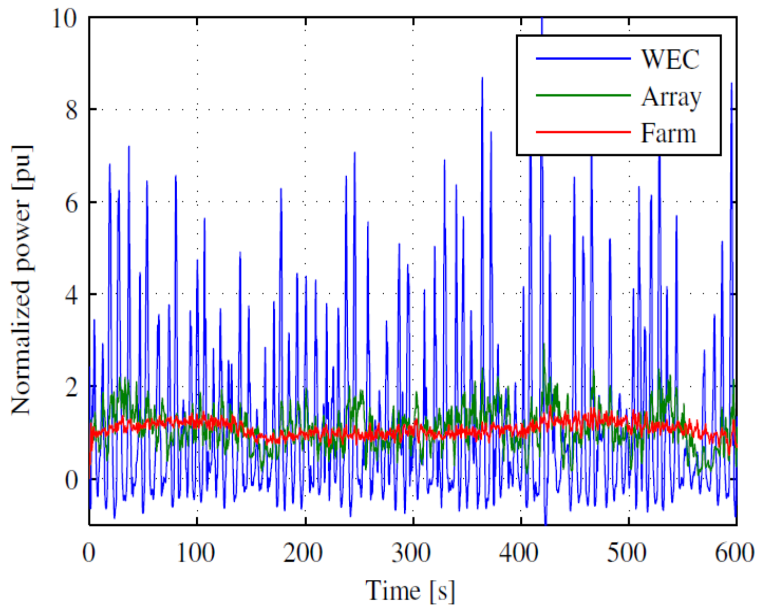

FIGURE 1: Simulated comparison of the power generated by an Fred Olsen “Lifesaver” wave energy converter compared to an array and farm of devices [3]

Performance	Integrity	Dynamic	Environmental
Device and array power production	Load and strain (i.e. mooring tensions, hull, or turbine blade stresses/strains)	Device motion (e.g. accelerometers, gyroscopes)	Near /far-field; Wind (speed and direction), Current (speed, direction) , Wave (height, period, directionality and spread)
Grid demand	Hull integrity/water detection	Device position (DGPS) and heading	Water and air temperature, salinity
Hydraulic/pneumatic system pressures and pump or turbine performance	Fire detection	Rotating component vibration detection (accelerometers)	Sonar mammal detection
Status of power take-off control systems (valves, limit switches etc.)	Fault analysis and diagnostic systems		
Remote sampling of lubrication oils	Status of storm contingency system (if an active system)		

TABLE 1: Example continuous monitoring activities

3 Maintenance

In order to keep the level of device availability at a commercially viable level (i.e. the device or devices are capable of generating electricity), repair and upkeep operations must be conducted throughout the operable lifetime of the device. To put this into context the level of availability for an offshore wind farm is typically between 90-95% [2]. The MRE industry is less mature and availability data is not readily available, except for a few examples (e.g. Wavestar [11]).

The required type and frequency of maintenance actions will clearly depend on the device design, the reliability of the components used and the number of opportunities available for access to the device.

Distinction can be made between scheduled or proactive maintenance and unscheduled or reactive maintenance. For scheduled tasks, a balance must be found between the specification of over-zealous routine maintenance (which will incur high costs unnecessarily) and a lack of maintenance (which could lead to revenue being lost through non-availability of devices). Maintenance operations typically involve physical intervention at the site, although some operations may be carried out remotely (i.e. the maintenance of IT equipment and networks and firmware updates).

3.1 Scheduled maintenance

This includes the repair or replacement of worn components identified from a routine inspection or condition monitoring. These measures are preventative in nature to avoid the failure of components which are necessary to the normal operation of the device. The alternative may be total loss of the asset, or damage and injury to other water users or adverse environmental impact. It may be necessary to carry out minor maintenance or inspection tasks [12] on a regular basis at the site, with larger operations carried out either at the site or nearby port at longer intervals. The required maintenance and inspection intervals for particular components will depend on the reliability for the given application and this can be determined from component testing programmes in representative conditions (i.e. sea-trials or destructive/non-destructive laboratory tests [13]) and the development of reliability prediction tools (e.g. [14,15]). The inspection routine may include periodic sampling of lubrication fluids as an early warning to wear or fatigue. Another factor will be the logistical effort required to complete the task. For example, the inspection of sub-sea mooring components is currently reliant on device position and load monitoring, sonar detection systems or visual inspections from remotely operated vehicles (ROV) and/or dive teams. More detailed inspections require the recovery of components and perhaps complete mooring lines (requiring vessels with lifting or winch equipment)[6]. Commercial Off-The-Shelf (COTS) equipment manufacturers can usually recommend (or specify as part of an equipment warranty) the required maintenance intervals and actions required for their equipment[7]. Typical tasks are listed in Table 2.

Medium interval **~6 months**	**Long interval** **~1 year**
Lubrication of universal joints	Replacement of hydraulic and transmission oil and filters
Underwater inspection of subsea mooring system components (ROV, Sonar probe, dive teams)	Removal of bio-fouling and reinstatement of preventive fouling measures
In-situ sampling of oils	Hull and mooring attachment point inspection
Adjustment	Mooring line re-tensioning
Firmware/software updates	Replacement of cathodic protection measures
Re-tensioning of transmission chains or belts	Replacement of transmission chains or belts
Cleaning of bio-fouling from exposed surfaces (i.e. solar panels, navigation lights etc.)	Above-surface inspection of mooring components (for distortion, cuts, gouges, cracks, corrosion, abrasion wear)

TABLE 2 : Example scheduled maintenance and inspection tasks

3.2 Unscheduled maintenance

In contrast to scheduled maintenance which can be planned far in advance, it may be necessary to repair or replace failed or damaged components at short notice to enable the continued operation of the device. The complete recovery of the device may be necessary. Reactive intervention may occur due to particular short duration events, caused by extreme weather conditions or impact by vessels/marine mammals. Although the replacement and inspection of critical components will feature in scheduled maintenance actions, early component failure may occur due to serial batch defects or the failure of other components. The risk of this happening can be mitigated through reliability prediction analysis refined by field experience, particularly in

[6] In-service maintenance and inspection considerations for synthetic mooring ropes are summarised in the MERiFIC deliverable *D3.5.2 Guidance on the use of synthetic fibre ropes for marine energy devices*

[7] COTS equipment utilised in an application which is different (i.e. a harsh marine environment) from what it is designed for will require special consideration. Standard equipment warrantees are unlikely to be valid in this case.

the fatigue performance of components. The consequence of failure can also be reduced by building redundancy into the system.

<table>
<tr><th>Mooring System</th><th>Power Take-Off System</th><th>Device</th><th>Navigation and Communications Equipment</th></tr>
<tr><td>Anchor displacement/pull out</td><td>Loss of lubrication</td><td>Corrosion</td><td>Loss of data link</td></tr>
<tr><td>Fatigue</td><td>Overheating</td><td>Composite osmosis/blistering</td><td>Navigation light failure</td></tr>
<tr><td>Corrosion</td><td>Failure of safety release valves</td><td>Damage due to wave impact or slamming</td><td rowspan="5">Corruption of data storage (i.e. hard drive or memory failure)</td></tr>
<tr><td>Misalignment/bending of chain links</td><td>Breakdown or damage of electrical insulation</td><td>Impact with other water users</td></tr>
<tr><td>Abrasion</td><td>Fatigue of conductive elements in cables</td><td rowspan="3">Structural failure due to overloading</td></tr>
<tr><td>Factors specific to synthetic components[8]</td><td rowspan="2">Failure of rotating components due to ingress of water or salt air</td></tr>
<tr><td>Extreme snatch loading</td></tr>
</table>

TABLE 3 : Possible failure mechanisms which may necessitate unscheduled intervention

3.3 Logistical Considerations

Logistics play a key role in the management of Operation & Maintenance. A large number of issues are to be considered, from the suitability of the onshore infrastructure to the availability of replacement components, as well as accessibility and transit time to the site. Some useful elements and references related to chain supply can be found in the MERIFIC *Procurement code of Practice* [16]. Assessment of weather windows for access to site and additional information on supply vessels can be found in MERIFIC report *D3.6.2 Guidelines for Installation operations* [17].

3.3.1 Onshore infrastructure

This refers to all onshore facilities which are directly related to the maintenance of the device(s) at sea. This location will most likely differ from the cable connection point and related infrastructure (i.e. substation, inverters, rectifiers and grid interface) or in the case of pumped systems, turbines and hydraulic control equipment. Port-side activity and facilities include: warehouses and storage space, on-site offices, vehicular access (including the capability to handle large lorries), lifting equipment and cranes, berthing space, vessel hire and trained maintenance personnel.

It may be necessary to use multiple ports if it is not possible for all operations to start from one location (i.e. due to harbour berthing or road access constraints). Port and harbour locations in the South West of the UK and Brittany, France are shown in Figure 7 (a - c) in Section 4. The port may serve only as a disembarkation and embarkation point for vessels and equipment. In addition, if the port has relevant expertise and suitable facilities it could be utilised for major maintenance and overhaul actions.

[8] Failure mechanisms specific to synthetic ropes are available in the literature, including the MERiFIC deliverable *D3.5.2 Guidance on the use of synthetic fibre ropes for marine energy devices*

3.3.2 Offshore Activities

The equipment, planning and resources required to carry out maintenance are summarised in this section. Considerations which also feature in device installation are not included in this report, instead the reader is directed to the MERiFIC deliverable *D3.6.2 Best practice report - installation procedures*.
A list of the Operation and Maintenance supply chain for the South West of the UK is summarised in Appendix 2. The survey of supply chain companies was undertaken in 2012 and the survey can only be used as an indicative information record and would need frequent updating.
Similar information on the Operation and Maintenance supply chain in Brittany and Finistère can be found in the document *Bretagne Energies Marines Renouvelables - Guide des compétences* published by Bretagne Développement Innovation [30].

3.3.2.1 Site accessibility

Tidal currents, wind and wave conditions can all affect various operations at sea and in order for a number of critical tasks during a deployment or maintenance to be successfully completed these procedures are often limited on specific thresholds. The exact level of this threshold will vary from operation to operation but it is often limited to currents velocities up to 1.5m/s and wave conditions up to H_{m0} = 0.75m. Figure 2 gives an example for tidal current at neap tides and slack water periods with a threshold of 2.5m/s, whilst Figure 3 gives an example for wave conditions with a threshold of H_{m0} = 1.0m. It can be seen from both simplified examples that the operation times are relatively short, where access time is not included in the consideration.
Clearly these limitations can have a massive effect on the likely success of marine operations. To achieve success the following alternatives are available:

- Design a simple operation which can be executed in these short slack water windows;
- Design a robust operation chartering a vessel allowing the operation to be executed in more severe conditions.

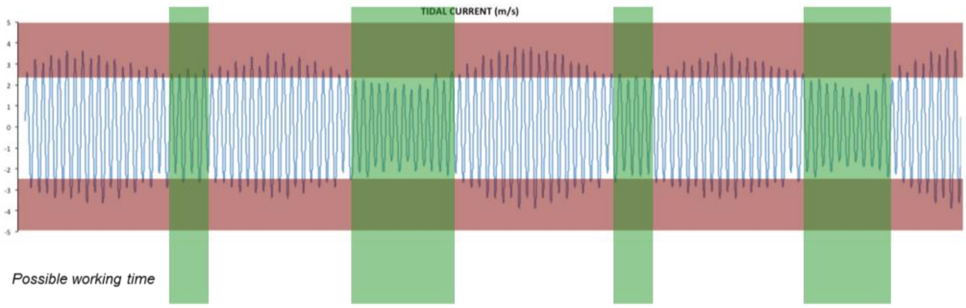

FIGURE 2: Tidal current velocity at neap tides and slack water periods (MOJO MARITIME, 2012)

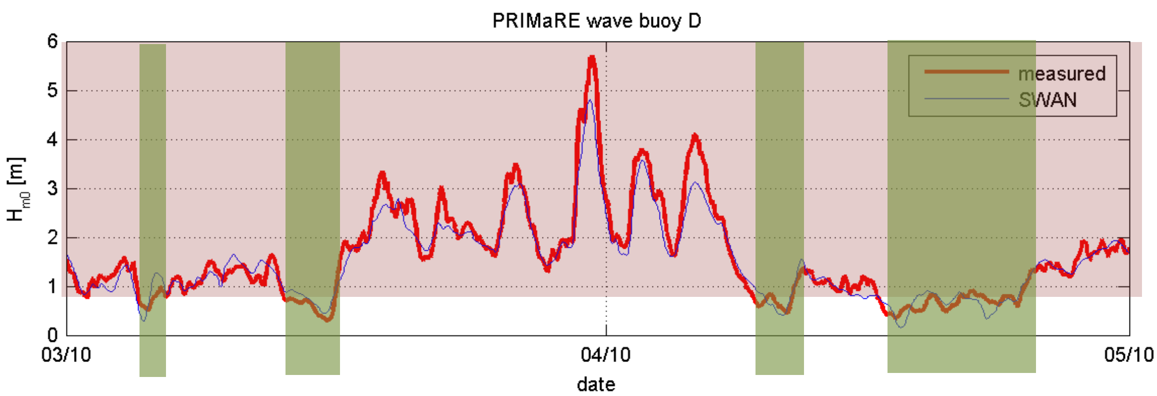

FIGURE 3: Wave conditions for 3rd and 5th October near Wave Hub site [27]

In areas with strong tidal currents were tidal turbines plants are likely to be deployed, strong wave-current interactions may occur that may induce periodic changes in characteristics of sea-states, mainly alteration of the significant wave height. Such fluctuations of the significant wave height will also affect the duration of access weather windows for a given threshold (Figure 4).

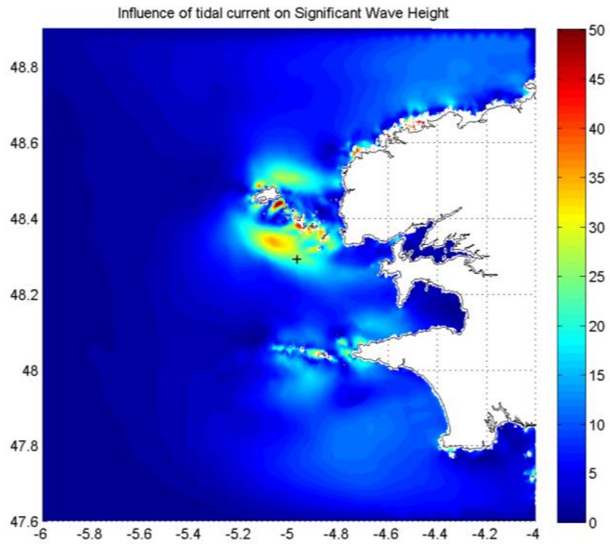

FIGURE 4 : Areas of influence of wave-current interaction on significant wave height in the Iroise sea

Larger maintenance operations will tend to be scheduled during the spring and summer months when there is an increased likelihood of favourable weather conditions for safe working. A detailed discussion regarding accessibility criteria for Iroise sea in France and South West of England in the UK is presented in the MERiFIC deliverable D3.6.2 [17]. The results of the findings are shown here in Figure 5 for access and waiting hours for deployment at Wave Hub from Falmouth over a one year period, based on statistical environmental conditions and specific operation requirements. It can be seen that waiting times are longer in the winter and shorter in the summer. The analysis also distinguishes between access to site, operation at site and return journey from site. The solid line at top identifies the overall hours per month.

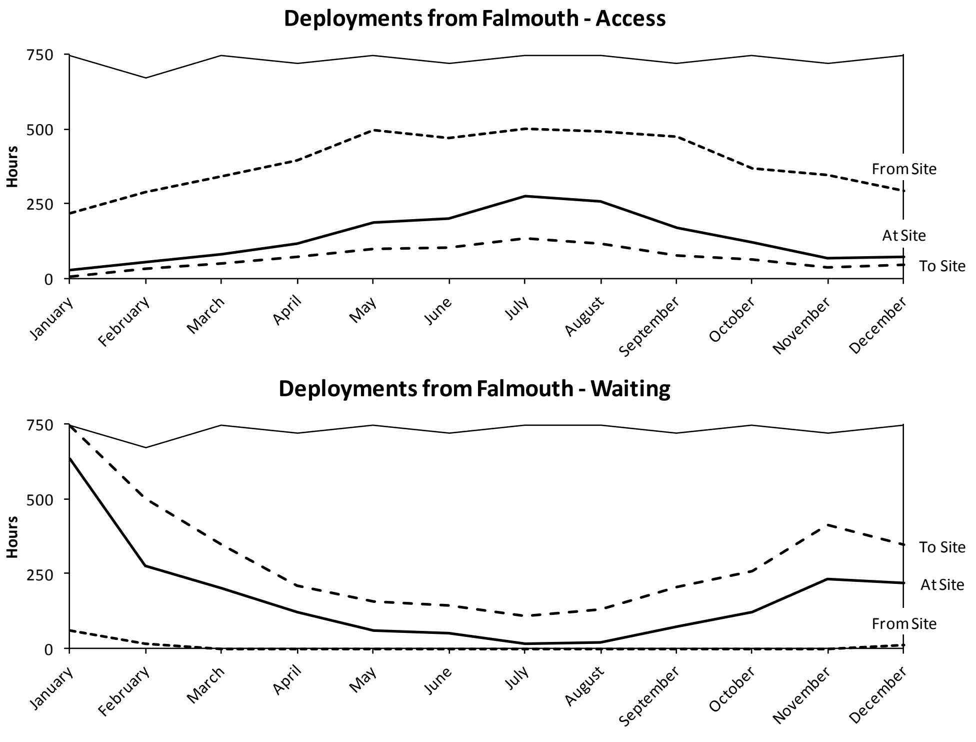

FIGURE 5 : Example of access and waiting hours for deployment at Wave Hub from Falmouth over a one year period

Slightly different information is provided in Figure 6 for the case of Iroise Sea for a point located off-shore, 49 nautical miles west of Brest harbour, based on a 19-year analysis. This figure presents the access time and waiting time for a weather window corresponding to a sea state with a significant wave height lower than 2 m for a continuous duration of 48 hours. It shows similar trends with longer waiting periods during the winter time.

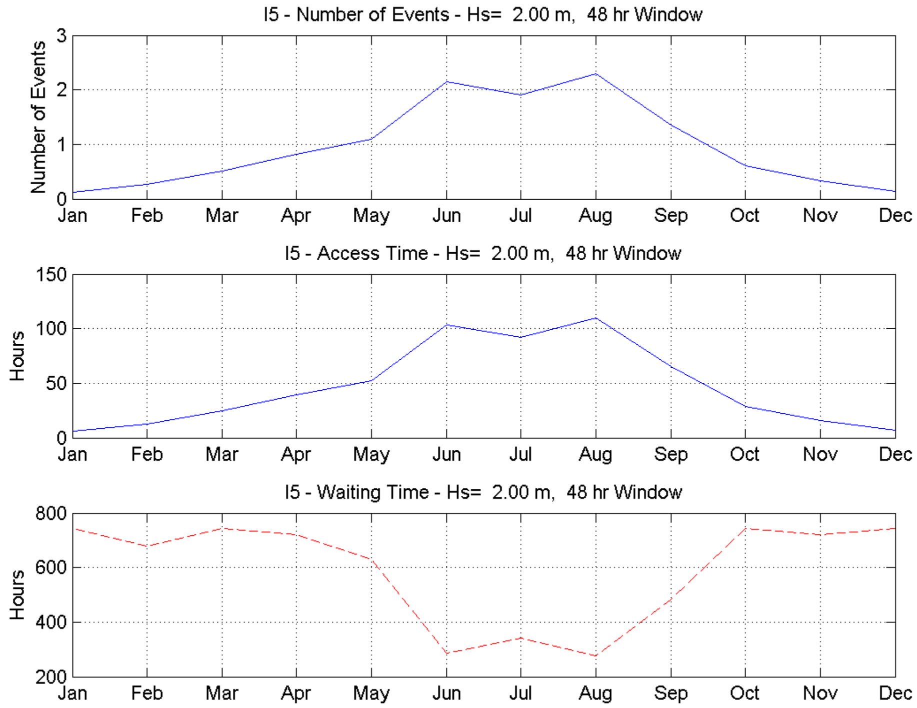

FIGURE 6 : Example of access and waiting hours at site I5 in the Iroise sea

Implementing predictive maintenance intervals in the summer month can reduce the risk of significant and unexpected power production interruption, and in the case of floating wind or wave energy devices operations can be conducted during months when available resources are relatively lower. However, for these reasons it is unsurprising that charter costs for vessels and crew are high during the summer months [18] and certain operations (i.e. unscheduled maintenance) may have to be carried out over the winter months when weather and sea-state conditions are harsher. Whilst the day rate of vessels is typically lower during the winter months, overall costs could be higher due to the risk of delays occurring as a consequence of adverse weather conditions. Charter costs are likely to include a standby charge if the task is delayed or interrupted. Maintenance is therefore a year-round requirement that requires carefully planning and implementation.

3.3.2.2 Transit or response time

Primarily this is a function of vessel power and speed (which will depend on the weather conditions and capabilities of the vessel) and distance from onshore facilities to the site. Assuming that the weather and sea-state conditions do not permit work vessels to remain at the site (on-board crew accommodation is not provided), fuel costs and transit time to the nearest harbour or port at the end of each work day will have to be included. Another important factor which will influence maintenance scheduling is the mobilisation time required, particularly if specialised vessels or equipment are required which may not be located close to the host port.

3.3.2.3 Component replacement

The lead time required for replacement components to be manufactured, ordered and delivered will also influence how a maintenance schedule will be formulated. This will also determine how quickly an unscheduled maintenance operation can be completed. By obtaining a stock of replacement parts, particularly those which have been identified to have high failure rates, the risk of delay due to component lead times can be reduced but will clearly incur capital and storage costs.

3.3.2.4 Number, size and layout of devices

Much in the same way as offshore wind developments, large scale MRE projects will feature multiple devices in array layouts in order to allow shared electrical or hydraulic infrastructure and mooring or foundation points. The spacing of devices will depend on the design in question, with the spatial distribution of tidal turbines dependent on wake effects [19,29]. Under particular conditions the hydrodynamic interactions occurring between closely spaced wave energy converters can have a positive influence on the level of power generated [20].

The spacing of devices will determine their accessibility and the selection of the vessel. A small, highly manoeuvrable vessel may be sufficient for routine maintenance procedures which require a small number of personnel and equipment. Larger operations such as device recovery or lifting will require a more substantial vessel. In this case access to devices on the edges of the array will be straightforward; however access to central devices could prove to be difficult if the devices are spaced close to each other and may necessitate the temporary removal of devices which are in the way. Allowances should be made for device and vessel drift during these operations.

The number of devices will determine the scale of the maintenance operation. A degree of redundancy may have been factored into the array layout, in which one or more devices which are under-performing may be temporarily decommissioned until the next maintenance interval.

4 Ports

Within the area of assessment for the MERiFIC project (Finistère and South West of England), multiple port facilities exist from minor ports to major port facilities. Some ports are shown for South of England in Figure 7 (a) and (b); whilst Figure 7 (c) identifies some ports for Finistère.

(a)

(b)

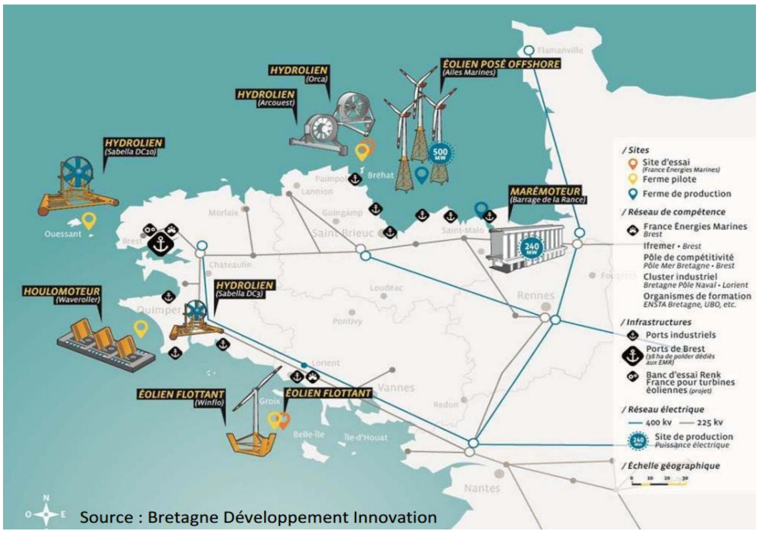

FIGURE 7 (a)- (C): (a) Port locations identified in the South West Marine Energy Park (SWMEP) prospectus, (b) identification of ports at the south coast of Cornwall, (c) Principal ports and harbours and existing and proposed test sites in Brittany[9]

[9] Image from *Marine renewable energies in France. Focus on Brittany* http://www.merific.eu/files/2012/06/Green-Cornwall-Show_Jeremie-Bazin_Technopole-Brest-Iroise.pdf (accessed: 05/12/2013)

4.1 South West of England

Currently the majority of the ports located in the South West of England are unlikely to have a major role in marine energy development, however, a more detailed investigation would be necessary to make final conclusions. Some possible ports have been investigated further identifying existing criteria.

FOWEY

FIGURE 8 : Aerial view of Fowey harbour

Location 50º20' N, 04º38' W

Current use: Commercial, china clay

Berth details: 6.7 to 7.3m depth, 100 to 120m max vessel length.

Constraints: Limited road access to Port of Fowey with height restriction of 3.8 metres via the privately owned Pinnock Tunnel. At present no trucks arrive in Fowey by public road. There is currently no storage capacity at Fowey. None of the jetties have spare area for significant storage.

PAR

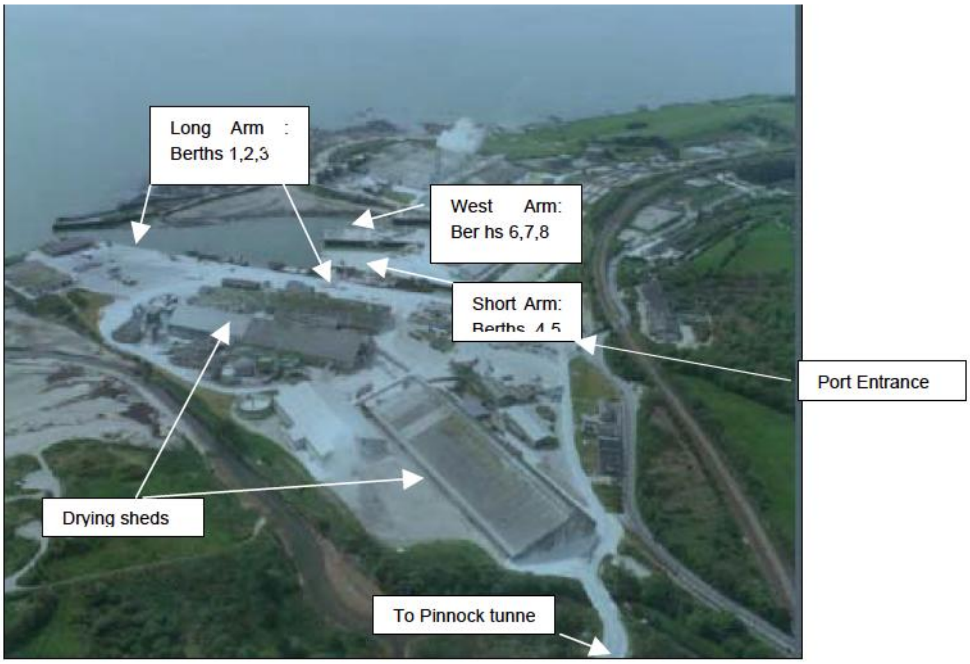

FIGURE 9 : Aerial view of Par port and china clay works

Location: 50 20N, 04 42W

Berth details: 8 berths, each vessel max length 100m.

Current operations: Not currently in use. Previously use as a bulk/bag berth.

Existing constraints: Par is a NAABSA port meaning that the port dries at low water and all vessels load safely aground on mud/shingle.

The Par Long Arm Quay at Par has the potential to provide good berthing opportunities for installation or O&M vessels. However, some capital investment is required, as currently there is no suitable loading equipment located at the berth. Par has good storage capacity but these areas need significant investment for upgrading. Table 4 shows an estimated cost for upgrading Par's port, including the dredging, construction of quay wall, reclamation, paving, 10% preliminaries and 20% contingency.

	Port works	
	Low Cost	High Cost
Par Long Arm (2 berths)	£4.38m	£6.54m
Par Long arm (1 berth)	£2.21m	£3.25m
Par Spending Beach (2 berths)	£7.97m	£11.64m

TABLE 4: Cost estimates for ports' upgrades (MDS Transmodal, 2013)

FALMOUTH

FIGURE 10 : Falmouth docks (A&P Group, 2011)

Location: 50 09N, 05 03W

Details: 4 berths, with length capacity of between 135 and 202m, and navigational draft between 6.00 and 7.50m

Current operations: Commercial.

Falmouth is one of the most capable ports for the development of the offshore projects. It is a fully sized commercial port with the key required criteria, with capacity for accommodating oversized vessels. Road links are available and the deck strength meets loading requirements. In addition there are 8 cranes available with capacities of up to 60 Ton /50m (load capacity/max. outreach). (A&P Group, 2011).

Falmouth could prove to be another solid choice for a staging port due to its size and facilities. It is also the location of major suppliers including A&P Falmouth who are developing a Renewables Quayside Facility (RegenSW, 2012).

CATTEWATER (PLYMOUTH)

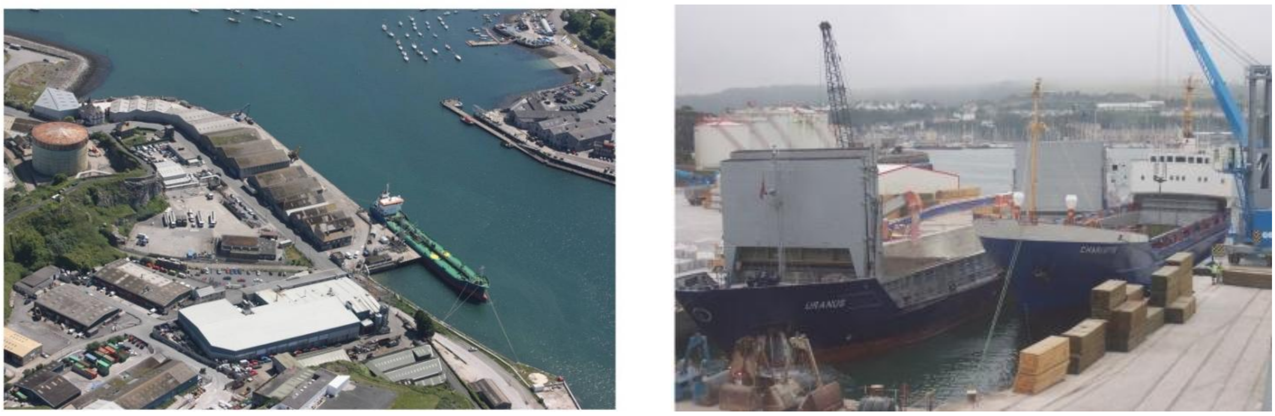

FIGURE 11 : Cattewater, Plymouth (Cattwater Harbour Commissioners, 2013)

Location: 50 21N, 04 07W

Berth details: Vessel capacity of up to 140m length and beam of 18m

Current operations: The port is home to two leading marine civil engineering companies who use the port as a mobilisation base for the many and varied activities. The port also offers extensive open and covered storage and modern cargo handling equipment, to enable quick dispatch of vessels. (Cattewater Harbour Commissioners, 2013).

HAYLE HARBOUR

FIGURE 12 : Hayle Harbour present and future (Hayle Harbour, regeneration news 2013)

Location: 50 11N, 05 25W

A major regeneration program is in progress for Hayle Harbour in four phases, enabling it to become an attractive port. Steps are taken towards a more efficiently use of available land. The four phases will allow land to be used for Harbour Operations whilst also identifying the land required for South Quay and North Quay regeneration.

4.2 Finistere

Whilst Brest would certainly be the major port for installation and O & M operations, a good number of ports exist in Britanny equipped with facilities that could also be considered suitable to provide a good support for maintenance operations. Lorient, in the south would probably be the best suited but fishing harbours along the south coast, from Concarneau to Douarnenez or the port of Roscoff on the north coast, with the facilities around the ferry terminal could also be considered. Even though none of them is at this time specifically equipped for the deployment or maintenance of Marine Renewable Energy devices, existing installations could be used or adapted for that purpose. Some of these ports were investigated and are presented here.

<u>*BREST*</u>

FIGURE 13 : Brest port aerial view

Location : 48°23'N, 04°28.5'W

Current operations : Commercial, repair.

Berths capacity:

General terminal : 4 berths

Bulk terminal : 3 berths, 300m length capacity, draught -13 m, 1 rail/road loading/unloading station, 160 000 Ton storage capacity.

Multimodal terminal : 600 m length capacity, draught -11.5 m, 3 cranes, rail connection.

Additional specific terminals : Roll-on, Roll-off, oil & gas, sand, fishing.

Repair Dry docks :

Dry Docks	Length	Width	Lifting capacity
Dock 1	225	27	1 crane 15 to 30 tons
Dock 2	338	55	3 cranes 5 to 80 tons
Dock 3	420	80	3 cranes 15 to 150 tons

TABLE 5 : BREST PORT DRY DOCKS CAPACITIES

Repair Berths: 320 m and 400 m max length, draught -9 m and -11 m

It should be noted that the port of Brest is undergoing developments so as to improve its capacity to producing and transporting large heavy-duty components (+2,000 T). New infrastructures, which are mostly based on requirements from the MRE industry will include :

- A175X40 m quay with 15T/m2 load capacity

- A 210X40 m quay with 15 T/m2 load capacity
- A 100 m multi-purpose quay with 4 T/m2 load capacity
- A handling platform of 1.3 ha with a 15 T/m2 load capacity
- Specific facilities for loading/unloading heavy-duty components
- Heavy capacity marshalling areas for bulky components
- Reinforced surfaces with 4 T/m2 load capacity (1% inclination)
- Road connections with large/heavy loads capabilities

Timeline of the development is decomposed in 3 phases with a first section available in 2015 and final completion in 2020.

LORIENT

FIGURE 14: Lorient port aerial view

Location : 47°44'N, 03°21.5'W

Current operations : Commercial.

Berths capacity :

Bulk terminal : one berth 250 m length capacity, draught 9 m, two 10 Ton and one 70 Ton capacity cranes and one berth 150 m length capacity, draught 8.5 m, one 8 Ton and one 6 Ton capacity cranes.

Agro Bulk terminal: 1berth, 2 panamax size vessel capacity, draught -12.5 m, rail/road loading/unloading station, 160 000 Ton storage capacity.

Additional specific terminals : Roll-on, Roll-off, oil, sand, fishing.

ROSCOFF

FIGURE 15 : Roscoff port aerial view

Location : 48°43'N, 03°58'W

Current operations : Commercial, passenger

*Berths capacity :*Bulk terminal : two berths 120 m and 90 m length capacity, bulk storage park and storehouse.

Additional specific terminals : Roll-on, Roll-off, ferry terminal, fishing.

DOUARNENEZ

FIGURE 16 : DOUARNENEZ PORT AERIAL VIEW (©GEOMAR)

Location : 48°06'N, 04°19.5'W

Current operations : Fishing

*BERTHS CAPACITY :*750 m length vessel capacity, draught -5 m, 1 slipway 420 Ton for boats up to 47 m, one off-loading winch.

5 Case study: Maintenance operations on the South West Mooring Test Facility (SWMTF)

An example of a procedure of maintenance operation for a simple system, the South West Mooring Test Facility, is briefly presented in this section so as to provide an insight on such operations.

5.1 Background

The South West Mooring Test Facility (SWMTF) is a multi-instrumented buoy located in Falmouth Bay which has been used since June 2009 in several studies focusing on the performance and reliability of mooring system components [21-23]. The unique nature of the facility combined with vessel availability and weather windows means that several operations are usually carried out during each visit, such as the case study reported in this section.

5.2 Weather conditions

Operations were conducted on the 3rd June 2013.

Over the duration of the operations, the conditions were calm with good visibility.

Sea state parameters were: H_{m0} = 0.2-0.5m, T_p = 2.1-6.2s.

Tide was high at 14:15.

5.3 Procedure

The major steps of the procedures are listed hereafter. A photo montage of these activities can be found on the following page in Figure 17.

a) Left Falmouth Dock at approximately 07:00 for SWMTF site on multi-purpose vessel MTS *Vector.*

b) Once in close proximity to SWMTF the WiFi link was utilised to connect to the data acquisition system.

c) A rope was attached to the SWMTF. The blades of the on-board wind turbine were tied up and a redundant antenna mast was removed.

d) Lifting slings (separated by a spreader bar) were then shackled to the lifting points on the SWMTF. The MTS *Vector* was positioned so that buoy was in front of vessel. The buoy lifted clear of the water so that the top of the mooring lines were visible.

e) The southern mooring line was attached to the vessel's winch cable and disconnected from the load cell shackle.

f) The SWMTF was lowered back into the water (now moored by two lines only). The vessel was then manoeuvred away from SWMTF.

g) The retained mooring line was winched in using the deck-mounted capstan winch. A significant build-up of kelp and other seaweed noted between the top 2-7m of the rope[10].

h) The southern anchor chain was then attached to one line comprising two 5m University of Exeter Mooring Tethers. Small floats and a light rope were attached to the top of this line which was then

[10] There was kelp growth down to 9m with a build-up of organic detritus on the rest of the rope.

lowered into the water. The vessel was manoeuvred towards to SWMTF during lowering to retain the correct orientation of the line.

i) Lifting slings were then reattached to the SWMTF and the buoy was lifted out of the water and onto the deck. To avoid damaging the load cells underneath, the SWMTF was supported by carefully positioned wooden blocks.

j) The tug winch cable was then attached to the top of the north east line and the line was disconnected from the load cell shackle.

k) Existing shackle anodes were replaced with new items.

l) A special plate and chain assembly were attached to the southern load cell. A chain and shackle assembly were attached to north east load cell. These assemblies will be used to determine the fatigue of steel components.

m) Two more Exeter mooring Tethers were attached to the southern plate and chain assembly. The SWMTF was lowered back into the water and wind turbine blades were untied. Both pairs of Exeter Mooring Tethers were joined with a shackle.

n) It was found that two axial load cells were not responding. The vessel was manoeuvred back towards SWMTF for closer investigation. The wind turbine blades were once again tied up. A GPS antenna was mounted on the communications mast for testing. The load cell connectors were rinsed out with fresh water.

o) An ADCP recovery was attempted but was unsuccessful due to fault on control unit screen.

p) The SWMTF was released from the vessel and the data acquisition system was checked. One axial load cell was found to still not work. The vessel was positioned back alongside the SWMTF and the load cell connectors were re-rinsed. The GPS antenna was removed and the wind turbine blades were untied. The SWMTF was then released.

q) The MTS *Vector* then motored back to Falmouth Dock, arriving at approximately 14:30.

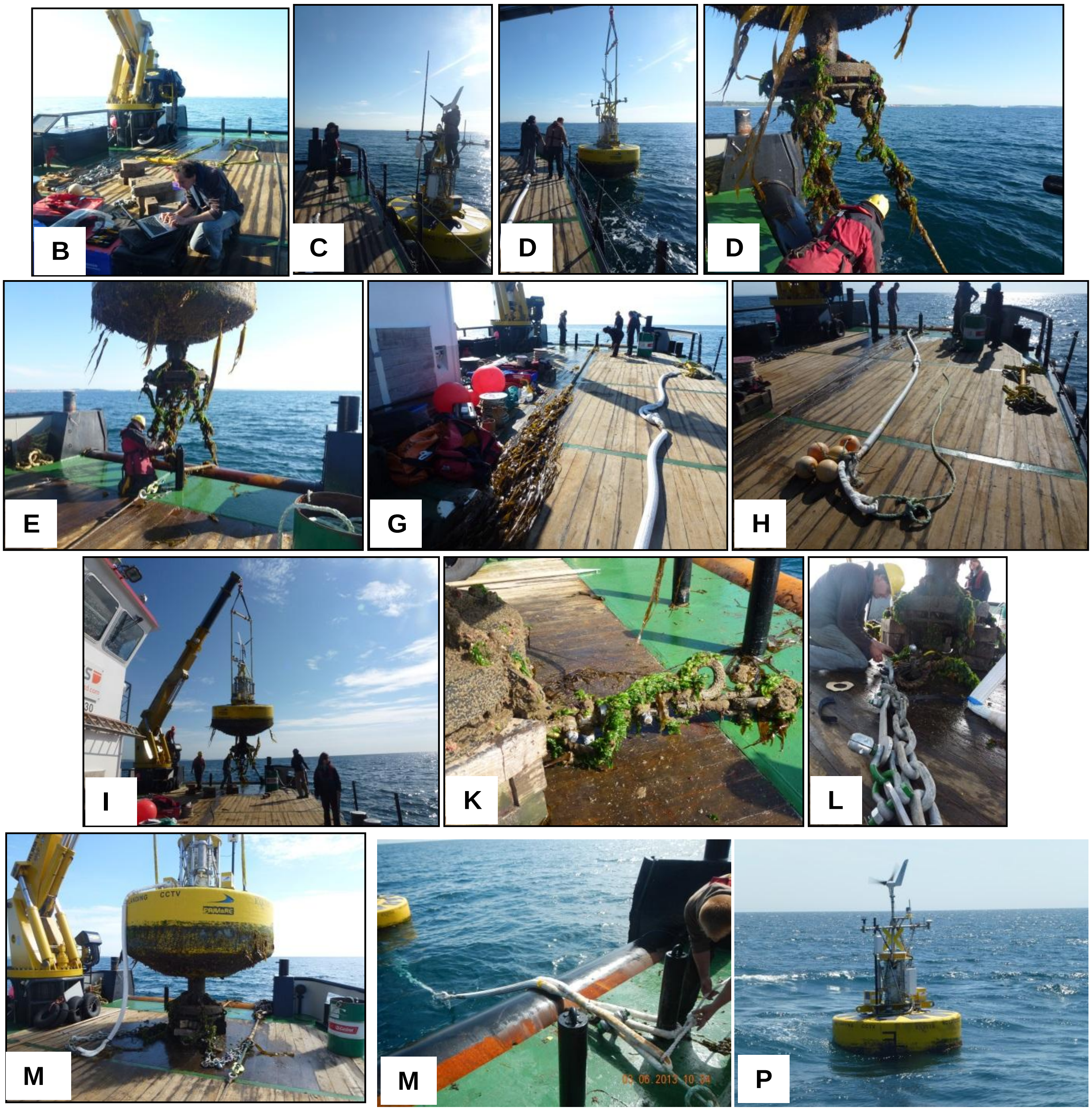

FIGURE 17 : Photo montage of SWMTF mooring line installation and maintenance operations. Each image has a letter corresponding to the operations list above

6 Pathways to reducing O&M costs

There is a pertinent need to reduce the costs associated with operations and maintenance, which according to the 2011 report *Accelerating Marine Energy* (prepared by the Carbon Trust and Black & Veatch [24]) account for approximately 25% of the levelised cost of energy for wave energy devices. A report produced for the SI OCEAN project recently estimated that O&M costs would represent 17% and 19% of lifetime costs for wave and tidal energy arrays respectively [25]. In this section several possible cost reduction pathways are suggested.

Increasing reliability to reduce the likelihood of premature failure and the need to conduct unscheduled maintenance

- Design the system so that less reliable components are easily accessible
- Incorporate redundancy into the system so that intervention may not be required until the next maintenance interval
- Use components/equipment which have proven use in the offshore environment or been rigorously tested in representative conditions
- Engineer out components or designs which have demonstrated early failures
- Component testing to improve reliability predictions
- Development of new technologies to avoid using certain components (e.g. direct drive wind turbines)

Decreasing the cost of offshore operations

- Use of local port infrastructure and vessels to reduce transit times, vessel charter, technician and fuel costs
- Device design to allow the easy recovery of the device (i.e. float and tow) to a sheltered location. The device will have to be easily disconnected from the mooring system and cabling. Several devices already use this principal
- Design for maintenance (ease of access to reduce time required and difficulty). Modular component/assembly design. Use of COTS equipment
- Commission special vessels, equipment and trained personnel. It is key to reduce reliance on existing offshore vessels which have highly variable cost and availability. Properly defined safe limits for working
- Improved ROV and autonomous vehicles to reduce reliance on (expensive) dive teams

Intelligent maintenance scheduling

- Avoid short maintenance intervals if possible. Maintenance must be preventative but not unnecessarily onerous
- Predictive maintenance scheduling based on reliability data (which is updated by offshore experience)
- Use of local ports which are capable of servicing and repair work to reduce maintenance and transport costs

- Use of condition monitoring systems as an early warning to component or system failure, in order for the occurrence of unscheduled activities to be more predictable. Remote monitoring is likely to be lower in cost than sending technicians out to sea.
- Use of remote operations (i.e. via shore-based station, over mobile or fixed networks or in close proximity/wifi where the risk of collision lower)
- Use of state-of-the-art planning tools which can be used to compare several maintenance scenarios and utilise accurate weather data, vessel charter costs and capabilities (e.g. *Mermaid* developed by Mojo Maritime)

7 Conclusions

This report provides an overview of guidelines and recommendations for the management of O&M operations necessary for an optimal exploitation of Marine energy plants, with a focus on the specific areas of South West Cornwall, UK and Iroise sea, Brittany, France. An overview of the onshore infrastructures and ports possibly suitable for management of such O&M operations is also provided. Management of scheduled and unscheduled maintenance operations is discussed in their various aspects including site accessibility. It should be noted that this topic, including weather window assessment for operations is discussed in more detail in the additional MERIFIC report *D3.6.2 Best Practice for installation procedures* [17].

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APPENDICES

APPENDIX 1 : Summary of Applicable Guidelines

Applicable standards and guidelines for operations and maintenance procedures of MRE devices. Further documentation relevant to installation procedures can be found in the MERiFIC deliverable *D3.6.2 Best practice report – installation procedures.*

Category	Document	Publication year	Author(s)
Operations and Maintenance	Provisional specification for maintenance regime related to reliability, risk and cost	2011	Components for Ocean Renewable Energy Systems (CORES) project
	Guidelines for Reliability, Maintainability and Survivability of Marine Energy Conversion Systems	2009	European Marine Energy Centre
	Lifecycle Assessment for Marine Renewables	2010	EquiMar
	Guidelines on the design and operation of wave energy converters	2005	Carbon Trust/Det Norske Veritas
	Guidelines for manufacturing, assembly and testing of marine energy conversion systems	2009	European Marine Energy Centre
	Pre-deployment and operational actions associated with marine energy arrays	2010	EquiMar
Decommissioning	Decommissioning of offshore renewable energy installations under the Energy Act 2004	2011	Department of Energy and Climate Change

TABLE 6: OPERATIONS, MAINTENANCE AND DECOMMISSIONING GUIDELINES WHICH ARE DIRECTLY RELEVANT TO MRE DEVICES

APPENDIX 2 : Supply chain references for South West UK

Company	Location	Services	Website	Phone number	Fleet
Keynvor Morlift Ltd	Devon	Marine operations & Management	http://www.keynvormorlift.co.uk/	+ 44(0)8455 193 123	Heavy lift crane barge, survey/ROV support vessel, combi-tug, tiwn screw landing craft, multipurpose workboat, fast crew boat
Mojo Maritime	Cornwall	Marine operations & Management	http://www.mojomaritime.com/	+ 44(0)1326 218 218	
Offshore Marine Management Ltd	Bristol	Marine operations & Management	http://www.offshoremm.com/	+ 44(0)8449 210 001	Barges, multicast, tugs, workboats...
Quest Underwater Services Ltd	Dorset	Marine operations & Management	http://www.questmarine.co.uk/	+ 44(0)1929 405 029	Charter: support vessel, barge, workboats, support boat
Svitzer Marine Ltd	Bristol	Marine operations & Management	http://www.svitzer.com/	+ 44(0)1179 822 021	
UMC International	Devon	Marine operations & Management	http://www.umc-int.com/	+ 44(0)1752 698 578	
ADPS Ltd	Devon	Vessels workboats & barges	http://www.adpsltd.com/	+ 44(0)1752 226 797	
Bay Marine	Falmouth	Vessels workboats & barges	http://www.baymarine.co.uk/	+ 44(0)1326 372 642	Multipurpose Work Vessel ,ROV, RIB
Carlin Boat Charters	Dorset	Vessels workboats & barges	http://www.carlinboatcharters.com/	+ 44(0)7976 741 821	6 charter boats
Challenger Marine	Falmouth	Vessels workboats & barges	http://www.challengermarine.co.uk/	+ 44(0)1326 377 222	
Ecocats, Ltd	Cornwall	Vessels workboats & barges			
FD Marine Ltd	Falmouth	Vessels	http://www.fdmarine.com/	+ 44(0)1326 374 736	15m workboat, 12m workboat, 5.5m support catamaran

		workboats & barges			
Howard Marine	Devon	Vessels workboats & barges	http://www.howardmarine.co.uk/		
JB Marine Services	Cornwall	Vessels workboats & barges	http://www.jbmarineservices.com/	+ 44(0)1637 871 280	11m workboat
Jenkins Marine	Dorset	Vessels workboats & barges	http://www.jenkinsmarine.co.uk/	+ 44(0)1202 668 558	Hopper barges, deck Cargo barges, multi role vessels, workboats
Lyme Boats Ltd	Exeter	Vessels workboats & barges	http://www.lymeboats.com/	+ 44(0)1392 439 919	Crew boat, catamaran, pilot boat, patrol boat
Offshore Marine Management Ltd	Bristol	Vessels workboats & barges	http://www.offshoremm.com/	+ 44(0)8449 210 001	Barges, multicast, tugs, workboats...
Offshore Marine Solutions Ltd	Cornwall	Vessels workboats & barges	http://www.offshoremarinesolutions.com/	+ 44(0)7831 634 125	25m twin-screw workboa
Offshore Marine Support	Gloucestershire	Vessels workboats & barges	http://www.offshoremarinesupport.com/	+ 44(0)7590 688 046	workboat
Penzance Scuba	Cornwall	Vessels workboats & barges	http://www.penzancescuba.co.uk/		12m catamaran
Shotline Charters	Dorset	Vessels workboats & barges			
Wind Wave Workboats, Ltd	Cornwall	Vessels workboats & barges	http://windwaveworkboats.co.uk/	+ 44(0)1736 364 182	12m Multipurpose catamaran, 17.5m workboat
Osprey Shipping Ltd	Bristol	Vessels workboats & barges	http://www.ospreyltd.com/	+ 44(0)1275 460 608	Tugs, barges
Dive Technologies	Portland	Sub-sea operations	http://www.divetechnologiesltd.com/	+ 44(0)1305 861 555	
Grimsey Marine Technology	Devon	Sub-sea operations			

Oceaneering International	Devon	Sub-sea operations	http://www.oceaneering.com/		
Pelagian Ltd	Wiltshire	Sub-sea operations	http://www.pelagian.co.uk/	+ 44(0)1666 861 222	
Quest Underwater Services Ltd	Dorset	Sub-sea operations	http://www.questmarine.co.uk/	+ 44(0)1929 405 029	Charter: support vessel, barge, workboats, support boat
Insight Marine Projects Ltd	Cornwall	Sub-sea operations	http://www.insight-marine.co.uk/		
Alpha Marine Services Ltd	Plymouth	Diving and ROV services	http://www.alphamarineservices.co.uk/	+ 44(0)1752 403 860	
Falmouth Divers Ltd	Cornwall	Diving and ROV services	http://www.falmouthdivers.com/	+ 44(0)1326 377 989	
Offshore Marine Support	Gloucestershire	Diving and ROV services	http://www.offshoremarinesupport.com/	+ 44(0)7590 688 046	workboat
Portland Oceaneering Ltd	Portland	Diving and ROV services			
Seawide Services	Cornwall	Diving and ROV services	http://www.seawideservices.co.uk/	+ 44(0)1326 317 517	Charters: 22m workboat, 17m workboat10m workboat
Specialised Technologies	Dorset	Diving and ROV services	http://www.stg-ltd.com/	+ 44(0)1305 861 555	
Subsea Vision	Dorset	Diving and ROV services	http://www.subseavision.co.uk/	+ 44(0)1202 656861	
Fugro Seacore Ltd	Falmouth	Drilling and piling	http://www.seacore.com/	+ 44(0)1326 254500	Jack up platform, marine drills, pile top drills
Large Diameter Drilling Ltd	Falmouth	Drilling and piling	http://www.lddrill.com/	+ 44(0) 1209 861 930	
Vecto Gray	Bristol	Drilling and piling			
Assetco Technical Rescue	Cornwall	Mooring and navigation buoys			
Longitude engineers	Devon	Mooring and navigation buoys	http://www.longitude.com.sg/	+ 44(0)1392 877 780	
Lumen Seamarks	Cornwall	Mooring and navigation buoys			
Norfloat	Devon	Mooring and	http://www.norfloat.com/	+ 44(0)1823 672 772	

International Ltd		navigation buoys			
Reflex Marine	Cornwall	Mooring and navigation buoys	http://www.reflexmarine.com/	+ 44(0)1872 321 155	
Seawide Services	Cornwall	Mooring and navigation buoys	http://www.seawideservices.co.uk/	+ 44(0)1326 317 517	Charters: 22m workboat, 17m workboat10m workboat
Aquatonics Ltd	Devon	Offshore Surveys	http://www.aquatonics.com/	+ 44(0)1363 776 456	
Coastal Research	Devon	Offshore Surveys	http://www.coastalresearch.co.uk/	+ 44(0)1363 774 577	
Coastal Science Ltd	Devon	Offshore Surveys	http://www.coastalscience.co.uk/	+ 44(0)1395 578 049	
Coastline Surveys Ltd	Cornwall	Offshore Surveys	http://www.coastlinesurveys.co.uk/	+ 44(0)1326 311 220	24m survey vessel
Ecospan Environmental	Plymouth	Offshore Surveys	http://www.ecospan.co.uk/	+ 44(0)1752 402 238	7.9m workboat, RIB
Fathoms Ltd	Somerset	Offshore Surveys	http://www.fathoms.co.uk/	+ 44(0)1458 251 140	5.3m survey craft, Diving, Salvage and Survey workboat, RIB, 18.5m workboat vessel, charters
Insight Marine Projects Ltd	Cornwall	Offshore Surveys	http://www.insight-marine.co.uk/		
Marine Ecological Surveys Ltd	Bath	Offshore Surveys	http://www.seasurvey.co.uk/	+ 44(0)1225 442 211	
Swathe Services	Cornwall	Offshore Surveys	http://www.swathe-services.com/	+ 44(0)1752 842 293	
Bax Global UK Ltd	Bristol	Logistics			
Bond Air Services	Gloucestershire	Logistics	http://www.bondairservices.com/	+ 44(0)1452 856 007	
Osprey Shipping Ltd	Bristol	Logistics	http://www.ospreyltd.com/	+ 44(0)1275 460 608	Tugs, barges
Latchways plc	Wiltshire	Safety equipment and access	http://www.latchways.com/	+ 44(0)1380 732700	
Anchor Marine Plastics Ltd	Cornwall	Other Marine			
Challenger Marine	Falmouth	Other Marine	http://www.challengermarine.co.uk/	+ 44(0)1326 377 222	

Falmouth Oil Services Ltd	Cornwall	Other Marine	http://www.fosoil.com/	+ 44(0)1326 211 333	
Hielaman	Dorset	Other Marine	http://www.hielaman.com/	+ 44(0)1202 319 810	
Knight Search & Recovery Services	Cornwall	Other Marine			
Mecal Ltd	Devon	Other Marine	http://www.mecal.co.uk/	+ 44(0)1822 615 500	
PC Maritime	Devon	Other Marine	http://www.pcmaritime.co.uk/	+ 44 (0)1752 254205	
R. Pearce & Co	Cornwall	Other Marine	http://www.rpearce.co.uk/	+ 44(0)1326 375500	
Sealander Marine International Ltd	Plymouth	Other Marine	http://www.sealandermarine.com/	+ 44(0)1752 772224	
Surtest Marine Ltd	Dorset	Other Marine	http://www.surtest-marine.ltd.uk/	+ 44(0)1305 824 341	
Symblast.com Ltd	Dorset	Other Marine	http://www.symblast.com/	+ 44(0)1202 387289	