MERiFIC
Marine Energy in Far Peripheral and Island Communities

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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 (WP3) "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 the 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 [17].

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The MERiFIC Project

MERiFIC is an EU project linking Cornwall and Finistère through the 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 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 . 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 and 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 cases of South West Cornwall, UK and Iroise sea, Brittany, France.

[1] http://www.offshore-technology.com/features/feature-operation-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/OpenHydro-PR-110911.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 are presented and discussed in the MERIFIC report

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]).

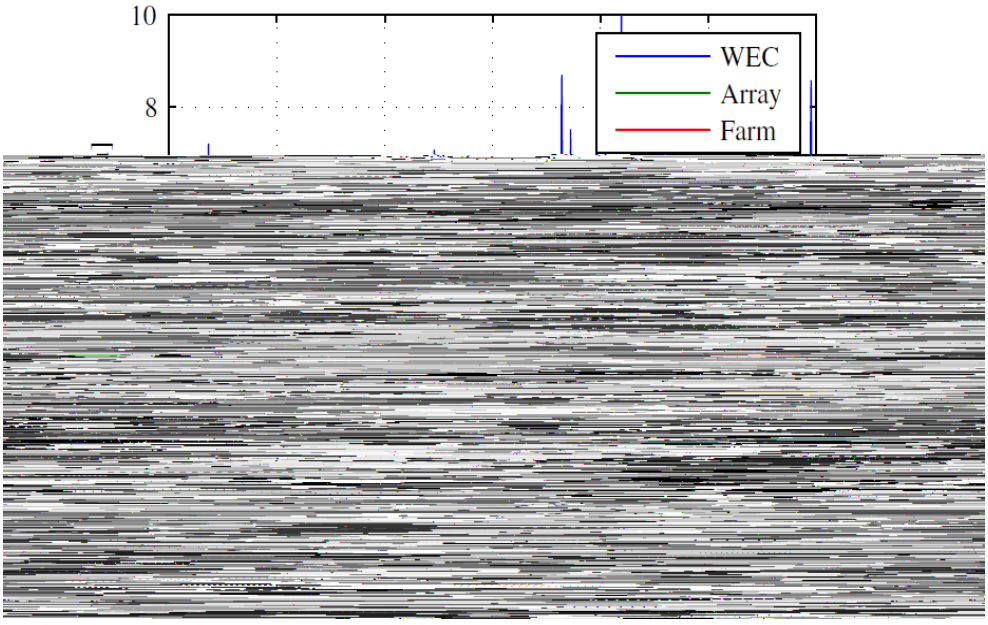

FIGURE 1: Simulated comparison of the power generated by an Fred Olsen "Lifesaver" wave energy converter compared to an array and farm of devices [3]

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 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. 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 subsea 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)[7] equipment manufacturers can usually recommend (or specify as part of an equipment warranty) the required maintenance intervals and actions required for their equipment. 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 retensioning
Firmware/software updates	Replacement of cathodic protection measures
Retensioning 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

[7] COTS equipment utilised in an application which is different (i.e. a harsh marine environment) from that it was 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.

Mooring System	Power Take-Off System	Device	Navigation and Communications Equipment
Anchor displacement/pull out	Loss of lubrication	Corrosion	Loss of data link
Fatigue	Overheating	Composite osmosis/blistering	Navigation light failure
Corrosion	Failure of safety release valves	Damage due to wave impac or slamming	
			Corruption of data storage (i.e. hard drive or memory failure)

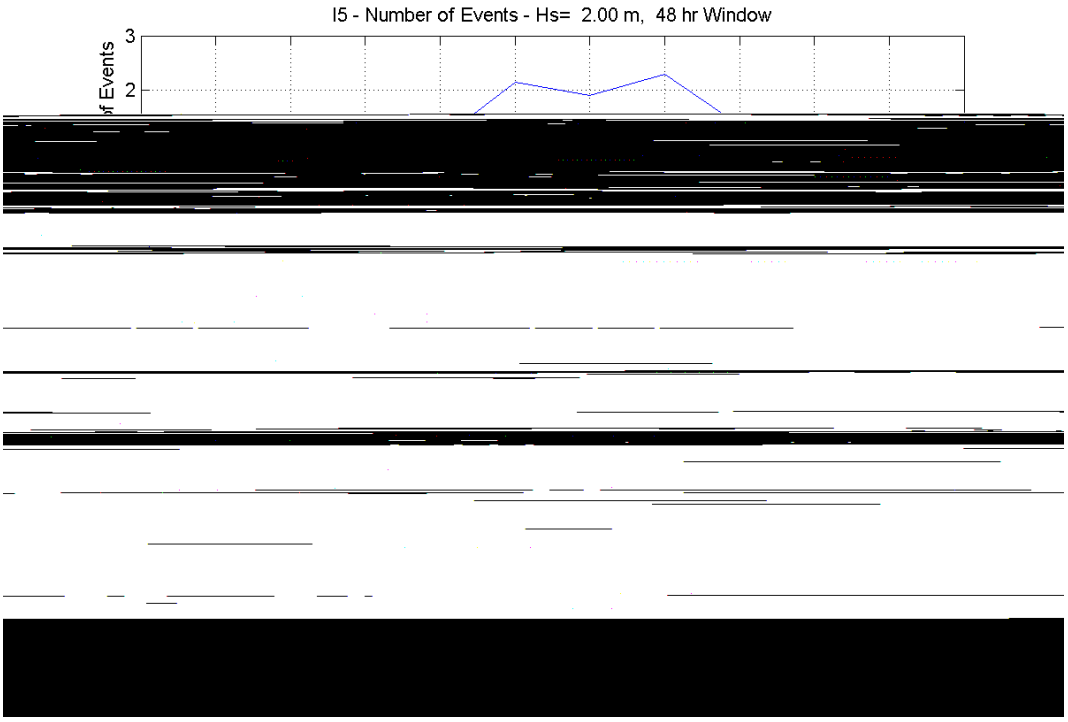

FIGURE 6 : Example of access and waiting hours at site I5 in the Iroise sea

Implementing predictive maintenance intervals in the summer month can reduce the risk of sight 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 (or 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.

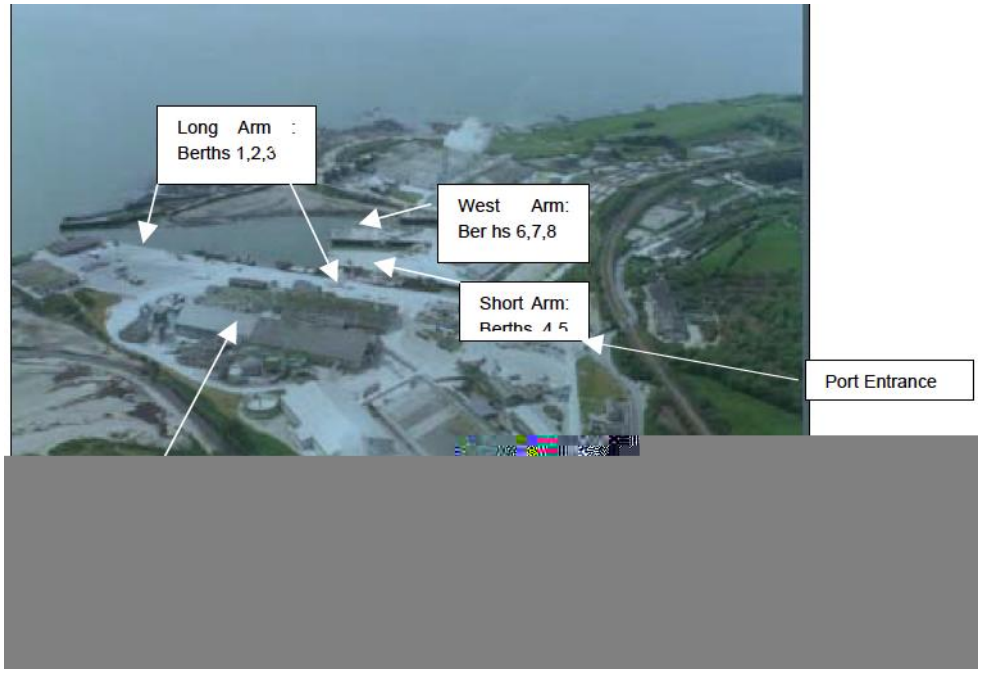

FIGURE 9 : Aerial view of Par port and china clay works

: 50 20N, 04 42W

: 8 berths, each vessel max length 100m.

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

: 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)

: 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)

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

: 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.

FIGURE 13 : Brest portaerial view

48°23'N, 04°28.5'W

Commercial, repair.

General terminal : 4 berths

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

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

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

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 DOCK CAPACITIES

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 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.

FIGURE 14: Lorient port aerial view

47°44'N, 03°21.5'W

Commercial.

Bulk terminal : one berth 250 m length capacity, draught 9 m, two 100 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: 1 berth, 2 panamax size vessel capacity, draught 12.5 m, rail/road loading/unloading station, 160 000 Ton storage capacity.

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

FIGURE 15 : Roscoff port aerial view

48°43'N, 03°58'W

Commercial, passenger

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.

FIGURE 16 : DOUARNENEZ PORT AERIAL VIEW (©GEOMAR)

48°06'N, 04°19.5'W

Fishing

750 m length vessel capacity, draught 5 m, 1 slipway 420 T on 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 [2, 13]. 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-board purpose vessel MTS

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 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 rinsed. The GPS antenna was removed and the wind turbine blades were untied. The SWMTF was then released.

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

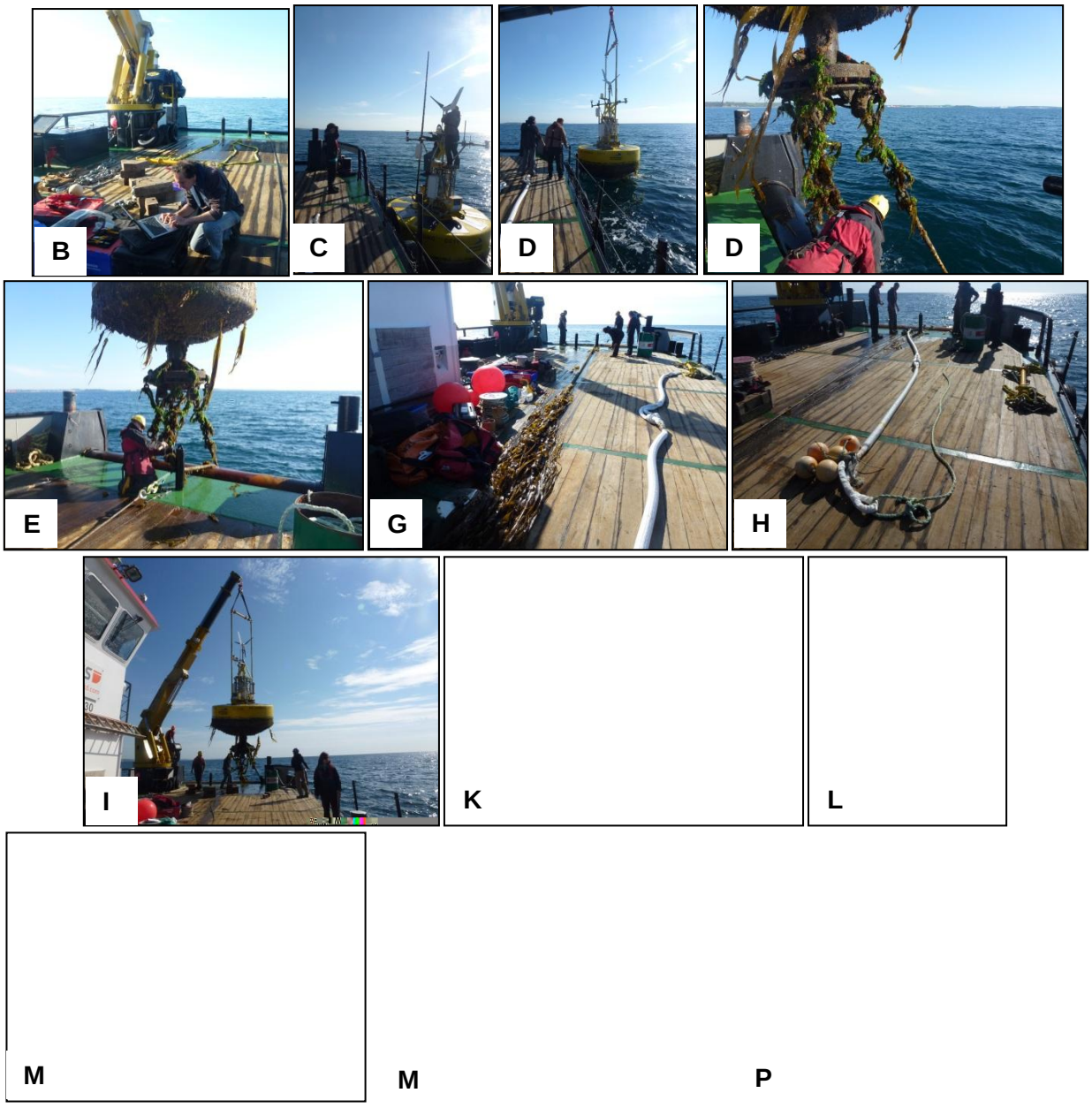

FIGURE 17 : Photo montage of SWMTF mooring line installation and maintenance operations. Each image has a letter corresponding to the operations list above