Development and demonstration of an automated, modular and environmentally friendly multi-functional platform for open sea farm installations of the Blue Growth Industry

D7.5 – Operation and Maintenance Manual

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LIST OF ACRONYMS AND ABBREVIATIONS

DAU	Data Acquisition Unit
EC	European Commission
GA	Grant Agreement
GUI	Graphical User Interface
HMI	Human Machine Interface
R&D	Research and Development
SHM	Structural Health Monitoring
TCP/IP	Transmission Control Protocol/Internet Protocol
UPS	Uninterruptible Power Supply
WEC	Wave Energy Converter
WP	Work Packages

APPLICABLE DOCUMENTS

[AD1] European Commission, Directorate-General for Research & Innovation, Grant Agreement Number 774426 The Blue Growth Farm (GA-2018-774426), 2018.

[AD2] Technical Annex I to the Grant Agreement Number 774426: "Description of Work", April 2018, Part A and Part B.

1. INTRODUCTION

The present report has been produced in the framework of Task 7.5 (WP7) activities of the Blue Growth Farm contract [AD1], [AD2].

Within the scope of WP7, is to produce design of the Blue Growth Farm multi-purpose platform, taking advantage of return of experience from the experimental campaign carried out on the outdoor prototype, , technical input and indications coming from the environmental assessment as well as suggestions and recommendation resulted from workshops with marine users and interested stakeholders, definition of the operation and maintenance tasks associated with the use and production of the Blue Growth Farm is the object of the present document to report about.

In particular, a complete set of operation and maintenance specifications for each subsystem has been identified and collected by manufacturer and technology providers and organised in a comprehensive manual such to enable end users / stakeholders interested in the Blue Growth Farm multipurpose platform a correct understanding of reliability of envisaged tasks and then derive the most realistic perception of risks associated to the investment. Evidence of the convenience of the integrated system from the point of view of the operations has been highlighted, as well as eventually criticalities and bottlenecks. This activity has benefited from 1) interface with manufacturers / technology providers; 2) return of experience from the experimental activities on the BGF experimental campaign; 3) use and potential adaptation of standards and recommended practice of classification companies (DNV-GL); 4) guidelines and recommendations where gaps are identified.

1.1 BGF infrastructure overview

Open sea farms are seen as having a more beneficial husbandry environment than nearshore ones due to:

- greater water exchange leading to increased oxygen, reduced ammonia, improved waste dispersion;
- lower impact on the benthos, owing to improved waste dispersal;
- more stable temperature and salinity conditions;
- reducing fouling of the equipment;
- better quality fish due to muscle use in stronger currents;
- reduced risk of disease due to open water location and better water quality characteristics.

Whilst open sea farming has evident benefits, infrastructure facilities must undergo an innovative design and a suitable development to overcome the challenges to replace more traditional inshore fish farming facilities. Infact, offshore farm systems must be able to withstand extreme weather conditions. Although the technology may be based on traditional cage technology farming, materials and structures must be much stronger to cope with large waves and strong currents. Difficulties in anchoring and/or submerging structures in medium/deep water is challenging as well. From the aquaculture point of view, there is the need to develop and implement greater mechanization and automation of routine operations for maintenance and harvesting, ranging from automated feeder systems and robotic cage cleaners to long-range WiFi communications, so to promote safety and efficiency by reducing human effort and make commercial-scale open ocean farming a reality. The opportunity to combine with offshore renewables makes aquaculture energy independent and offer electric recharge possibility to O&M hybrid propelled specialized vessels, thus opening a completely new chance of contribution of pollution decrease at sea.

In particular, the proposed BGF infrastructure wants to represent an example of efficient and sustainable multi-purpose offshore farm based on a modular floating structure moored to the seabed, where aquaculture and renewable energy production systems are suitably integrated to cope for the following objectives:

A. guarantee a nominal **2.000t/y fish production**, operating with advanced automation and remote control capabilities, with a potential extension up to **5.000t/y** depending on the optimisation of the breeding process;
B. minimize the introduction of pollution to the ecosystem when exploiting the marine natural resources;
C. maximize the electricity production in the Blue Growth Farm potential installation area ecosystem, guaranteeing energy supply to onboard electrical equipment, dispatching extra produced electric energy to the grid and providing sea electric station service to shipping.

1.1.1 System overview

The main composition of the BGF full scale configuration infrastructure is reported in Figure 1. In particular, the infrastructure is composed of:

- A semi-submersible type floating platform based on industrialized modular concrete caissons' technology suitably joined to form a monolith assembly. This floating platform is 210 m long by 162 m wide. The platform is kept in position in typical water depth of 100 m (max 200 m) by multiple sea-bed anchors, occupying approximately 0.9 x 0.9 km (≈ 80 ha). A Structural Health Monitoring (SHM) system installed at critical areas of the platform enables a continuous monitoring of structural deformation leading to a better knowledge of environmental loading history experienced through the entire life.
- An industrial aquaculture system, based on 6 net cages (50 x 50 m), which are protected over three edges of the concrete caisson platform, being the fourth more transparent to waves to enable an appropriate internal re-circulation and dispersion of waste from the pool. The 6 cages guarantee a fish production of 2.000 tonnes/year of salmon, sea-bass or sea-bream (depending on environment). The net cages, which are hung on the structure, are kept in position and open by weights at their bottom. Net cages extend to 35 m below sea-level, being the first 20 m protected by the monolithic infrastructure. The presence of the protective service platform opens opportunities for system automation and management not normally available to offshore fish farms. As well, all activities that are carried out manually on current systems by operators staying on workboats aside the aquaculture plant are sited on the BGF platform with the support of service cranes. Other routine operations, such as net cleaning and repair, fish grading and vaccination, and the fish harvesting, processing, packing and storing, are greatly simplified by automation.
- A complex set of offshore energy production system is equipping the BGF platform. It is composed of a DTU 10 MW wind turbine technology, different WEC technology devices (evolution of REWEC patented solution) and PV panels located on the roof of the infrastructure operations building located in the aft side of the platform. As the BGF platform is conceived to be oriented along a predominant wave streaming, both wind tower and WEC are installed on the front side of the platform. Additional WECs can be also considered for installation over the two longitudinal sides of the floating platform, depending on the wave characteristics of the installation site, as well as on economic considerations. The WECs are embodied in the reinforced concrete caissons, so they are integral part of the monolithic structure. Whilst protecting the internal pool of the structure from the incoming waves by absorbing part of their energy and transforming it into electric energy, WECs also protect the water sheet into the platform (for fish cages) from green water and overtopping. The produced electric energy makes the infrastructure energetically independent. Electric energy services for battery recharge of service vessels are also provided. The excess of energy left from the BGF operations is transferred to the land grid via the umbilical cable.
- An Automation & Control system interfaces the different systems of the multipurpose platform. The system provides real time interaction with the instrumentation for monitoring water and

environmental parameters, electrical energy production systems, fiber-optic sensors for monitoring structures, the complete automation of fish feeding system, the surveillance and navigation safety system. With specific reference to the aquaculture automation and control, modern aquaculture automation technology is asked to enable real time estimation of total number of fish and size distribution, biomass control, selective breeding in parallel to environmental monitoring and biological indicators. In particular, the aquaculture automation enables a) a better feed management, including performance monitoring, including benchmark cage / population data; b) continuous automated monitoring to optimize farming operations & fish welfare, based on continuous automatic environmental monitoring (i.e. oxygen, chlorophyll, algae, etc.) in order to assess fish reaction to different farming operations and environmental influences; c) data measurement to quantify juvenile quality (morphology, physiology, health, stress); d) monitoring of anomalies and deviations from desired standard; e) data measurement to improve disease diagnosis. All information coming from sensors and cameras are directed to the Local Control Room, placed on BGF infrastructure operations building. The Control Room System is composed of servers and terminals to enable local supervision and control when the platform is manned. The Remote-Control Room, which hosts a copy of information available onboard, allows a real time monitoring of all functions running onboard when the platform is not man-operated (e.g., when access to platform is not safe due to exceptional weather conditions). Overall subsystems control by means of machine learning techniques (BGF_AQUARES) enables early alerting on anomalous trends of specific parameters under monitoring.

- An offshore electric substation provides with all the power conversion equipment to collect wind turbine, wave devices and PV panels produced energy and suitably transform it in order to distribute and adequately supply all electric loads installed onboard and to dispatch to onshore the electricity excess.
- A set of capabilities to enable shipping operations required to accomplish the following tasks: a) daily operations carried out by a regular staff assisting the onboard production; b) periodic controls and maintenance activities to all systems onboard; c) fish feed stock loading; d) fish production and harvesting; e) other functions like waste recovery to land, transport of produced microalgae to Clients, hosting specialised activities by suppliers' (e.g., assisted diving operations of inspection to the mooring and anchors on seabed, etc.). An assisted docking / undocking facility is placed along the aft side of the platform, thus benefitting from the calmer sea conditions. This platform is equipped with a charging system to serve full electric or hybrid propulsion-based vessels / boats providing services to the platform.
- A logistic sub-infrastructure to enable all platform operations, represented by the two-levels aft side building, sized 110 m length x 12 m width x 6m height, to allocate three distinct functional zones: a) living (manned area); b) functional area; c) electric substation area. The living (manned area) hosts all human operations, including the supervision and control activity deployed at the Local Control Room located in the Control Tower. The functional area accommodates a composition of specific volumes and related devices to support the BGF infrastructure fish production and management, in terms of Fish feeding, Fish feed storage (silos), Fish health monitoring, including a clinical diagnostic laboratory, Oxygen production and distribution, and micro-algae production. Operations support functions are deployed in terms of: potable and sanitary water production, Fire-fighting pumping, Ballasting pumping, HVAC conditioning, workshops (including a divers store, equipment store, net store, spares parts store, and electro-mechanical laboratory for maintenance and repairing tasks). The platform deck operations are mainly limited to the fish farming tasks (net maintenance, fish harvesting, etc.) by means of deck cranes, maintenances of energy harvesting devices, off platform

operations based on ROVs (BGF installation environmental monitoring, inspection and survey to the submerged structures, maintenance to the navigation safety devices, etc.) and on small boats lifted by vertical landing structure placed on the right side of the platform (for instance to enable small operations by staff within the pool).

- An integrated set of Surveillance and Security system (SSS) in charge of ensuring the physical integrity of the platform and of the people involved in its operations / maintenance. In particular, a) the External Surveillance and Security System (ESSS), combining surveillance Radars, AIS and long-distance cameras to produce a real time picture of navigation traffic far from the BGF installation and in particular vessels approaching the platform to monitor eventual unexpected events (accidental or deliberate actions) and to provide prompt or early alert; and b) the Internal Surveillance and Security System (ISSS) integrating a smart security network of cameras to implement access control of operators and surveillance of accuracy in carrying out tasks in safe conditions, thus promoting adequate behaviour during platforms operations. Navigation safety devices, according to applicable normative and to conform to the National Maritime Authority competent for the installation area are implemented in the BGF infrastructure design. Data managed at Local Control Room level are transmitted to the Remote Local Control (onshore) by redundant means: a) Fiber optic line (through the umbilical cable); b) Data transmission system (radio link). In particular, the Local Control Room monitoring videos are predominantly transmitted "through the umbilical" connection and only some information is replicated on the radio link, via satellite, thus enabling an overall traffic of 500 Mbit / s.

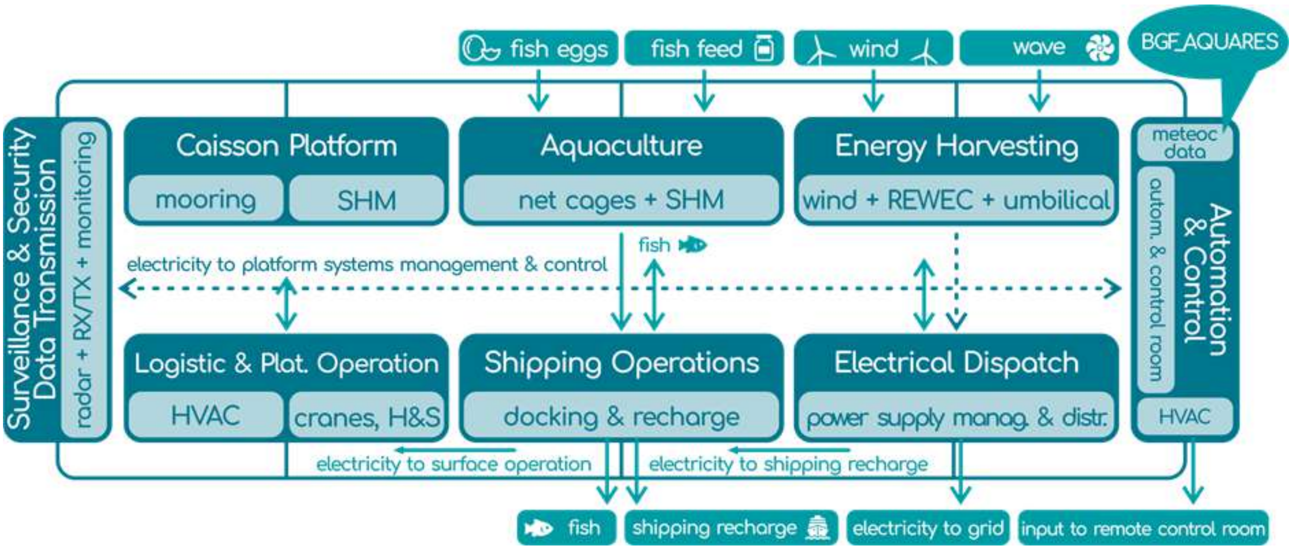

Figure 1. The BGF full scale configuration architecture

1.1.2 BGF infrastructure 3D model

The snapshots of the overall 3 D infrastructure model, which describe how the overall infrastructure looks like, are given in the following Figure 2.

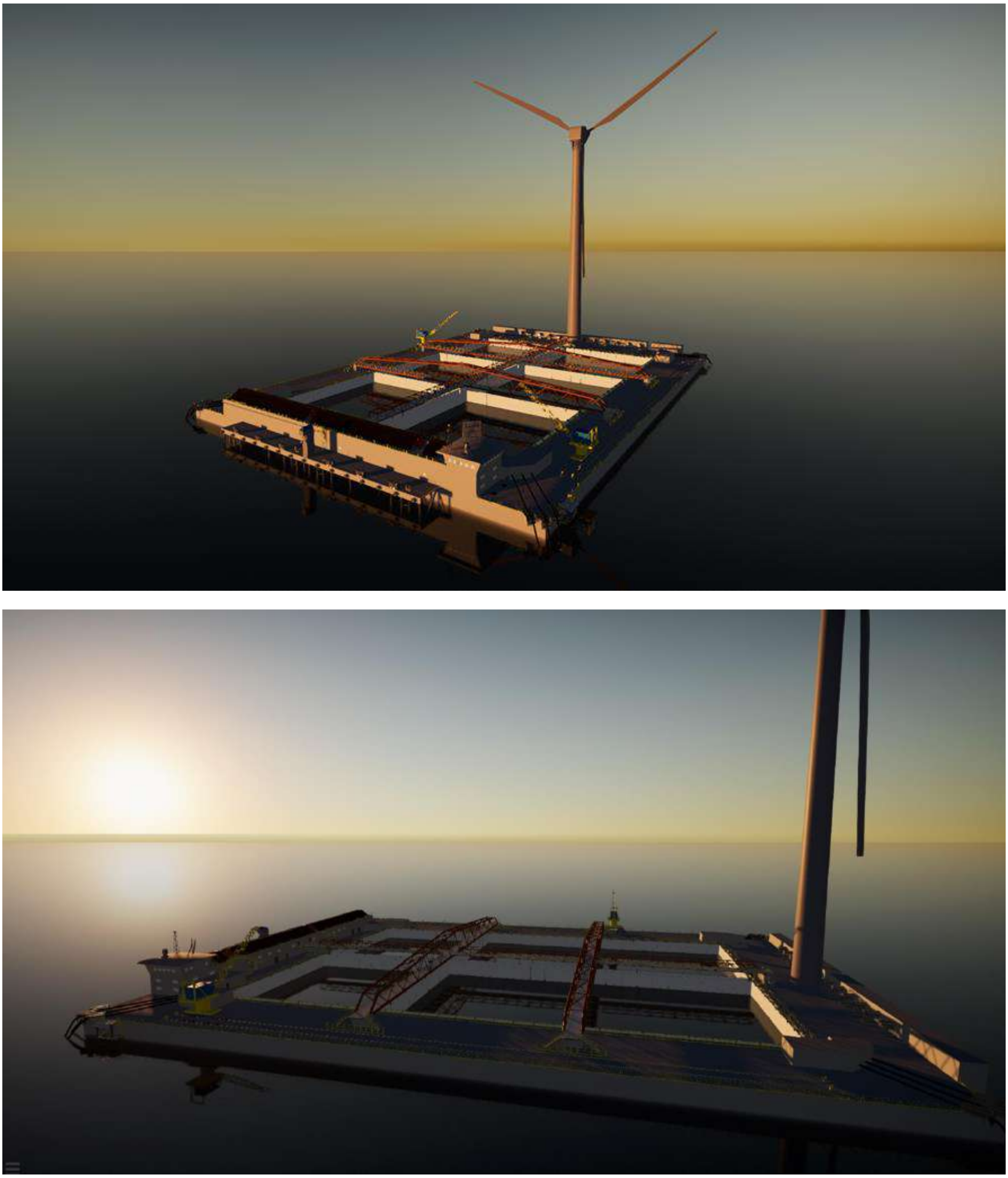

Figure 2. The BGF full scale 3D model (snapshots)

1.2 Interfaces of the Blue Growth Farm System

A map of the overall sub-systems interface is described in Table 1.

Table 1. Sub-systems interface matrix

	STEEL CAISSONS PLATFORM	AQUACULTURE	ENERGY HARVESTING	AUTOMATION AND CONTROL	ELECTRIC DISPATCH	SHIPPING OPERATIONS	LOGISTICS AND PLATFORMS OPERATIONS	SURVEILLANCE AND SECURITY DATA TRANSMISSION
STEEL CAISSONS PLATFORM		X	X		X	X	X	X
AQUACULTURE	X						X	
ENERGY HARVESTING	X			X	X		X	X
AUTOMATION AND CONTROL			X		X			X
ELECTRIC DISPATCH	X		X	X			X	X
SHIPPING OPERATIONS	X							
LOGISTICS AND PLATFORMS OPERATIONS	X					X		
SURVEILLANCE AND SECURITY DATA TRANSMISSION	X			X	X		X	

1.3 Identification of the document and its structure

The present document is identified as Deliverable D7.5 "*Operation and Maintenance Manual*" of the Blue Growth Farm Contract [AD1], [AD2].

The contents of the document are organized according to the following sections:

- Section 1 contains the introduction to the present document;
- Section 2 reports a summary of BGF integrated functions description;
- Section 3 described the BGF infrastructure operations;
- Section 4 summarises the BGF infrastructure maintenance tasks;
- Section 5 reports the conclusion of the document;
- Section 6 lists the quoted references.

2 SUMMARY OF BGF INTEGRATED FUNCTIONS DESCRIPTION

A synthetic description of subsystems functions as integrated in the BGF infrastructure is provided in the following paragraphs:

- § 2.1 BGF infrastructure production;
- § 2.2 BGF infrastructure services.

2.1 BGF Infrastructure production

2.1.1 Aquaculture and harvesting systems

2.1.1.1 Automated feeding system

The fish feed in the form of pellets is contained totally in eight silos (HxLxW 14.45 m x 4.5 m x 9.1 m), separated by feed size and nutritional characteristics (juveniles and adult fish) for an overall amount of up to 2.000 tons. The silos will be filled by fish feed boats, either using a bulk-bag and crane lifting system, or by pumping feed by a dedicated air blower and hose from the supply vessel.

The feeding system architecture is based on (Figure 3):

- a feed blower, which generates the air pressure to transport the feed from each silo;
- a cooling system, which guarantees to cool down the compressed (1 bar overpressure max) air as well as surrounding components from a max 120°C to a minimum (25°C) acceptable before it reaches the dosers;
- dosers, which are used to transfer feed into the air flow. According to the need, both feed doser valves and feed augers with gate valves are provided;
- selectors, which represent the connection point for the HDPE feeding pipes;
- rotor spreader, which guarantees correct feed spread in cages. It is composed of lightweight aluminium rotor pipes that allow for lower air speed for start-up and rotation;
- air control system, which is installed between the air cooler and the feed doser. It allows for real time measurement of airflow, back pressure and temperature, ensuring optimal feed handling, as well as reduced risk of malfunctions (the lower the speed, the higher the risk of pellet breakage and pipe blockage; the higher the air speed, the higher the dust formation and pipe blockage);
- smart control, which is based on a control SW tool (Figure 4) enabling a remote monitoring of the feed system, on the basis of the environmental sensors data and videos from the feeding cameras;
- cleaning feed pipes, represented by an injector installed between the air control and the first doser in the feed line. It works as an entrance for the cleaning plugs that collect condense and feed parts and general waste out through the feed hoses.

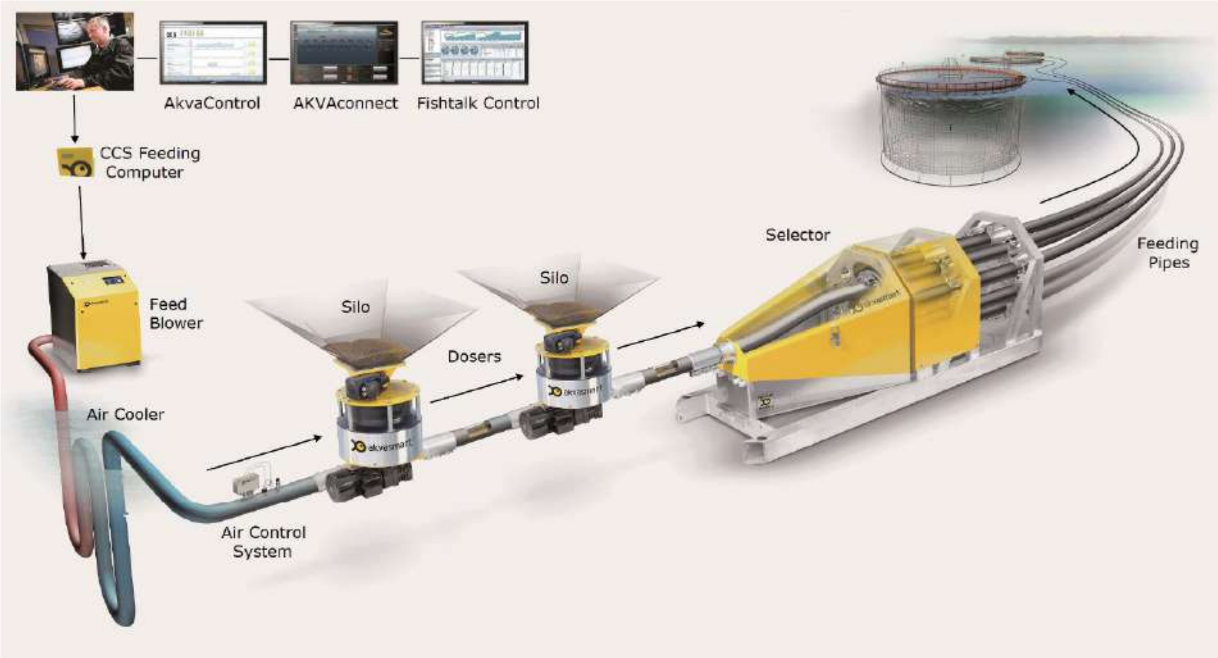

Figure 3. Feeding system characteristics

Figure 4. Feed levels management SW graphical interface

Ambient conditions inside the caisson and silo (moisture) (Figure 5) are normally monitored, in terms of temperature and humidity. The feeding system is programmed on a daily basis for the optimal amount of feed at each feeding time. The system can handle a certain number of feed lines running in parallel to supply a different number of net pens. All operations are automatically managed from the automation and control system, but the operator may switch the process to manual mode from the Local Control Room whenever appropriate.

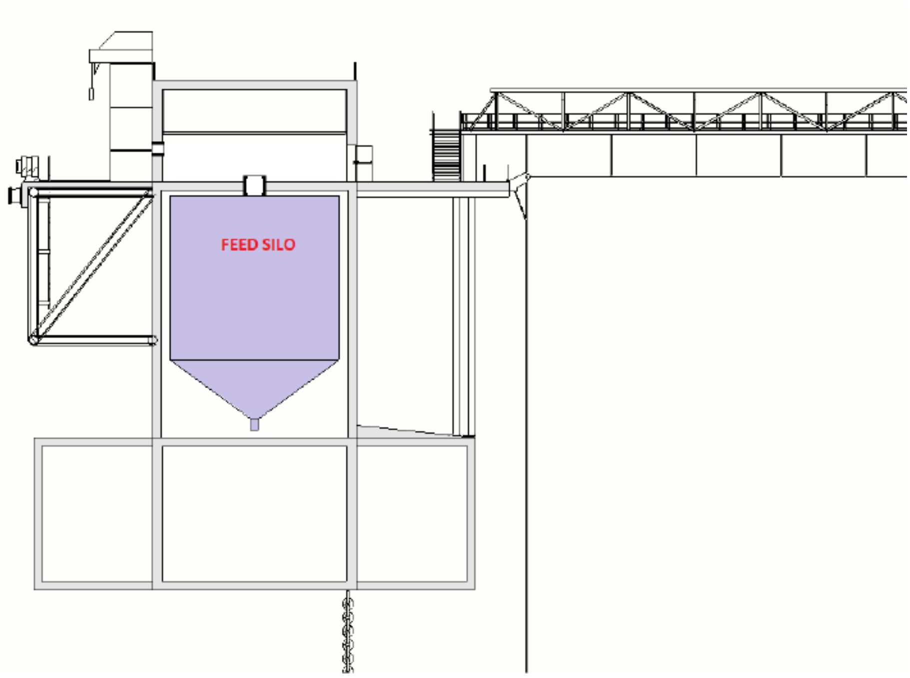

Figure 5. Feed Silo positioning

Feed Dozer Valves (FDV) are used to transfer feed into the air flow (Figure 6). These components are similar to rotary valves used in solids storage and transport, but they are specifically designed to carefully and accurately transfer the pellets down to the feed pipe, minimizing the dozer clogging risk and causing minimum pressure contact and pellet damage. The pellets are transported in controlled separate doses from the silos to the feeding pipe below, and then they are blown out to the cages.

Figure 6. Feed dozer valve

Feed Selector Valve (Figure 7) is the connection point from the HDPE feeding pipes and the hoses that distributes feed to the cages and allows selection of cage to be fed.

Figure 7. Feed selector valve

One rotor spreader (Figure 8) distributes the feed on cage surface. The rotor is constituted by an inflatable buoy, a bottom stability weight attached to a subsea pole, and the distributor pipe that rotates moved by air pressure. Smooth rotation is ensured by a stainless-steel ball bearing.

Figure 8. Feed distribution system – Rotor spreader

The feed system software controls the feeding regime for each group of fish based on accurate monitoring of fish average weight, numbers, appetite (by cameras monitoring) and environmental data (oxygen, water temperature, current).

2.1.1.2 Net cleaning

The net cleaning system is automatised thanks to a ROV based assembly (Figure 9). Filtered high pressure sea water is used to remove marine fouling on the nets, using rotating cleaning discs mounted on support frames in various shapes and combinations. High pressure pumps are used to drive the cleaning discs. The rig can be operated via a handheld mobile console or from the control room. An intuitive positioning system keeps track of which parts of the pen that has been cleaned and automatically generate necessary documentation for each cleaning event. The ROV is designed to work equally well whether working horizontally, vertically or in an inverted position. Its design allows for easy cleaning and disinfection between uses.

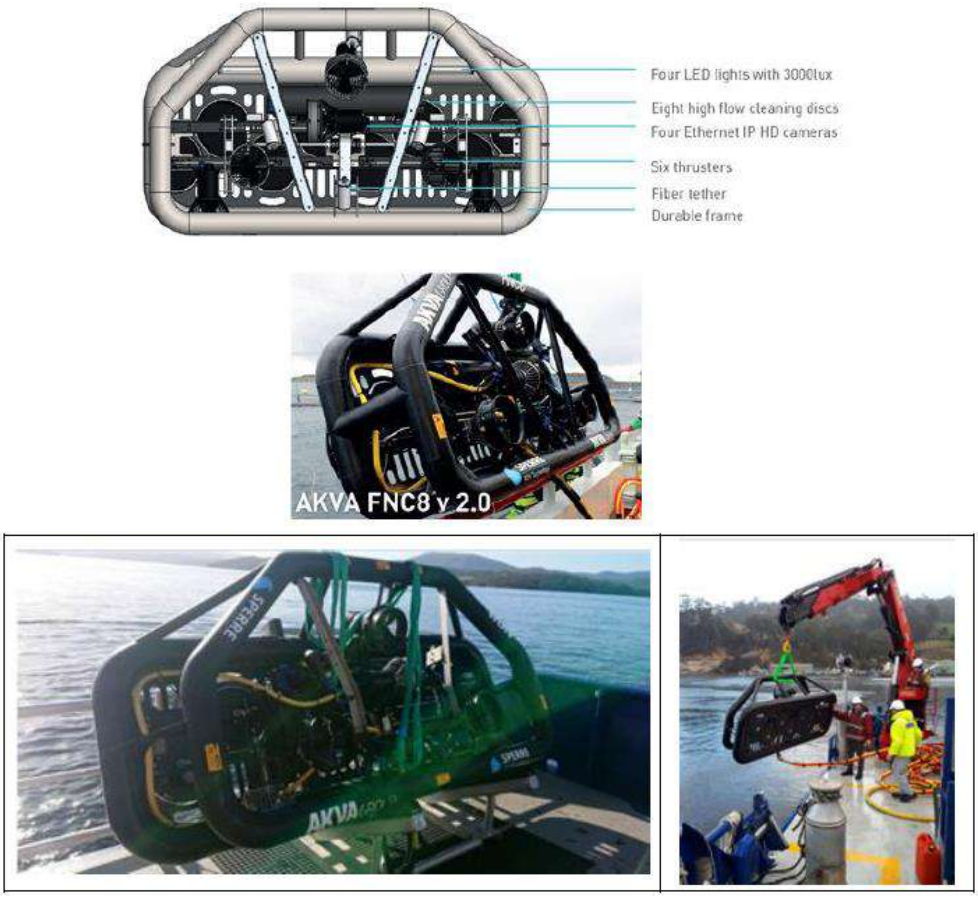

Figure 9. Net cleaning system

2.1.1.3 Fish state monitoring system

A continuous automated monitoring system is provided to ensure the maximum fish welfare, based on the control of biometric variables and management of safety devices for the fish farm. The system can log all the collected data showing real-time status of fish farm and the history trend of the observed variables. Artificial Intelligence (AI) solutions are available to correlate fish welfare to the ambient and fish specific conditions. These solutions are easily integrated with existing hardware at the site for fish and water state monitoring.

All real-time data (values, device status, alarms) is collected and presented to the operator with a graphical overview of the current fish welfare status to enable prompt intervention.

2.1.1.4 Sea Lice and Other Diseases Treatments

The BGF pool is protected by the concrete caissons-based platform, which offers a primary barrier, considering that the natural habitat of sea lice is in surface waters, from around 0 to 10 m depth. Nevertheless, a risk remains so systems need to be in place bot reduce that risk and, in case of occurrence mitigate its severity.

One such solution is provided by a pump, which filters large quantities of seawater through a specialized filter. Water is sucked through the holes in the top of the device and lice and algae are caught in the filter bag below (Figure 10). It captures lice at every stage of the organism' life cycle – from larvae to mature lice. During crowding and delousing, it collects any lice that detach from the fish, thus preventing the louse from finding a new host. Furthermore, the device also collects algae and other particles, e.g., debris from net cleaning, ensures increased circulation inside the cage and filters seawater, which promotes good gill health.

Figure 10. Sea lice collector

The BGF platform is equipped with sensors (pool cameras) that can help identifying lice eggs on the surface thus, to enable prompt reaction by the collector. The collector system also provides real-time information on the filter's condition, thus providing useful information on the presence of lice eggs from start of filtering following the alert received by the BGF sensors.

Artificial intelligence can help in better addressing by risk mapping of sea lice eggs formation in the concerned area based on ambient characteristics. In case of sufficient data for the concerned site are available and a correlation between causes and effects (sea lice eggs) are established, the collector system can also be used continuously during the most critical periods identified by the sea lice risk mapping.

If, despite the above, sea lice levels exceed those recommended for good fish welfare, then the preferred treatment option is to the pump the fish to a wellboat for in-tank bathing in a proprietary treatment product or by warm water bath, and then pumping them back to the holding cage. To achieve this, the fish will be concentrated in one half of the pen by lifting it from one side and the empty half of the net dropped back into the water to make a receiving section for treated fish.

Should any other parasitic infections occur e.g., AGD in salmon, Sparicotyle chrysophrii in sea bream, Dactylogyrus in bass, the treatment regime would be like similar to the above i.e., pumping to wellboat tanks for bath treatment.

The risk of the most common bacterial and viral diseases in salmon, bream and bass can be avoided by stocking only fully vaccinated juveniles. However, should any bacterial infections occur, they can usually be resolved by in-feed antibiotic treatment which can readily be programmed into the automatic feeding system.

2.1.1.5 Fish position sensors

A system reporting net positioning underwater under the effect of wave/current is required to address the fish behaviour under the different conditions they may experience in the BGF pool (Figure 11). A series of acoustic beacons are positioned at the net bottom and connected to a submerged acoustic receiver on the platform. This latter records the signal from beacons and transmit it to a 2.4 GHz hub that will dispatch them to a SW processor, which provides sensor positioning over a 3-D map. In particular, the surface camera (1), underwater stereo **video camera** (2) and **sonar system** (3) produce data on the fish within a sub-volume in the cage (delimited by dashed lines for each system), the **acoustic telemetry** system (4) collects data on the individual fish carrying acoustic transmitters regardless their location in the cage.

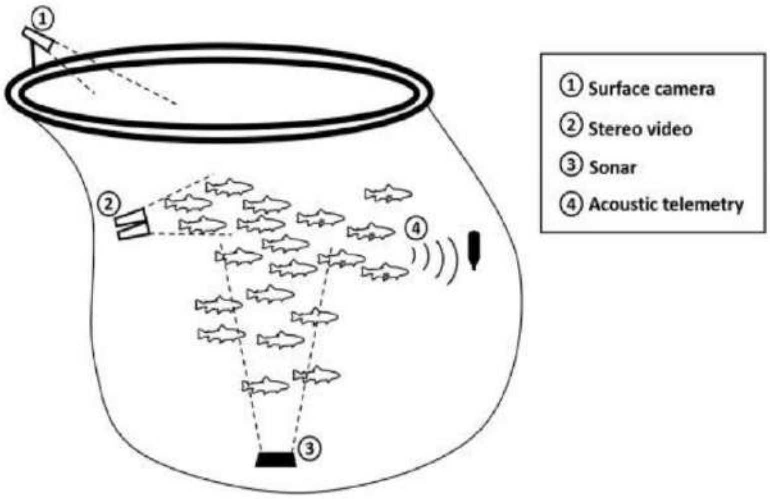

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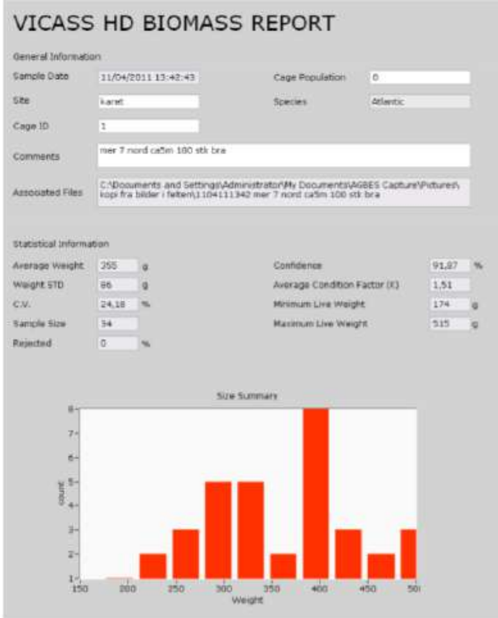
Figure 11. Fish position sensor scheme

2.1.1.6 Fish Sizing Systems

Biomass estimation is carried out through Video Image Capture and Sizing System (Figure 12). This camera measures live fish average weight; it is accurate fast and does not cause stress to the fish. A stereoscopic video image measures the height and length of each fish while it is swimming in the cage. Advanced geometry algorithms specific for the particular fish species accurately estimate the live weight of the fish and provides a detailed biomass report which includes accurate size distribution graphs. The output from the sensors is fed directly into the fish feeding control system to allow the quantities and sizes of feed fed to each population to be constantly updated in real time.



Camera | Fish sizing report

Figure 12. Fish sizing system characteristics

2.1.1.7 Cage monitoring cameras (on platform)

Cameras with a high optical zoom capability are mounted at the 4 corners of the platform to monitor water surface from air predators (birds), fish appetite and feeding visual control, the correct operation of the feeding system, fish swimming and jumping behaviour, sea lice or other sickness sign, as well as the human activities and safety of staff working around the cages.

2.1.1.8 External anti-predator nets

Six top nets are deployed to provide a continuous protection from external aerial predators, especially pelagic birds. They are anchored at bridge level from one side and at deck level from the opposite side. They are easily retractable to enable operations on fish nets.

The net rolling and unrolling task is automated in order to reduce human effort, with specific rail guides being placed at the interface with bridge and deck. A switch sensor communicates the Local Control Room about the state of opening and closing of the net panels.

2.1.1.9 Dead Fish collecting system

A conical bowl (mort cone) provided with a ballast weight is used to collect dead fish from the bottom of each cage (Figure 13).

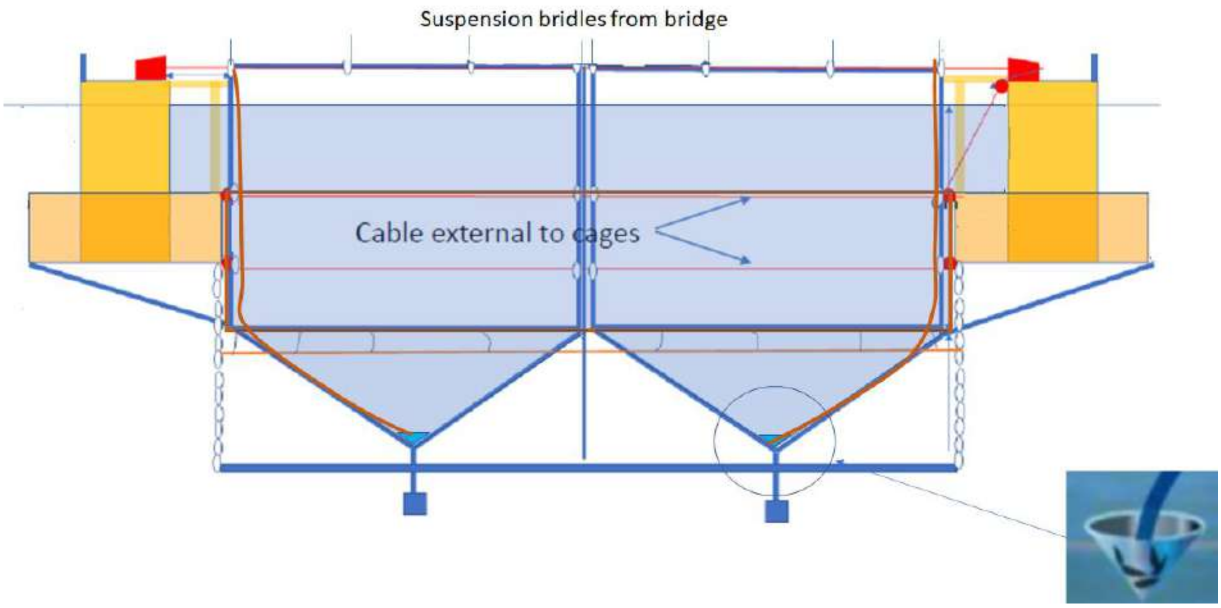


Figure 13. Dead fish collecting system characteristics

The collection system is operated by sending pressurised air through a hose into the top of the mortality collection cone assembly. As in an airlift pump, the air mixes with the water in the up-pipe lowering its density so this low density water/air mix rises to the top of the pipe creating suction which pulls water and dead fish from the cone into the pipe and upwards with the rising water to the dewatering separator at the surface. At this interface a simple automatic count records the number of mortalities removed from the cage and transfers this information to the local control room.

This mortality handling system can be used continuously, avoiding the accumulation of any mortalities within the cage thereby reducing the risk that predators damage the net whilst attempting consume the morts. It also reduces the risk of parasites and diseases that may have contributed to the mortality from being readily transferred via cannibalism to other fish in the cage.

A container for ensiling the dead fish is housed at platform level. This system features: 1) a rotating knife grinder for reducing the size of the dead fish, designed to handle the whole fish; 2) a plastic material acid tank with dosing pump to keep pH around 4 or below and two storage tanks (the first is used whilst the second is being emptied or awaiting emptying, capacity 8000 l) made in stainless steel. All components are connected by a stainless-steel piping and managed through a control panel.

Figure 14. Dead fish treatment system characteristics

2.1.1.10 Harmful organisms

Harmful algae blooms (HABs) are typically of concern in coastal areas, where conditions such as pollution, nutrient upwelling, water temperature and confinement tend to be conducive to algae proliferation. This combined with the fact that such areas are where some inshore fisheries and most marine aquaculture activities are located, makes HABs a serious risk to animal and human health and, consequently, to an increased economic risk for producers. An example of this is the regular winter/spring blooms of *Pseudochattoella farcimen* which occur in Scandinavian coastal waters causing significant economic damage to fish farmers in the area.

As BGF has been designed for use in offshore ad exposed locations, where the conditions are less favourable for the generation of algae blooms than, for instance, Nordic fjords or Scottish lochs, the potential risk of HABs is very much reduced. However, that noted, algae blooms, perhaps generated elsewhere, can be taken into offshore locations by winds and currents (see), so whilst the risk of HABs affecting BGF may be very small it cannot be completely dismissed.

There is, however, one aspect of the BGFs design that reduces the risk of an HAB entering the pool area. Being photosynthetic planktonic organisms, HAB algae are expected to be more highly concentrated in the upper few metres of water, so the 20m deep skirt around BGF may offer a significant barrier to the entry of any significant concentrations of HAB algae into the pool area.

Furthermore, the value of monitoring for HABs within or very close to a BGF unit is somewhat debateable since by the time that it is detected the options for responding to it are effectively very limited. For blooms that cause physical clogging of the gills, the installed oxygenation system for the pool may alleviate the problem but is unlikely to have much impact on cytotoxic blooms. For this reason, it has been deemed more appropriate to utilise remote sensing (as part of the monitoring dashboard of the overall control system through connection to CMEMS satellite-based services) to detect blooms that may be some distance away from the platform, but which may be heading towards it.

This early warning alert capability, jointly to the onboard oxygen generation system to be activated when the dissolved oxygen conditions fall below threshold values, represent the countermeasures implemented for the BGF infrastructure to face algae bloom risk.

2.1.2 Onboard energy production systems

The BGF infrastructure represents a single marine infrastructure using combined wind and wave generation with the objective of optimize the utilization of the resources of WEC and wind turbine and the energy implementation, such to become a self–sustaining farm. In order to maximise the energy produced on site a PV farm has been also considered to be placed on top aft side, where it is unlike to be reached by sea waves.

The electric flow scheme generated by BGF infrastructure is described in Figure 15.

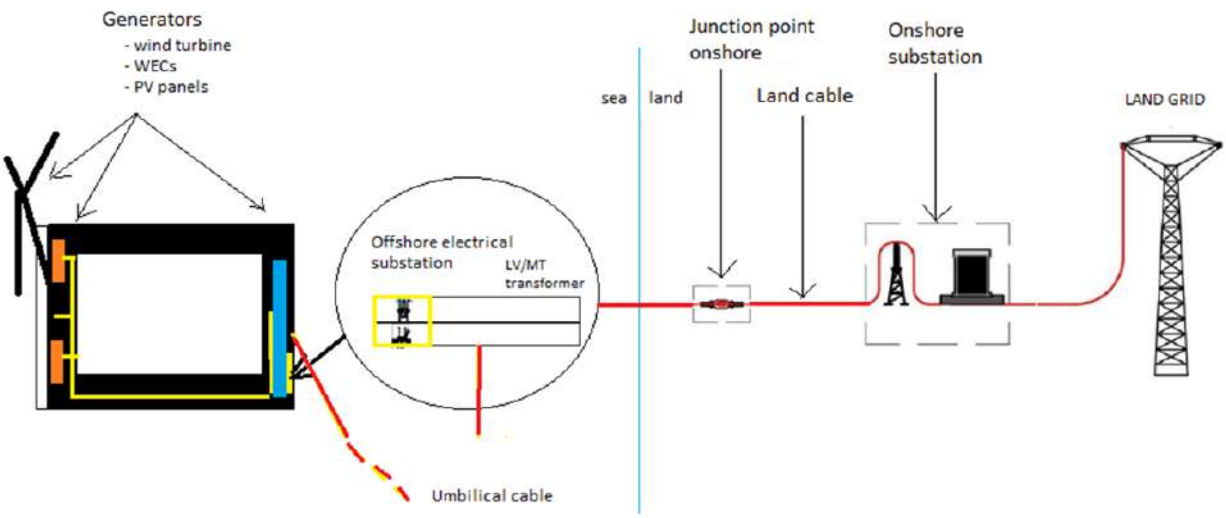


Figure 15. Electric flow scheme of the BGF infrastructure own energy production

2.1.2.1 *Wind Energy system*

The wind energy generation is designed to obtain the real power from the wind resources of the prevailing wind direction, and it represents the main energy production of the platform. For the reason of the present investigation, the application case of the 10 MW DTU turbine reference (Figure 16) has been considered in order to be exploit all information already published and available on the subject, otherwise impossible is making reference to a commercial technology.

Description	Value
Rating	10MW
Rotor orientation, configuration	Upwind, 3 blades
Control	Variable speed, collective pitch
Drivetrain	Medium speed, Multiple stage gearbox
Rotor, Hub diameter	178.3m, 5.6m
Hub height	119m
Cut-in, Rated, Cut-out wind speed	4m/s, 11.4m/s, 25m/s
Cut-in, Rated rotor speed	6RPM, 9.6RPM
Rated tip speed	90m/s
Overhang, Shaft tilt, Pre-cone	7.07m, 5° , 2.5°
Pre-bend	3m
Rotor mass	229tons (each blade ~41tons)
Nacelle mass	446tons
Tower mass	605tons

Figure 16. Key parameters of the DTU 10MW RWT

The DTU 10-MW reference turbine assumes a medium-speed permanent-magnet generator (PMSGs) with an estimated efficiency of 94%. In terms of power conversion, several options are available, yet it is anticipated that direct-drive turbines with permanent-magnet generators will have the greatest applicability offshore.

Nevertheless, since the evolution of commercial wind turbine is well progressing also on the offshore sector and production efficiency is growing whilst roughly maintaining similar geometric characteristics, the BGF infrastructure will accommodate any best technology available in the near future according to the market opportunities (see for instance SIEMENS GAMESA and XALIADE-GELECTRIC 14 MW wind turbine solutions, which offer an increase in Annual Energy Production (AEP) more than 25% compared to its predecessor (10 MW) in similar conditions).

2.1.2.2 Wave Energy system

The technology used in the BGF project to capture wave energy is the Oscillating Water Columns (OWC). Their major advantage when compared with other technologies is the simplicity of the energy conversion mechanism: waves induce oscillations of the water column into the semi-submerged chamber and thereby force a reciprocating airflow through an orifice located in the air chamber. This airflow is transformed into electricity by means of a turbine-generator group.

The REWEC3 technology employed in the BGF multipurpose platform covers the wave-to-electricity chain in three stages (Figure 17). The primary conversion is from wave to pressurized air. The secondary stage is transforming the mechanical energy to rotatory energy of the turbine shaft, and the last stage is converting the mechanical rotation into electric power through electric generators.

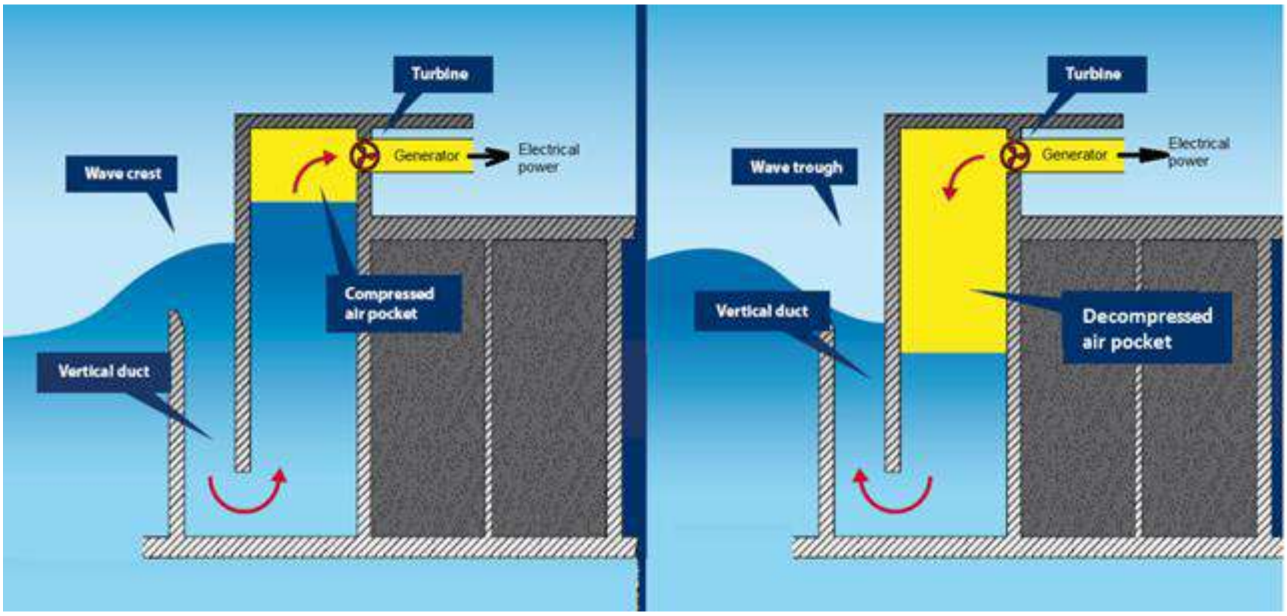


Figure 17. REWEC3 technology scheme for floating applications

Since the air alternately flows from the chamber to the atmosphere and back, self-rectifying air turbines, whose rotational direction is independent of the direction of the air flow, are usually employed. Different types of self-rectifying turbines have been developed over the years. The turbine is used to drive the shaft of the electric generator, with generator producing variable frequency and variable amplitude AC voltage.

2.1.2.3 Photovoltaic system

A contribution to the solar energy generation onboard BGF infrastructure has been considered to support electric consumption of the microalgae production system and the sea water desalination. The photovoltaic panels (N_p= 700, Panel type: SPR-220-BLK-U Solar Panel from SunPower) are installed on the aft building roof, along its entire length.

2.1.3 On site oxygen generation and distribution

To cope with potentially temporary reduced dissolved oxygen levels in the pool water due, for example, to reduced current flow, or high temperatures in the summertime, an oxygen generator is installed onboard (Figure 18). This produces high pressure compressed oxygen from ambient air via the use of a molecular sieve. The oxygen can then be dissolved into the water in the cages via an underwater sparging system (Figure 19) thereby ensuring that dissolved oxygen levels do not fall below those needed to maintain fish survival, health and welfare.

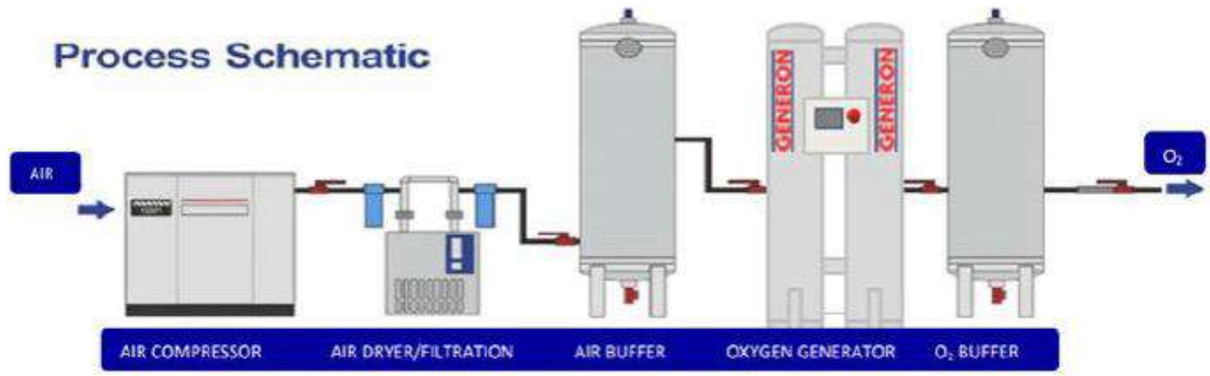


Figure 18. Oxygen generation process characteristics

Figure 19. Oxygen distributor

2.1.4 Microalgae production system

Production of microalgae at aquaculture sites, although presently ongoing in 13 European countries, is still at an early stage of development in Europe in terms of production volumes and number of production units. Nevertheless, containing not only high levels of protein and essential fatty acids, microalgae also offer great potential as an ingredient in formulated aquaculture feeds, and for direct use in hatcheries for rearing live feed organisms (zooplankton) or for greening larval tanks.

The case of BGF application, one technology solutions is to install photobioreactors systems (PBR's) supplied in containerised form (20" or 40" foot (6,10m or 12m x 2,44m x 2,59m) as shown in Figure 20. Here all the equipment necessary for the cultivation of microalgae under optimized conditions of light, temperature, and pH (main factors) are integrated in a turn-key module. The algae produced will be held in a chilled tank ready for transport back to shore for processing. These PBR packages offer high productivity in a controlled environment, preventing or minimizing contamination in the culture media, while reducing the required labour and modulating the nutritional composition of biomass produced.

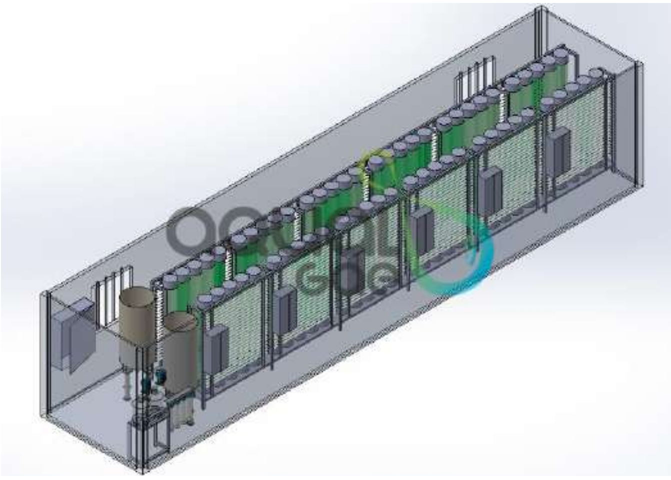


Figure 20. Photobioreactors integrated container

2.1.5 Desalinated water production system

Reverse Osmosis (RO) desalination system is employed onboard the BGF infrastructure to obtain fresh water from the sea (Figure 21). The reverse osmosis unit separates the salts still present in the water, generating a certain percentage of fresh water (permeate) and discharging the remaining concentrate. The ratio of permeate to concentrate provides a measure of the efficiency of the entire process, which increases as the size of the treatment plant increases.

The pre-filtration at the inlet eliminates all particles suspended in the water and reduces water turbidity, by passing through filters that physically retain them. This preventive process, with which a first improvement in the quality of the water is achieved, also has the important function of preventing the suspended particles, flowing directly to the reverse osmosis unit, could compromise its efficiency and effectiveness through time.

When necessary, a chemical pre-treatment section is added to prevent the formation of incrustations and inorganic fouling in the membranes of the reverse osmosis unit thanks to the use of appropriate chemical additives (anti-precipitants). This pre-treatment can be carried out with different solutions based on the type of water to be treated, having as its main objective that of making the raw water suitable for passing over the osmotic membranes.

The High Pressure (HP) pump gives the water the correct pressure required to access the reverse osmosis section. Pump characteristics and performances depend on the type of water to be treated (sea or brackish) and on the required production capacity.

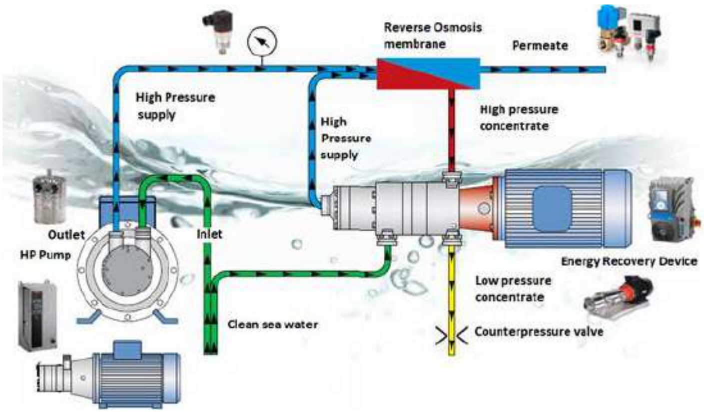


Figure 21. Reverse Osmosis process system architecture characteristics

The fresh water thus obtained can be further treated, if necessary, with a UV sterilization, which definitively reduces the bacterial and pathogenic load in general, followed by with a post-filtration with activated carbon, to improve the organoleptic characteristics or by a chemical post-treatment (chlorination, for example), for greater safety of conservation in storage tanks.

The entire process is managed by an electronic control unit and by a command & control instrumentation panel. The process can also be automated.

For the BGF application a potable / clean water production of 5 m^3/h (700÷1800 rpm, 13,7 kW at maximum pressure of 80 bars) is fitting the purpose of infrastructure operations, that includes use for the following needs: a) crew living areas; b) cleaning of surfaces / equipment; c) laboratory activities; d) microalgae production; e) cleaning of PV panels.

2.2 BGF infrastructure services

2.2.1 Mooring and anchoring system

The mooring system is composed of 12 mooring lines (3 lines per each platform corner) of 1000 m length, connected to anchors at the opposite extreme. An optimisation analysis has considered the possibility to reduce this length up to 500 m, depending on the seabed characteristics. The maximum mooring tension in the chain line is 772t, in intact condition.

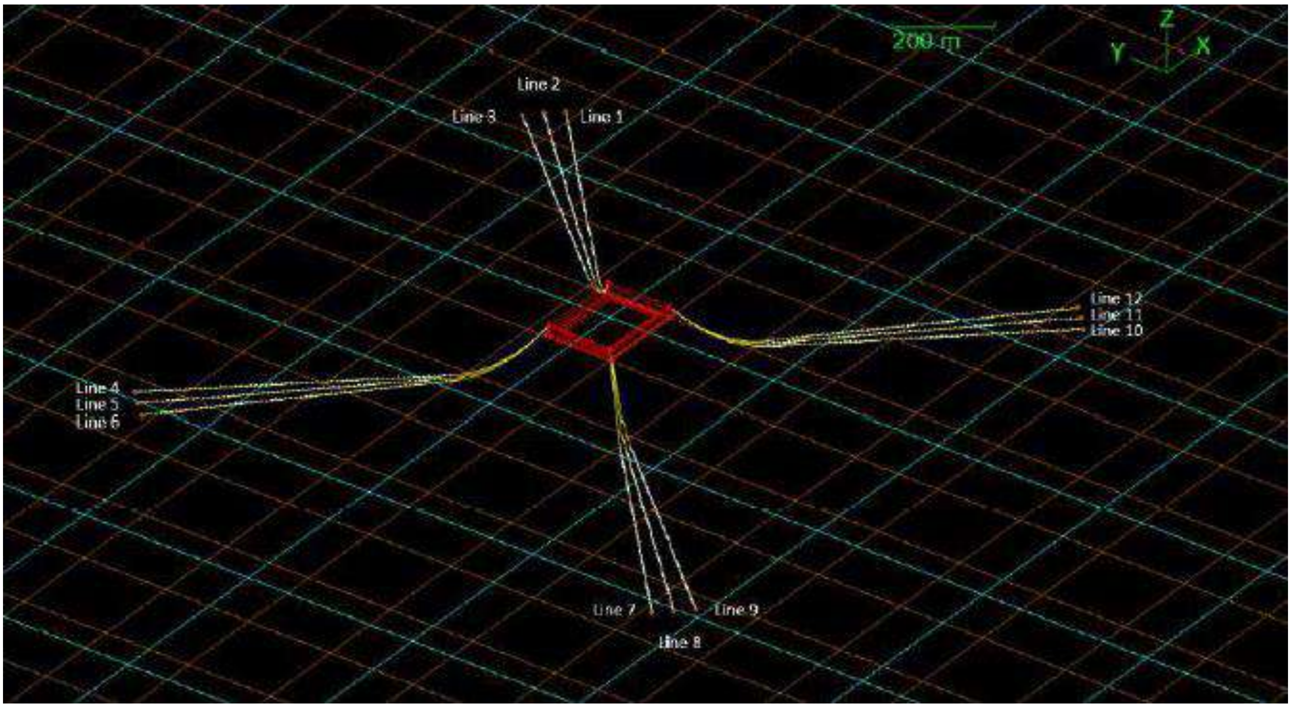


Figure 22. General mooring layout for the 12 mooring lines of the BGF platform

Two different anchoring systems are defined based on the seabed characteristics. The 30t Stevpris Mk5 drag anchor is selected for typically sandy soils (Figure 23). Specific modular dead man anchor system is to be preferred when interfacing rocky soils.

Figure 23. Stevpris Mk5 drag anchor characteristics

2.2.2 Ballasting system (optional)

The water ballast system manages the water quantity inside the platform ballasting cells. Modalities to manage it are matter of platform customisation. The platform ballasting system is composed of a certain number of invertible pumps to balance the resulting 41.477 t resulting from the design. Because of the cost implications, the final decision about the nature of the ballasting function (passive or active) is left to BGF customer decision.

2.2.3 Water state monitoring system

Water conditions are monitored both inside and outside the cage by means of dedicated sensors. In particular, the following variables are object of analysis: sea temperature, dissolved oxygen (DO), pH, salinity, turbidity, current speed and direction, wave frequency and height.

Multiprobe sensors (Figure 24), pH and conductivity (Figure 25) and turbidity (Figure 26) are distributed at different points of the pool area as local water state measurements stations (Figure 27).

Figure 24. Multi probe sensor characteristics

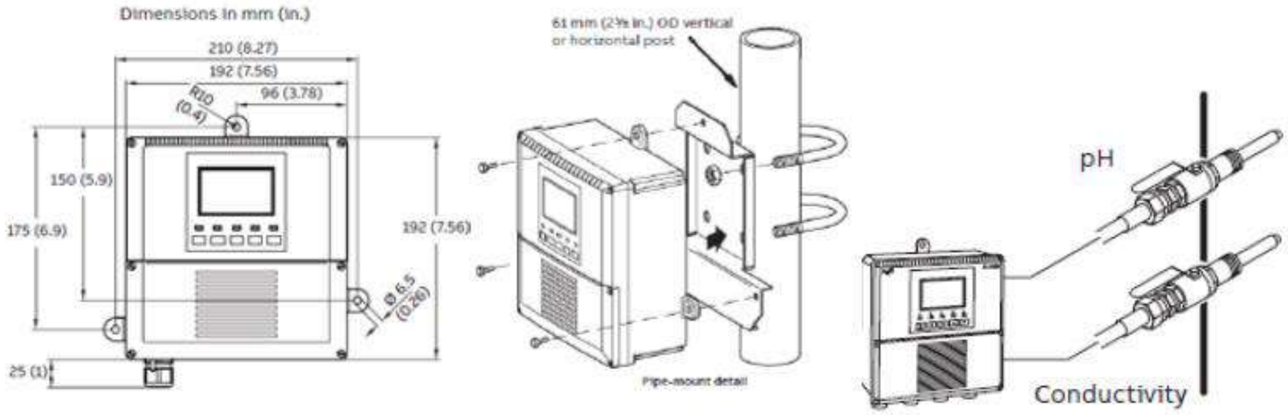


Figure 25. pH and conductivity sensor characteristics

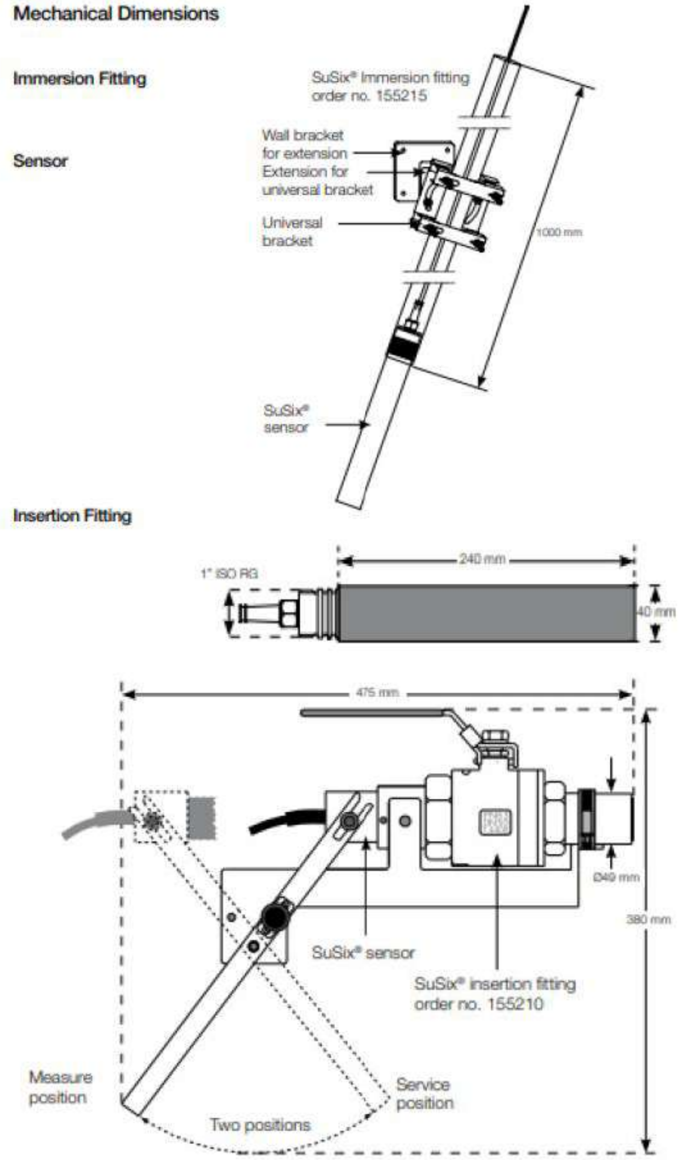


Figure 26. Turbidity sensor characteristics

Acoustic doppler current profilers as well as wave height, current and speed direction sensors are placed at specific points to measure the water movement within the pool.

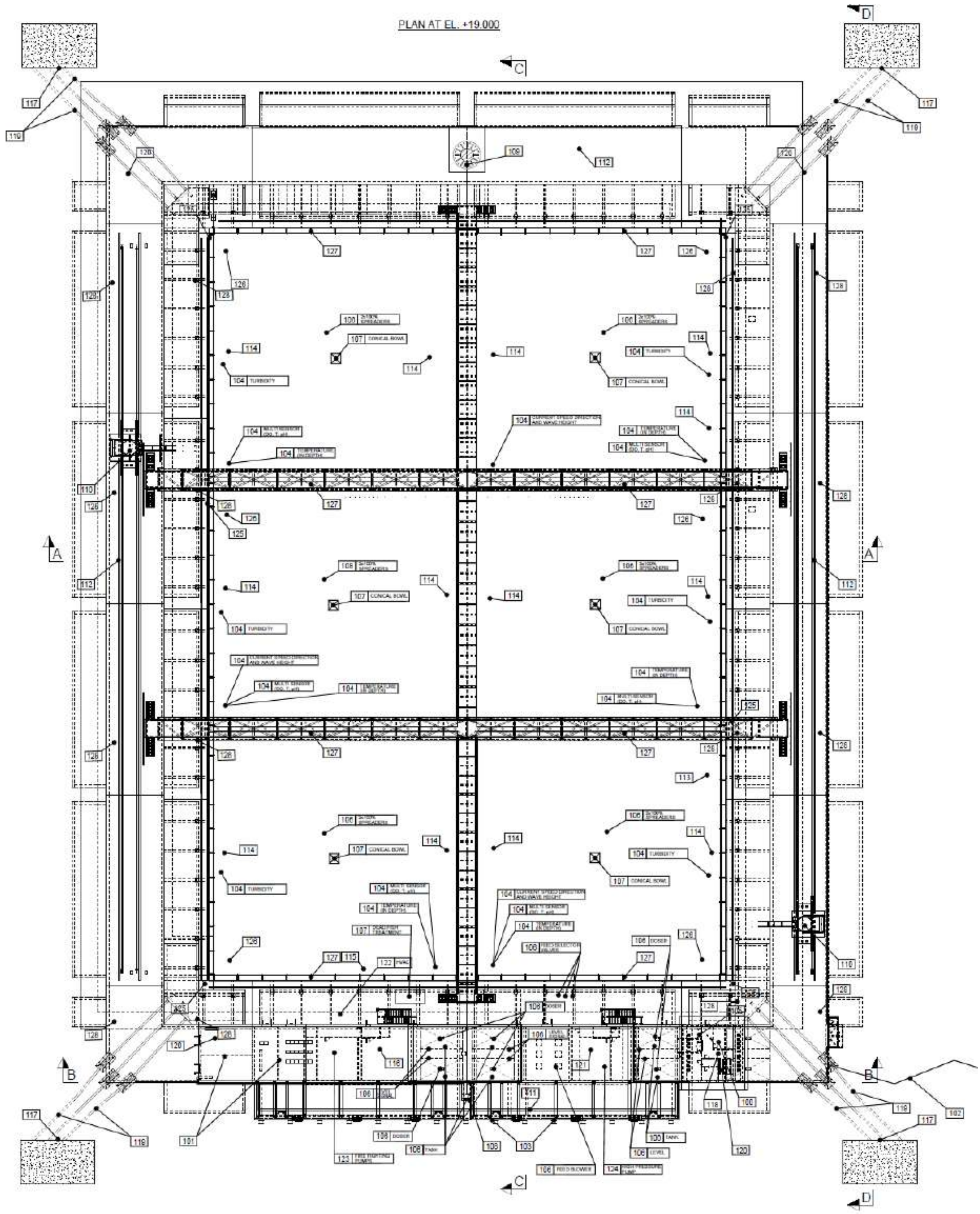


Figure 27. Water sensing distribution on the BGF pool

2.2.4 Recirculation system (optional)

The BGF platform configuration foresees a transparent aft edge to enable natural water surface recirculation once the platform is aligned parallel to the prevalent sea wave current. As well, deeper natural recirculation is expected to occur at 20 m depth of the platform draft. Nevertheless, in given circumstances the desired three water exchanges per hour in the pool needed to maintain healthy water conditions especially at the sea surface level that may not be guaranteed by natural water exchange alone. Water re-circulation pumps can be envisaged to guarantee a buffer capacity, for instance in case of less energetic waters. This system is considered then as optional, given that the dissolved oxygen replenishment (§ 2.1.3) is assumed to be sufficient for the majority of BGF infrastructure potential installations.

2.2.5 ROV (Remote Operated Vehicles)

In addition to the robotic device used for net cleaning, the BGF platform is equipped with two Remote Operated Vehicles (ROVs): a) one dedicated to underwater activities within the BGF pool and outside it, b) the second employed to broad inspection tasks related to the environmental monitoring.

The ROV considered for the above two applications are a portable device that can be managed by an operator from the Control Room. Remote control is carried out through copper or fiber optic cables. The device can be equipped with several built-in features, including advanced camera systems and sensors to perform various monitoring tasks (Figure 19).

Figure 28. Remotely operated vehicle (ROV) system characteristics

2.2.5.1 ROV for underwater platform activities

ROV for cleaning operations is equipped with a) one camera to visualize the net and the lower parts of the concrete caissons, b) navigation sensors, c) a scanning sensor for the seabed analysis around the anchors.

The ROV for inspection has also hydraulic manipulators used for simple jobs, like net checking, etc.

Additional device’s capabilities include:

1. mechanical arm for specimens’ collection. Collected specimens may be analysed directly onboard, within the control room if the necessary instruments are available or may be transferred onshore for laboratory analysis. Nevertheless, considering the significant presence of automatic instruments already installed in the proximity of the cages, this type of practice should be implemented only occasionally, for instance to meet regulatory requirements or where other specific information is needed;
2. acoustic sensors (e.g.: hydrophones), which can detect sound levels in the area of the BGF platform and can support an improvement of knowledge about noise emissions generated by the BGF installation, including the operation of its energy generation systems;

3. instruments (e.g.: probes) that measure water clarity, water temperature, water density, light penetration, and temperature to be used to perform measurements outside the cages and at the distance foreseen by the monitoring plan, where currently installed sensors cannot be effective.

2.2.5.2 ROV for environmental monitoring

ROV for environmental monitoring is managed via a service boat, which provides the required power supply through the umbilical cable. Main details about each inspection performed with the ROV are to be systematically recorded in an Excel file, including personnel performing the inspection, location of the inspection, time of inspection and main parameters observed (qualitative and quantitative) in order to carry out an exhaustive high-level monitoring database, especially of benthic communities, as foreseen by the monitoring plan. In addition to this high-level kind of data processing, a more specific analysis of images/videos recorded during the inspection is systematically implemented.

Data transfer from the ROV can be done either manually, by plugging the internal memory of the ROV to the desired laptop, or remotely by the dedicated software, in case the instrument is set for remote data transfer. However, in general, due to limitations in wireless technologies, communication is usually fed through the umbilical. The transmission mediums for communications are metallic conductors or fibre optics. The latter are beginning to become more prevalent in inspection-class ROVs.

2.2.6 Concrete caissons biofouling monitoring and removal system

Concrete caisson biofouling is monitored through ROV periodically (see §2.2.5). Whilst uniform settlement of biofoulers covering an entire concrete surface can protect the structure from deterioration, a nonuniform deposit can lead to severe localized pitting corrosion. Despite the concrete surface at direct contact with water is pre-treated with a protecting anti-biofouling thickness, the contrast to this phenomenon do not eliminate the corrosion problem but it can reduce it.

Control and biofouling removal is processed via ROV as well (Figure 29). It rapidly, safely and thoroughly cleans even damage-prone surfaces without clogging, or performance degradation regardless of water depth. Because of the regularity of the BGF submerged infrastructure, the ROV guidance is such to enable an automated accurate cleaning of concrete pre-treated surface. Nevertheless, compatibility of the rotary stress and friction mobilised by the technology with pre-treated surface characteristics has to be accurately verified in order not to endanger the treatment efficiency in reducing the attack from fouling.

Figure 29. ROV based technology for biofouling removal from submerged surfaces

2.2.7 HVAC and fire-fighting system

2.2.7.1 HVAC system

The Technical Building and the silos room are permanently ventilated / conditioned (temperature and humidity), whilst the Local Control Room is normally conditioned only with operators are onboard, except for the server's room.

The Air Flow System Control is in place to maintain under control the correct ratio of return air and fresh air volume.

Silos and Warehouses humidity is controlled via a desiccant dehumidification package.

2.2.7.2 Fire-fighting system

The automatic safety system intervenes in case of a fire event in conjunction with the fire-fighting system.

At Control Room level, a Fire Alarm Control Panel (FACP) displays the potential presence of a fire in each controlled area. Fire detection devices are provided in relevant areas of the platform for an early detection of any fire initiation and to suitably provide warning either at the local control room or at the remote-control room.

The following types of fire detectors are provided: a) Heat Detection Systems – Heat Sensitive Cable Type, b) Smoke Detection Systems – Optical High Sensitivity Temporized Type, c) Heat Detection Systems – Rate of Rise, d) Flame Detectors.

Manual call points are provided throughout the platform areas, connected in a common loop. Activation of any manual call point shall initiate a fire alarm. Manual alarm call points are installed at all passages corners.

The detection of a confirmed fire causes an emergency alarm status in the immediate area, as well as in the control room, and the activation of the sprinkler fire-fighting system.

2.2.8 Structural health monitoring (SHM) system

The SHM system enables real-time monitoring of the following structural platform parameters: a) local strain of the platform in the most critical sections; b) strain at modules joint level; c) inclinations (for measurement of the platform rotations); d) differential displacement (for global measurement of the platform deformability); e) accelerations and vibrations in three directions.

Typical sensors are shown in Figure 30.

Temperature sensor

Tri-axial accelerometer

Figure 30. Typical SHM sensor characteristics

2.2.9 Electric dispatching system

The substation of the floating platform will collect the energy generated by the Wind Turbine (10 MW), Wave Energy Converters (1.2 MW max) and the Solar Energy Plant (0.154 MW) and will also power the platform itself and the electric boat recharging system.

An output at 33 kV is assumed but the details of the onshore connection point would require an in-depth analysis, so it is assumed that this voltage level is reached on the coast and the floating platform would be connected:

a) to an existing substation;
b) to a new substation.

The umbilical cable devoted to the excess electric energy transmission to shore presents the following characteristics:

- Voltage drop and power losses around 2%.
- Submarine cable data from ABB-Submarine Cable Systems[1] (Figure 31).

Cross-section of conductor	Diameter of conductor	Insulation thickness	Diameter over insulation	Cross section of screen	Outer diameter of cable	Cable weight (Aluminium)	Cable weight (Copper)	Capacitance	Charging current per phase at 50 Hz	Inductance
mm²	mm	mm	mm	mm²	mm	kg/m	kg/m	μF/km	A/km	mH/km
Three-core cables, nominal voltage 30 kV (Um = 36 kV)										
70	9.6	8.0	28.0	16	100.6	16.9	18.2	0.16	0.9	0.46
95	11.2	8.0	29.6	16	104.0	17.7	19.5	0.18	1.0	0.44
120	12.6	8.0	31.0	16	107.0	18.4	20.7	0.19	1.0	0.42
150	14.2	8.0	32.6	16	110.5	19.3	22.1	0.21	1.1	0.41
185	15.8	8.0	34.2	16	114.0	20.1	23.6	0.22	1.2	0.39
240	18.1	8.0	36.5	16	118.9	21.4	25.9	0.24	1.3	0.38
300	20.4	8.0	38.8	16	123.9	22.6	28.2	0.26	1.4	0.36
400	23.2	8.0	41.6	16	129.9	24.6	32.0	0.29	1.6	0.35
500	26.2	8.0	45.0	16	137.3	26.7	36.0	0.32	1.7	0.34
630	29.8	8.0	48.6	16	145.1	29.2	40.9	0.35	1.9	0.32
800	33.7	8.0	52.5	16	154.4	32.2	47.2	0.38	2.1	0.31

10-90 kV XLPE 3-core cables		
Cross section mm²	Copper conductor A	Aluminium conductor A
95	300	235
120	340	265
150	375	300
185	420	335
240	480	385
300	530	430
400	590	485
500	655	540
630	715	600
800	775	660
1000	825	720

Figure 31. 36 kV Cable data

[1] https://new.abb.com/docs/default-source/ewea-doc/xlpe-submarine-cable-systems-2gm5007.pdf

The dynamic cable is linked to the floating platform by one electrical preconnector, that allows a quick mechanical coupling. It is also ready for quick disconnections and reconnections, for platform O&M operations. This electrical preconnector is compatible with other cable ancillary protections, such as bend stiffeners.

2.2.10 Offshore electric substation

The main components in the offshore electric substation are represented by:

- Five 36kV/630A Switch Unit for power cable inputs from Wind Turbine, WECs Clusters and the Solar Plant.
- One 36 kV/630A Circuit Breaker Unit connected to the Ancillary Services Transformer.
- One 33/0.42 KV 1250 kVA Ancillary Services Transformer.
- One 36 kV/630A Circuit Breaker Unit connected to the Reactive Power Compensation System.
- One 36 kV/630A Circuit Breaker Unit connected to the Energy Storage System.
- One 36 kV/630A Current and Voltage measurement Unit to control the energy flow between the onshore grid and the floating platform.
- One 36 kV/630A Circuit Breaker Unit to protect the submarine cable that connects the floating platform with onshore network.

2.2.11 Shipping operation systems

Shipping operations are required to accomplish the following tasks:

- Periodic controls and maintenance activities to all systems onboard;
- Fish feed stock loading;
- Fish harvesting.

Specific services to accomplish these functions are given by the:

- docking / undocking system;
- electric recharge system.

2.2.11.1 Docking / Undocking system

The BGF docking / undocking facility is placed along the aft side of the platform, as it is less exposed to predominant sea wave's impact and, as well, easier to access thanks to its lower-level protective wall. On the other hand, under this configuration the approaching vessel is subject to the sea water outflow from the aft windows.

Different typologies of vessels are expected to dock / undock from the Blue Growth Farm multipurpose platform, including Live Fish Carrier, Fish harvesting Vessel, Forage Carrier, and Support Vessel for logistics and maintenance. Additionally, a certain number a number of recreational electric engines-based vessels that could take advantage of the availability of the sea electric recharge station to recharge their batteries necessitate to find docking opportunities.

Six docking robots' systems have been accommodated (Figure 32) to host a variety of service and specialised vessels approaching the platform. In particular, 25 m to 80 m length vessels are served through the different mobilisation of the docking elements (n. 2 for the shortest vessel, n.6 for the longest one). Combinations of docking approach are possible, depending on the vessel size and functions deployed, along the docking area length.

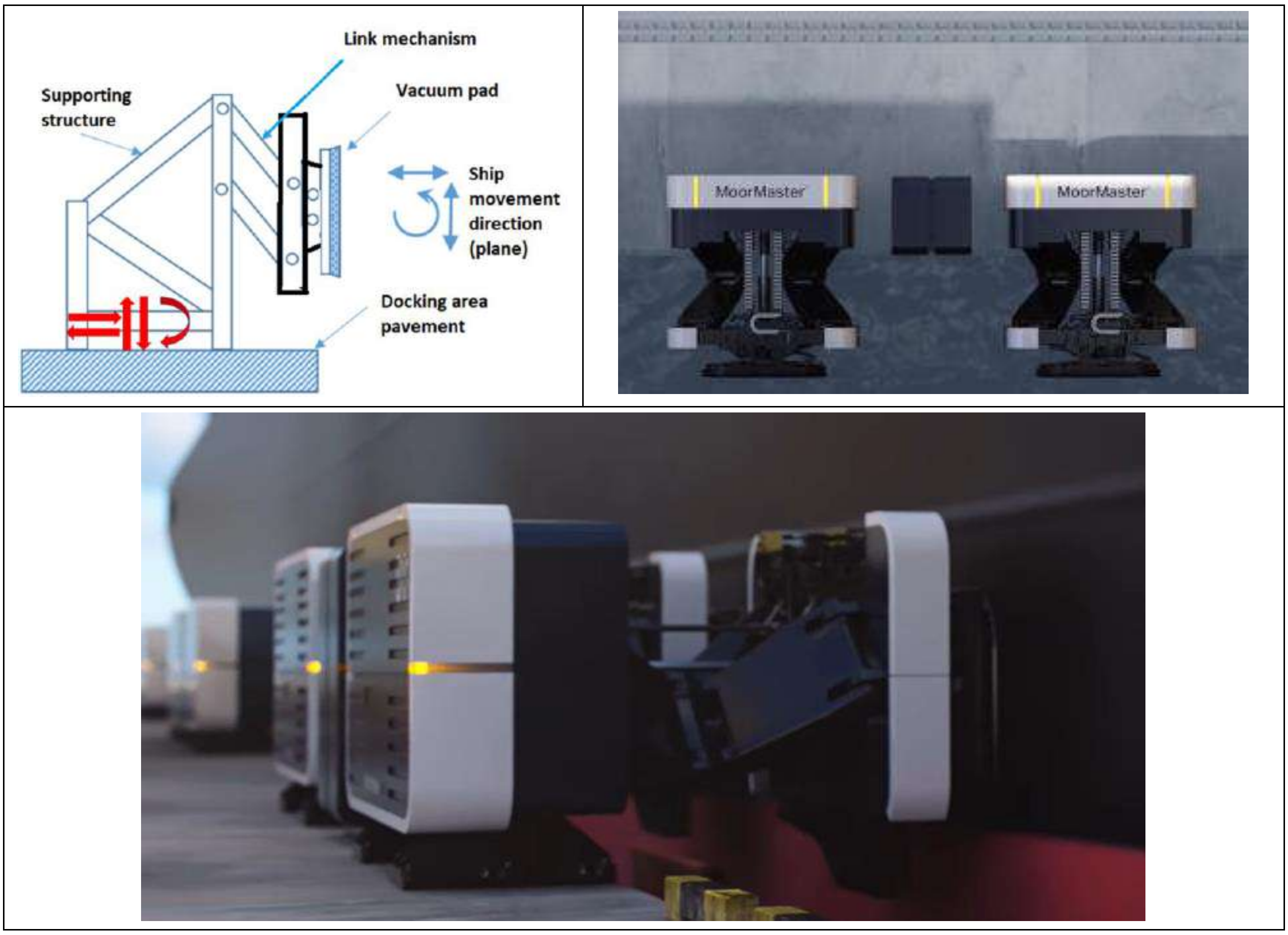


Figure 32. Docking robots' system

2.2.11.2 Electric recharge system

The electric recharge system enables electric or hybrid engine-based service vessels to recharge batteries when in safe docking conditions (Figure 33). The energy supply is supervised by the platform Energy Management System, which controls how much energy could be released without endangering the energy consumption needs for ongoing platform operations.

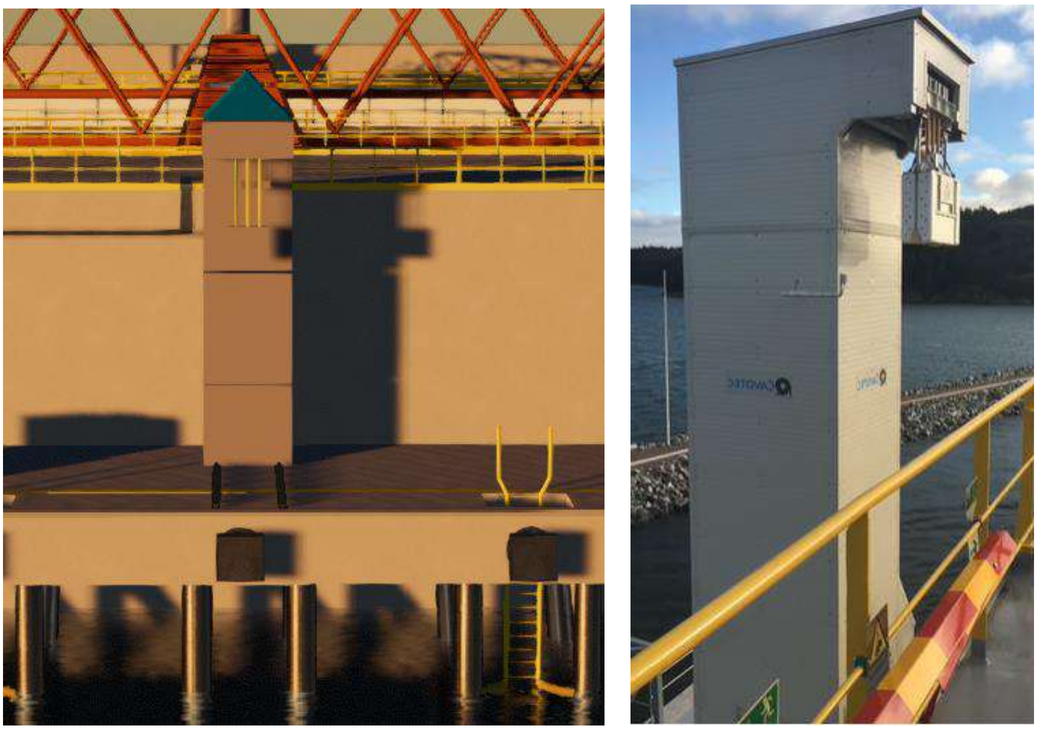
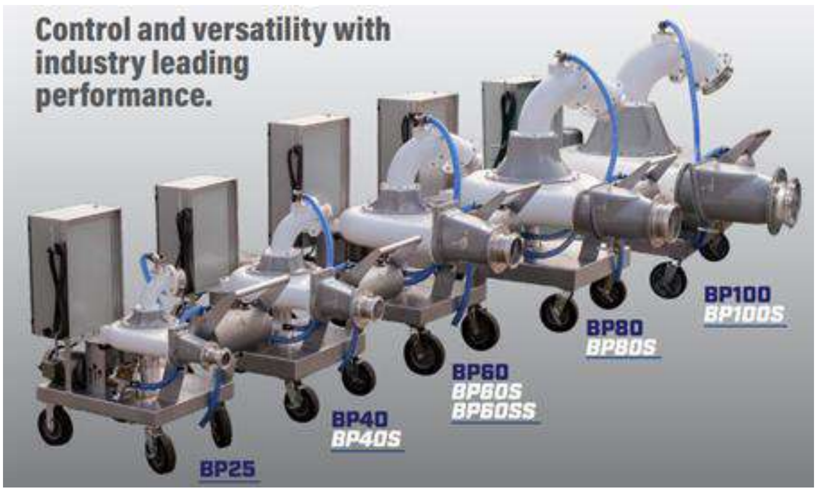


Figure 33. Electrical recharging tower

2.2.11.3 Fish stocking and harvesting

The harvesting and stocking of fish and, where necessary, their transfer from cage to cage, is carried out by using a combination of rigid pipes and a flexible hose connected to fish pumps

Each cage is provided with a submergible flexible pipe that is immersed in the water during the loading / unloading operation. The flexible pipe is collected to the rigid pipe positioned on the inner edge of the platform and connects the pool area with the ship docking zone. Here, flexible tubing enables loading / unloading from a wellboat by means of a portable suction pump available on the platform or via the pumps installed within or on the fish harvesting/juvenile delivery wellboat. Depending on the type of operation downstream of the pump a fish / water separator as well as a fish counting, and weighting system can be utilised (Figure 34). Harvested fish are then transported alive in the fish wells back to the shore for culling, processing and packing.



	BP25	BP40 - S	BP60 - S - SS	BP80 - S	BP100
Intel/Outlet Size	2.5 in (65mm)	4 in (100mm)	6 in (150mm)	8in (200mm)	10in (300mm)
Main Pump Drive	2hp	3hp & 7.5hp	5hp - 7.5hp - 10hp	15hp & 20hp	25hp & 30hp
Priming Pump Drive	1hp	1hp	1.5 hp	1.5hp	1.5hp
Fish Pumping Cap	4 t/hr	8 t/hr	16 t/hr	24t/hr	55 t/hr
Pump Output Max	170 gpm	480-807 gpm	800-1200-1500 gpm	2400-2700 gpm	3300-3900 gpm
Maximum Head	24.6 ft (7.5m)	29.5-46 ft (9-14m)	29.5-36-46 ft (9-11-14m)	29.5-36 ft (9-11m)	29.5-36 ft (9-11m)
Maximum Distance	300m	800m-3000m	600m-1500m-2700m	800m-2000m	700m-1500m
Maximum Avg Fish Size	95g	300g	600g	1.5kg	2.7kg

*limits and specifications vary depending on the application, species and setup. Specificatons cannot be achieved simultaneously.

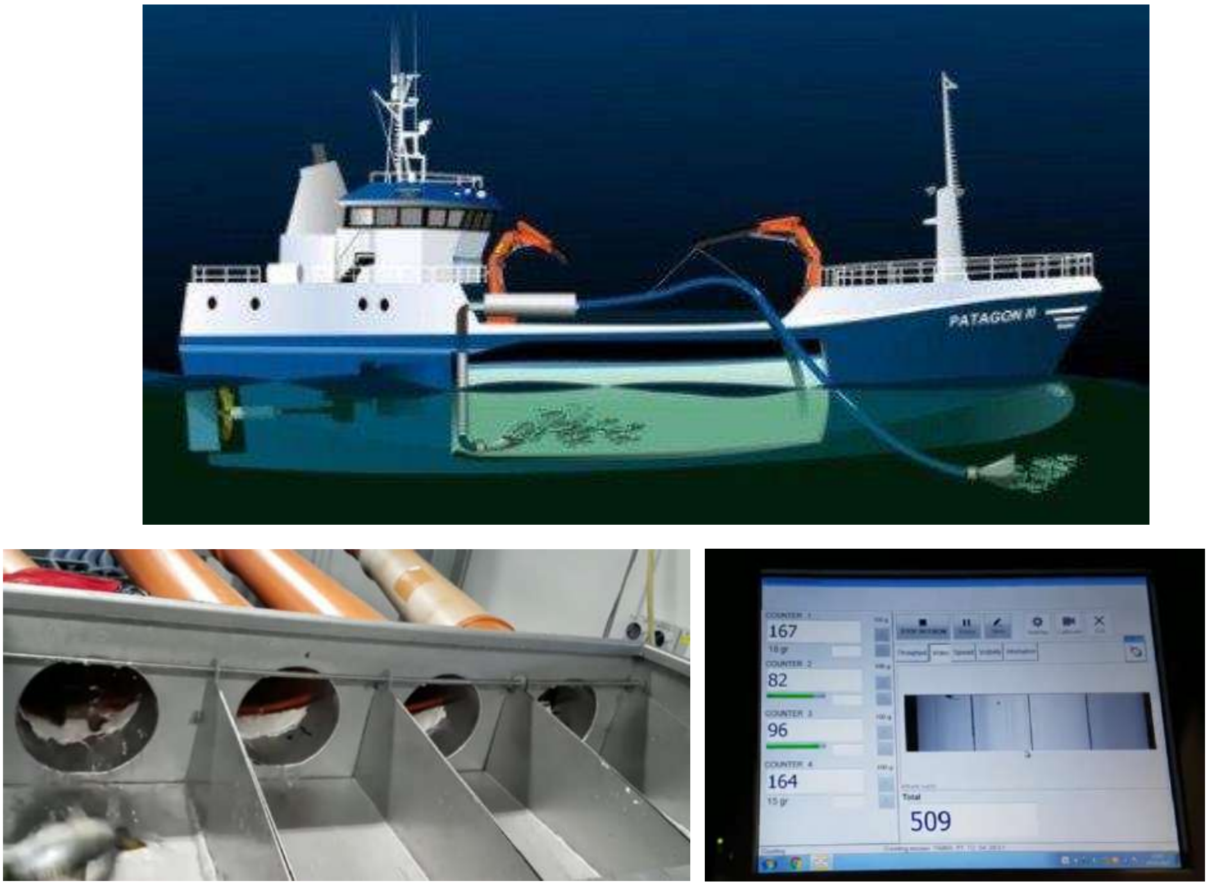


Figure 34. Fish pump system and wellboat characteristics

2.2.12 Surveillance and Security systems

Surveillance and security systems are key elements for a multipurpose offshore platform as the BGF, which is not subject to a full-time human presence, but thanks to automatization and remote surveillance, it can be operated with less risk to humans.

Surveillance and security data are managed by the Local Control Room, under the monitoring of the Remote-Control Room (located on mainland), which receives processed data in real time. The aim is to ensure that the platform is always managed even when human access to the platform is not safe, for instance in case of harsh weather conditions.

Connection between the two control rooms is provided by means of the following links:

- the fiber optic cable which runs parallel to the umbilical cable;
- the BGF infrastructure radio channel.

An integrated system of radar and cameras enables the achievement of a real time picture of activities and vessels approaching the platform. The system Surveillance and Security system (SSS) oversees the physical integrity of platform and people involved in its operations and maintenance. In particular, a twofold technological approach has been defined:

- **External Surveillance and Security System** (ESSS), exploiting the integration of information of the surveillance Radars, AIS and long-distance cameras to provide an accurate surveillance of maritime traffic and to identify eventual unexpected events (accidental or deliberate actions).
- **Internal Surveillance and Security System** (ISSS), based on a smart security network of cameras to implement access control of operators and surveillance of accuracy in carrying out tasks under safe conditions, thus promoting adequate behaviour during platforms operations.

In the context of the ESSS, the long-range radar is responsible for detecting any vessel in the proximity of the platform as well as its movement pattern. This information is exploited to focus the PTZ long-range camera in such a way that the vessels are clearly visible and traceable.

On the other hand, the ISSS is focused to the security of the platform. For this reason, is designed as a more traditional video-surveillance /perimeter protection system. The key requirements are relevant to people safety, as well as critical structural components (such as wind tower).

2.2.12.1 Surveillance systems

Surveillance and transmission antennas that enable surveillance of the navigation system and the transmission of data to the remote-control room (onshore) are located on the roof of the Local Control Tower. They are constituted by:

- Surveillance radar.
- Long distance cameras.
- AIS (Automatic Identification System).

In particular, the radar system works in combination with long-distance cameras. This integration provides an accurate surveillance of maritime traffic, capable to include identification of potential intrusion by small boats approaching the platform.

2.2.12.1.1 Surveillance radar

The surveillance radar is responsible for detecting any vessel in the area around the platform, as well as its movement pattern. This information is used to guide the PTZ long-range cameras, towards the target, in such a way that the vessels become clearly visible and traceable (within the Line of Sight) (Figure 35).

Figure 35. Marine radar system characteristics

2.2.12.1.2 Long distance cameras

The external surveillance function is complemented by long distance cameras (Figure 36). They have PTZ (Pan, Tilt and Zoom) capability to be able to track a specific target selected by the operator based on alerts provided at control and surveillance console. In particular, the integration with the radar allows to obtain a higher level of maritime traffic surveillance capability, with identification of potential intrusion by small boats approaching the platform.

Both IR and video cameras feature powerful optical zoom lens allowing the operator to both detect and then zoom into the area of interest. Both thermal and video outputs are provided simultaneously. The aluminium housings are rated to IP67 and with appropriate anodization and powder coated to withstand harsh environmental conditions. Optical encoders ensure positional accuracy and are coupled to a self-correction system that automatically keeps the cameras in the desired position. The harmonic drive train is virtually zero backlash, eliminating image bounce as the camera pans between pre-sets.

Figure 36. Long range camera

2.2.12.1.3 AIS (Automatic Identification System)

The purpose of the AIS is to provide identification information relevant to the vessels that are present in the specified area. These mainly include Vessel Maritime Mobile Service Identity (MMSI code), unit type, position, course, speed. This information is displayed on the operator screen and used by the system to give an automatic alarm in the event of a potential collision risk is acknowledged. The transmitted data also allows maritime authorities to monitor the movements of the concerned vessels.

The AIS consists of a VHF transceiver connected to a positioning system, such as a LORAN or a GPS receiver, jointly with other electronic navigation sensors. The transmission takes place on two channels (87B and 88B) of the band intended for radio transmissions between vessels. The data are transmitted periodically using algorithms that allow avoiding the interference among the transmissions of the various units.

The symbol for every significant vessel within the radio range is visualized on a Radar screen or Electronic Chart Display system. Each symbol is characterized by a velocity vector (indicating speed and heading). Each vessel "symbol" can reflect the actual size of the ship with position to GPS or differential GPS accuracy. Ship name, course and speed, classification, call sign, registration number, MMSI and other information are discoverable simply by clicking on the vessel symbol. Manoeuvring information, Closest Point of Approach (CPA), Time to Closest Point of Approach (TCPA) and other navigation information, more accurate than information available from an automatic radar plotting aid, are also made available (Figure 37).

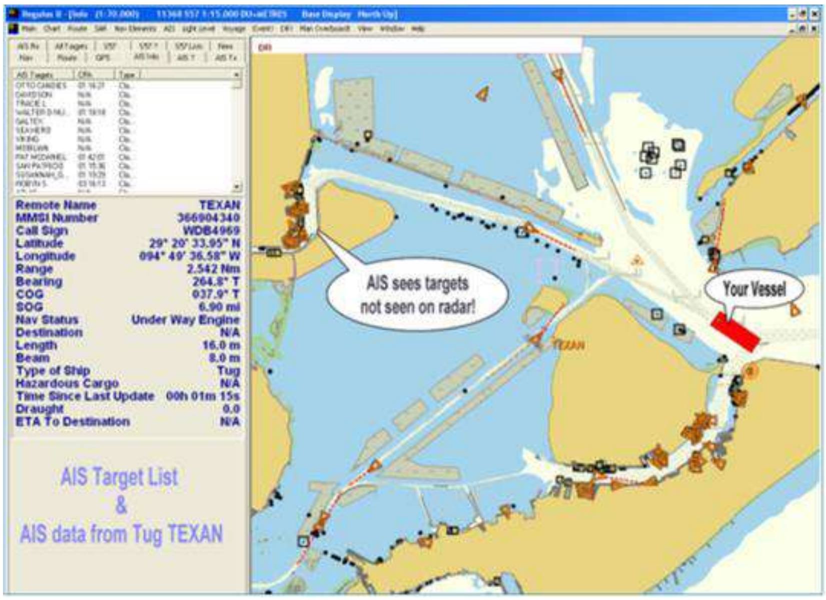


Figure 37. Target not visible to the Radar

2.2.12.2 Security systems

The internal surveillance of the platform is carried out by means of CCTV Camera system which include different type of sensors:

- PTZ Cameras Indoor/outdoor;
- Fixed Cameras Indoor/Outdoor
- camera in the visible spectrum;
- IR camera.
- Underwater cameras.

Each camera is connected, via Ethernet/optical fiber, to a network switch able to transmit a redirect the signals to the elaboration and recording unit.

ISSS is designed as a more traditional video-surveillance /perimeter protection system. The key requirements are relevant to people safety, as well as critical structural components (such as wind tower).

2.2.12.3 Access control

The access control is granted only to people with a specific badge provided by the BGF infrastructure operator. Everyone will have access only to the rooms necessary to carry out their work on the basis of the "Need to work" principle. Given the security needs of the platform, it is advisable to choose badges of the "Mifare" type at 13.56 MHZ.

When the badge approaches the reader, entering the radiofrequency field emitted by this, the two devices begin a secure communication session using shared encryption keys. When communication is established, the card transmits its data, after which the dialogue is completed.

2.2.13 Navigation safety

The Navigation Safety System is designed according to IALA Recommendation O-139 on Marking of Man-made Offshore Structures, which includes the offshore aquaculture farms in national waters. The marking is proposed to the National Maritime Authority, competent for the area, to obtain the authorization for the installation (formal communication).

According to its position with respect to the marine traffic, the special marks can be mounted in integration with Beacon radar through an anchored positioning at relevant position of in correspondence of the main sides of the platform. For the BGF installation a Radar beacon (short racon) is integrated in the fixed navigational mark, which works as a transmitter-receiver. When triggered by a radar, it automatically returns a distinctive signal that appears on the display of the triggering radar, providing range, bearing and identification information (Figure 38).

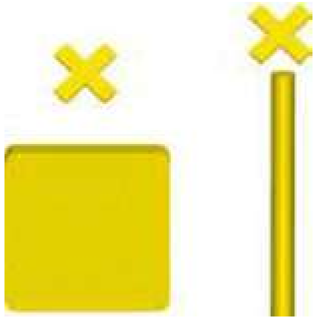


Figure 38. Special marks positioning with respect to the platform location

2.2.14 Data transmission system

Data managed at Local Control Room level are transmitted to the Remote Local Control (onshore) by redundant means:

- Fiber optic line (umbilical)
- Data transmission system (radio link).

2.2.14.1 Fiber optic cable connection

Taking advantage of the umbilical cable that electrically connects the BGF infrastructure with the grid on land, a fiber optic connection is easily deployed through this line to enable data transmission to the Remote-Control Room. Therefore, basically, the monitoring of the videos of the control room is predominantly transmitted on the "umbilical" connection and only some information is replicated on the radio link.

Cabled data transfer for BGF infrastructure is based on a single-mode fibre as it has a significantly greater bandwidth than the multi-mode fibre. The single-mode cable supports connections over a much greater distance than the multi-mode cable reaching up to 40 Km and is therefore perfectly suited to the BGF application. It is, in fact, used in applications that require large bandwidth and in long-range network connections distributed over large areas, such as cable television and the creation of backbones.

VPNs is configured to control, at Remote Control Room level, equipment and devices within the Local Control Room. Virtual Private Network (VPN) technology routes the internet traffic through a VPN tunnel, which is an encrypted connection between the device and the destination on the web. A VPN tunnel not only encrypts the data, but it also hides the IP address and location. Like an armoured van, it takes a person from point A to point B in total secrecy, protecting the person against any danger lurking outside. It is necessary to install and update Antivirus software on Remote and Local locations. It is also advisable, in relation to the exchange of sensitive information, to use hashing and digital signature algorithms to be sure of the identity of the senders of the communications.

2.2.14.2 Radio link

The Radio link is designed considering 2 Mbps for each video flow to transmit (including Video radar). Considering that each video stream provided, as per design specifications, does not exceed 2 Mbit / s, it can reasonably be estimated that the overall video stream will not exceed 500 Mbit / s.

Therefore, the chosen antennas, in transmission and reception, has to respect the listed requirements. Based on this, the following design solutions for the BGF infrastructure is identified:

- SATCOM Systems: the connection is through a satellite link which, however, must allow overall traffic of 500 Mbit / s. The need to encrypt various information, in fact, weighs down the traffic produced.

3 BGF INFRASTRUCTURE OPERATIONS

In the present paragraph, an overall description of the operations designed for the BGF infrastructure functioning is provided for the main subsystems and functions outlined in Paragraph 2.0. For these sub-systems a procedural sheet has been prepared and included in Annex A and Annex B (for production and services, respectively) to report the following information:

- function description;
- typology of equipment concerned;
- list of main suppliers;
- layout of the sub-system;
- synthetic view of the key technical aspects of the technology;
- some insight about the key operational aspects concerning how the described function and related activities is deployed;
- eventual clues for trouble-shooting.

3.1 BGF Infrastructure Production

As anticipated in Paragraph 2.0, the BGF Infrastructure Production functions, which are relevant to be here described in terms of procedural operation sheets, include the following assets:

- Aquaculture
- Energy
- Oxygen
- Microalgae
- Desalinated sea water

All these functions are introduced in the following sub-paragraphs, with a direct recall to the technical sheets reported in Annex A.

3.1.1 Aquaculture

3.1.1.1 Fish Net System

The fish containment system of the BGF production site is a complex assembly of netting and ropes which contains the fish to grow. In particular, the 6 square size net cages allow for up to 5.000 t/y of fish production. It represents an important asset for which a substantial support in the mechanisation of weight movement is offered to the operators by the cranes available on the platform deck.

The reference operation sheet is provided in Annex A.

3.1.1.2 Fish Net Cleaning System

Operativity and survivability of the net systems is provided by the fish net cleaning system, whose function is to regularly decrease the net weight and allow for water exchange through netting panels to flush oxygen and nutrients. This function is labour intensive and then necessitates to be automated and mechanised, as much as practicable, to maintain high levels of production and, at the same time, safe conditions to the asset and operators.

The reference operation sheet is provided in Annex A.

3.1.1.3 Fish feeding

Fish feeding is another function highly automatised and mechanised to download the human contribution. The automated fish feeder assists the offshore aquaculture operator to feed the fish at the proper volume and frequency. As described in Paragraph 2.1.1, the feed system architecture is a complex architecture based on: feed blower, cooling system, dosers, selectors, rotor spreaders, air control system, smart control, cleaning feed pipes.

The reference operation sheet is provided in Annex A.

3.1.1.4 Dead Fish Collecting and Treating System

As described in Paragraph 2, the collection system is aimed at preserving healthy conditions at the bottom of the net system, where dead fish naturally deposit, thus avoiding human intervention at depth. The system is operated by sending pressure air through an air hose into the mort cone. The air will move upwards inside the mort cone, creating a vacuum and a current that will create a suction effect and thus transporting mort's up through the system and out from the cage. The system is used continuously, avoiding the accumulation of any mortalities.

The reference operation sheet is provided in Annex A.

3.1.2 Energy Production

3.1.2.1 Wind Turbine System

The Wind Turbine System constitutes the primary source of electric energy for the BGF infrastructure. Operation and service (O&S) activities are conceived to obtain balance of plant and associated transmission assets during the lifetime of this production system. The focus of these activities during the operational phase is to ensure safe operations, to maintain the physical integrity of the wind turbine and to optimise electricity generation. Turbine availability is the percentage of time the wind turbine is ready to produce power if the wind speed is within the operational range of the turbine.

Planning of logistics and access is vital to securing higher availabilities. BGF infrastructure, thanks to its ample deck and easy way to dock, provides an important ease to access. Accommodation and volumes availability onboard facilities the operational support, which is typically 24 hours a day, 365 days a year, including responding to unexpected events and turbine faults. Nevertheless, outside normal operating hours this support is provided from remote control rooms which monitor wind farm SCADA data.

The reference operation sheet is provided in Annex A.

3.1.2.2 WEC System

Wave Energy Converters (WECs) represent a promising technology in the range marine energy devices, even if no product is still clearly emerging with a proven commercial viability. The WEC solution identified for the BGF energy combines the transformation of the wave mechanical energy into electrical energy with the capacity to subtract energy from wave through the platform structure to downsize the wave elevation and current intensity within the pool, which are critical for the fish growth and welfare. In particular, the BGF solution is based on a modification of the REWEC3 patented solution for fixed installation to comply with floating conditions.

The reference operation sheet is provided in Annex A.

3.1.2.3 PV System

As described in Paragraph 2, a contribution to the solar energy generation onboard BGF infrastructure has been considered to supply electric consumption of the microalgae production system and the sea water desalination. The photovoltaic panels (N_p= 700, Panel type: SPR-220-BLK-U Solar Panel from SunPower) are installed on the aft building roof, along its entire length.

The reference operation sheet is provided in Annex A.

3.1.3 Oxygen Production

The oxygen production system capacity onboard the BGF system is specifically conceived to downsize risk of oxygen penurity in particular conditions of the year, jointly to potential detrimental climate change effects. This circumstance might be potential just I a few of the different choices for the BGF siting, as in offshore areas healthier conditions, including dissolved oxygen content, are anyway naturally guaranteed. Nevertheless, the risk of losing the entire stock because of untimely local temperature, scarce surface water recirculation and rise in conjunction with blooming of pest and algae imposes planning such a capacity to be mobilised in specific time slots of the BGF infrastructure production and for specific destination sites.

The reference operation sheet is provided in Annex A.

3.1.4 Microalgae Production

Combined to the fish production, the extensive use of platform volumes made available has revealed the opportunity to develop a microalgae production farm. Dedicated ISO-type containers, fully equipped with industrial culture growing systems, are placed on top of the aft side building, far from green water impact and well positioned to enjoy light and solar energy for its own processing. Despite the industrial production of microalgae is still far from being remunerative, it is anyway attractive to accommodate such a function in the BGF infrastructure in order to be ready when more competitive and efficient technologies could raise to the commercial attention. The proposed production size is also useful for the BGF aquaculture hatchery, in particular to constitute the primary source of nutrition for juvenile stages of fish.

The reference operation sheet is provided in Annex A.

3.1.5 Sea water desalination Production

Desalinated sea water is another key function to enable the BGF infrastructure use of potable water for human, sanitary and operation needs. As described in Paragraph 2.0, Reverse Osmosis (RO) desalination system is the technology employed onboard the BGF infrastructure to obtain fresh water from sea. The reverse osmosis unit separates the salts present in the water, generating a certain percentage of fresh water (permeate) and discharging the remaining concentrate.

The reference operation sheet is provided in Annex A.

3.2 BGF Infrastructure Services

As anticipated in Paragraph 2.0, the BGF Infrastructure Services functions, which are relevant to be here described in terms of procedural operation sheets, include the following assets:

- HVAC
- Electric Offshore Substation
- Shipping

- Surveillance and Security
- Structural Health Monitoring
- Mooring System

All these functions are introduced in the following sub-paragraphs, with a direct recall to the technical sheets reported in Annex B.

3.2.1 HVAC

The BGF infrastructure offers onboard accommodation facilities, in terms of suitable indoor ambient conditions for manned operations and living at sea, as well as operative conditioning for the electric / electronic equipment, laboratory chambers, pharmacy and other biological needs related to the offshore cultures production. The HVAC system is based on commercial equipment with particular requirements to operate in harsh environment like the one at sea, for instance those already in use in the marine and offshore industry.

The reference operation sheet is provided in Annex B.

3.2.2 Electric Offshore Substation

The Electric Offshore Substation supervises the acquisition and transformation of the electricity produced by the various renewable sources and provides for the correct distribution to on-board utilities, as well as for the dispatching of the excess energy to the land grid. The characteristics of the Electric Offshore Substation are provided through its main sub-components, that is:

- Dry-type transformers;
- Medium Voltage Switchgear;
- Medium Voltage AC cables.

The reference operation sheet is provided in Annex B.

3.2.3 Shipping Operations

If the combination of offshore wind energy and offshore aquaculture proves to be feasible and profitable in practice, there may be an additional possibility to reduce the O&M costs by synergy effects of the combined operations. Logistic waiting times, for example, can result in substantial revenue losses, whereas timely spare-parts supply or sufficient repair capacity (technicians) to shorten the logistic delay times are beneficial. Shipping services fall within the area of potential costs optimisation. Despite the longer transport distances result in higher O&M costs than for coastal sites, operational time onboard and overall time mobilisation of the service vessel is conducive to costs saving. Two specific assets are detailed in the framework of the BGF infrastructure shipping operations, which are candidate to produce a portion of the above cited costs savings, namely:

- Automated Docking System;
- Electric Recharge System.

The specific section related to the service vessels typology and its incidence in the O&M costs is not intentionally addressed in the present Manual. Literature studies[2] reports about Offshore Wind and Fish

[2] Röckmann, C., S. Lagerveld and J. Stavenuiter, 2017, "Operation and Maintenance Costs of Offshore Wind Farms and Potential Multi-use Platforms in the Dutch North Sea" Chapter 4 of the book Aquaculture Perspective of Multi-Use Sites in the Open Ocean, edited by SpringerLink, 2017, pgs 97-113.

Farming Support Ships as attaining 10% savings on O&M costs when fulfilling specific requirements, which include:

- capable to transport and accommodate 40 persons, working in 3 shifts for one week
- wind farm spares transport and repair capability
- different biomass species transport capability
- operation capability in harsh environment (a dynamic position system (DP-2), motion compensated crane, a wide working deck; capability to work on 24/7 h with a significant wave height up to 3 m (North Sea conditions).

These characteristics are now included in the design of many service vessel typologies that shipbuilders are offering to the offshore operators. The BGF infrastructure services are already considering these capabilities and are ready to interface with and to produce reciprocal value by means of:

- facilitating the docking automation, the positioning of the ship for loading / unloading operations, reducing to minimum the risk for operators and the latency times for landing and departure;
- delivering electric recharge to the electric or hybrid propelled vessel batteries, thus maximising consumption of renewable energy on site.

The reference operation sheet is provided in Annex B.

3.2.4 Surveillance and Security

One of the main concerns regarding the Multipurpose Offshore Installations is their surveillance and security capability to guarantee the investor and related insurance companies involved in the asset protection context about such a risk. The BGF infrastructure Surveillance and Security System is based on commercial technologies already proven for Marine Traffic Management, whilst specific needs related to the fish production are customised for the application. Other onboard security constraints are derived from well-known Oil&Gas offshore platform operations.

The reference operation sheet is provided in Annex B.

3.2.5 Structural Health Monitoring System

The Structural Health Monitoring (SHM) system enables to record the history of structural deformation of the platform at its critical points subject to environmental loading for the duration of its service life. This capability represents a key instrument to judge about its resilience through time to provide the expected services under safe conditions, to discover as early as possible a potential degradation of its linear behaviour in the loading / resistance cycles in order to set up and implement mitigation measures to protect the asset before a major failure could occur. All these aspects are crucial input factors to:

- deployment of asset insurance for the service life;
- further assessment of service life extensions, at the end of technology long lead items replacement (25 years).

Fiber Optic Sensing (FOS) solution and, in particular, Fiber Bragg Grating (FBG) sensors, has been selected for the SHM system of the Blue Growth Farm, due to its unique and peculiar combination of features. Moreover, GPS sensors of the GNSS type are considered to complete the sensing functionalities.

The reference operation sheet is provided in Annex B.

3.2.6 Mooring System

Floating foundations allow access to deep-water sites with typical strong wind and wave resources to capture electric energy for own platform production. In addition, floating foundations generally offer environmental benefits compared with fixed-bottom designs due to less-invasive activity on the seabed during installation.

The BGF infrastructure mooring system is based on drag anchors connected to the platform fairleads with metallic chains, for those seabed conditions are favourable (silty, soft soils), whilst gravity-based anchors are employed in case of harder soils.

Once deployed, in general, the time interval for periodic inspections to the mooring lines is five years, if the Design Fatigue Factor (DFF) is applied. For reducing O&M cost and implementing advanced O&M strategies as well as monitoring systems are a key enabling technology. Monitoring systems may indicate mooring line failures in real time or at least on short term, whereas inspections will only detect mooring line failures on pre-set inspection intervals or after major events.

The reference operation sheet is provided in Annex B.

3.3 Personnel involved in the BGF Infrastructure Operations

The following Paragraph 3.3.1 and 3.3.2 list the numbers and grades of whole team required to operate the BGF infrastructure. The team is also supposed to carry out maintenance tasks described in Paragraph 4.3.1 and 4.3.2, then the duty cycle indicates the % of time spent on these different tasks.

It has been assumed that the staff transport and supply vessel will be retained on long terms charter with the required crew included in the charter contract. It has been assumed that the staff transport and supply vessel will be retained on long terms charter with the required crew included in the charter contract. Maintenance of the vessel will be the responsibility of the charter operator.

Similarly, it has been assumed that the fish produced will either be sold delivered to shore, or that the operator of BGF will be an established fish farming company which already has the necessary in-house facilities services and staff available for all shore-based operations.

The ROV based environmental monitoring, planned to be periodically deployed to assess cumulative impacts around the BGF infrastructure installation at specific points and according to a procedure agreed with authorities is considered as supplied by an external service provider.

3.3.1 Production

N°	Role	Duty Cycle	Aquaculture	Energy	Oxygen	Microalgae	Sea water desalination
1	Control Room Operator (3)	70%	X	X	X	X	X
2	Fish Production Manager (2)	80%	X				
3	Energy Systems Manager	60%		X			
4	Deck operations responsible	10%	X	X	X	X	X
4	Automated ship docking & recharge control manager	0%					
6	Aquaculture biologist (2)	80%	X			X	
7	Husbandry staff (10)	80%	X				
8	Mechanical staff (2)	20%	X	X	X	X	X

9	Electrical staff (2)	20%	X	X	X	X	X
10	Divers (5)	45%	X				
11	Remote Control Room Operator (1)	40%	X	X	X	X	X

3.3.2 Services

N°	Role	Duty Cycle	HVAC	Electric Offshore Substation	Shipping Operations	Surveillance and Security	Structural Health monitoring	Mooring System
1	Control Room Operator (3)	20%	X	X	X	X	X	
2	Fish Production Manager (2)	0%						
3	Energy Systems Manager	20%		X				
4	Deck operations responsible	70%	X	X	X	X	X	X
4	Automated ship docking & recharge control manager	70%		X	X	X	X	
6	Aquaculture biologist (2)	0%						
7	Husbandry staff (10)	0%						
8	Mechanical staff (2)	30%	X	X				X
9	Electrical staff (2)	30%	X	X	X	X	X	
10	Divers (5)	5%						X
11	Remote Control Room Operator	40%	X	X	X	X	X	

4 BGF INFRASTRUCTURE MAINTENANCE

In the present paragraph, an overall description of the maintenance aspects designed for the BGF infrastructure survivability is provided for the main subsystems and functions outlined in Paragraph 2.0. For these sub-systems a procedural sheet has been prepared and included in Annex C and Annex D (for production and services, respectively) to report the following information:

- function description;
- typology of equipment concerned (reminder to the previous operation sheet);
- list of main suppliers;
- layout of the sub-system;
- synthetic view of the key technical aspects of the technology;
- some insight about the key operational aspects concerning how the described function and related activities are deployed;
- Eventual clues for trouble-shooting.

4.1 BGF Infrastructure Production

As anticipated in Paragraph 2.0, the BGF Infrastructure Production functions, which are relevant to be here described in terms of maintenance aspects sheets, include the following assets:

- Aquaculture
- Energy
- Oxygen
- Microalgae
- Desalinated sea water

All these functions are introduced in the following sub-paragraphs, with a direct recall to the technical sheets reported in Annex C.

4.1.1 Aquaculture

4.1.1.1 Fish Net System

Fish net maintenance is crucial to guarantee the required production and to limit fish escape to the minimum practicable. To ensure an optimal service life, it is important that it is checked regularly during the infrastructure life. This inspection and maintenance task is also facilitated by the available underwater technologies, thus limiting human risks.

The reference maintenance sheet is provided in Annex C.

4.1.1.2 Fish Net Cleaning System

Cleaning nets is a complex problem resolved by technology. Different solutions are possible, but the final target is to be the creation of the optimal environment for the fish. Reducing the risks of net breakage and / or force dynamics not predicted in the anchorages design is as well important.

The reference maintenance sheet is provided in Annex C.

4.1.1.3 Fish feeding

Maintenance tasks to the automatised feeding system and associated machineries are as crucial as those related to the fish net given that they directly impact on the stock production rate. Therefore, adequate integrated strategy is to be carefully implemented in order to reduce downtime to the minimum practicable.

The reference maintenance sheet is provided in Annex C.

4.1.1.4 Dead Fish Collecting and Treating System

Thanks to the healthier conditions when breeding at offshore areas, combined to the protection provided by the BGF infrastructure to its internal pool, casualties during the fish growth are expected to be less than other application cases. Nevertheless, the collector and treatment system is anyway to be installed to assure high hygiene level, then the required maintenance is to be planned, even if minimal, to guarantee constant efficiency.

The reference maintenance sheet is provided in Annex C.

4.1.2 Energy Production

4.1.2.1 Wind turbine System

Maintenance and service activities ensure the ongoing operational integrity of the wind turbine and associated balance of plant, including planned maintenance and unplanned service in response to faults, either proactive or reactive

The initial service agreement typically covers the period of the turbine defect warranty, which is usually five years. During this period, turbine technicians are typically employed by the wind turbine supplier. The service agreement may specify that on expiry technicians' contracts are transferred to the infrastructure owner.

Activity is divided into preventive maintenance (scheduled) and corrective service (unscheduled) works. The bulk of preventive works will typically be carried out during periods of low wind speeds to minimise the impact on production, however, in practice, this is not always achievable.

Corrective service is performed in response to unscheduled outages and is often viewed as more critical, due to accruement of downtime until the fault is resolved. The primary skills required are mechanical or electrical engineering, with further turbine-maintenance training often provided by the relevant turbine provider.

Typical maintenance includes inspection, checking of bolted joints, and replacement of worn parts (with design life less than the design life of the project).

Unscheduled interventions are in response to events or failures. These may be proactive, before failure occurs, for example responding to inspections of from condition monitoring or reactive (after failure that affects generation has occurred).

Structural Health Monitoring (SHM) and Condition Monitoring (CM) have significantly increased their relevance for offshore wind turbines in the last years because of their significance for a predictive maintenance strategy.

SHM assesses the integrity of in-service structures through a continuous monitoring in real-time. Making suitable decisions and recommendations is done by comparing the measurements at the same location at different predefined moments in time on the structure while it is in operating condition.

This process of monitoring, computation, signal processing, communication and non-destructive evaluation can bring further cost reductions through:

- predictive and preventive maintenance strategies allowing to schedule inspections and maintenance actions.
- increased safety, reliability and durability.
- design improvements thanks to post-processing of the data saving materials (weight and thickness) as well as manufacturing time (shape and replicability).
- minimizing downtimes and dismounting parts without defects/damages.

The reference maintenance sheet is provided in Annex C.

4.1.2.2 WEC System

Accurate maintenance of the WEC system is of crucial importance for the BGF infrastructure because of its front position to main waves impact. Efficiency of the translation of mechanical energy from waves into electric energy, whilst subtracting energy to the platform movement improves the stabilisation of the platform and contribute to the power supply for the BGF operations.

The reference maintenance sheet is provided in Annex C.

4.1.2.3 PV System

PV systems technology is mature since diverse years for land application, but sea-based pilot applications are today experiencing endurance trials. Nevertheless, efficiency of the translation of solar energy into electric energy follows practises and maintenance protocols already established for the mature land-based market. PV installation on the BGF infrastructure possesses similarities with

The reference maintenance sheet is provided in Annex C.

4.1.3 Oxygen Production

The purpose of maintenance of Oxygen Generator is to prevent failure rather than eliminate it. Maintenance can avoid the occurrence of failure and prevent the impact on production when failure occurs. External and internal inspection of tanks/columns and other pressurized equipment must be carried out according to manufacturer procedures.

Generally speaking, the maintenance cost of Oxygen Generator is far lower than the repair cost. The maintenance of the Oxygen Generator can not only ensure energy consumption efficiency, but also extend the normal service life of the equipment.

The reference maintenance sheet is provided in Annex C.

4.1.4 Microalgae Production

Microalgae biomass can provide a wide variety of organic compounds of commercial interest and can be used as food and animal feed because of its high protein content. The production of biomass from microalgae requires several stages: cultivation, harvesting, and drying. The cultivation stage generates most of the process costs due to its high energy demand.

Closed microalgae culture systems such as photobioreactors (PBRs) have several advantages over open culture systems. Some of the advantages of PBRs are a better control of the cultivation conditions, to obtain a biomass with homogeneous characteristics, and to minimize contamination by other microorganisms that can affect the quality of the biomass. PBRs allow the cultivation of a single species of microalgae for prolonged periods with less risk of contamination increasing the potential of use for biomass, but PBRs operating costs are more expensive than open culture systems. A reduction of costs is possible when using electric energy by renewable sources.

Maintenance tasks in an industrial installation is reduced to minimum, especially when some problems like adhesion of microalgae to the transparent PBR surfaces leading to biofouling which reduces the solar radiation penetrating the PBR and decreasing biomass productivity is resolved by designing PBR surfaces with proper materials, functional groups or surface coatings, to prevent microalgal adhesion.

The reference maintenance sheet is provided in Annex C.

4.1.5 Sea Water Desalination Production

A reverse osmosis (RO) water maker has become an increasingly more important piece of equipment on board offshore platforms, as well as on a vessel. Luckily, RO water makers only require minimal amounts of maintenance to keep them in a healthy state and prolong their lifespan.

The reference maintenance sheet is provided in Annex C.

4.2 BGF Infrastructure Services

As anticipated in Paragraph 2.0, the BGF Infrastructure Services functions, which are relevant to be here described in terms of procedural maintenance sheets, include the following assets:

- HVAC
- Electric Offshore Substation
- Shipping
- Surveillance and Security
- Structural Health Monitoring
- Mooring System

All these functions are introduced in the following sub-paragraphs, with a direct recall to the technical sheets reported in Annex D.

4.2.1 HVAC

HVAC specifically designed for marine offshore environment are based on modular industrial packages with excellent corrosion resistance characteristics, whilst ensuring optimal temperatures for both people and equipment.

The reference maintenance sheet is provided in Annex D.

4.2.2 Electric Offshore Substation

The Electric Offshore Substation is the most important structure in an offshore installation devoted to produce energy from renewable sources. This is where all the energy produced is brought together and converted by transformers to a high voltage transmission. This is necessary to ensure that as little energy as possible is lost during transmission over long distances to the next onshore grid node.

If a technical fault occurs on the Offshore Electric Substation, then the energy production systems in the offshore platform will fail to function. This means that maintenance and repairs services must meet extremely meticulous and high-quality standards.

For the most part of the activity that can be deployed directly onboard, maintenance includes inspection, maintenance, and repair tasks. Important repair that cannot be handled onboard or replacements necessarily involve specialised suppliers' intervention.

The reference maintenance sheet is provided in Annex D.

4.2.3 Shipping Operations

The automated docking system and the electric recharge system selected for the BGF infrastructure requires simple routine maintenance checks. For the automated docking robot, any heavy failure or rupture necessarily implies its dismounting and replacement. This task is anyway easily carried out through a plug and play modality. The electric recharge requires routine maintenance tasks to protect it from corrosion and fouling.

The reference maintenance sheet is provided in Annex D.

4.2.4 Surveillance and Security

The BGF infrastructure surveillance and security system is composed of different items, each of them with different maintenance tasks requirements. Radar maintenance needs include checking to the transmitted power, the aiming, the amount of scattering in reception. It is equally important to check device components lifetimes and replace them before any failures could happen. The long-distance camera is to be routinely checked to ensure that the configuration is not unaltered by atmospheric events. AIS requires adequate checks on the cable connections and on the monitor configurations. Whilst the access control system applies to updating the software, when appropriate, as well as the refreshment of the list of personnel authorised to access it, as and when required.

The reference maintenance sheet is provided in Annex D.

4.2.5 Structural Health Monitoring System

The Structural Health Monitoring System requires very simple but accurate and periodic maintenance tasks.

The reference maintenance sheet is provided in Annex D.

4.2.6 Mooring System

The purpose of mooring inspections is to check for deviations along the line, around the moorings, and at the sea bottom in order to establish any preventive or corrective actions that need to be undertaken. This activity is typically operated via ROV. Mooring system component replacement is likely during the operative life of the BGF infrastructure, including a failed chain line, but in no case are safety conditions compromised.

The reference maintenance sheet is provided in Annex D.

4.3 Personnel involved in the BGF Infrastructure Services Maintenance

The following Paragraph 4.3.1 and 4.3.2 list the numbers and grades of the whole team required to maintain the BGF infrastructure. The team is also supposed to carry out operation tasks described in Paragraph 3.3.1 and 3.3.2, then the duty cycle indicates the % of time spent on these different tasks.

It has been assumed that major maintenance activity that cannot be carried out onboard (including replacement) be undertaken / supported by the supplier staff and equipment.

The ROV based environmental monitoring, planned to be periodically deployed to assess cumulative impacts around the BGF infrastructure installation at specific points and according to a procedure agreed with authorities is considered as supplied by an external service provider. The related maintenance to ROV equipment is then part of the service contract.

4.3.1 Production

N°	Role	Duty Cycle	Aquaculture	Energy	Oxygen	Microalgae	Sea water desalination
1	Control Room Operator (3)	5%	X	X	X	X	X
2	Fish Production Manager (2)	20%	X				
3	Energy Systems Manager	10%		X			
4	Deck operations responsible	10%	X	X	X	X	X
4	Automated ship docking & recharge control manager	0%					
6	Aquaculture biologist (2)	20%	X			X	
7	Husbandry staff (10)	20%	X				
8	Mechanical staff (2)	20%	X	X	X	X	X
9	Electrical staff (2)	20%	X	X	X	X	X
10	Divers (5)	45%	X				
11	Remote Control Room Operator (1)	10%	X	X	X	X	X

4.3.2 Services

N°	Role	Duty Cycle	HVAC	Electric Offshore Substation	Shipping Operations	Surveillance and Security	Structural Health monitoring	Mooring System
1	Control Room Operator (3)	5%	X	X	X	X	X	
2	Fish Production Manager (2)	0%						
3	Energy Systems Manager	10%		X				
4	Deck operations responsible	10%	X	X	X	X	X	X
4	Automated ship docking & recharge control manager	30%		X	X	X	X	
6	Aquaculture biologist (2)	0%						
7	Husbandry staff (10)	0%						
8	Mechanical staff (2)	30%	X	X				X
9	Electrical staff (2)	30%	X	X	X	X	X	
10	Divers (5)	5%						X
11	Remote Control Room Operator	10%	X	X	X	X	X	

5 CONCLUSIONS

The present document has been identified as Deliverable D7.5 "*Operation and Maintenance Manual*" of the Blue Growth Farm Contract [AD1], [AD2]. This document presented the Operation and Maintenance requirements related to the production and services related activities of the Blue Growth Farm Infrastructure.

In particular, a complete set of operation and maintenance specifications for the main subsystems related to the production and services cluster of activity has been identified and collected by looking at manufacturer and technology providers catalogues and organised in a comprehensive manual such to enable end users / stakeholders interested in the Blue Growth Farm multipurpose platform a correct understanding of reliability of envisaged tasks and then derive the most realistic perception of risks associated to such a Multi-purpose Offshore Installations investment.

A set of qualified personnel required to deploy the BGF infrastructure Operations and Maintenance activities as conceived for the efficiency and profitability of such an installation has been identified and characterised in their roles and grades. This result constitutes input for the assessment of Health and Safety aspects of personnel working onboard, as well as for the identification of the Training Needs required to adequately train specialised professionals to operate in such a context, where automation helps in reducing the crew at offshore but, at the same time, the new multidisciplinary skills is challenging if compared to current practises.

6 REFERENCES

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Annex A. Operation procedures (BGF Infrastructure Production)

A.1 Aquaculture production

1. Fish Net System Operation sheet
2. Fish Net Cleaning System Operation sheet
3. Fish Feeding Operation sheet
4. Dead Fish Collecting and Treating System Operation sheet

A.2 Energy production

1. Wind Turbine System Operation sheet
2. WEC System Operation sheet
3. PV System Operation sheet

A.3 Oxygen production

1. Oxygen System Operation sheet

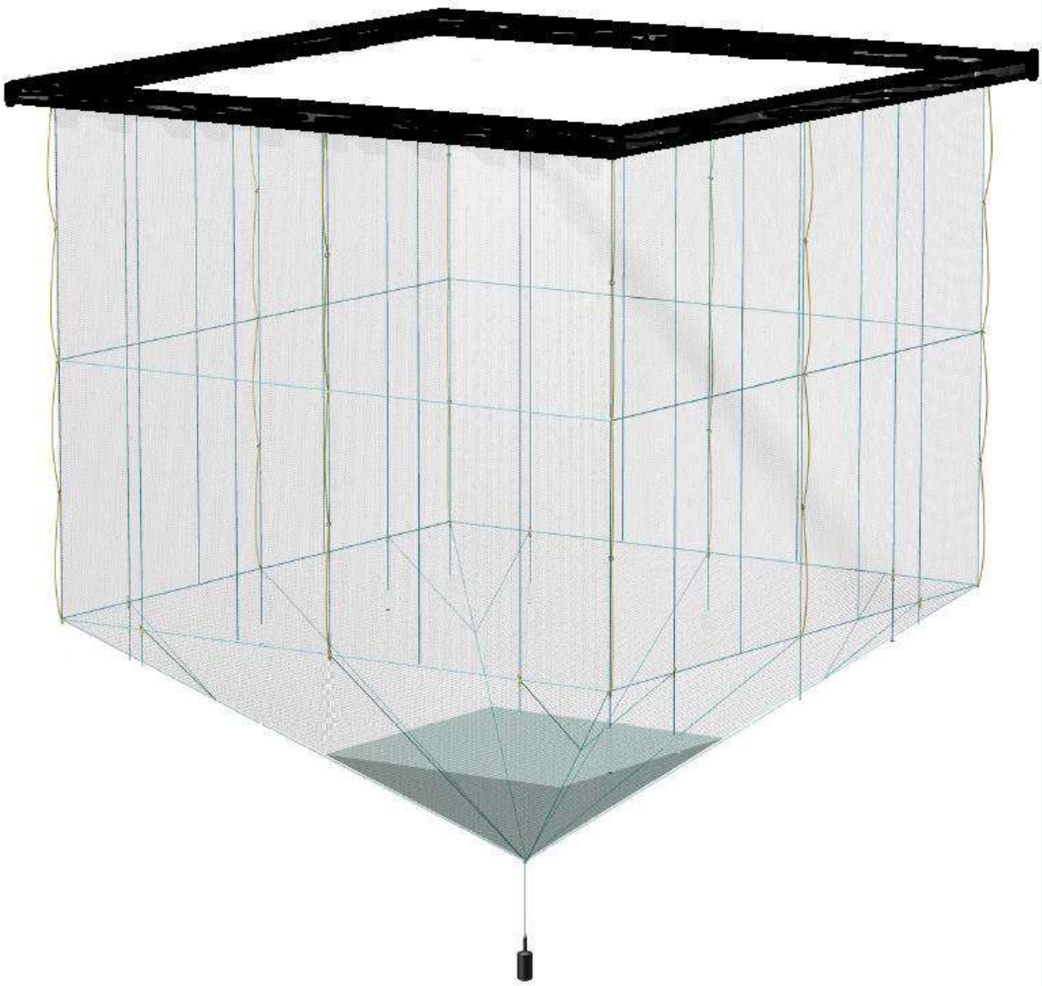
A.4 Microalgae production

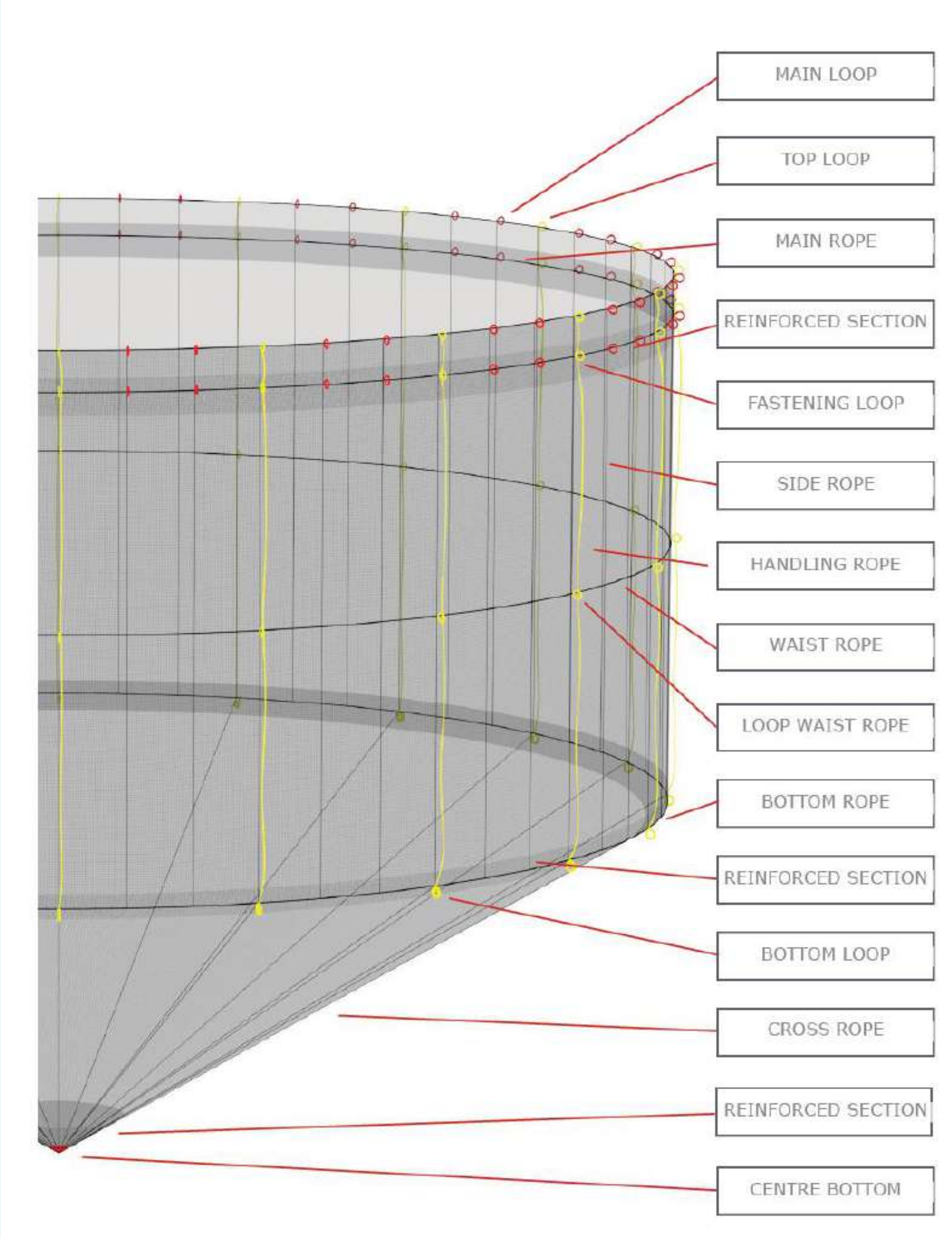
1. Microalgae System Operation sheet

A5. Sea Water Desalination production

1. Reverse Osmosis System Operation sheet

A.1 Aquaculture production

FISH NET SYSTEM Operation sheet	
FUNCTION	The fish containment system consists primarily of netting and ropes. The rope frames create the tri-dimensional structure of the fish cage and are designed to absorb the loads applied to the net panels under the various sea-states for which the net has been designed. Every rope has a dynamic function, and it is important to recognise that not all ropes are designed to withstand/absorb all types of loads. The net must therefore always be handled correctly and within the tolerance threshold for which it is designed, and inspection and maintenance must be performed and logged in accordance with the recommended procedures. The following are current standards for aquaculture and fishing nets and should be used as reference when undertaking net testing, either by the farm or by a certified third party: • ISO: 1197 – Fishing nets – Nettings – Basic terms and definitions. • ISO: 1806: Fishing nets – Determination of mesh breaking force of netting. • ISO: 1805: Fishing nets – Determination of breaking force and knot breaking force of netting yarns. • ISO: 1530: Fishing nets – Description and designation of knotted netting. • ISO: 3790 Fishing nets – Determination of elongation of netting yarns. • NS - 9415/NYTEK – Technical Requirements for Fish Farming Installations – Norwegian Standard. • Scottish Technical Standard for Containment at Marine and Freshwater Finfish Farms (under development).
Equipment	

Suppliers	DSM, MoreNot, Egersund, Badinotti, SIREC
Layout	
Key technical aspects	The load applied to nets varies greatly, depending on currents and wave conditions at the site, as well as on the stretching system used. Incorrect installation of the stretching system can cause an uneven load and lead to the net tearing or even failure. Lifting the net at high speed will also produce significant loads and potentially weaken or tear the netting. If a site has a dimensioning significant wave height in excess of 2.5 m and/or a current velocity higher than or equal to 0.75 m/s, only nets approved for dimension classification 0, under NS 9415, may be used. The same applies if the net's depth to centre exceeds 40 m and its circumference exceeds 169 m.

Nets must be stored in such a manner that they are not exposed to external factors capable of causing damage to filaments, ropes or the net as a whole. In particular, the net must be protected against the long-term effects of strong sunlight due to the effects of UV rays.

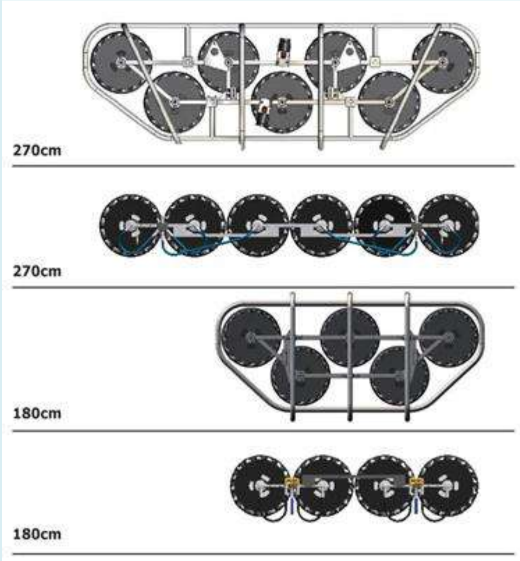
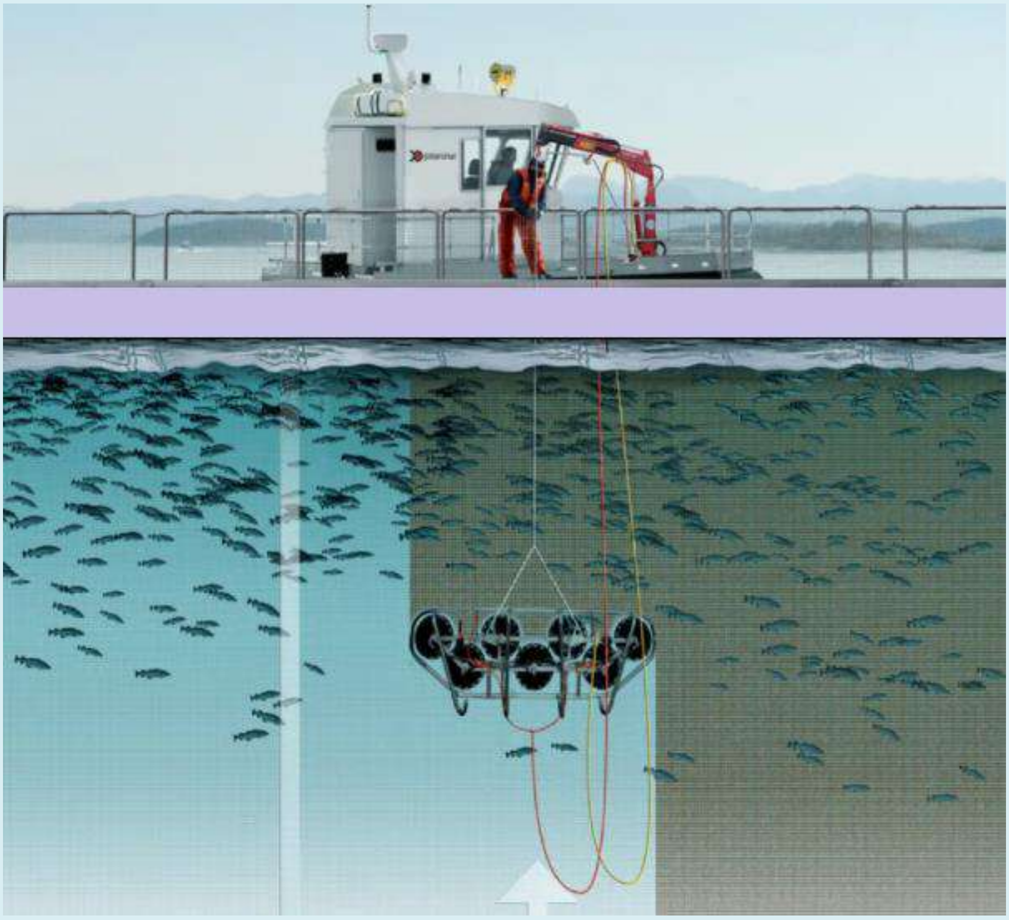
Single net installation phase

- Measure and cut by a welding cutter the rope necessary to connect the loops to the top handrail, to base handrail and to sinker frame; ensure that ropes are selected basing on expected load plus the appropriate safety factor; ensure that fiber rope elasticity complies with the required load cycle; ensure that rope length allows for connection at the proper distance from handrails and sinker, plus the length necessary to handle and make knots and safety;
- lie down the net on a flat surface large enough to contains at least 2 times the distance between vertical ropes and long as the wall depth plus the cone side length, plus the space necessary to manoeuvre by a forklift;
- stretch out on the ground the net panel included between two vertical ropes, from top to bottom;
- visually inspect the stretched net panel;
- tie all prepared ropes to corresponding loops, leaving them free outside the net panel;
- pull over the laying net panel the further net panel, caring that the two lay on the ground completely stretch out;
- connect ropes to the loops, and repeat the previous operations until all net panel are fully distended and packed one over the previous; loop ropes have to be free at net side;
- fully distend the bottom cone, and fold it over the last distended net panel;
- roll over the whole net, starting from the bottom rope with the help of two forklift;
- tie the net roll tightly, and arrange a lifting rope at net roll center of gravity, to allow suspension of the net roll by a crane;
- Install the sinker frame to the platform bottom;
- set at the correct depth the sinker frame;
- set at the same tension level all suspension bridles of the sinker frame;
- position the net inside the handrail, and connect to handrail the some of the corresponding ropes;
- cut the handling rope and let the net stretch out in water;
- moving by side, lift by a crane the main rope and proceed securing the corresponding rope;
- proceed in this way until all handrail ropes are secured;
- secure all ropes to handrail base;
- connect the vertical ropes composing the corners of the square cage to the sinker frame;
- connect all the bottom ropes to the sinker; use a support rope on a winch or crane to supply the necessary tension strength;
- lift the net bottom section out and attach the dead fish collection system and the central weight by means of the platform crane.

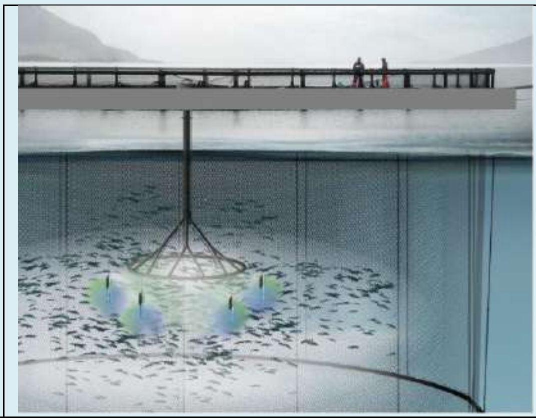
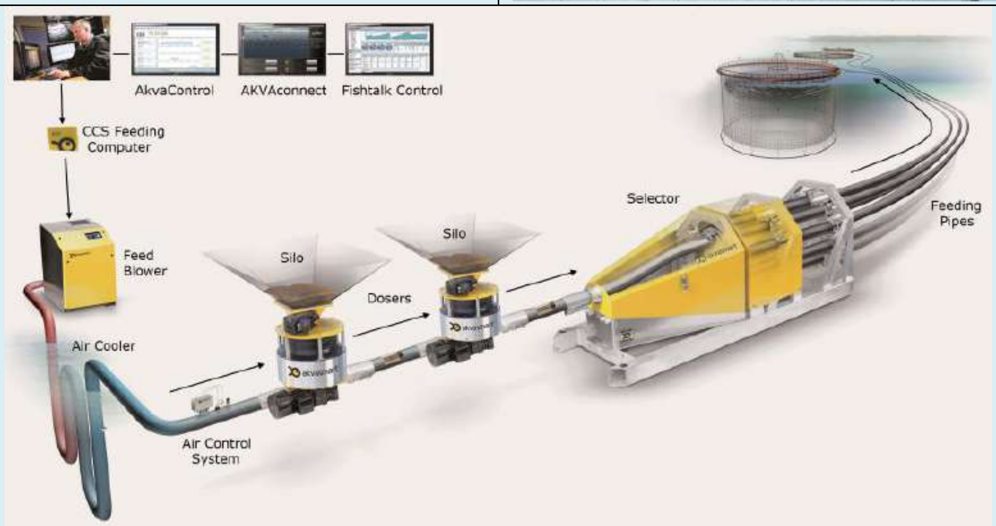
Check after installation

	A net must be checked after installation and mandatorily before fish stocking, even if the net is new or has come directly from service. A visual inspection is required to identify any damage or faults that may have arisen during the installation, or for non-conformities in production process. In particular, ▪ Check that all attachment loops have been properly installed. ▪ Check that the stretching system is not in contact with the net. ▪ Check that the jump net is not carrying the weight of the net. ▪ Check that there are no holes in the netting. ▪ Check that all panels are properly sewed ▪ The sinker system must be installed correctly and in such a manner that the net does not come into contact with it.
Key operational aspects	**Handling the net** When performing operations, correct handling of the net is essential to maintaining its service life. There are diverse operations that are carried out regularly, and they must follow a specific procedure. These operations include: ▪ Placing the net; ▪ Inspecting the net ▪ Repairing the net ▪ Changing the net; ▪ Delousing or other form of treatment performed on the fish; ▪ Harvesting fish. Some practical precautions are to be considered, as per any net panel installation, in order to reduce the risk of damage when handling the net: ▪ never lift the net by the netting. Only use a lifting rope to lift the net, or a handling rope attached next to a lifting rope. The complete net change or repair is usually planned after the harvesting period, when net can be safely handled without putting fish stock at risk. In case a net requires to be changed while fish is in, this is primarily achieved by inserting the new net outside the old one, after reducing the volume of the existing net. Changing a net is a risky operation but the BGF infrastructure is conceived to support human activities, thus reducing risk to the minimum. Repairing failure in net can be achieved by divers or by dedicated tools now available on ROV.
Trouble-shoot	-----

FISH NET CLEANING SYSTEM Operation sheet	
FUNCTION	To detach fouling adherent to yarn net filaments in order to decrease net weight and allow for water exchange through netting panels to flush oxygen and nutrients.
Equipment	High speed rotatory pressure washer; High pressure water pump, diesel/electrical driven; crane for handling and suspension.   
Suppliers	AKVA, AquaClean Tas

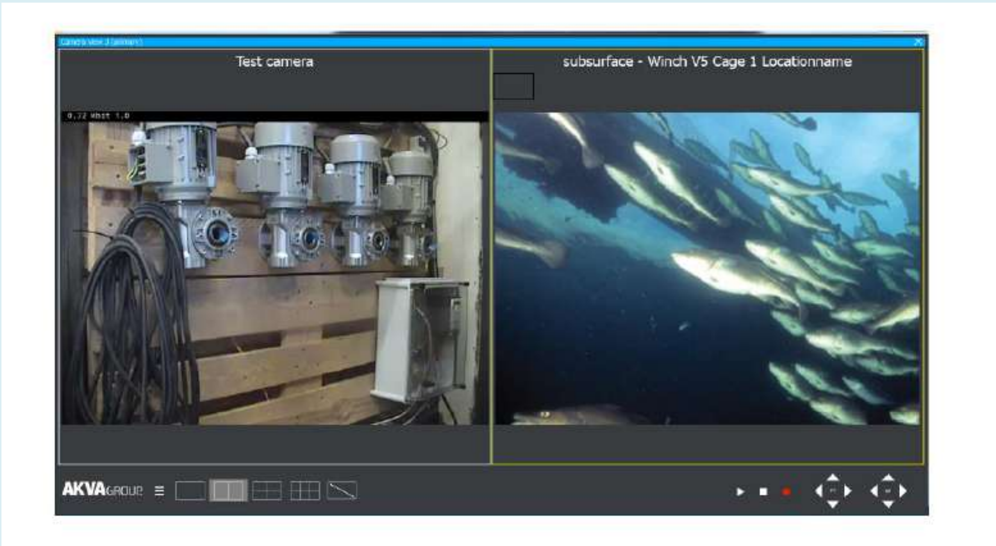
Layout	Metal frame holding up to 8 high-speed rotating steel disk, driven by high pressure water generated by a surface pump; frame hold and moved by a winch or crane. Alternative system by rotating high-torque blades hydraulically driven by a surface pump.  
Key technical aspects	Engine driven by electricity or diesel, thus needs safe electrical connection or diesel leakage-proof container. Water pump needs filtration before passing through pump high pressure stages.
Key operational aspects	Heavy frame to be moved over the net wall by a dedicated crane. One operator is dedicated to attend cleaning operation. Cast away fouling is deposited around cage. Turbidity plume is provoked.

	The rope for lowering and lifting the frame is connected via a safety hook. This prevents wearing and tearing the rope and prevents it from breaking. The cleaning process is more efficient when the frame is being pulled upwards. When going down in the water, the operator does not have enough control over the frame to provide a precise cleaning. Whether using crane when cleaning the net, let the frame sink to the bottom of the net, and then raise it slowly and controlled to achieve the best possible result. The net cleaner frame must always be held under water when the machinery is running. For testing the nozzles, however it can be run above water, but only using feeding pressure.
Trouble-shoot	----

FISH FEEDING Operation sheet	
FUNCTION	The automated fish feeder assists the offshore aquaculture operator to feed the fish at the proper volume and frequency, thus avoid human error and reducing major risks especially during hostile weather. It allows for reducing excessive food and consequent contamination of the surrounding environment. At the same time, the growth and health of fish is guaranteed with minimum operations cost.
Equipment	Silos to contain feeds; Anti-clogging devices Feed loading equipment (cranes, blowers) Reductors, dosers Cooling system Sensors Selectors Piping system UW camera Doppler system and monitoring system    
Suppliers	AKVA

<table>
<tr><td>Layout</td><td>


A Camera Control is used to match fish monitoring and feed system control.



</td></tr>
<tr><td>Key technical aspects</td><td>
CCSC feeding

The ‘Centralized Control System Computer (CCSC)’ methods is selected for the BGF production needs.

All functions are programmed, stored and executed in the same working devices. The CCSC communicates with the feeding different components (Blowers, Dosers, Selectors). The following parameters are to be addressed in the functions programming.

Feed rate
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	Feeding rate: the rate that the dosers is set to distribute the feed to the cage units. This can be shown as kg/min, kg/ton/min or pellet/fish/min. ***Feeding tables*** Tables consisting of how much feed required (in % of bodyweight) with different temperatures and size of fish. If a temperature sensor is connected, the corresponding amount is directly calculated from a feeding table. Fish size can be either be input manually by the feeding supervisor or by a biomass estimator. ***Meal duration*** Period of time during the day when the fish is planned to be fed (visits). ***Meal per day*** Meals can be multiple during daylight or even at nigh time, depending on temperature, fish size and feeding strategy. ***Transport time*** The time required for the feed to move between: - Silo and selector - Selector and unit(s) Transport time is normally measured, starting when the pellet leaves the doser and stopping when the pellet reaches the outlet of the pipe in the cage unit. A safety margin is normally assumed. A reference pellet speed is 10-15 m/s. This implies the transport time is around 7 s to reach the first line of cages (nearer to aft side) and 15 s to reach the second line (nearer to the front).
Key operational aspects	**Adjust daily feed amount for cages** Fish may show different appetite than expected, depending on various reasons. It is then wise to adjust feed amount per cage per day. Husbandry operations, presence of predators, parasites, diseases, fish overcrowding, poor water quality can affect fish feed intake, as well feed energy mismanagement. The automated fish feeding system support operators in reaching the optimum feed intake level, while respecting fish welfare and minimizing nutrients release. For each cage, the pellet size is determined on the basis of fish size, fish number and feeding strategy. The feeding supervisor set up the feeding strategy for that specific fish batch, adjusting feed energy, number of pellet/fish, daily feeding rate to match expected growth with temperature and husbandry operations. Artificial Intelligence system can support the supervisor in feeding strategy, integrating recorded values from sensors with forecast on the expected fish behaviour.
Trouble-shoot	**Fish feed mechanical alarms management** Air monitor alarm: High pressure

	1. Firstly, it is important to find out why backpressure increased. Normal reasons for higher backpressure are: a) increased doser speed will increase backpressure since higher speed gives more feed in the pipe (kg/min) due to the increasing resistance to flow b) increased doser calibration (g/s). On a pulse basis, doser amount increase will result in more feed per pulse c) change feed type. If new feed type has poorer technical quality than the previous, backpressure may increase due to slower pellet speed because of increased friction d) oil/dust increase friction in the pipes and leads lower pellet speed, which again gives higher backpressure e) increased air temperature inside pipes can cause oil leakage from the pellets, due to improper air-cooling system f) dirty and/or old feed pipes can be affected by deposits that cause more friction – lower pellet speed – and increased backpressure 2 Clean pipes with air: a) start with approximately 50% blower speed and increase by 5% every 20 second or so until pipe is open (90% maximum speed) b) insert sponge and clean pipe. Check if sponge is very dirty and repeat if necessary c) start blower and check that backpressure is on a normal level d) test feeding with a small dose e) always check that backpressure is stable f) if backpressure is not stable, repeat cleaning procedure or increase blower speed by 5% g) last solution, when the above checks are complete, is to increase pressure limits to max 0,1 bar above normal backpressure while feeding Monitor alarm: Low pressure 1 stop the ongoing feeding 2 Make sure that all settings are correct: feeding settings – transport time/blower settings 3 Check that the pipe hasn't loosened from the back of the blower or on the selector 4 Search for holes in the feed pipe and connections on steel pipes 5 Check that rotor spreader hasn't loosened from feed hose

DEAD FISH COLLECTING AND TREATING SYSTEM Operation sheet

FUNCTION

Collect dead fish in the bottom end of each cage, move it up to the top deck and then transfer to the treatment facility, minimizing mort fish diving collection. The system allows the collection of dead fish that concentrate in the bottom cone following their own weight or the body displacement operated by the current.

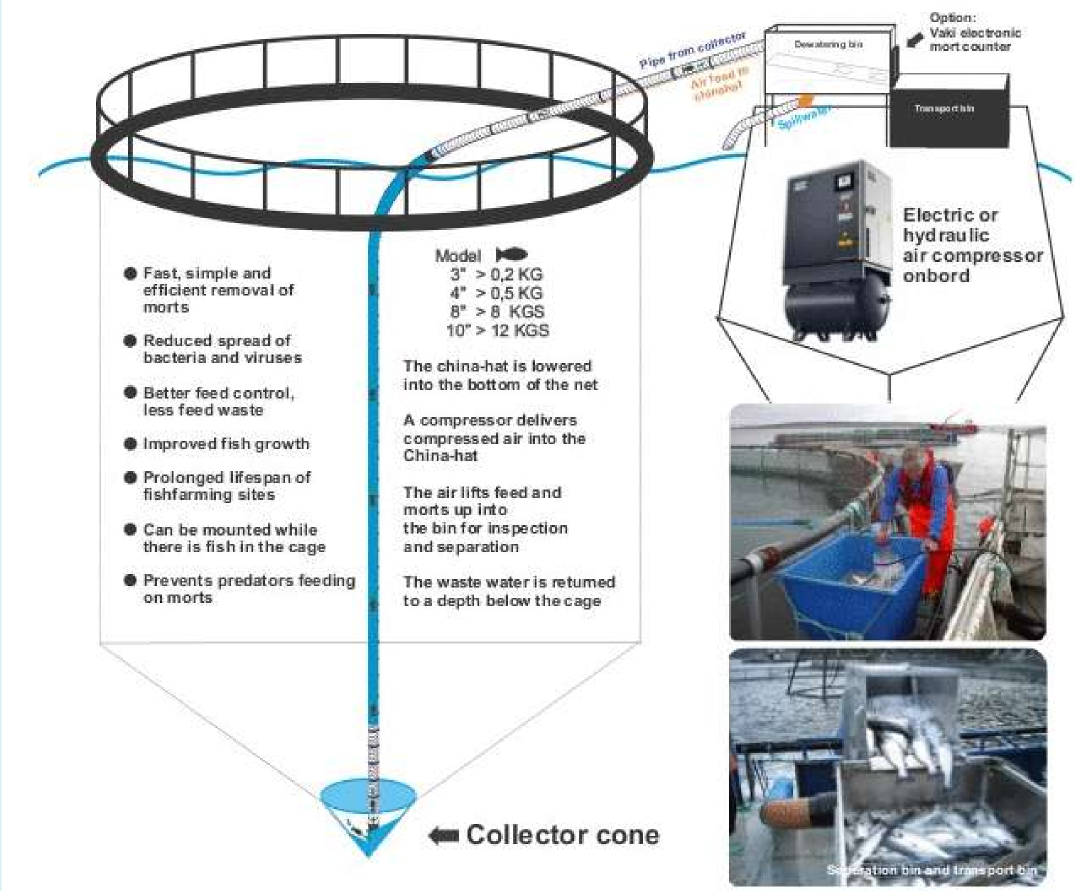
This system is mainly used in cold waters or where divers' intervention is not advised due to harmful environmental conditions, as current, wave, turbid waters, excessive depth.

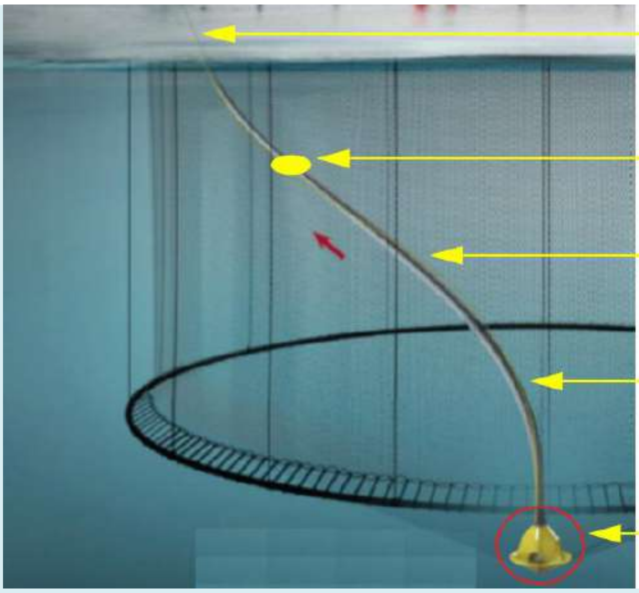
Equipment

- Collection cone
- Ballast
- Lifting pipe
- Air hose
- Joints
- Fish/water separator
- Fish collector
- Air compressor

Suppliers

AKVA, Seatools, Bjordal

Layout	
Key technical aspects	The LiftUp system for fish cages is an automatic system for collection and retrieval of dead fish by high pressure air. The system consists of a china-hat collector cone lowered to the bottom of the net; the size of the collector is chosen based on the size of the fish in the cage. Compressed air is delivered to the collector cone, lifting feed, feces, and dead fish through a hose to a dewatering bin on the surface. After dewatering the number of dead fish can be recorded manually or transported through a Vaki counter. The compressor may be controlled by a timer or by the sensor mounted in the collector, so that dead fish is retrieved once it is registered by the sensor. The LiftUp system has a high capacity for retrieving dead fish and is not labour demanding. It is thought to have little effect on the cage environment (for instance disturbing the fish in the cages) and can be tailored to specific cages/plants. Ultrasound and X-ray are potential technologies for scanning the content of mort collectors.
Key operational aspects	**Controlling and running the system**



It is best practice to control that the system functions as it should do directly after installation. This procedure is be followed when collecting mort's and must be performed as a part of the daily routines.

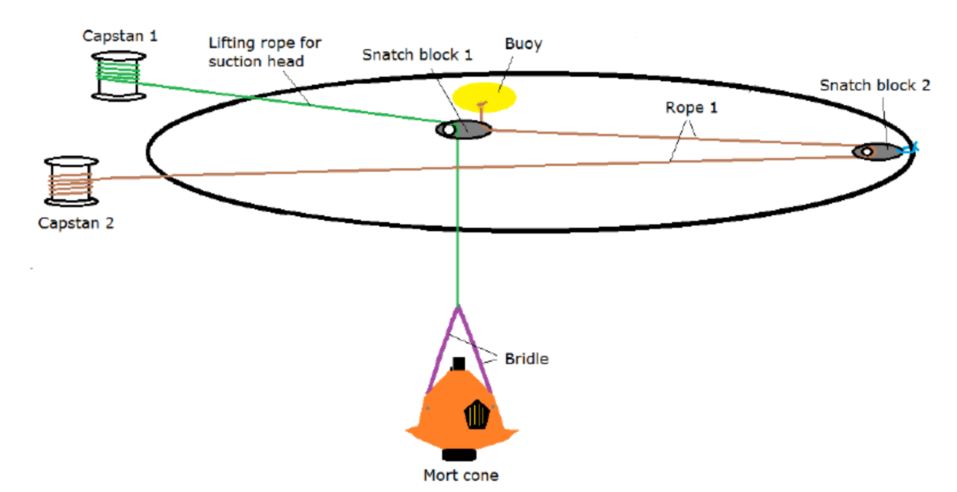
Procedure:

1. Make sure that the air vent is closed
2. Start the compressor and let it run idle for around 10 minutes. Control the air supply system for leakages. Even the smallest leakage may have great impact to the systems efficiency.
3. Attach a strainer installation to the open end of the handrail pipe.
4. If there are no signs of leakages, the air vent may be opened. Start by opening the vent to about 20%, and let the water slowly work its way up to the strainer.
5. Check the hose system has not twists or bends. If there are any such blockages in the hose system, turn off the compressor, loosen the upper lay flat hose from the handrail pipe, spin the hose and re-attach the hose to the handrail pipe.
6. When tasks 1-5 are checked and found to be ok, the system is ready to be operated. Open the air valve to 30% to start with normal operation of the system. The water stream is then constant.
7. During periods with higher mortality, or when larger fish are dying, it may be necessary to close the air vent during use, letting the pressure build up in the compressor to increase the effect: Open the air vent to 100% for about 10 seconds, then turn it back down to 30% to create a shock-effect that can help bring up mort's *This method may stress the hose system, and thus increase risk of hose damage.*
8. After the system is empty of mort's, close the air vent (use the underwater camera to see if there are more fish around the mort cone) and de-attach the de-waterer. Secure the air vent to make sure that it stays closed during bad weather or other occasions.
9. Use the underwater camera to see if there are any more mort's surrounding the mort cone.

Bringing up the mort cone using snatch block

This method is for when the system is already installed inside the cage and is being moved or is being brought up for repairs, service or other maintenance and for bringing the system up for storage.

Sketch of suspension for the floating the system is reported in the following figure:



Necessary equipment:

- 2 snatch blocks (Snatch block 1 and Snatch block 2)
- Service boat with 2 net drags (Net drag 1 and Net drag 2) and crane
- 1 lifting rope (attached to the cage edge and mort cone)
- 1 rope (Rope 1)
- 1 buoy

Procedure:

1. Empty the Mort Collection System entirely 3 Use the underwater camera to control that the system is empty
2. If the system is brought up for moving to another location, also bring up the centre weight (attached to the mort cone)
3. Attach snatch block 1 to the buoy, and attach one end of rope 1 to snatch block 1
4. Loosen the lifting rope from the cage edge, tread it through snatch block 1 and attach it to net drag 1
5. Attach snatch block 2 to the handrail on the opposite side of the cage (from the service boat) and pull rope 1 from snatch block 1 through snatch block 2 and back. Attach the loose end of rope 1 to net drag 2
6. Pull rope 1 with net drag 2 so that the buoy by snatch block 1 lies in the centre of the cage
7. Pull the lifting rope in by net drag 1, and pull the mort cone up from the cage net bottom
8. 1If the system is just going to be adjusted inside the cage, do this by running net drag 2 in- or outwards
9. If the system is taken out from the cage, use crane and lift the mort cone just over the water surface and transport it along the surface to the cage edge
10. Make sure that no one resides in the area and lift the mort cone over the edge and back to the surface, and transport it up to the boat deck
11. Remove the center weight if this is installed
12. Place the mort cone on the storage base, personnel on board assists crane driver to place it correctly
13. To drain all water from the hose system, attach a strap on the middle of the hose system, and attach the strap to the crane. Lift the hose and empty out all the water. If necessary, move the rope and repeat until all water is out.

Trouble-shoot	----

A.2 Energy production

WIND TURBINE SYSTEM Operation sheet	
FUNCTION	The operation and maintenance strategies play an important role for the economic operation onboard BGF infrastructure. Major issue is the trade-off between the production losses when the system fails and the costs of the offshore maintenance action, which is based on how maintenance is carried out. Under nominal conditions, BGF wind turbine operations are mainly based of inspections. Given that several variables are monitored at the Local Control Room level, physical inspections on equipment and sub-systems are limited to the minimum. In particular, planned periodic inspections are due as described in the following table:

COMPONENT	SUB-COMPONENT	INSPECTION	INTERVAL
Wind Turbine	Drive train inspection	Structural integrity, coating, corrosion, leakage, vibration diagnostics, oil level, function control, noise, etc.	1 year
Wind Turbine	Condition control of the rotor blades	Structural integrity, grease and oil condition, function of pitch, etc.	2 years

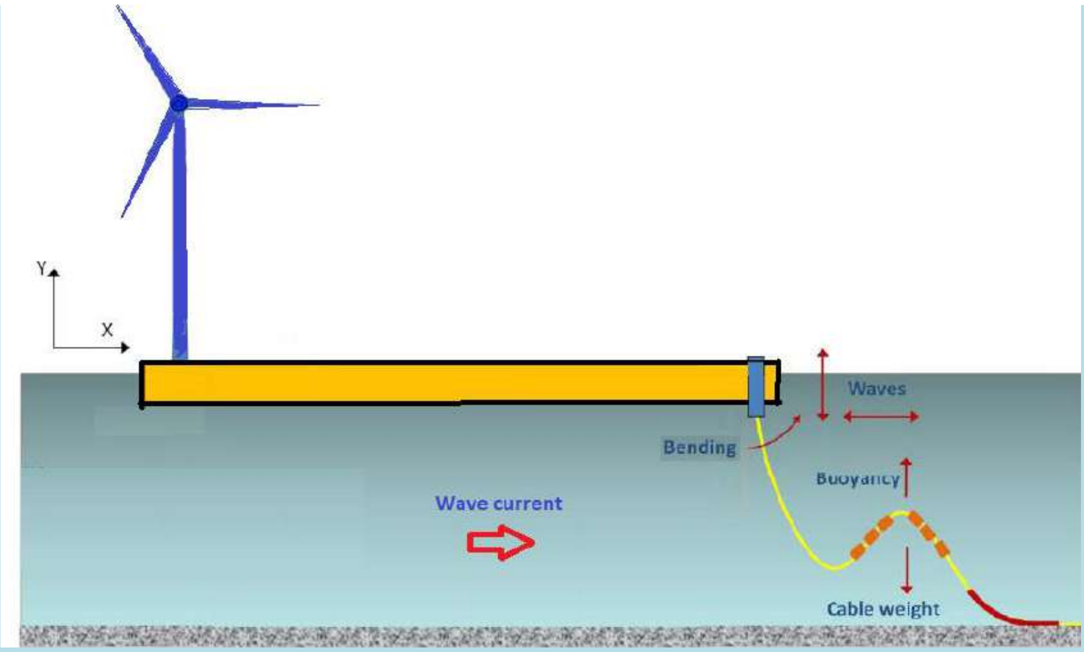
DNV GL-ST-0126[3] described a risk-based inspections approach for wind farm. Nevertheless, it is noted that current standards have not specifically developed for floating structures. Non-inspectable items need to be designed with sufficient durability for the entire operation lifetime. For other items, especially for critical items, a different inspection interval can be considered (for instance, during the warranty period, inspection rates are subject to the component supplier/fabricator and OEM requirements). Inspection rate might also depend on the inclination angles (in roll and/or pitch) the platform is subject to experience during its operative life. With regard to this latter point, the BGF platform is expected to offer a high hydrostatic stability, such to reduce risk of degraded performance or increased failure modes if compared to offshore fixed installations.

Visual inspection to the tower and blades, in addition to the insight already provided by the monitoring system embedded in the wind technology (typically strain gauges sensors, accelerometers, etc.), is performed vi small drone guided by operator standing on the BGF deck. Scope of a visual inspection is to assess external:

- material degradation
- Condition of issues from previous periodical inspections
- Corrosion
- Pitting
- Cracks
- Indication of weld defect (tower)

A specific inspection plan is required for the submerged umbilical cable (see figure below).

[3] DNV GL, DNVGL-ST-0126: Support structures for wind turbines, 2016.



The following variables are subject of the underwater investigation:

- free spans including mapping of length, height and end-support conditions
- condition of artificial supports installed to reduce free span
- local seabed scour, settlement, subsidence or instability affecting the cable integrity
- mega ripple / sand wave movements affecting the cable integrity
- cable settlement in case of exposed sections
- the integrity of cable protection covers (e.g., protection sleeves)
- mechanical damage to cable or cable ancillary elements
- major debris on, or close to, the cable or cable components that may cause damage to the cable.

Critical sections of the cable system vulnerable to damage or subject to major changes in the seabed conditions (touchdown) are to be inspected at suitable intervals.

Additionally, monitoring can be used to detect changes in the operating conditions and to take mitigation actions. Conditions of the cable which are monitored may include:

- electrical - voltage, current, power
- thermal - temperature
- mechanical - tension, bending, vibration;
- leakage - inside cable or inside platform.

Dynamic cables are likely to suffer damage in various sections during their operational time, as illustrated in the table below:

DAMAGE CATEGORY	TYPE OF DAMAGE	LIKELIHOOD
Installation	Loss of Dynamic Positioning	Medium
	Anchoring damages	Medium
	Kink	Low
	Loading / re-loading	Low
	Trenching	Low
	Small bending radius	Medium
	Abrasion and cut	High
Human activities	Fishing equipment	Low
	Anchors	High
	Jack up	Medium

Operational	Free span	Medium
	Joint failure	High
	Geo-hazards	High
	Internal defects	Medium

Equipment

Suppliers

VESTAS, SIEMENS GAMESA

Layout

The reference 10 MW DTU design has been considered for the BGF engineering investigation. Nevertheless, any technology upgrade capable to go beyond DTU performance and availability on market will be accommodated for inclusion in the final BGF business model. To this respect, and in the view of a potential upscale of the power production, the main references are here considered: the 10 MW DTU and the IEA Wind 15-MW Turbine.

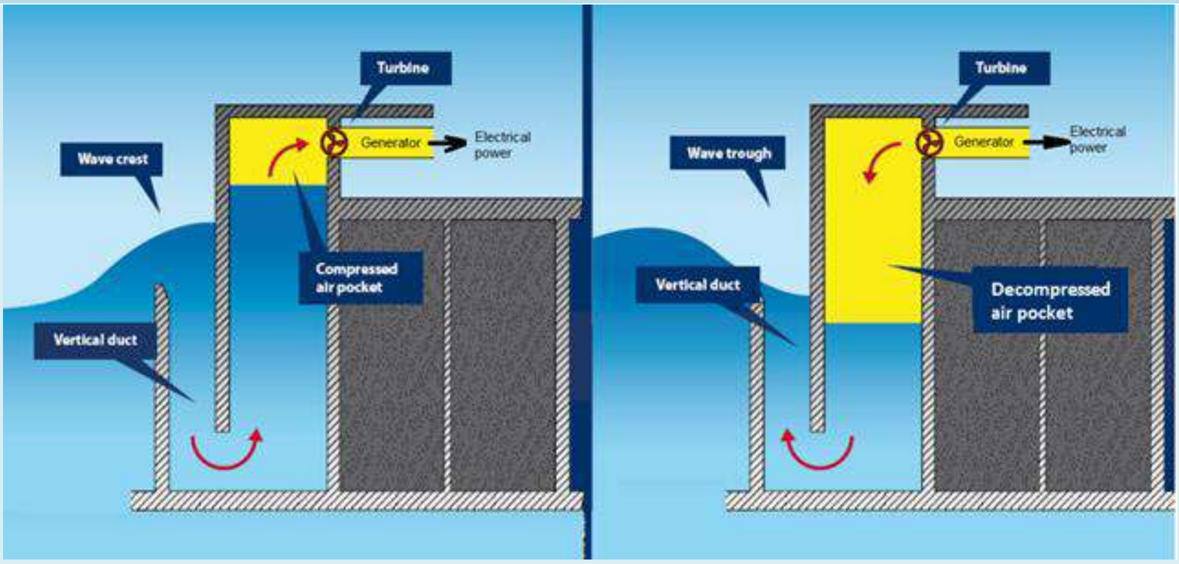
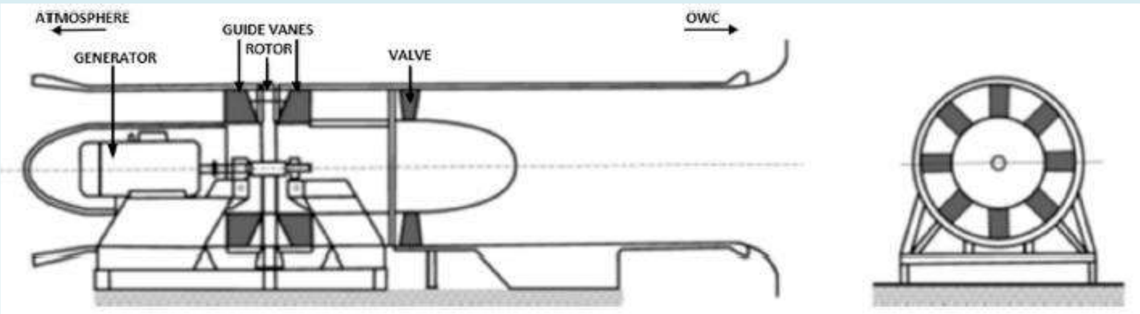
PARAMETER	UNITS	DTU 10-MW Turbine	IEA Wind 15-MW Turbine
Power rating	MW	10	15
Turbine class	---	IEC Class 1B	IEC Class 1B
Specific rating	W/m^2	401	332
Rotor orientation	---	Upwind	Upwind
Number of blades	n.	3	3
Control	--- ---	Variable speed Collective pitch	Variable speed Collective pitch
Cut-in wind speed	m/s	4	3
Rated wind speed	m/s	11,4	10,59
Cut-out wind speed	m/s	25	25
Rotor diameter	M	178,3	240
Airfoil series	---	FFA-W3	FFA-W3
Hub height	m	119	150
Hub diameter	m	5,6	7,94
Hub overhang	m	7,1	11,35
Drivetrain	---	Medium speed Multiple-stage gearbox	Low speed Direct drive
Design tip-speed ratio	---	7,5	9
Minimum rotor speed	rpm	6	5
Maximum rotor speed	rpm	9,6	7,56

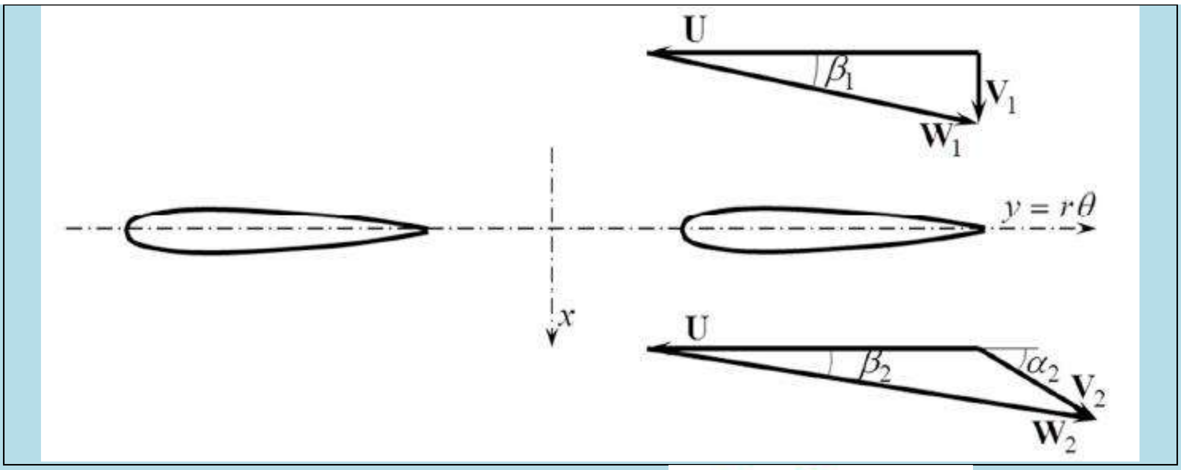
	Maximum tip speed	m/s	90	95	
	Gearbox ratio	---	50	---	
	Shaft tilt angle	degree	5	6	
	Rotor precone angle	degree	-2,5	-4.0	
	Blade prebend	m	3,332	4	
	Blade mass	t	41	65	
	Rotor nacelle assembly mass	t	674	1.017	
	Tower mass	t	987	860	
	Tower base diameter	t	8	10	

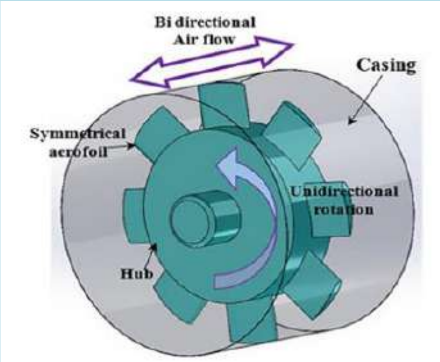
Key technical aspects	Careful planning of routine and unscheduled activities with due consideration of weather conditions and availability of spares and specialist vessels is critical. For the BGF infrastructure, wind turbine SCADA data are monitored H24 either onboard (Local Control Room) or on land (Remote Control Room). The Operations Duty manager knows when, where and by who tasks are carrying out or are planned to be carried out. Continuous SCADA data and prognostic condition monitoring is aimed, through performance analytics and data correlation, performance benchmarking and predictive behaviour, at timely providing preventative maintenance before failure occurs.
Key operational aspects	**OFFSHORE LOGISTICS** The industry is increasingly adopting software simulation tools to maximise operational efficiency in relation to scheduling tasks and deploying resources, taking into account weather conditions, sea state, vessel capability and operational priorities. Robust communication equipment and infrastructure is a key element of offshore logistics to ensure live communication between all personnel. **SAFETY CRITICAL ITEMS** Safety critical items are subject to a statutory inspection regime, where there are legal requirements including recommended inspection frequencies and method of inspection. Inspections are carried out by qualified personnel, either as part of the primary turbine maintenance works or by a team of independent inspectors. Inspections of safety-critical devices and equipment including: ▪ Fall arrest systems. ▪ Anchor points. ▪ External gates and railings and floor gratings. ▪ External evacuation and rescue equipment. ▪ Pressure systems. **TRAINING** Training is related to both technical aspects and to health and safety (H&S) skills and awareness regarding the wind turbine operation. The technical training will involve the specific operations of the turbine model and include operational safety practises for high voltage switching. A number of H&S certificates are required by personnel likely to be present on the BGF infrastructure, including: ▪ Emergency first aid and advanced medical training ▪ Offshore survival training, including marine transfer ▪ Working at height ▪ Working in confined spaces ▪ Wind turbine rescue ▪ Manual handling ▪ Lifting and hoisting, and

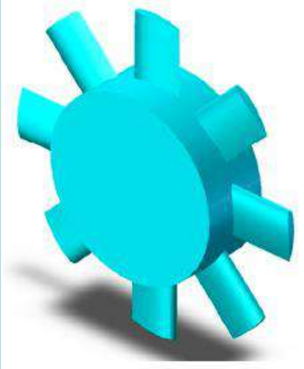
	▪ Electrical safety awareness. **INSPECTIONS** Inspection frequency will be six-monthly or annual, depending on the equipment. Drills of health and safety procedures are routine. Where there is a requirement for periodic statutory inspections and certification, such as for fall arrest systems, independent certifiers will provide these services. Inspections prior to other planned work are to be carried out in the summer months to minimise the likelihood of weather delays and ensure equipment remains certified for use. **HEALTH, SAFETY AND PERSONAL PROTECTION EQUIPMENT** ▪ First aid kits for minor injuries. ▪ Advanced medical kits. ▪ Eye-washing kits. ▪ Gloves and safety boots. ▪ Ear defenders and safety eyewear. ▪ Fuel and diesel spill kits. ▪ Fire extinguishers and suppressants. ▪ Survival suits, personal locator beacon, life-vests and floatation devices. ▪ Emergency rations and water. ▪ Emergency communications devices. ▪ Rescue equipment including descenders, spinal boards and stretchers, hub rescue equipment.
Trouble-shoot	----

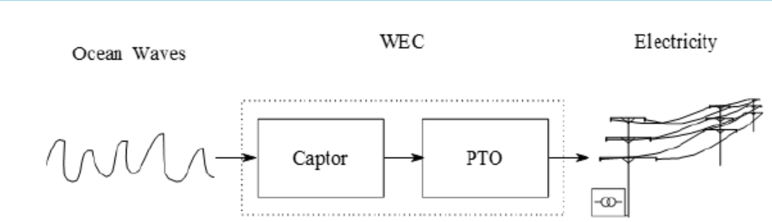
WEC SYSTEM Operation sheet	
FUNCTION	Renewable energies aim at diversifying sources of clean electricity and offering an optimized energy mix while having a minimal impact on the environment. There exists a wide diversity of potential in marine energy devices, one is based on Wave Energy Converters (WECs). Many companies have gone through design concepts and prototypes development processes, but so far, no products have proven commercial viability. Engineering challenges, such as efficiently absorbing energy from waves and surviving extreme loads during storms, are one of the major barriers to the world deployment of these technologies. Nevertheless, ocean technologies are one of the most promising untapped energy resources and recent improvements in the design can represent a huge step towards the adoption of WECs. In particular, the BGF solution is based on a modification of the REWEC3 patented solution for fixed installation to comply with floating conditions.
Equipment	 Commissioned in 2011, the 296kW Mutriku plant generates enough energy to power 250 households. Credit: EVE.

	
Suppliers	Wells type turbine technology providers
Layout	 
Key technical aspects	In its simplest form, the Wells turbine is an axial-flow turbine whose rotor blades are of symmetric aerofoil profile with the chordal plane normal to the rotational axis. The aerodynamic force on a rotor blade section has basically two components: lift (perpendicular to the relative flow velocity W) and drag (in the direction of that velocity).









The PTO converts the power absorbed by the captor into electricity. The mechanical power extracted from ocean waves is characterized by high forces and low speeds, with high variability and an alternating direction. Therefore, the PTO has to withstand these high loads related to the wave forces with a consequent high cost. The wave energy converters based on the oscillating working principle reduce the large wave forces through the oscillating water column and convert the low speed of the water surface into higher air speed. The rotational speed range of the turbine is compatible with commercial electrical generators.

The following characteristics are considered for the PTO:

- Outer diameter: 0,75 m.
- Number of blades: 8.
- Hub-to-tip ratio: 0.68.
- Solidity at hub: 0.64.
- Airfoil contour: constant thickness blade NACA 0015.
- Turbine characteristic parameter: 0.3.
- Generator rated power: 20 kW.

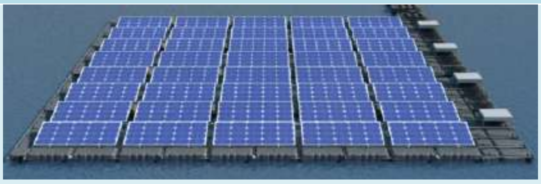
	The technology is simple and robust with few moving parts and few energy conversion steps. The associated drawback is the low-quality electrical output. The generator output power will have a low voltage level, with varying frequency and amplitude, as well as an alternating phase order. This makes it necessary to use power electronics to condition the power according to transmission preferences or governing grid standards.
Key operational aspects	The aim is to design a turbine that has high aerodynamic efficiency and is matched with the OWC system for pressure drop and flow rate, regarding the wide range of sea conditions. The efficiency of aerodynamics increases with flow ratio up to a critical value. It decreases at a turning point. To avoid transonic effects the maximum Mach number on the blades should be less than the critical Mach number. In order to render the wave energy converter more efficient by increasing the overlap between the (changing) ocean wave spectrum and the response of the converter, some tuning is necessary. The process of adapting the wave energy converter to behave as in resonance over a broad band of frequencies is referred to as control. The physical characteristics of the wave energy converter, like size, mass and shape, are often difficult to vary according to the incoming waves, but the behaviour of the converter can be adjusted by acting on the stiffness and/or the damping of the system. These variables are accessible through the PTO system of a wave energy converter. By controlling the behaviour of wave energy converters through their PTO system, one can increase the efficiency of the system and hence its cost-effectiveness. In order to verify adequate performance, the following inspections are considered relevant for the equipment during the operation service life: ▪ Planning of non-destructive test on the material to reveal potential premature fatigue failure of key components and related supports; ▪ Wash regularly the turbine blades with fresh water to eliminate salt accumulation, which may induce a sudden performance drop (not only in terms of vibration but also significant aerodynamic losses); ▪ Periodic removal of salt accumulation of the cooling system of the generator (heatsink), which can cause drive overheating and subsequent turbine trip.
Trouble-shoot	….

PV SYSTEM Operation sheet

FUNCTION

Renewable energy production from Solar PV panels is the third component implemented in the BGF infrastructure to support own operations. Solar PV panels convert sunlight into direct current (DC) electricity. Exposition of the PV array in the upper aft side of the platform enables a privileged condition, regardless the platform orientation with respect to the sun path. Efficiency can then be maximised when addressing the selected orientation of the platform in the specific installation site, taking into account an optimal balance of waves (primarily), wind and sun exposure.

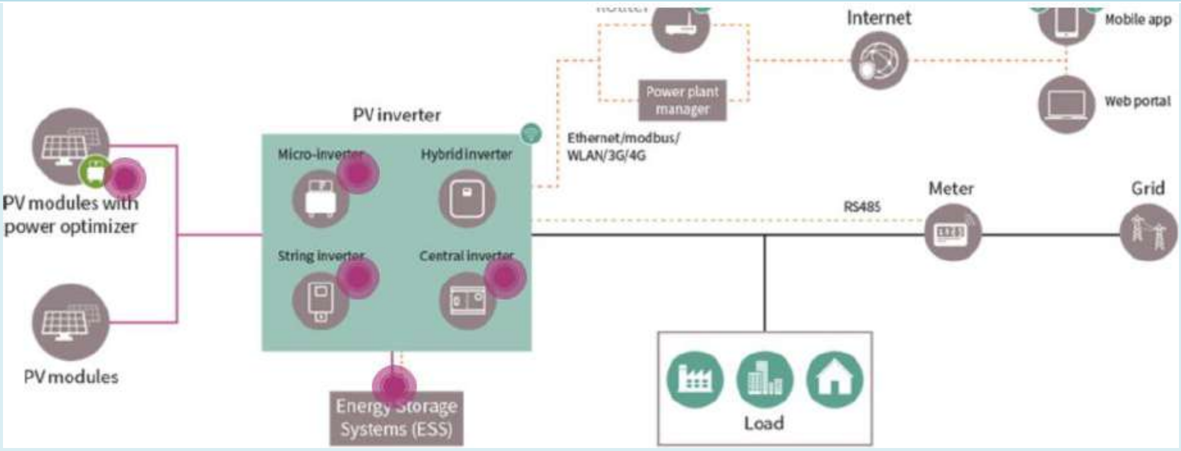
Equipment



Suppliers

Swimsol, Sungrow, SolarDuck, Infineon, Tractable

Layout



Key technical aspects

Modern Solar PV system are designed for automatic operation without need for user intervention. There are no moving parts or need for the owner to interact with its operation. In the case of mains grid supply failure, the inverter will immediately and automatically be disabled. This is known as **"anti-islanding"** and it protects linesmen from an electric shock from your system when they assume the grid is "dead". Once the grid power has been restored, the inverter will be automatically re-enabled.

Safety operational notes

Review and follow all safety instructions supplied with all components of the procured solar PV system.

Do not attempt to clean or come in contact with the surface of a solar PV panel with broken glass. This could result in a dangerous electric shock.

Be aware that power may be present at any point in electrical circuits despite the opening of circuit breakers or isolators.

| Key operational aspects | **Technology Monitoring**

When high performance, low downtime and rapid fault detection is required, automatic data acquisition and monitoring technology is essential. This allows the yield of the plant to be monitored and compared with calculations made from solar irradiation data. Monitoring and comparison also help raise warnings on a daily basis if there is a shortfall. Faults can be detected and rectified before they have an appreciable effect on production.

The Power Plant Controller itself is a control system that can manage several parameters such as active and reactive power and ramp control of PV plants. The set points can normally be commanded either remotely or locally from the SCaDa.

The following control parameters are considered in the BGF PV plant:
▪ Absolute active Power Control.
▪ Power Factor Control.
▪ Ramp Control (active and reactive Power if needed).
▪ Frequency Control.
▪ reactive Power Control.
▪ Voltage Control.

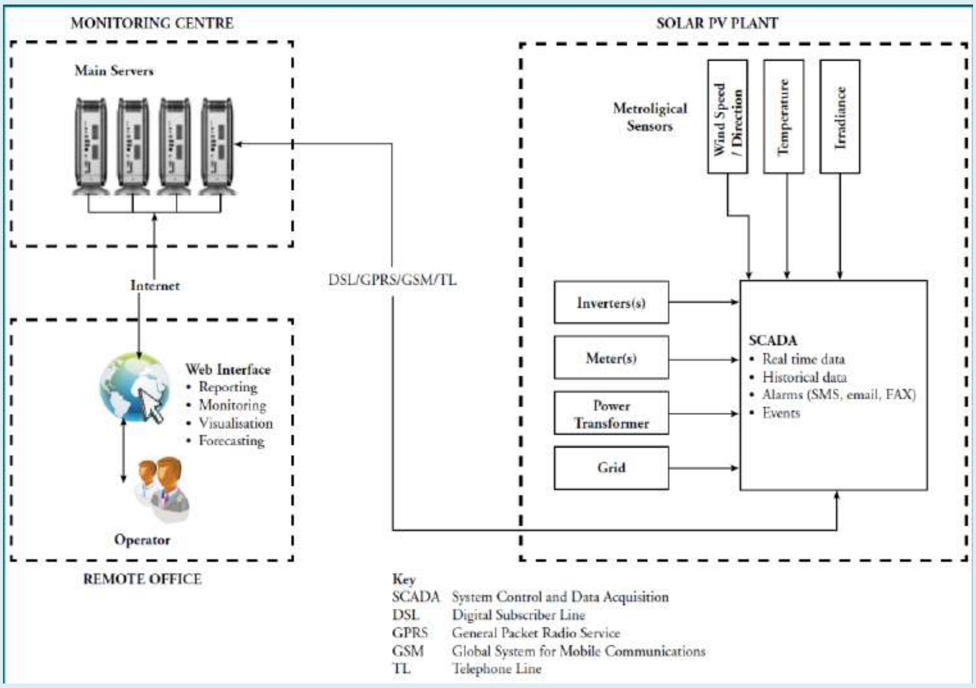
The following data measurements are used to calculate KPis:
▪ AC Power produced (kW).
▪ AC Energy produced (kWh).
▪ AC Energy metered (kWh).
▪ Reactive power (kVar).
▪ Irradiation (reference for the plant or the sub-plants) (W/m^2).
▪ Air and module temperature (Celsius degrees).
▪ Alarm, status code and duration.
▪ Outages, unavailability events.

The key to a reliable monitoring and fault detection methodology is to have good knowledge of the solar irradiance, environmental conditions and plant power output simultaneously. This allows faults to be distinguished from, for example, passing clouds or low resource days. There are three main methods for obtaining the solar irradiance and environmental conditions:
▪ **On-site weather stations –** To measure the plane of array irradiance, module temperature and preferably horizontal global irradiance, humidity and wind speed. This is the option of preference for many current utility scale PV power plants. It allows data to be collected and compared remotely with yield figures on a daily basis for immediate fault detection.
▪ **Meteorological data gathered from weather satellites –** Simulation and calculation algorithms measure the projected power plant output. This figure becomes the benchmark for comparing values received from the PV plant on a daily basis and helps detect faults immediately. This method removes the need for an onsite weather station. A number of good commercial providers of packages use this technique in Europe. Rapid fault detection depends on data being made available from satellites and being analysed quickly.
▪ **Local weather stations –** This is the least desirable of the three options as data may not be available for several months. During that period, the plant may lose considerable revenue if faults |

in the plant go undetected. It is also possible that the local weather station does not accurately track the conditions at the site (especially if it is some kilometres distant).

Data-loggers can be used to collect data from the weather station, inverters, meters and transformers. This information is transferred once a day to the related server which carries out three key functions:

- **Operations management –** The performance management (either onsite or remote) of the PV power plant enables the tracking of inverters or strings.
- **Alarm management –** Flagging any element of the power plant that falls outside pre-determined performance bands. Failure or error messages can be automatically generated and sent to the power plant service team via fax, email or text message.
- **Reporting –** The generation of yield reports detailing individual component performance and benchmarking the reports against those of other components or locations.



Module Cleaning

Module cleaning produces significant and immediate benefits in terms of energy yield. The suggested frequency of module cleaning is at least twice annually.

Module Connection Integrity

BGF PV park is monitored at string level, then a module connection integrity is not necessary to be provided. Under these conditions, faults within each string of modules may be difficult to be detected.

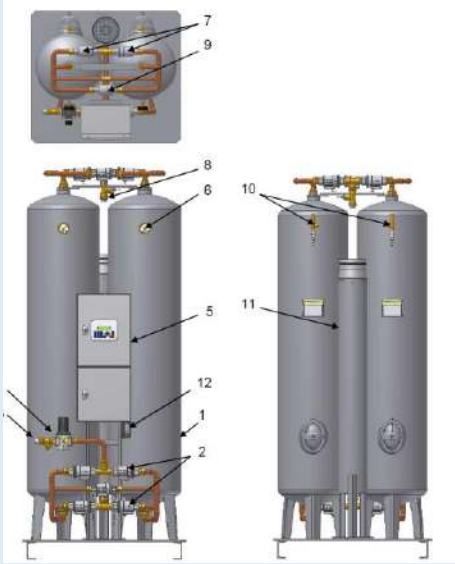
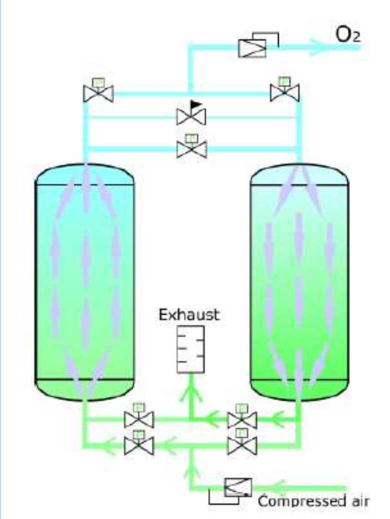
Junction or String Combiner Box

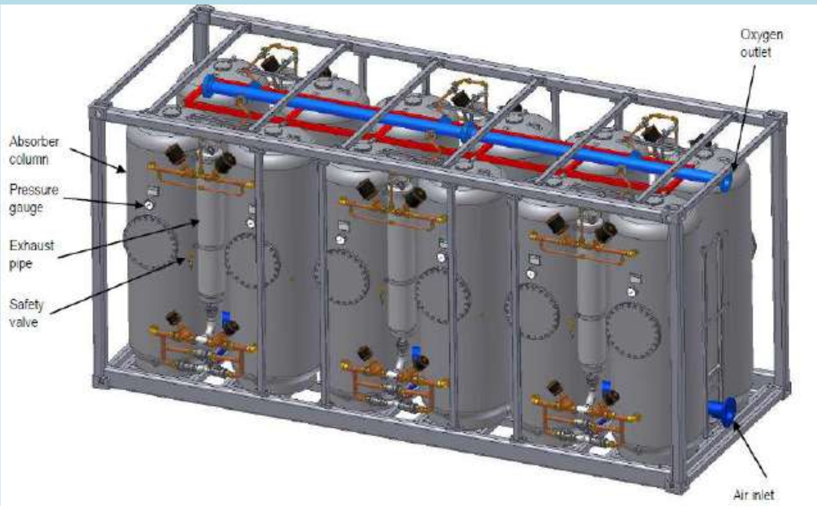
All junction boxes or string combiner boxes are to be checked periodically for water ingress, dirt or dust accumulation and integrity of the connections within the boxes. Loose connections affect the

	overall performance of the PV plant. Any accumulation of water, dirt or dust may cause corrosion or short circuit within the junction box. **Hot Spots** Potential faults across the PV plant can often be detected through thermography. This technique helps identify weak and loose connections in junction boxes and inverter connections. It can also detect hot spots within inverter components and along strings of modules that are not performing as expected. Thermography is to be carried out by a trained specialist using a thermographic camera. **Inverter Servicing** Generally, inverter faults are the most common cause of system downtime in PV power plants. Therefore, the scheduled maintenance of inverters plays a central part of the O&M strategy (visual inspections, cleaning/replacing cooling fan filters, removal of dust from electronic components, tightening of any loose connections, etc.). **Structural Integrity** The module mounting assembly, cable conduits and any other structures built for the PV plant are to be checked periodically for mechanical integrity and signs of corrosion. This will include an inspection of the structure connection to the base pavement to exclude corrosion initiation. **Tracker Servicing** Similarly, tracking systems also require maintenance checks. These checks will be outlined in the manufacturers' documentation and defined within the warranty conditions. In general, the checks will include inspection for wear and tear on the moving parts, servicing of the motors or actuators, checks on the integrity of the control and power cables, servicing of the gearboxes and ensuring that the levels of lubricating fluids are suitable. The alignment and positioning of the tracking system should also be checked to ensure that it is functioning optimally. Sensors and controllers are to be checked periodically for calibration and alignment. **Balance of Plant** Monitoring and security systems, auxiliary power supplies, and communication systems within the PV plant are to be checked for signal strength and connection on a periodic basis.
Trouble-shoot	----

A.3 Oxygen production

OXYGEN SYSTEM Operation Sheet	
FUNCTION	This oxygen generator is an on-site oxygen-generating machine. Coupled with the air compressor, refrigeration air dryer and filtration system, it takes air and separates the oxygen from other gasses. The separation is accomplished with an inert ceramic material (molecular sieve) that does not require replacement (when maintained and used according to this instruction manual). The process is completely regenerative which makes it reliable and virtually maintenance free.
Equipment	 
Suppliers	OXYMAT
Layout	

		2. Absorber column 3. Axial valves for cycle operation 4. Feed air inlet 5. Feed air pressure regulator 6. Cabinet containing electrical parts (PLC, etc.) 7. Cycle pressure gauge 8. Valves for delivery of oxygen 9. Outlet to product tank 10. Axial valve for equalization of pressure 11. Safety relief valves 12. Exhaust pipe 13. Valve block
Key technical aspects	The Oxygen generator system is designed to accept compressed feed air into its filter assembly (at 6.0 – 10.0 bar(g) and deliver 90-95% oxygen when supplied with a minimum feed air pressure of 6.0 bar(g)., or at 11 – 14 bar(g), according to different models (2 column – 2C (see picture above) or 3 column – 3C)). The incoming compressed air must be filtered through an air-conditioning system consisting of water drain filter, refrigeration air dryer, pre- and micro filtration units. All filtration units must be equipped with automatic drain valves for removing water and oil. The pre-filter and micro filter removes condensed water and oil, dirt, scale, etc., and the coalescing filter removes oil vapour (oil aerosols). The normal flow of air  through the oxygen generator is as described in the picture aside. After exiting the filter, the compressed feed air is regulated down (to 4.0 – 6.0 bar(g) and to 10 – 12 bar(g), according to 2C or 3C model) and then directed by pneumatic activated valves into one of two (2C) or three (3C) absorber columns containing molecular sieve. Molecular sieve has the unique property that it physically attracts or adsorbs nitrogen from the air, leaving the oxygen to pass through to the product tank and can, when saturated with nitrogen, be regained to clean sieve again by purging with oxygen under lower pressure conditions. The oxygen generator consists of two or three absorber columns working in alternate operation, e.g., the processes always run in antiphase to one another in such way, that one absorber column with cleaned sieve delivers oxygen while the other absorber column regenerates saturated sieve. After a certain pre-set period, the processes shift, so that the first absorber column now regenerates saturated sieve, while the second is delivering oxygen through a cleaned sieve. The oxygen from the absorber column is stored in the product tank. From the product tank the oxygen is regulated to 0 - 11.0 bar(g), depending upon model and the specific working pressure.	

	For both 2C and 3C model, an increase of the cycle pressure to more than the above specified range results in higher feed air consumption and lower generation efficiency. Higher peak cycle pressures are feasible, but only under special modification developed by the manufacturer. As well, for operation at lower cycle pressures a slight modification is required. In particular, a x-generator assembly scheme is possible. It consists of X-number of single oxygen generators working in a counter phase (image below). 
Key operational aspects	The oxygen generator must be located in a well-ventilated indoor area which remains above 5°C and below 45°C. Air from your compressor or feed air supply must be less than 40°Cmax, before it reaches the oxygen generator. Exhaust gas from the oxygen generator contains only 8-21 % oxygen. Exhaust gas must be piped out of the room to the outside. The room must always be well ventilated. **Normal start-up** ▪ Turn on the air dryer power supply. ▪ Allow the refrigeration air dryer temperature to stabilize at the pre-set value +3°C. ▪ Turn on the compressor power supply or open for the central compressed feed air supply. ▪ Observe that the feed air pressure is above the minimum pressure requirements. ▪ Turn on the power supply to the oxygen PSA generator. ▪ Turn the mode selector switch in manual position. ▪ Observe that the drains are working. ▪ Observe that the peak cycle pressure does not excess the design value. ▪ Turn the mode selector switch in auto position. ▪ After a while observe that the oxygen generator automatically stops, when the product tank pressure reaches pressure set point stop stated by the manufacturer. ▪ Further observe that the oxygen generator automatically re-starts after about 0.5 pressure drop unless stated otherwise by manufacturer. **Operation**

The oxygen generator can operate in either auto or manual mode or can be in stand-by mode. The operation mode is selected on the mode selector switch on HMI.

Shut down

Turn of oxygen application/consumption (close off central oxygen application/consumption. This will ensure that the product tank is full the next day even if oxygen discharge valve is left open).

Ensure that the mode selector switch is in the AUTO position and wait until the oxygen generator stops cycling. This allows the product tank to fill completely with oxygen for immediate use required. It also allows the unit to shut down at the proper point in the cycle.

NOTE: Failure to wait or immediate or accidental stop of operation during a cycle will result in temporary lower oxygen purity during subsequent use.

Turn off Power

- Turn the selector switch to stand-by position
- Turn off the compressor power switch
- Turn off the air dryer power switch
- Turn off the PSA generator power switch

Extended shut-down

To shut down the oxygen generator for 24 hours or longer, in addition to what specified for the shutdown operation, the following actions add:

- fully close all manual valves to isolate the oxygen in the product tank to prevent the loss of pressure in the product tank, in order to enable a normal start-up. Turn off all electric powers, e.g., compressor, air dryer and oxygen generator.
- keep columns pressurized and sealed to protect contained molecular sieve against ambient moisture.
- close of the pressure reduction valve on probe inlet.

Start-up after an extended shut-down

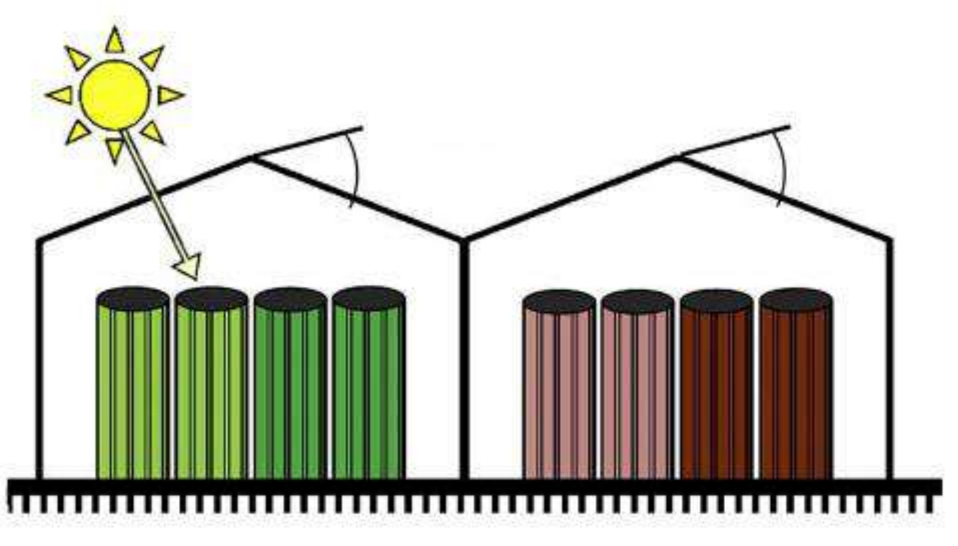
After an extended shutdown or an unexpected shutdown, such as an electric power failure, it is required to purge the product tank of any low purity oxygen before the oxygen generator can supply oxygen within the purity specifications.

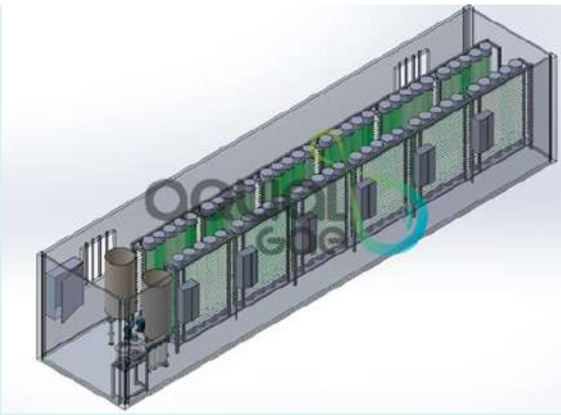
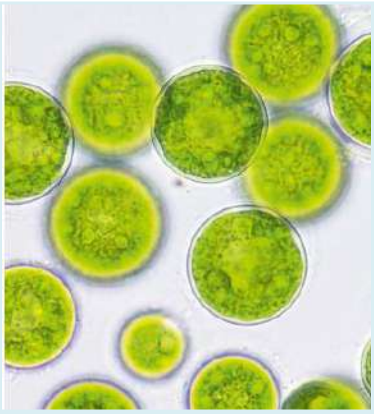
To purge the product tank, the following steps are to be considered:

a. Check that oxygen consumption is closed off.
b. Open up for flow from feed air supply/compressor.
c. Start the feed air supply/compressor.
d. Start the oxygen generator and let it run for about 15 minutes.
e. Check that pressure in product tank reaches the design value.
f. Open for oxygen consumption. Adjust flow to approximately to 50 % of design flow.
g. Let the generator run in manual mode until design purity is reached. Duration 0.5 - 8 hours depending on purity and capacity.

	h. When design purity is reached close off oxygen consumption switch PSA generator to auto mode and let the PSA generator run until it stops automatic. This should occur within 10 minutes. If the generator does not stop as described refer to section for pressure set point procedure.
Trouble-shoot	--------

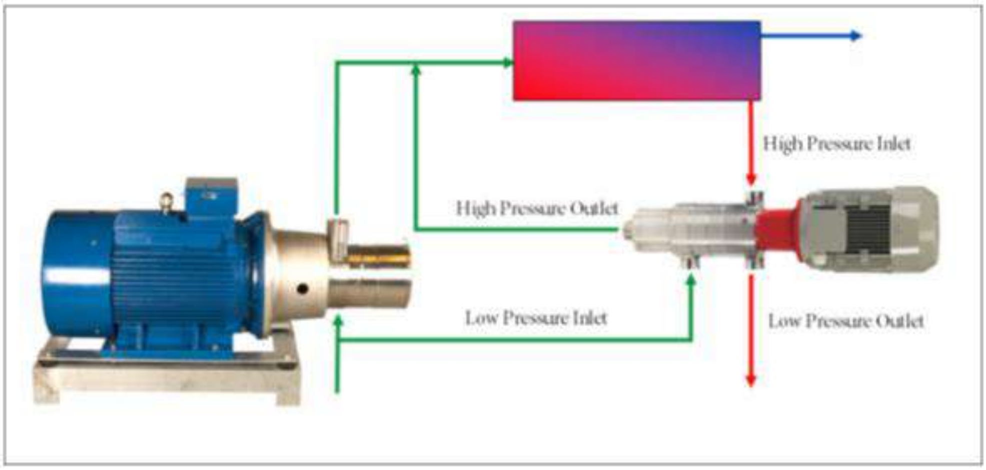
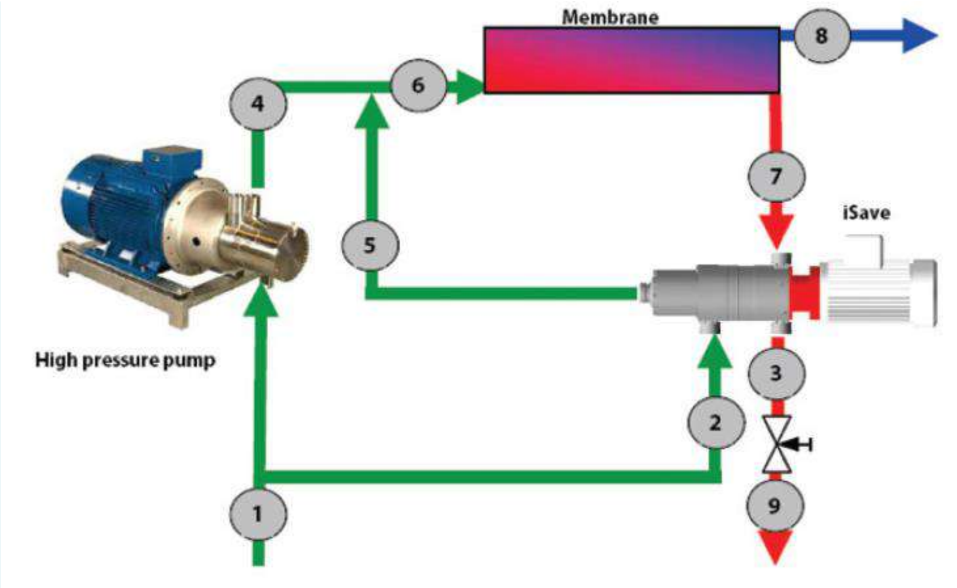
A.4 Microalgae production

MICROALGAE SYSTEM Operation Sheet	
FUNCTION	Photobioreactor is a bioreactor system used to culture phototrophs such as microalgae in an enclosed system which does not allow direct exchange of material between the culture and environment. The system provides a closed and highly controlled growth condition for the culture, thus able to produce a contamination free, single strain microalgae culture. In addition, the highly controlled culture condition can also translate into higher nutrient and metabolic efficiency which results in higher biomass production per unit of substrate. In particular, vertical column bioreactor is constructed by a transparent vertical cylindrical tubing and a sparger which pumps in air bubbles to enable homogenization of the culture and allows transfer of carbon dioxide and oxygen between air and microalgae culture. This culture system offers the best gas-liquid mass transfer efficiency compared to other system owing to the capability of the sparger used in this system to generate smaller bubbles which provide larger total surface area for more efficient transfer of substance.
Equipment	
Suppliers	AQUALGAE, SCHOTT
Layout	Vertical columns are suitable to produce all kind of microalgae, tubular PBR are only suitable for some species. A complete production unit is available already assembled in container format: Modules of 20’ (6,10m x 2,44m x 2,59m) integrates 5 PBR5C modules Modules of 40’ (12m x 2,44m x 2,59m) integrate 12 PBR5C modules

	 
Key technical aspects	The automated tubular photobioreactor to produce marine microalgae use 100% recyclable materials that will reduce the use of thermoplastic polymers to less than 5%. The equipment is composed mostly of borosilicate glass, a 100% recyclable material, with an average lifetime of 50 years, inert in nature, and with better physical characteristics to be used in the production of microalgae as it prevents formation of biofilm in the PBR inside.
Key operational aspects	**<u>Inside Pressure</u>** When operating the photobioreactor make sure to not exceed the specified, maximum operating pressure. Note that the friction of the water flow increases with a square law dependence with the flow speed and therefore higher flow speeds may increase the inside pressure above tolerable levels. Prevent pressure bursts from the pumps. **<u>Temperature</u>** When the outside temperature drops below 0°C the photobioreactor must be emptied. Freezing water inside the tubes will break the tubes. Heating /cooling system of the container helps reducing such risks. 

	High yield photobioreactors in microalgae production plants are monitored and supervised. Process control provided the operator with alarm notifications and production monitoring synthetic notes. Microalgae culture media is normally sold in optimised optimized or classic formulas, both in solid and liquid format with full preparation instructions. For instance, **Aqualgae GoldMedium (GM)** from Aqualgae, is suitable for: ▪ Tetraselmis sp., Isochrysis sp., Monochrysis (Pavlova) sp., Nannochloropsis sp.; **DiatoMedium (GM)** is suitable for: ▪ Chaetoceros sp., Skeletonema sp., Thalassiossira sp., Nitzschia sp., Amphora sp., Cylindrotheca sp., Phaeodactlylum sp.
Trouble-shoot	-----

A5. Sea Water Desalination production

REVERSE OSMOSIS SYSTEM Operation Sheet	
FUNCTION	The Reverse Osmosis equipment consists of a rotating isobaric pressure exchanger and a positive displacement pump, also called booster pump. The rotation speed of the pressure exchanger and the pump is the same, as they are driven by the same electric motor.
Equipment	
Suppliers	DANFOSS
Layout	
Key technical aspects	The high-pressure (HP) concentrate (7) flows to the low-pressure (LP) concentrate outlet (3). The LP sea water (2) flows to the HP sea water outlet (5). The rotor, moving between the high-pressure and low-pressure streams, removes the high-pressure concentrate (7) and replaces it with feed water (2). The flow rate on the HP sea water outlet (5) is controlled by the iSave alone.

The flow rate on the LP concentrate outlet (3) is controlled by the sea water feed pump (1) and the back pressure valve. This means that changing the LP feed flow (2) will not affect HP outlet flow (5) and, vice versa, that changing the HP outlet flow (5) will not affect the LP outlet flow (3). As LP sea water (2) is flushing the LP concentrate to LP outlet (3), it is essential that the flow on the LP inlet (2) is equal to or slightly higher than the HP inlet (7). Otherwise, there will be an "under-flush" and higher mixing will occur in the HP outlet (5). This higher mixing will result in a slightly higher pressure at the membrane.

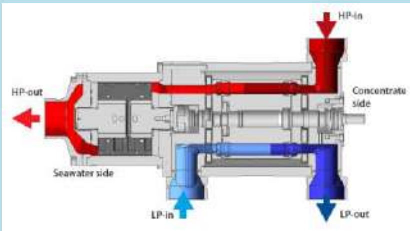
The booster pump integrated in the iSave must only overcome the pressure drop from the high-pressure outlet (5) to the high-pressure inlet (7).

During the RO process operation, water is pumped into the HP-membrane feed (6) by the HP pump (4) and the iSave (5). Almost all water coming from the HP pump (4) penetrates the membranes (8). Only a slight amount of the water is used as lubrication flow in the iSave. The lubrication flow is measured as the difference between the HP pump flow rate (4) and the permeate flow rate (8). The resistance to permeate in the membrane pressurises the HP loop.

The isobaric pressure exchanger technology changes the HP concentrate into HP seawater that is feed into the HP membranes. The iSave energy recovery technology thus significantly reduces flow needed from the main HP pump (4).

Overall energy consumption of a plant using the iSave depends on the recovery rate. The operator can change the recovery rate to optimise the RO system performance. Changing the recovery rate in an RO system equipped with iSave is easy. Using the VFD, change the speed of the iSave and thereby the flow in the HP flow rate. Then change the LP feed (2) flow to the iSave to minimise mixing and optimise energy consumption. Make sure that flow and pressure are within the rated parameter of the iSave in question.

I-SAVE



The iSave consists of a rotating isobaric pressure exchanger and a positive displacement pump, also called booster pump. The rotation speed of the pressure exchanger and the pump is the same, as they are driven by the same electric motor.

Pressure exchanger function

The pressure exchanger consists of two port plates, one at the concentrate side and one at the seawater side. In between there is a rotor with several ducts that connect the concentrate side with the seawater side.

The pressure exchanger transfers pressure from the high-pressure (HP) concentrate (HP in) to the low-pressure (LP) seawater coming from low-pressure feed pump (LP in).

To separate the HP side from the LP side there is a sealing zone on both port plates. A single duct in the rotor is either on the HP side, or on the LP side or in the sealing zone. A single duct is never in contact with more than one zone at the time. When the rotor rotates a duct will go from the LP zone over the first sealing zone into the HP zone, and hereafter from the HP zone over the second sealing zone and back to the LP zone.

The flow through the HP side of the iSave is forced and controlled by the booster pump.

When the high-pressure concentrate is flowing into the iSave it pressurizes the sea water in the duct coming from "LP in". The pressurized seawater is then pumped out of "HP out". Just before the HP concentrate in the duct comes to the seawater port plate, the duct goes into the sealing zone and the flow in the duct stops. When the duct goes into the LP zone the concentrate water is de-pressurized. The (LP) seawater coming from the LP feed pump (LP in) forces the LP concentrate out of "LP out".

This pressure exchange process is repeated for each duct with every rotation of the rotor, and the ducts are thus continuously filling and discharging. The flow on the HP side and LP side of the iSave is nearly constant over time.

There is no physical barrier in the ducts between the concentrate and seawater. This means that there will be a small amount of mixing between the two liquids. When the iSave is rotating the water always flows respectively from LP-in to HP-out, and from HP-in to LP-out. However, if the feed flow into LP-in is higher than the flow into HP-in, some of the LP feed flow will flow directly to LP-out.

When the iSave is not rotating the seawater can only run directly from LP-in to LP-out.

When the iSave is rotating the water always flows respectively from LP-in to HP-out, AND from HP-in to LP-out. However, if the feed flow into LP-in is higher than the flow into HP-in, some of the LP feed flow will flow directly to LP-out.

When the iSave is not rotating the seawater can only run directly from LP-in to LP-out.

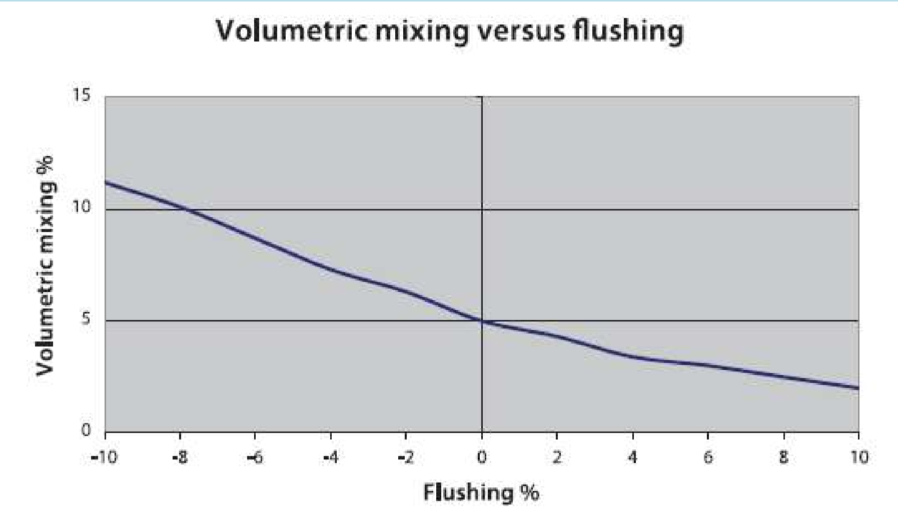
The booster pump is a positive displacement pump, which means that the flow is controlled by the speed of the electric motor, e.g., if the rotation speed of the electric motor is raised by 10%, the flow will be 10% higher and vice versa. The required rpm can be calculated based on the "rated flow" of the specific iSave.

Lubrication flow

To lubricate the moving parts in the pressure exchanger there is a well-defined leak between the port plates and the rotor, as well as in the high pressure bearing between the pressure exchanger and the booster pump. This leak is typically called "lubricating flow".

The leaks go from the high-pressure side to the low-pressure side of the pressure exchanger, and from the booster pump to the low-pressure side of the pressure exchanger.

Mixing

	There is no physical barrier in the ducts between the concentrate and seawater. This means that there will be a small amount of mixing between the two liquids. Because the two liquids are in contact for a short amount of time, the mixing is relatively low. On the RO market the mixing rate is defined as "balanced flow" when HP-in is equal to LP-in. Experience from the market shows that the corresponding increase in membrane operating pressure is about 1 bar. One can reduce mixing by over-flushing the LP feed with excess feed water, according to the following figure:  Over-flushing means energy loss. Optimal over-flushing is obtained when the energy loss on LP feed is equal to or less than the energy loss caused by the excess pressure at the membrane.
Key operational aspects	**Initial start-up and flushing** Prior to the initial start-up, all piping associated with the iSave unit should be thoroughly flushed to assure that no impurities enter the iSave. Inadequate pre-flushing will strongly affect the life of the iSave and may lead to its eventual breakdown. It is recommended to disconnect all connections to the iSave and to thoroughly flush the piping before the iSave is connected to the inlet and outlet connections. It is essential that the water used for the final pre-flush is pre-filtered to to assure optimum service life of the iSave. A true graded density melt-blown depth filter cartridge rated at 3 µm is therefore recommended. Poor pre-filtration of the feed water will result in reduced service life of the iSave. **Initial start-up and settings of safety equipment** The high-pressure pump feed water into the high-pressure line may be able to generate a pressure higher than the maximum allowable pressure in the system. There is thus a risk of personal injury and/or damage to the iSave.

Depending on the type and size of the feed pump of the RO system, this pump may be able to generate a pressure higher than the maximum allowable pressure in the LP system. There is thus a risk that the iSave or the LP equipment could be damaged by over-pressurisation. To prevent such over-pressurisation, appropriate relief valves should be used, and procedures should be implemented to safeguard the HP and LP sides of the iSave and/or the RO system.

Flushing

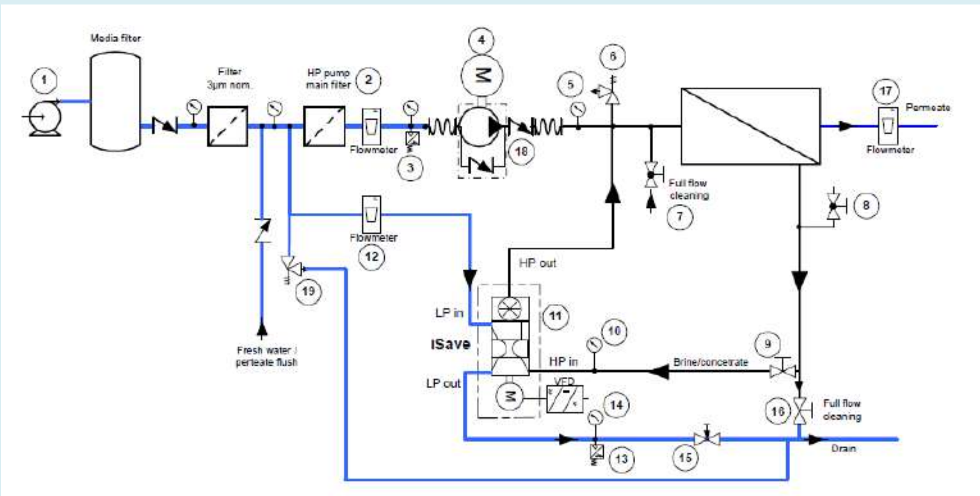
RO membranes require periodic flushing to limit biological fouling. There are two types of flushing: feed water (Seawater) flush and fresh water (Permeate) flush.

Regardless of the flush water used, the water must be pre-filtered. All parts of the iSave must be flushed, i.e., LP- and HP flow channels. Feed water flushing is part of a normal shutdown sequence. After the HP pump has been stopped, the permeate and concentrate production will continue until the high-pressure drops below the osmotic pressure. Both the iSave and the LP seawater feed pump must run until the conductivity measured at point (7) and (3) are satisfactory.

Fresh water flushing is performed before every extended shutdown of the RO plant. Permeate is simultaneously fed into the iSave at LP in (2), and either to the HP pump inlet (1) or through some other injection point such as the CIP connections or full flow cleaning connection. Permeate may be produced during this flushing process.

Special attention should be given to the pressure in the HP line (7) as the iSave may start to cavitate when it runs at high speed and the pressure in the HP line (7) drops below 3 bars. This can be avoided by reducing the speed of the iSave to about 750 rpm and keeping the pressure in the HP line at the minimum of 1 bar. At this low pressure the iSave may only run for a maximum of 10 minutes. Failing to flush the iSave with fresh water before extended shutdowns may result in extensive biological growth and cause corrosion in the iSave and other equipment in the RO system.

System Start-up



P&I scheme

With reference to the P&I scheme, the following procedure has to be followed at the start-up of the system.

1. Make sure that all valves are set in normal operating positions. 2. Start the seawater supply pump (1) 3. Make sure all pipework is flushed with water. Vent all air from the system through air valve (8) and iSave unit (11). iSave has ¼” plugs to vent both the HP and LP side. 4. Start the iSave unit when the pipwork is full of water and the system and iSave unit has been bled. NB! Always start the iSave unit before the high-pressure pump is started. The speed of the iSave unit must be ramped up over a period of minimum 10 seconds. If possible, run the iSave at maximum 750 rpm. 5. With a pressure control valve (15), adjust the back pressure of the “LP-out” to a minimum of 1 bar/14.5 psig (14). 6. An “over flush” of the iSave can be done to bleed any remaining air from the system. Flush minimum 10% higher flow rate (12) at “LP in” compared to the flow rate on “HP out”. Flush over a period of minimum 5 minutes. 7. Adjust the speed of the iSave unit to desired flow. The speed is controlled by a VFD. 8. Start the high-pressure pump (4), and the system pressure (5) will rise until the permeate flow (17) almost equals the flow (2) from the high-pressure pump. Check the low-pressure flow rates (12), and if required, adjust flow to achieve balanced flow to the iSave unit. It might be a benefit to “over flush” the iSave with up to 10% to lower the mixing. 1. If the “LP-in” flow (12) is too low and the “LP-out” pressure (14) is higher than 1 bar/14.5 psig, increase flow and pressure on the pressure control valve (15). 2. If the “LP-in” flow (12) is too low and the “LP-out” pressure (14) is below 1 bar/ 14.5 psig, adjust the flow by raising the flow from the seawater supply pump (1). 3. If the “LP-in” flow (12) is too high, reduce flow by the pressure control valve (15) or the flow from the seawater supply pump (1). 9. Check that the pressure (14) of “LP-OUT” is at least 1 bar/14.5 psig.

System Shutdown

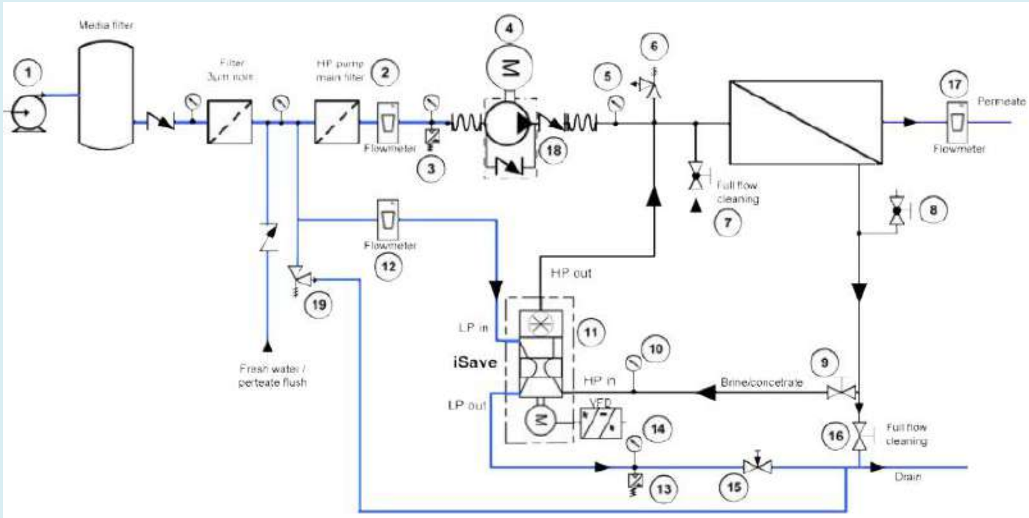
1. The system is running in normal operation and producing permeate flow. 2. Stop the high-pressure pump (4). 3. Keep the iSave unit (11) running until the wanted pressure (5) at the membranes is reached and the TDS in the high-pressure line is equal to the TDS in the low-pressure line. If the pressure (10) at “HP in” drops below 3 bars/43.5 psig, the sound will change in the iSave. This is due to cavitation. “HP in” pressure between 1-3 bars/43.5 psig is acceptable for less than 10 minutes within a period of 6 hours. If possible, run the iSave at maximum 750 rpm. 4. Stop the iSave unit (11). 5. Stop the seawater supply pump (1).

System Long term shutdown

For a long-term shutdown period, the RO system including the iSave units must be thoroughly flushed with fresh water to remove any salt. Run the “1-3 days’ system shutdown” procedure (see below). Further, any biological growth should be prevented. Make a final flush of the iSave unit with the same solution used to preserve the RO membranes. Flush both the high-pressure and low-pressure sides of the iSave (11). The high-pressure flush is performed by circulating the solution through the iSave unit and the membranes by rotating the iSave unit. If possible, run the iSave at maximum 750 rpm.

1-3 days system shutdown procedure

1. The system is running in normal operation and producing permeate flow.

	2. Stop the high-pressure pump (4). 3. Keep the iSave unit (11) running until the wanted pressure (5) at the membranes is reached and the TDS in the high-pressure line is equal to the TDS in the low-pressure line. If the pressure (10) at "HP in" drops below 3 bars/43.5 psig, the sound of the iSave will change. This is due to cavitation. "HP in" pressure between 1-3 bars/43.5 psig is acceptable for less than 10 minutes within a period of 6 hours. Also see datasheet for iSave. If possible, run the iSave at maximum 750 rpm. 4. Stop the iSave unit (11). 5. Stop the seawater supply pump (1). **Cleaning procedure**  According to the P&I scheme above, 1. Stop the high-pressure pump (4), and stop the iSave (11). 2. Stop the seawater supply pump (1). 3. Close valve (9) and open valve (16). 4. Pump mixed cleaning solutions to the vessel at conditions of low flow rate and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no or little permeate is produced. A low pressure minimizes re-deposition of dirt on the membrane. Dump the brine/concentrate to prevent dilution of the cleaning solution. 5. Recycle: After the process water is displaced, cleaning solution will be present in the concentrate/ brine stream. Recycle the cleaning solution from the piping to the cleaning solution tank. 6. Turn of the pump and allow the elements to soak Feed the cleaning solution at high flow into the "full flow cleaning" adapter (7). The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. 8. Flush RO permeate or deionised water into the "full flow cleaning" adapter (7). Flush out the cleaning solution. It is essential that the water used for the final pre-flush is pre-filtered to a level described in the datasheet. 9. Open valve (9) and flush trough the iSave. The iSave may start to rotate backward – this is OK. 10. When flushing is finalised – assure that no foulants remain in the piping or valve (9). 11. Close the high pressure "full flow cleaning" valve (7) and close valve (16)
Trouble-shoot	**Over-pressurisation caused by low pressure isolation** If the low-pressure side of the iSave is blocked and the iSave is exposed to high-pressure, there is a risk that the iSave or the LP piping could be damaged by over-pressurisation.

To prevent such over-pressurisation, appropriate relief valves should be used, and procedures should be implemented to assure that the HP of the iSave is depressurised prior to the isolation of the LP side.

Over-pressurisation caused by the high-pressure pump

The HP pump may be able to generate a pressure higher than the maximum allowable pressure for the iSave or the system – particularly if the HP pump is a positive displacement pump, the pump will be able to generate extremely high levels of pressure.

To prevent such over-pressurisation, appropriate relief valves should be used, and procedures should be implemented to assure that the HP of the iSave is protected against excess pressure.

Safety Regulations

The operator ensures that all inspection and installation work is performed by authorised, qualified specialist personnel who are thoroughly familiar with the manual.
Before intervening in the iSave/system; ▪ The power must be shut off and the starting device be locked. ▪ The pressure in the High-Pressure lines must be drained to Low Pressure side. ▪ •The water in all connected pipes must be drained.

PROBLEM	POSSIBLE CAUSE	ACTION
VFD can't start the iSave at initial start-up.	VFD is not designed for constant torque.	Choose a VFD that is designed for constant torque.
	Ramp-up settings in the VFD is not correct. VFD is tilting.	Set Ramp-up parameters correct.
	Valve (9) is closed.	Open valve (9).
	Pressure in the HP line (5) is too high	Start the iSave only when the pressure in the HP line is low.
Torque on iSave too high during operation	Pressure difference from HPout (5) to HP-in (10) is too high.	Clean or change membranes.
		Debris in the booster pump or iSave.
		Wear in the booster pump or iSave.
		Design of the basic plant doesn't fit the performance of the iSave.
Permeate production is too low (17).	Valves (6), (7), (8) or (16) are leaking.	Repair or change valve.
	Internal leakage in iSave.	Repair iSave.
	HP pump flow (2) is to small.	Incorrect speed on the HP pump.
		Check the HP pump and repair if necessary.
Pressure on the membranes (5) is too high.	Fouling on the membranes.	Clean the membranes.
	Mixing in the iSave is too high.	Check flow on LP-in (12) and adjust flow.
	Flow out of the iSave is too low, causes a recovery rate that is too high.	Check speed on iSave and change if necessary.
		Booster pump in the iSave is worn out. Perform service on the VP.

	Pressure on the membranes (5) is too low.	Valves (6), (7), (8) or (16) are leaking.	Repair or change valve (s).
		Internal leakage in iSave.	Repair iSave.
		HP pump flow (2) is too small.	Incorrect speed on the HP pump.
			Check the HP pump and repair if necessary.

Annex B. Operation procedures (BGF Infrastructure Services)

A.1 HVAC

1. HVAC System Operation sheet

A.2 Electric Offshore Substation

1. Dry Type Transformers Operation sheet
2. Medium Voltage Switchgear Operation sheet
3. Medium Voltage AC Cables Operation sheet

A.3 Shipping Operations

1. Automated Docking System Operation sheet
2. Electric Recharge System Operation sheet

A.4 Surveillance and Security

1. Surveillance Radar Operation sheet
2. Long Distance cameras Operation sheet
3. Automatic Identification System (AIS) Operation sheet
4. Security Systems Operation sheet
5. Access Control System Operation sheet

A5. Structural Health Monitoring System

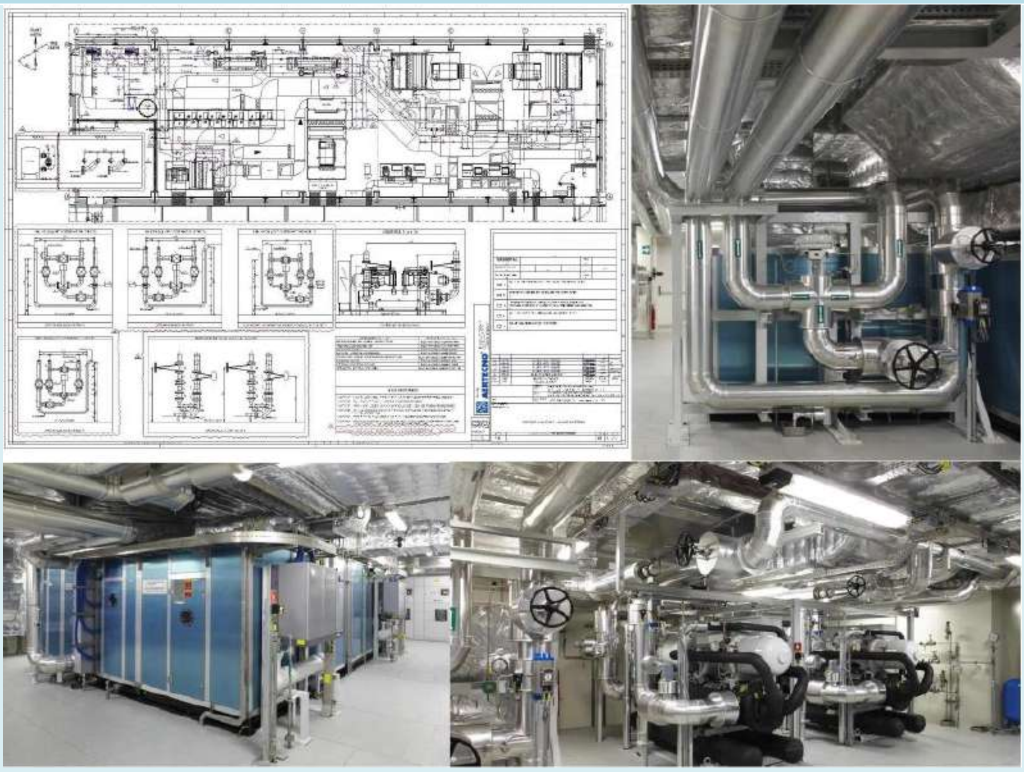
1. Structural Health Monitoring System Operation sheet

A6. Mooring System

1. Mooring System Operation sheet

A.1 HVAC

HVAC Operation sheet	
FUNCTION	The purpose is to provide suitable indoor ambient conditions for manned operations and living at sea, as well as operative conditioning for the electric / electronic equipment, laboratory chambers, pharmacy and other biological needs related to the offshore cultures production. The HVAC system is based on commercial equipment with particular requirements to operate in harsh environment like the one at sea, for instance those already in use in the marine and offshore industry. HVAC system controls over: ▪ Dry-bulb temperature ▪ Humidity ▪ Air movement ▪ Fresh air ▪ Cleanliness of the air ▪ Noise levels
Equipment	   

Suppliers	AERON (AF Gruppen), DAIKIN, Heinen and Hopman, Johnson Controls, AROS Marine, Novenco marine
Layout	
Key technical aspects	HVAC system is articled through basic subsystems. These subsystems are normally referred to as "loops." There are five primary loops for the present application: ▪ Airside loop ▪ Chilled-water loop ▪ Refrigeration loop ▪ Heat-rejection loop ▪ heating and humidifying ▪ Controls loop Design parameters are taken into account for the HVAC installation: ▪ Segregation of hazardous and non-hazardous areas. ▪ Area classification. ▪ Installation safety philosophy. ▪ Fire compartmentation scheme. ▪ Pressure differential between segregated areas. ▪ Fire and gas detection and protection systems. ▪ Emergency shutdown and emergency power philosophies. ▪ Equipment redundancy and standby philosophy. ▪ Equipment selection appropriate to operating conditions. ▪ Requirements for removal of excess heat. ▪ Standardisation of components used in HVAC systems to provide interchangeability between systems.

	▪ Smoke and gas control philosophy (i.e., prevention of ingress of smoke or gas into accommodation spaces, control stations, enclosed escape routes or enclosed muster areas). HVAC services to areas are normally fan powered, except where it is demonstrated that natural ventilation can provide adequate safety protection to the installations. Separate ventilation / air conditioning systems are provided for hazardous and non-hazardous areas. HVAC system does not impair the integrity of fire / watertight bulkhead separation of the installations. The principle is to stop the supply of combustion air and to prevent fire, gas or smoke spreading, or where relevant sea water entry, through the ductwork system. Local and remote controls, status indication, alarms and interfaces of HVAC services are to be available to provide input to the emergency shutdown logic of the installations. In particular, an integrated HVAC control and alarm strategy for normal and emergency operation is to cope with guidance to SI, SOLAS and MODU codes. Equipment that may require to be purged should be capable of: ▪ Pre-purge. ▪ Continuous purging while the equipment is in use. ▪ Purge, where necessary, after shutdown.
Key operational aspects	Air-conditioning packages are provided for different types of the platform rooms. VAV/CAV unit with intelligent automation and room thermostat can operate as stand-alone unit or in a network. Network enables air-conditioning in cabins to be controlled, monitored and adjusted by supervision system. **<u>Chiller</u>** The capacity of the chiller is controlled by: 1. Staging the compressors on and off; 2. By adjusting the capacity of each compressor by opening or closing the inlet vanes to control the quantity of refrigerant entering the impeller; and, 3. Varying compressor speed to change capacity. The speed control and vane control work in conjunction. As load decreases, compressor speed is reduced as low as possible but above the point where stall might begin. If further capacity reduction is required, the guide vanes will close to whatever position is required to match the compressor capacity to the load. <u>Operating parameters</u>: It is a responsibility of the technician executing the first or annual start-up, to check chiller operating parameters to assure the correct operation of the chiller (e.g., to be sure there was no refrigerant leak during transportation, installation or long shutdown period). Main operating parameters to be checked are: 1. Evaporating pressure. 2. Condensing pressure. 3. Refrigerant superheat at compressor suction 4. Refrigerant superheat at compressor discharge 5. Subcooling of liquid coming out of the condenser banks. **Control sensing**

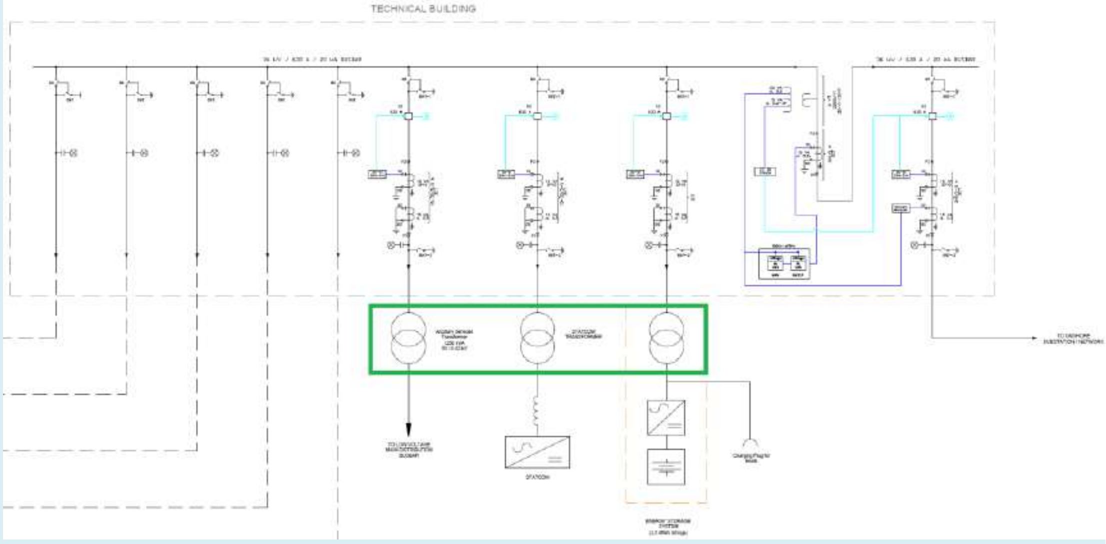
	All sensors are preassembled and connected to the microprocessor. The descriptions of each sensor are listed below: Evaporator outlet water temperature sensor – This sensor is located on the evaporator outlet water connection and is used by the controller to control the unit load depending on the system's thermal load. It also helps control the evaporator's antifreeze protection. Evaporator inlet water temperature sensor – This sensor is located on the evaporator inlet water connection and is used for monitoring the return water temperature. Evaporator differential pressure switches – Two sensors are located between the evaporator inlet and outlet water connections and is used to protect evaporator against loss of water flow. Condenser inlet water temperature sensor – This sensor is located on the condenser intlet water connection and is used by the controller to control the tower bypass valve depending on the system's thermal load. Condenser outlet water temperature sensor – This sensor is located on the condenser outlet water connection and is used for monitoring the leaving water temperature. Condenser differential pressure switches – Two sensors are located between the condenser inlet and outlet water connections and is used to protect condenser against loss of water flow. The following sensors are located inside the compressor and managed by the compressor integrated electronic controller: ▪ Compressor discharge pressure transducer ▪ Compressor discharge temperature sensor ▪ Compressor suction pressure transducer ▪ Compressor suction temperature sensor

Trouble-shoot

PROBLEM	POTENTIAL CAUSES	TROUBLESHOOT
Low suction pressure	Rapid load swings	Stabilize load.
	Lack of refrigerant.	Check for leaks, repair, add charge. Check liquid sight glass.
	Fouled liquid line filter drier.	Check pressure drop across filter drier. Replace.
	Expansion valve malfunctioning.	Repair or replace and adjust for proper superheat.
	Condensing temperature too low.	Check means for regulating condenser temperature.
	Compressors not staging properly.	See corrective steps- Compressor staging intervals too low.
	Insufficient water flow.	Correct flow.
	Excess or wrong oil used.	Recover or change oil.
	Evaporator dirty.	Back flush or clean chemically.
Compressor thermal protection switch open	Operating beyond design conditions.	Correct so conditions are within allowable limits.
	Discharge valve not open.	Open valve.
	Short cycling.	Stabilize load or correct control settings for application.
	Voltage range or imbalance.	Check and correct.
	High superheat.	Adjust to correct superheat.
	Compressor mechanical failure.	Replace compressor.
High discharge pressure	Low lift, inverted start.	Control issues.
	Compressor running in reverse.	Check unit and compressor for correct phasing.
	Improper piping or support on suction or discharge.	Relocate, add, or remove hangers.
	Compressor mechanical failure.	Replace.

A.2 Electric Offshore Substation

DRY-TYPE TRANSFORMERS Operation sheet	
FUNCTION	A transformer is an electrical element that allows increase or decrease the voltage in an alternating current circuit, while maintaining power. In summary, is a device that converts alternating electrical energy of a certain voltage level into alternating energy of another voltage level, based on the phenomenon of electromagnetic induction. Transformers are elements that practically do not require any intervention during their operation, so this section will describe those necessary points to provide a proper location and installation. The particularity of the operating environment means that the power transformers to be installed on the platform should be dry type, as they do not have any moving parts (not like liquid fill Transformers) and do not require an oil collecting pit in case of an accident. Its windings are encapsulated in cast resin, and are cooled by natural air or forced ventilation, all safely without affecting the frequency, and require very little maintenance. For further information it is recommender to consult the following standards: - IEC 60076-11: Dry-type transformers. - IEC 60076-12: Loading guide for dry-type power transformers.
Equipment	
Suppliers	ABB, SCHNEIDER, SIEMENS, TESAR.

Layout	
Key technical aspects	The main applications for dry-type transformers are as follows, including some advantages and disadvantages points (compared with oil filled transformers): - Indoor use but with the proper enclosure it is possible to achieve an ingress protection index (IP) if required. - Cast resin dry-type transformers are used in high moisture areas due to the encapsulation prevents moisture from penetrating the winding. - As it is with non-inflammable winding insulation, it offers low risk to fire hazard. Zero leakage of flammable or contaminating substances. - High mechanical strength. Capable of withstanding the most severe rolling and vibrating conditions. - Good overload capacity. - Higher operation sound level than oil filled. - Easy maintenance. - Electrical losses higher than oil filled type. - Up to 72.5 kV and 63 MVA.
Key operational aspects	Power Transformers are designed to operate autonomously during their service life and only authorized and qualified personnel can operate on them during inspections, restoring service or maintenance operations. In any case, every employee must follow the indications given by the manufacturer of the equipment, apart from the safety standards for operation in electric-risk environments. **Five "golden rules" for electrical safety:** 1- Disconnect completely. 2- Secure against re-connection. 3- Verify the absence of electrical voltage. 4- Carry out earthing and short-circuiting. 5- Signalling the working zone and provide protection against adjacent live parts **Pre-installation inspection** - New transformers should be inspected upon receipt to determine if any damage is evident or if there is any indication of rough handling. - If there is evidence of damage, an internal inspection will be required. In this inspection, note should be made of loose or broken connections, damaged or

- displaced parts, cracked insulators, dirt or foreign material, and evidence of free water or moisture.
- Corrective measures should be taken where necessary.

Installation requirements

- Dry-type transformers should be installed over foundations that are properly leveled and capable to withstand their weight.
- There should be a minimum spacing of 0,5 m between transformers or between the transformer and any adjacent wall in order to facilitate the access for inspection and ventilation (depending of the voltages).
- The room where the transformer will be installed should be well ventilated to provide proper natural ventilation. If natural ventilation is not sufficient, fans can be installed to force the air flow in the room or implement a refrigeration system in the room where the transformer will operate (take care of water condensation).
- The location of the transformer should comply with all safety codes, and will not interfere with the normal movement of personnel, equipment, and material.

Connections

- The transformer has both high voltage (HV) and low voltage (LV) winding connections. Solidly connect all terminal elements and bus bar to avoid heating and arcing which may result in connection failure.
- All non-current carrying metal parts in a transformer must be properly grounded to remove static charge that accumulates in the unit by dissipating the charge back into the earth.
- Tap connections may be changed only when the transformer is totally de-energized. These taps are provided to furnish rated output voltage when the input voltage differs from the nominal voltage.

Before Operation

- Check if the name plate ratings are in accordance with the ratings foreseen for the place of installation.
- Check if all connections at the tap change panel are firmly tightened and at the same position in the three phases.
- In case of transformers fitted with a thermal protective device, check the connections of the circuit, making sure that the voltage is in accordance and that the alarm and shut-off contacts are connected to their corresponding loops.
- It is recommendable to check the insulation resistance by making measurements between the LV and HV windings and from the windings to the ground.
- Voltage shall be applied while the transformer is set to no load, and such voltage shall be measured at the secondary winding to check for the corresponding output ratings.

Summary Checklist

Electrical inspection

- [ ] All external connections have been made properly (Phasing of connections to terminals, etc.)
- [ ] All connections are tight and secure
- [ ] All accessory circuits are operational
- [ ] All tap connections are properly positioned
- [ ] The neutral and ground connections have been properly made
- [ ] Fans (if supplied) are operational
- [ ] Proper clearance is maintained from high voltage and low voltage bus to terminal equipment
- [ ] All windings are free from unintended grounds. A 500V megger test is recommended
- [ ] There is continuity in all windings

Mechanical inspection

- [ ] There is no dust, dirt, or foreign material on the core and coils
- [ ] There is no visible moisture on or inside the core and coils or enclosure
- [ ] There is no visible damage to or shifting of core and coil assembly
- [ ] All plastic wrappings are removed from the core and coils
- [ ] All shipping members have been removed
- [ ] There are no obstructions in or near the openings for ventilation
- [ ] No tools or other articles are left inside of, or on top of, the core and coils or enclosure
- [ ] All protective covers are closed and bolted tight

Trouble-shoot

ID	PROBLEM	POSSIBLE REASON	POSSIBLE SOLUTION
1	Overheating at the HV and LV terminals and connection points and the switching panel.	Poor contact	Clean the areas of contact. Tighten bolts and nuts.
2	Overheating of the Transformer	Overload above the foreseen level.	Reduce the load. Increase cooling.
		Insufficient circulation of cooling air	Clean the cooling air channels of the transformer. Check the cooling air circulation ducts/openings for proper size and obstructions.
		Temperature of the cooling air above the foreseen level.	Reduce the load. Increase the circulation of cooling air.
3	Actuation of the protective relay (Alarm and/or shut off)	Overheating of the Transformer.	Same ID 2
		Lack of supply voltage for the relay.	Check the relay for proper supply voltage. Check the relay and its wiring for proper operation.
4	Discharge between HV terminals. Discharge between HV and mass.	Reduction of the superficial resistivity of the insulating material due to the existence of foreign bodies.	General cleaning, removing all foreign bodies settled on its surface.
	Discharge between HV and LV terminals. Discharge between LV and mass.	Destruction of the insulating material due to over-voltages, overheating or mechanical strains above the foreseen level.	Replace or repair the damaged part.

	5	Excessive noise	Voltage higher than the foreseen one. Base of the transformer not evenly seated in. Resonance with other surfaces around the equipment.	Check for the most suitable voltage and adjust it to the most suitable tap. Check it for loose metallic surfaces (panels, closets, ducts, doors, etc.), which could cause vibrations.
			Resonances transmitted by the connections.	Install flexible elements between the transformer terminals and the installed cables.

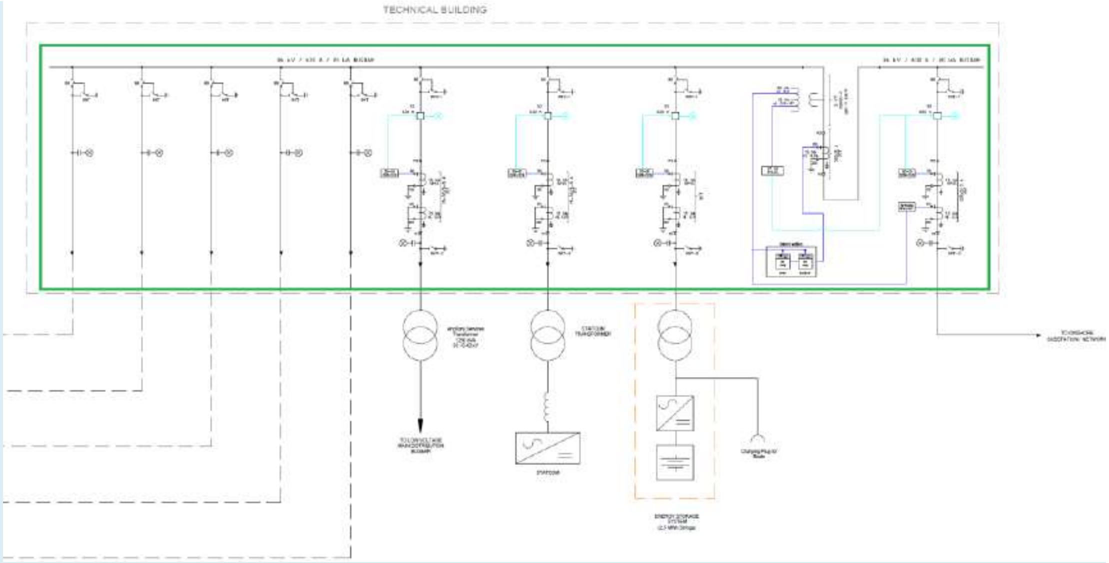
<table>
<tr><th colspan="2">MEDIUM VOLTAGE SWITCHGEAR Operation sheet</th></tr>
<tr><td>FUNCTION</td><td>
The Switchgear System include all those elements necessary for the operation of the electrical system under the established conditions of safety, reliability and efficiency and whose main functions are operation, measurement, and protection.
There are several units with their own functionalities within the power switchgear, such as switching, protection, metering among others.
Medium voltage (MV) switchgears are divided mainly in two families:

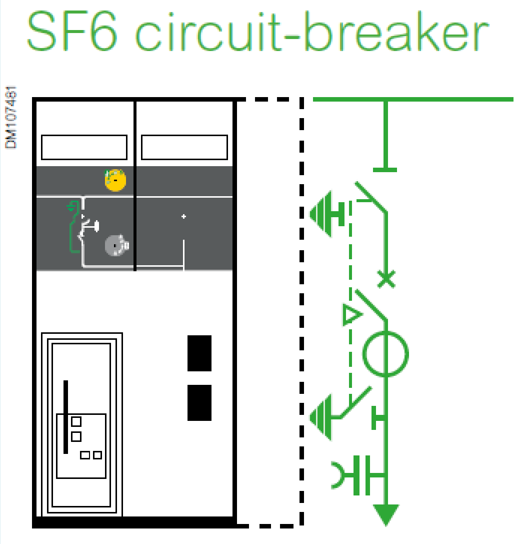
MV switchgear for primary distribution (Metal Clad): used in applications where high reliability and continuity of service is fundamental. This type of switchgear has the peculiarity of having the main component, the circuit-breaker, withdrawable for easy replacement. Furthermore, it can be divided into compartments metallically segregated from each other.
MV switchgear for secondary distribution (Metal Enclosed): used in applications which less stringent requirements on continuity of service.

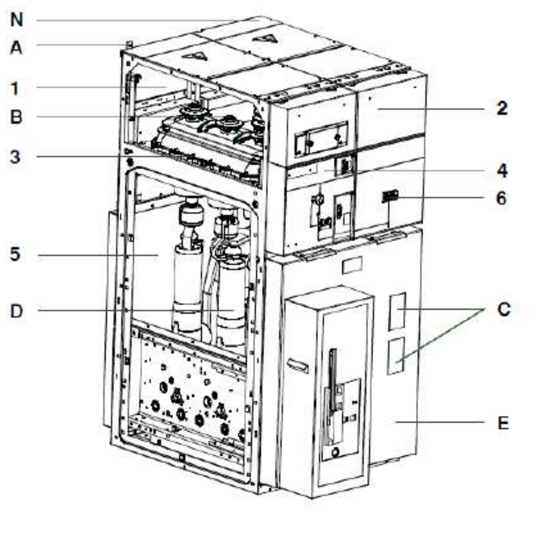
For additional information, it is recommended to consult the following standard:

IEC 62271: High-voltage switchgear and controlgear - ALL PARTS

</td></tr>
<tr><td>Equipment</td><td></td></tr>
<tr><td>Suppliers</td><td>ABB, ORMAZABAL, SCHNEIDER, SIEMENS.</td></tr>
</table>

Layout	
Key technical aspects	An important aspect for consideration during the operation (and subsequent maintenance) concerns to the insulation of the internal components such as the circuit breakers or disconnectors. Insulating medium refers to the environment within the switchgear enclosure used to protect the energized devices from undesired arc faults. The most commonly used are: - **Air:** the most common insulator and the least expensive. In contrast, air has the lowest dielectric strength properties and require more space to extinguish the electric arc. Very few of this type of equipment are still being produced in favour of vacuum technology. - **Vacuum:** for industrial environments, this type of insulation is more popular than air technology due to their compact size and improved reliability. - **Gas:** offers significantly improved dielectric strength compared to air. The arc generated is extinguished in a chamber filled with pressurized sulfur hexafluoride (SF6) gas, an inorganic, non-flammable gas that is an excellent electrical insulator. SF6 circuit breakers are similar to vacuum circuit breakers but one distinct advantage that gas have over vacuum is if there is a pressure leakage in the arc-extinguishing chamber, the residual SF6 gas can be enough to allow the breaker to open safely under a normal load. The main disadvantage of SF6 is its negative effects on the atmosphere as a potent greenhouse gas. - **Fluid:** offers improved dielectric when compared to air, while also adding a cooling benefit. Various fluids can be used for electrical insulation as for example mineral oil and FR3 (natural ester).
Key operational aspects	In the same way as power transformers, medium voltage switchgear will operate autonomously and only authorized and qualified personnel can operate on them during inspections, restoring service or maintenance operations. The basic operations for a circuit breaker unit (DM1 SF6 from Schneider) are briefly described below; it is important to recall that the operator must follow the indications given by the manufacturer and the safety standards. **Circuit Breaker Unit Description**

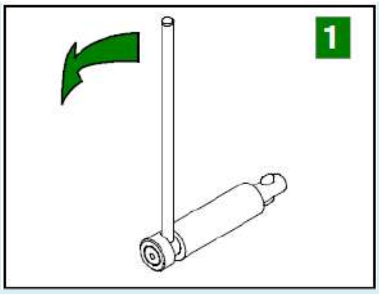




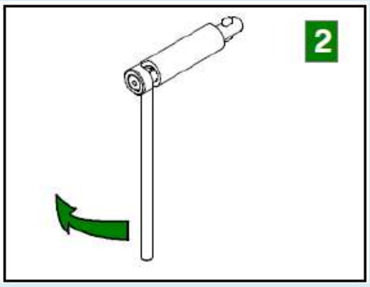
1- Busbar compartment
2- Control cabinet
3- Switchgear compartment: line disconnector
4- Operating mechanism cabinet
5- Lower busbar or cable connection compartment
6- Voltage presence unit
A- Earth bar connection pad
B- Busbar connection pads
C- Inspection windows
D- Circuit breaker
E- Front panel
N- Rear extension sheet metal

Disconnector operating handle positions

- Position the lever as indicated for downward (opening) operations.

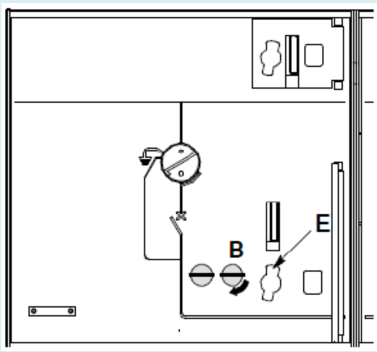


- Position the lever as indicated for upward (closing) operations.

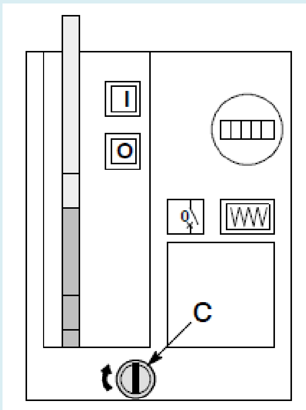


Circuit breaker operating tests before energising: The Initial conditions are line disconnector in open or earthed position and circuit breaker locked in open position.

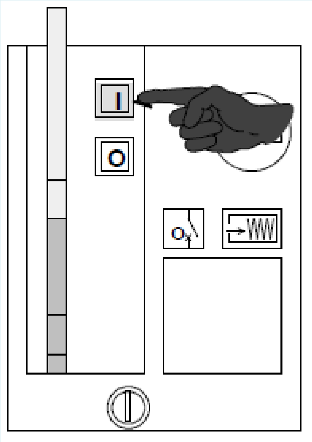
- Lock the lever hole "E" of the line disconnector with the key in lock "B".



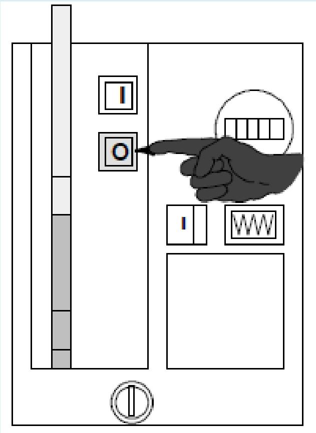
- Remove the key from "B" and insert it in "C". Unlock and then charge the operating mechanism of the circuit breaker.



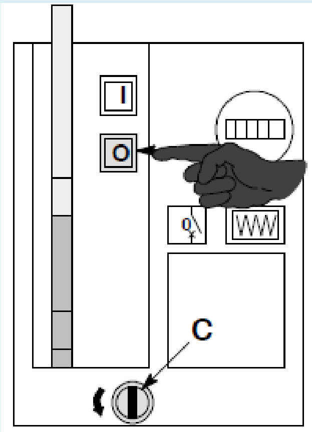
- Press the | (ON) pushbutton to close the circuit breaker



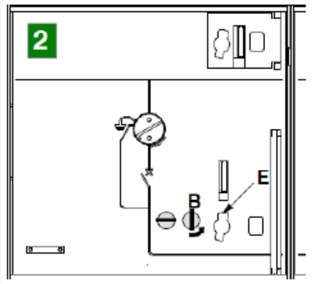
- Press the O (OFF) pushbutton to open the circuit breaker



- With the key in "C", lock the circuit breaker in open position by pressing the O (OFF) pushbutton.

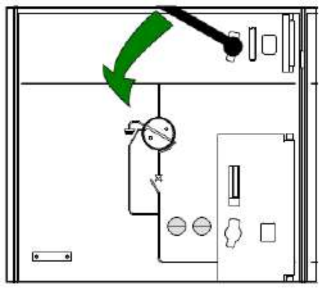


- Remove the key from "C" and insert it in "B". Unlock the line disconnector lever hole "E".

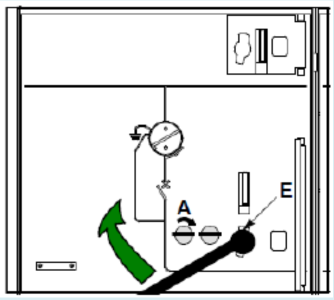


Energising the downstream part of the installation: The Initial conditions are line disconnector in earthed position and circuit breaker locked in open position. Front panel in place.

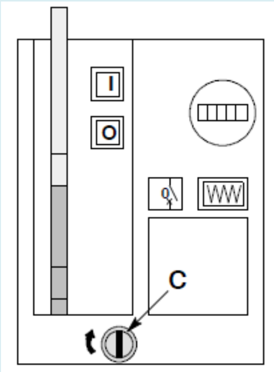
- Set the line disconnector to open position using the operating lever; for a DM1 cubicle, the downstream earthing switch opens at the same time.



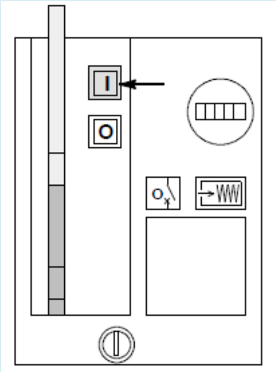
- Set the line disconnector to closed position and then, with the key in “A”, lock the lever hole “E” of the line disconnector.



- Remove the key from “A”, insert it in “C” and unlock the circuit breaker. Charge the circuit breaker operating mechanism.

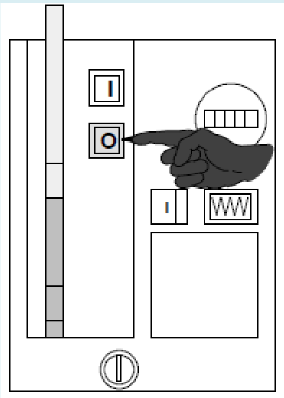


- Press the | (ON) pushbutton to close the circuit breaker. The downstream part of the installation is now energised.

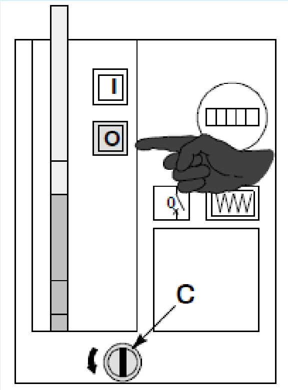


De-energising the downstream part of the installation: The initial conditions are line disconnector in closed position and circuit breaker in closed position.

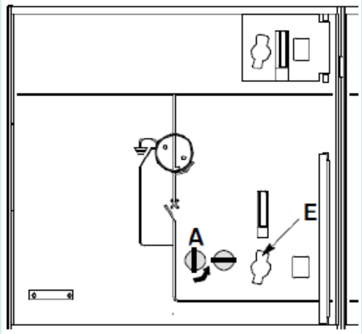
- Press the O (OFF) pushbutton to open the circuit breaker.



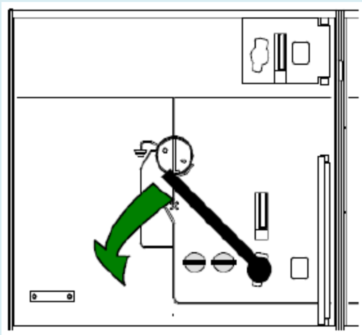
- With the key in "C", lock the circuit breaker in open position by pressing the O (OFF) pushbutton.



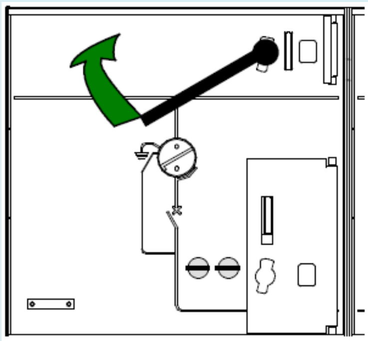
- Remove the key from "C" and insert it in "A". Unlock the line disconnector lever hole "E".



- Set the line disconnector to open position.



- Set the line disconnector to earthed position. The front panel can now be removed (for a DM1 A cubicle, the downstream earthing switch closes at the same time).

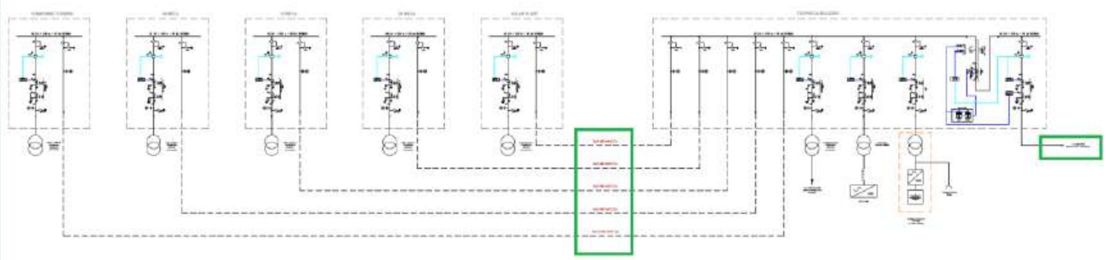
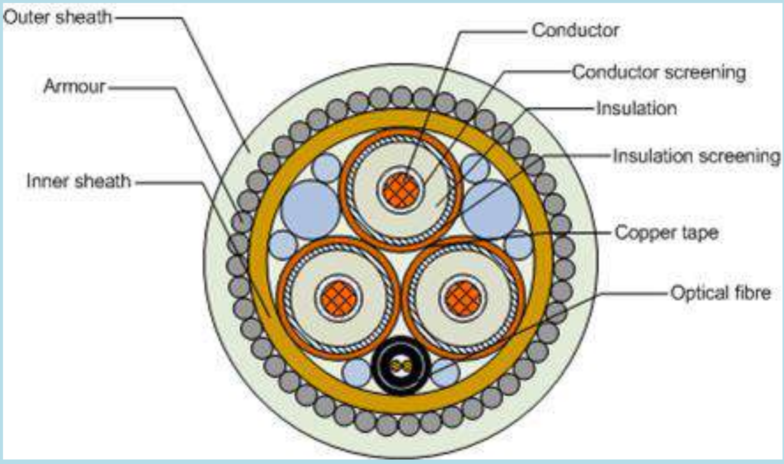


Trouble-shoot

ID	PROBLEM	POSSIBLE REASON	POSSIBLE SOLUTION
1	Flashover in insulation parts	Support insulator failure	Clean insulator; take insulation resistance (IR) value between busbar and panel. If value obtained is less than 10,000 MΩ, replace insulator.
		Inter-panel insulating barrier failure	Clean the barrier and take the IR value between busbar and panel earth. If value obtained is less than 10,000 MΩ, replace the barrier.

		Insulation rod failure	Take IR value between inserts of operating rod. If value obtained is less than 10,000 MΩ, replace the operating rod.
		Insulation shutter surface tracking	Replace the shutter.
2	Circuit Breaker failure	Loss of insultation medium.	The interrupter cubicle should be replaced by a new one (if removable).
3	Instrument Transformers failure	External flashover due to insulation failure	If cracks or burning marks are observed, replace the transformer.
		Current Transformer saturation	This should be checked by giving secondary current and measure primary current. If reading does not increase with the increase of current in secondary, it indicates saturation; replace de transformer.
4	Breaker not closing	Motor not charging spring due to supply voltage less than 85% of the nominal value.	Ensure supply voltage
		Motor not charging spring due to jamming of gearbox.	Replace gearbox
		Motor not charging spring due to broken shaft.	Replace motor
		Closing coil burnt	Replace closing coil.
		Closing coil not developing sufficient force	Check the electrical resistance; if not adequate, then replace the coil
		Auxiliary switch continuity missing due to contamination of contacts	Clean de contacts
		Electrical problem in the supply circuit	Replace the faulty components
	Breaker not opening	Tripping coil no developing sufficient force	Check the electrical resistance; if not adequate, then replace the coil
		Tripping coil burnt	Replace Tripping coil
		Problem in tripping circuit	Check and replace faulty components

MEDIUM VOLTAGE AC CABLES Operation sheet

FUNCTION	AC cables are generally made up of several layers and since the primary function is the transmission of electrical power (and possibly communication or measurement signals) the cross-section is generally composed by one or more central cores containing the conductor. Each core requires appropriate insulation and possibly a screening layer to keep the electrical field stress homogeneous. The whole ensemble is typically enveloped within a sheath. For further information it is recommender to consult the following standards: ▪ IEC 60502: Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV)
Equipment	
Suppliers	JDR, NEXANS, NKT, PRYSMIAN.
Layout	
Key technical aspects	The composition and design of medium voltage cables is defined by the following elements:  *Typical AC three-core cable cross section*

1- **CONDUCTOR:** the conductor size must enable the cable to carry the desired load current without overheating and maintain voltage drop within desired limits. Copper is generally preferred to aluminium for the conductors as its use permits a higher current density, thereby reducing the overall diameter of the cable and its higher tensile strength is an advantage considering the dynamic stresses likely to occur during operation.
There are different conductor types of for submarine cables: solid, stranded, profiled wire, hollow conductor (oil filled cables), milliken.

From upper left to bottom right: solid, stranded, profiled, hollow, milliken

2- **INSULATION:** provides an effective barrier between potential surfaces with an extreme potential difference. Its function is to contain the voltage within the cable system. Each conductor requires a proper thickness of insulation to meet its design voltage with the necessary degree of safety and reliability. An extra insulation of the conductive core is usually made in order to separate it from a potential metallic outer sheathing layer.

Material	Operating temperature	Short-circuit temperature
Low density Polyethylene	70 ºC	125 ºC
XLPE (Cross-linked Polyethylene)	90 ºC	250 ºC
EPR (Ethylene Propylene Rubber)	90 ºC	250 ºC
Oil-paper	85-90 ºC	-

Operational temperature for some cable insulation materials (IEC 60502)

3- **INSULATION SHIELD:** the outer shielding is comprised of two conductive components: a semi-conductive layer (semi-con) under a metallic layer. The principal functions of the insulation shield system are:
- Confine the electric field within the cable.
- Obtain a symmetrical radial distribution of voltage stress within the dielectric.
- Protect the cable from induced potentials.
- Limit radio interference.

- Reduce the hazard of shock.
- Provide a ground path for leakage and fault currents.

The shield must be grounded for the cable to perform these functions. There are different grounding methods each with its own advantages and disadvantages:

Different grounding methods

Grounding method	**Continuous, at 2 points:** The metallic screens are earthed at least at both ends of the line.	**At one point:** The metallic screen is earthed at one end and connected to a voltage limiter (SVL) at the other.	**Cross-bonding:** The metallic screens are earthed directly at each end. The cross-bonding of the screens cancels the total induced voltage generated in the screen of each phase. This is achieved by connecting the metallic screens using joints and screen separations.
Line characteristics	• Line length greater than 200m • Cable cross-section under or equal to 630 mm^2	• Circuit length under 1 km	• Long Circuits • High capacity, cross-section greater than 630 mm^2 Cu • Joints • Number of sections: multiples of 3 of almost equal lengths
Necessary equipment	• R2V cable or low voltage insulated cable	• Sheath voltage limiter • R2V cable or low voltage insulated cable	• Joints with screen separations • Coaxial cable • Sheath voltage limiter at the screen cross-bonding point
Advantages	• Easy to implement • No equipotential cable installed along the circuit	• Optimal use of transmission capacity • Earth-cable protection possible	• Optional equipotential cable along the circuit • No induced currents in the screens
Drawbacks	• Reduced transmission capacity • No earth	• Equipotential cable along the circuit • Use of sheath voltage limiters	• Maintenance • Cost

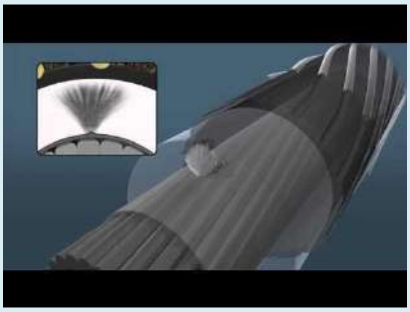
Grounding methods

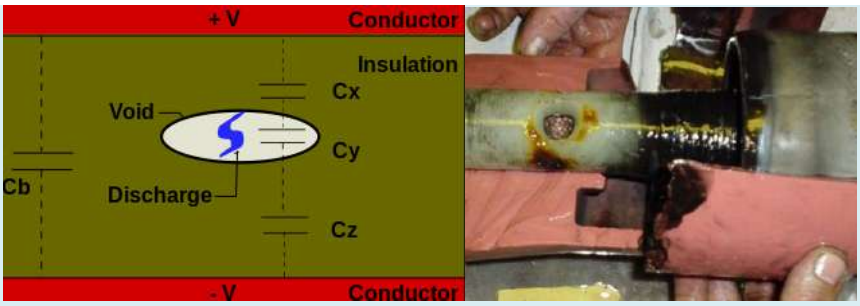
The semi-conductive component is available either as a tape or as an extruded layer. The metallic shield is the current carrying component that allows the insulation shield system to perform the functions mentioned before.

4- **OPTICAL FIBRES:** Data exchanges are necessary between the control and operation entities (monitoring for instance). This function should be carried out by optical fibres incorporated inside the electrical power cables cores, granting the optical system the adequate mechanical protection (mainly bending radius and tensile strain limitations).

5- **ARMOURING:** not present in all cables but depending on the natural and manmade hazards, and environmental condition, some cables may require additional protection. Some of the key features for this cable layer include:

- Carrying tension during laying, operation and retrieval.
- Providing some physical protection against impacts.
- Controlling the bending radius to avoid kinking if laid over a sharp object.
- Providing abrasion resistance.

	6- **SHEATHS:** Typical designs include sheaths for protection against corrosion and water entry. The most common cross-section configurations include a sheath layer covering the insulated cores and an outer over sheath for protection against abrasion of the armour and the cable as a whole. Extruded polyethylene provides the most impermeable barrier to moisture ingress and is used practically universally for the anticorrosion sheath. Some studies claim for a "Wet Design" without a sheath where the water blocking is performed by the XLPE or EPR insulation, assuming a possible degradation by occurrence of water treeing in return of a cost reduction compared with the traditional "Dry Design". 7- **CABLE PRETERMINATION:** For quick connection and disconnection of the cable to/from the floating platform, the conductors and O.F. can be electrically preterminated onshore, and protected against water filtering and mechanical loads by using one preconnector (watertight casing), that remains permanently clamped to the cable armouring. On the other hand, the platform is provided with one Housing that allows the quick and safe coupling /decoupling with the preconnector.
Key operational aspects	Main operational issues for power cables comes from external impacts, damage during the installation phase for friction or fatigue, overcurrent, thermal damage, or during manufacturing process. Spontaneous failures can occur within the cable lifetime, but this is likely to be a failure caused by another risk sited above. ▪ **PRIMARY STRUCTURAL FAILURE:** A cable failure almost always exhibits itself as either an open circuit or a short circuit. Open circuits are usually the result of failed connectors or broken and/or corroded conductors. Short circuit failures will most often cause the protection system to operate and interrupt the current flow to the load. *Water trees:* usually propagate in the direction of the electric field. They occur only in the presence of water in the insulation and cable sections which are in a state of tension such as in bends. Water trees reduce the breakdown strength of the cable and the dielectric strength of the insulation.  They are caused by voids, impurities and defects in the insulation. Water trees may be converted to Electrical trees (especially if accelerated by overvoltages) and produce partial discharge. *Partial Discharge (PD):* It is a localised breakdown of a small portion of a solid or fluid electrical insulation system, which does not bridge the space between two conductors.



Left: A partial discharge within solid insulation. Right: Partial discharge damage to electrical insulation

- **MECHANICHAL DAMAGE:** Cable system components can be damaged mechanically during handling in the factory, shipment, handling at the warehouse or job site, during installation, movements and vibration during operation. Such damage can involve cuts, scrapes, excessive sidewall force, and possibly the intrusion of water into the strands of the core conductor. In service, damage to the insulation shield or insulation is likely to produce partial discharge and lead to failure. Damage to the jacket may allow water to permeate the space between the jacket and insulation shield and result in corrosion of the metallic shield. Failure to connect the metallic shield properly can also lead to failure. The voltage and current normally carried to ground by the metallic shield may produce leakage current and tracking if not correctly connected or if left unconnected.
- **ELECTRICAL DAMAGE:** Operational damage can occur when the cable system is exposed to severe load cycling, overloads, or short-circuit currents. Load cycling may have a more severe impact on splices and terminations because they may be physically restrained and may therefore experience significant compressive or tensile forces. Such forces may cause components within the splice or termination to shift, resulting in voids or gaps at insulating and semiconducting interfaces which could lead to partial discharge. Overloads and short-circuit currents can have similar or even greater effects.

Trouble-shoot

During operation, there are several causes that can lead to a cable failure:

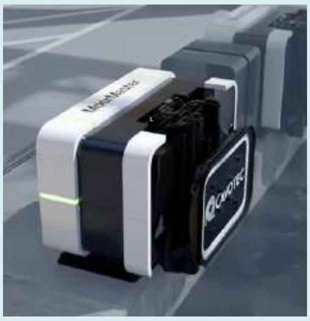
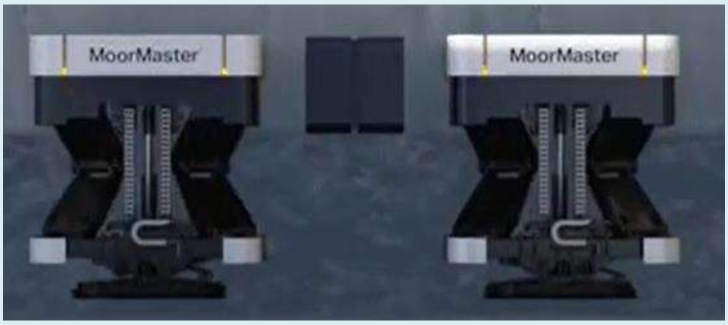
- Damage by third party
- Damage due to brittleness of outer sheath
- Ingress of water in the insulation
- External mechanical stress, thermal stress, improper clamping/mounting
- Improper preparation of joints and terminations
- Movement of cable due to thermal cycling
- Improper laying (installation) of cables, cable damage while cable laying (installation)

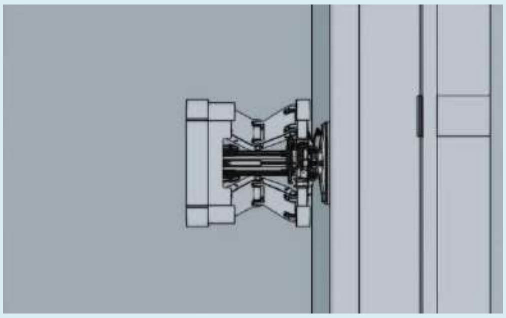
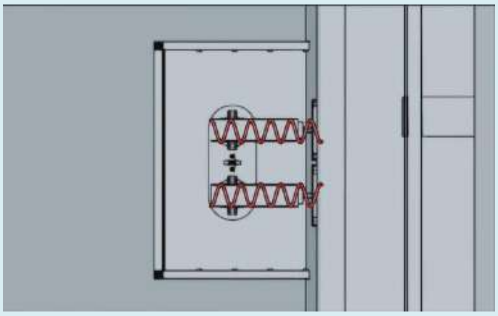
A preventive plan to anticipate a future problem in the cable:

- Regular check of proper earthing and earth connections.
- Check excessive loop at one place to be corrected.
- Dirt accumulation on terminations to be cleaned regularly.
- Check cable corridors that near other utility pipelines or hot spots that might be affecting to those cables.
- Thermograph of high loaded circuits for hot spots.
- Ensure proper support and clamping.
- Regular check of the mechanical loads at the Housing and bolt tightening at the preconnector clamp.
- Look for water leakages around Housing and inside the preconnector.
- Regular check of the cable ancillary systems such as preconnector and protections (all mechanical fitting in place, performance of galvanic protections).

A.3 Shipping Operations

<table>
<tr><th colspan="2">AUTOMATED DOCKING SYSTEM Operation Sheet</th></tr>
<tr><td>FUNCTION</td><td>The docking phase is automatised thanks to an assistant robot capable to radically replace the system of anchoring ships using ropes and chains, particularly impracticable for the present application, then keeping employees safe.</td></tr>
<tr><td>Equipment</td><td>



</td></tr>
<tr><td>Suppliers</td><td>CAVOTEC</td></tr>
</table>

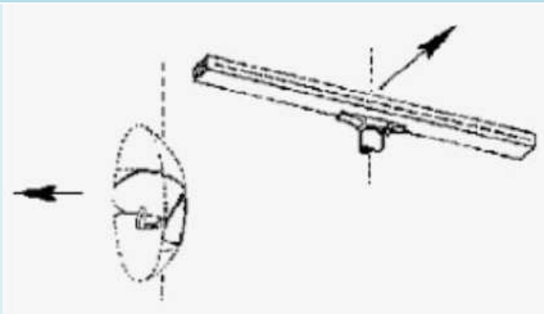
Layout	  
Key technical aspects	MoorMaster eliminates the need for hazardous mooring lines by replacing with automated vacuum pads that moor and release vessels in very short time. Once moored, the service vessel is not required to stay with engines on for seakeeping reasons, as the vessel is physically retained to the moor system, taking also advantage of the favourable downstream conditions provided by the platform. Retaining forces are through the MoorMaster suction cups that hook the ship positioned at a distance of about 5 meters from each other along the entire side of the vessel. Once hooked with this system, the ship can only move vertically following the natural movement of the waves, but remains completely still with respect to the horizontal axis, it does not move with respect to the docking point on the quay.
Key operational aspects	All operations are carried out at Local Control Room operator level and at vessel helm bridge. Data collected from lasers are continuously elaborated to predict the position of the approaching vessel at the following time step. Once the vacuum pad is plugged, the appropriate force is transferred to regulate ship movement in position.
Trouble-shoot	----

ELECTRIC RECHARGE SYSTEM Operation Sheet	
FUNCTION	The Electric Recharge System enables fast and safe connection to and disconnection from electrical power for e-vessels, maximising charging capacity during the time spent by service vessels when moored at the BGF infrastructure.
Equipment	
Suppliers	CAVOTEC
Layout	

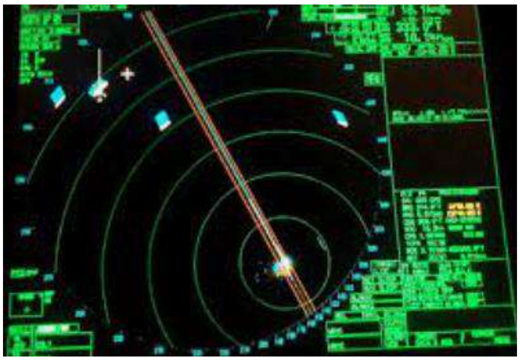
Key technical aspects	The Electric Recharge System selected for the BGF infrastructure, which includes 1.2 MW Charging Tower, presents different advantages, which include: ▪ Safe operations due to automated connection and electrical interlocks. ▪ Limited infrastructure costs. ▪ Minimum modifications required to vessels and berths. ▪ reduces operations and maintenance costs. **<u>Performance requirements</u>** Different aspects are at the base of expected electric recharge time and performance: 1. Charge power. This determines how much energy can be loaded aboard the vessel in a given time, or conversely, how much time is required to transfer a given amount of energy. 2. Operating voltage. The decision is essentially between low-voltage and medium-voltage systems. a. Medium-voltage requires thicker cable and transformer insulation, more careful grounding and ground fault protection measures, insulated busbars and additional design, construction, and testing safeguards. b. Low-voltage systems will require higher amperage to pass the same amount of power. They will therefore require larger copper conductors, busbars and transformer windings leading to added weight. 3. Time to connect and disconnect. As charge duration has a significant effect on performance and costs, connecting quickly upon arrival and disconnecting immediately before departure maximizes charge duration. For the BGF installation, this requirement is important but not stringent as the average time for deploying the service exceeds the recharging time. 4. Range of motion. 5. Dependability (the ability to connect under most foreseeable weather conditions and vessel motions is key). 6. Structural and mechanical robustness (the system requires excellent corrosion resistance, galvanic protection, and minor impact resistance to improve performance and increase service life). 7. Serviceability (accessibility to wearing parts, quick trouble shooting and repair, and intuitive operation are advantageous). 8. Safety (circuit protection must include not just short circuit and overload trip settings but also quick acting and sensitive platform fault trips. In case of medium-voltage connection equipment either on the vessel or pier-side may require supplementary earthing conductors back to power sources and insulating layers between the metal casings of connection equipment and pier-side or vessel metallic structures).
Key operational aspects	The Electric Recharge System is mounted in a Tower, allocated on the BGF infrastructure docking area, which enables the service vessels docking alongside. It is an enclosed tower which features a plug assembly that lowers into a receptacle installed in the side of the vessel.

	As the service vessel approaches the berth, MoorMaster docking system is operated and activated by the Local Control Room operator, in conjunction with a remote-control panel from the vessel. Once the vessel is securely moored, the mooring system automatically signals to the Electric Recharge System unit, which moves on its rails up to the docking platform bord. Once there, a sensor then guides a connector socket onboard the vessel to connect the ship's battery to electrical power to start charging the ship batteries. When the charging sequence is complete, the charging socket disconnects, and the Electric Recharge System unit return to its original position. Once the service vessel operations at the BGF infrastructure are complete, then the MoorMaster™ system releases the vessel allowing it to leave the berth.
Trouble-shoot	----

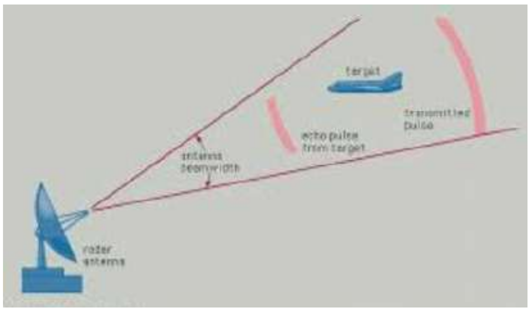
A.4 Surveillance and Security

SURVEILLANCE RADAR SYSTEM Operation Sheet	
FUNCTION	The long-distance radar function includes the following operations: • See long-range targets • Integrate his contributions with those of the long-distance cameras • Improve night vision and in difficult weather conditions.
Equipment	
Suppliers	Leonardo, Furuno, JRC, Decca
Layout	
Key technical aspects	The following indications are to be related to the use of the device: • Review the radar operation manuals and become familiar with its capabilities and constraints. • The radar should always be in use.

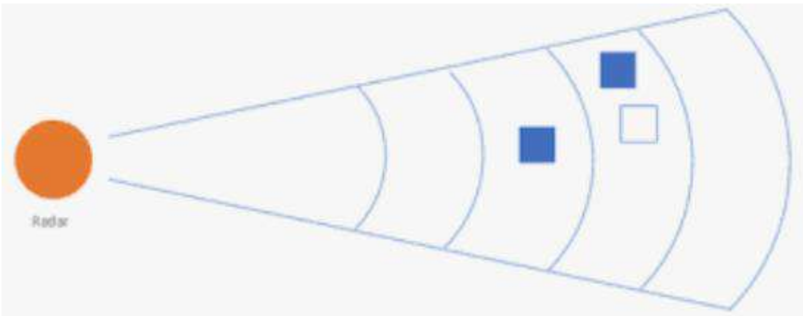
- It is mistaken to think that the working life of the radar can be prolonged by switching it off. Radar is designed for constant use.
- Ensure that the range scale in use is appropriate to the prevailing circumstances and conditions.



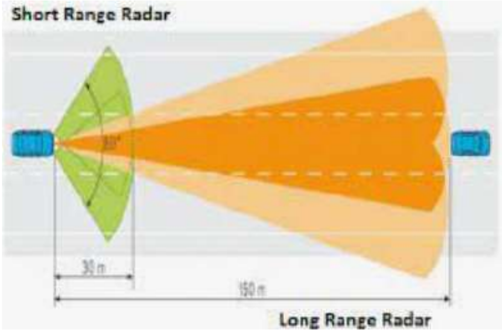
- Use long range scanning periodically to detect targets.



- Check and adjust the brilliance, gain, tune and clutter controls regularly to ensure that they are optimised for the prevailing conditions.



- Ensure that the radar pulse length is optimised for the range scale in use: shorter pulse lengths for lower ranges, longer pulse lengths for higher rangers. Remember that long pulse lengths have poor range discrimination and may cause targets merged if they are close to each other.



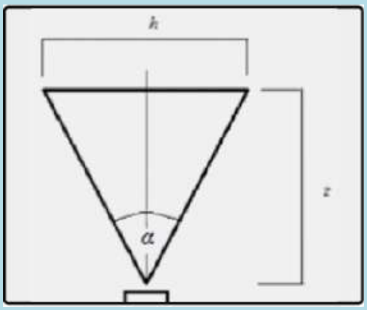
- Adjust the manual clutter controls and use the automatic clutter controls regularly to ensure that targets are not being masked by sea or rain clutter, or by the anti-clutter feature.

- Electronic picture enhancements such as echo averaging, target expansion and interference rejection should be employed. Be familiar with the positive and negative effects that these features may have on the radar picture.
- Use, if it is possible, the performance monitor to check the radar at regular intervals, ideally at least once every day.

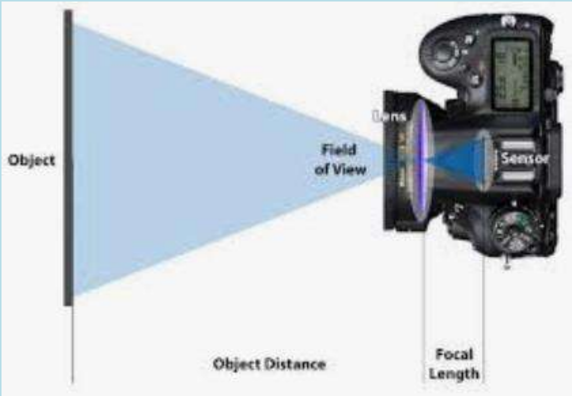
Key operational aspects

- **Choice of range scale**. Appropriate range scales should be used depending on the prevailing circumstances and environmental conditions.
- **Center display**: Own position can be displaced to expand the view field without switching to a large range scale.
- **Target trails**: Target trails can be of great assistance to the radar observer in making an early assessment of the situation. The trail can be relative or true. Relative trail shows relative movement between platform and ship. The true path presents the true movements of the target relative to the ground.
- **Parallel index lines**: This is a useful method of monitoring. It helps to understand the distance between the platform and a ship on a particular route.

	• **Mark**: The "Mark" menu enables to mark any prominent target or a point of particular interest. • **Presentation modes**: Radar users must clearly understand what they are seeing. For this reason, you need to select the best viewing modes.
Trouble-shoot	There are several problems that could affect the radar. Among others we can mention: • **Power problems.** The power cable can be damaged or broken. In this case it is necessary to replace it. • **The radar antenna breaks.** It could happen that, due to the wind, a radar antenna or the whole antenna array breaks down. In this case it is necessary to contact the vendor.  • **The radar antenna breaks.** It could happen that, due to the wind, a radar antenna or the whole antenna array breaks down. In this case it is necessary to contact the vendor. • **The radome breaks**. In this case it is necessary to evaluate a repair with the vendor. 

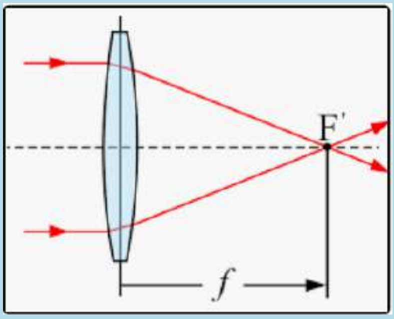
LONG DISTANCE CAMERAS Operation Sheet	
FUNCTION	Long distance camera's function is to enable monitoring capability to integrate surveillance radar information.
Equipment	
Suppliers	Sony, Raymarine, AOBOCAM, DV Tech
Layout	
Key technical aspects	The points to take into consideration to better manage the vision are the following: viewing angle, objective, zoom, focal distance and resolution. • The **viewing angle** determines the space displayed by the video cameras. You can increase or decrease your viewing angle using the video surveillance camera installation options. 

- The **objective** through its size determines the view in the distance. If the target is large, you can see but with a narrow field. Conversely, a smaller target will give a shorter distance but with a greater width.

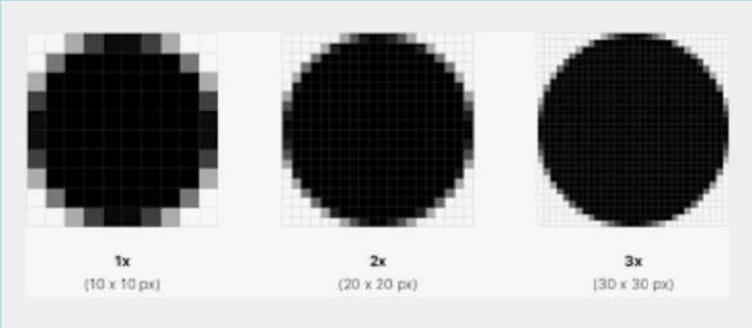


- **Zoom**. In this case, the discussion moves to the magnifying glass. It is important to zoom in without excessively degrading the image quality.

- The **focal distance** indicates the area to be covered. In this case, if the field of vision increases, it decreases. It is measured in mm.



- The **resolution** is closely related to the image clarity. For a superior video quality, a resolution of HD 5 megapixel would be needed, for clear images and corresponding to reality in colours and in contrasts.



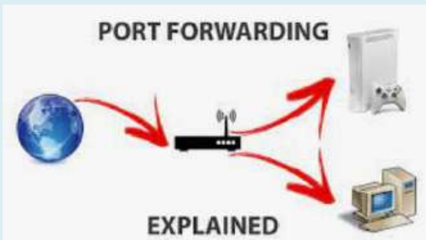
Key operational aspects

Security camera systems are internet connected driven in great part by customer demand for remote video access. The systems range from cloud-managed surveillance systems, traditional DVR/VMS/NVRs connected to the internet and traditional systems connected to a local network which, in turn, is connected to the internet.

With cyber-attacks accelerating, physical security integrators and internal support staff must keep up-to-date on cyber security attack vectors which can impact the camera video management systems they sell and support. These systems require the same level of protection from cyber security vulnerabilities given to traditional IT systems.

Therefore, the following actions are recommended:

- Change the **passwords** of the cameras at least once a month. The ideal best practice is to assign a unique long non-obvious password for each camera. Such a meticulous process takes time to setup, is more difficult to administer and is very hard to track. Therefore, many installers, unfortunately, use a single password for all of the cameras in an account.
- **Port forwarding**. Most end users demand and expect video access from remote mobile devices. This typical exposure to the internet of an HTTP server is extremely dangerous; in fact, there are a large number of malicious exploits that can be used to obtain access. Machines open to the Internet are, typically, scanned more than 10,000 times a day. If it is possible, do not connect your unprotected server to the internet. Also minimize port forwarding.



- **Software update**: Check if the camera software is up to date. At least once a month, perform the manual update.

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Checking the connection: It is imperative that the connection be encrypted with SSL or equivalent.

Video Encryption: In addition to insecure connections, due to lack of encryption, there are the same privacy risks when the video is not encrypted when stored on the disk or in transit.
Video Recording Software: Video Management Software use a lot of components beyond the operating system, such as Microsoft database applications. As with the operating system itself, these components must be upgraded and secure.


</td>
</tr>
<tr>
<td>Trouble-shoot</td>
<td>

Camera has difficulty focusing or images are blurry. Most camera focusing systems require a certain amount of light to work properly and if it is too dark, they will not be able to focus. If the camera does not focus on a dark environment, it is necessary to switch to manual focus.
Parts of the image are too dark or too bright compared to the rest. Exposure compensation is a feature found on all cameras. You can use the exposure compensation feature to quickly tell the camera to make the image brighter or darker.

</td>
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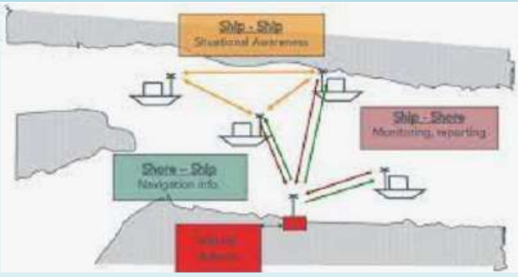
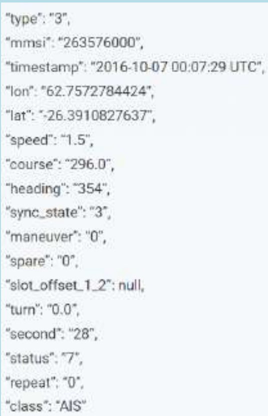
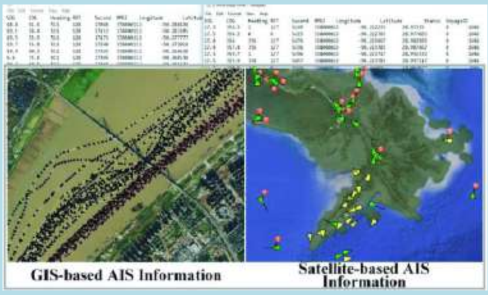
</table>

	• **Camera works badly at night**. Camera is essentially a device which is used to turn available light into recorded information. When there is not much light available, many cameras will struggle to capture enough light information to make a usable image. In this case you need to see the recording settings and change them.

AUTOMATIC IDENTIFICATION SYSTEM (AIS) Operation Sheet	
FUNCTION	AIS is intended to allow maritime authorities to track and monitor vessel movements. It works by integrating a standardized VHF transceiver system with an electronic navigation system. AIS is used in navigation primarily for collision avoidance.
Equipment	
Suppliers	Raymarine
Layout	
Key technical aspects	• **Statistical data**: Constantly check the data in the "Own information" menu. These data cannot be modified without specific authorization. • Check the **update rate** of dynamic information. • Check the menus related to **text messages**. Specifically, check the list of sent messages. "type": "3", "mmsi": "263576000", "timestamp": "2016-10-07 00:07:29 UTC", "lon": "62.7572784424", "lat": "-26.3910827637", "speed": "1.5", "course": "296.0", "heading": "354", "sync_state": "3", "maneuver": "0", "spare": "0", "slot_offset_1_2": null, "turn": "0.0", "second": "28", "status": "7", "repeat": "0", "class": "AIS" • Verification of the configurations of **EMMA** (European Multiservice Meteorological Awareness) messages relating to meteorological situations.

- Enabling messages relating to the height of the water level.
- Check the time difference from **Universal Time Coordinated** (UTC).
- Activate the **reception of AIS data**.

- **"Chart"** menu configuration. Some settings do not apply to all cards. Some options require the connection of accessories, such as a radar.
- **Chart levels**: User can activate chart levels and customize chart functions. Each setting is specific to the chart or chart display used.

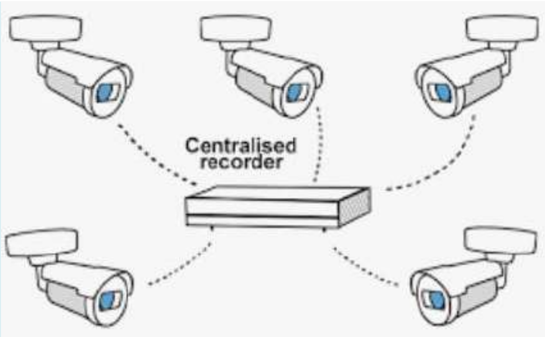


- **Communications with wireless devices**: Chart plotters allow creating a Wi - Fi network to connect wireless devices. The first time the operator accesses the wireless network settings, he/she will be prompted to configure the network.

Select Settings -> Communications -> Wi-Fi Network -> Wi-Fi -> Enabled -> OK.

Key operational aspects	In order to use the device correctly, it is advisable to keep the following parameters under control: • TX power • Data update frequency • MMSI (Maritime Mobile Service Identity)

	• SoG (Speed Over Ground) • Position error • Latitude and longitude • CoG (Course over Ground) • Date / Time of the information • Name of the vessel • Type of ship • Ship size • GPS position • Navigation status • Rotation level and direction • IMO Number • Radio Call Sign • Sea current • Destination name • Estimated time of arrival
Trouble-shoot	**The device is not acquiring GPS signals**. If the device is not acquiring satellite signals, there may be several causes. If the device has moved a lot from where it acquired satellites or has been turned off for several weeks or months, the device may not be able to acquire satellites correctly. • Make sure the device is using the latest software. If not, update the device software. • Make sure your device has a clear view of the sky so that the antenna can receive the GPS signal.  **The device does not turn on.** Devices that do not turn on may indicate a problem with the power supplied to the device. Check these items to try to resolve the cause of the power problem. • Make sure the power source is generating power. You can control this function in several ways. For instance, you can check if other devices powered by the source are working. • Check the fuse in the power cable. Verify that an appropriately sized fuse is installed. Refer to the label on the cable or installation instructions for the exact fuse size required.

SECURITY SYSTEMs Operation Sheet (Security systems)	
FUNCTION	These are cameras of various types to monitor the critical points of the platform. Since these are cameras, it is possible to extend the observations made for long distance cameras.
Equipment	 
Suppliers	Hikvision, Pelco, Sony, Samsung, Bosch, Tiandy.
Layout	
Key technical aspects	See long range camera.
Key operational aspects	See long range camera.
Trouble-shoot	See long range camera.

ACCESS CONTROL SYSTEM Operation Sheet	
FUNCTION	The function of the access control is to allow entry only to authorized people. The list of people must be kept up to date with insertions / removals.
Equipment	
Suppliers	Zucchetti, RS PRO, Elmat, Cisa
Layout	
Key technical aspects	The system mainly consists of two important components: badges and readers. Badges are the same for all employees and contain a photo of the person. They also have an electromagnetic value that allows access. Therefore, they must not be kept near other sources of electromagnetic fields; in fact they could demagnetize. Each employee of the platform has their own personal badge. Access to the rooms is allowed on the basis of the work to be carried out. The badge has the dimensions of a credit card compliant with ISO / IEC 7810 in the ID-1 format and can be equipped with microcontrollers, RFID or EEPROM memories, for use with computer and electronic equipment. Badges may contain personal information, photographs and useful information for the purpose for which they are used. For example, the job title, access privileges or department of responsibility might be indicated. Inside them, on suitable supports, information such as password, clinical situation, employee code, etc. can also be stored. The badges must be displayed to the public using suitable accessories (clips, rigid or flexible displays, ribbons, etc.) or kept in a pocket protected by a rigid or flexible case. 

The other important device is the badge readers. They are connected, through the network, to a server which verifies whether an employee can access the room in question. The general technical characteristics are:

- Stamping storage capacity
- Controllable sites
- Controllable areas
- Controllable zones
- Managed access profiles
- Terminals configurable according to the characteristics of the server
- Types of time controls
- Graphic configuration of areas and terminals
- Automatic or non-automatic terminal diagnostics.

The technical characteristics of the communication are:

- Communication protocol in "https" between central server and terminals.
- Ability to authenticate users based on LDAP / Active Directory.
- Periodic data backup on a second hard disk and / or external magnetic support using a manual procedure.

Key operational aspects	**Sharing and Reviewing Everything** The people operating, responding and maintaining the system, need to understand the plan to address the various functional requirements. Understanding how the system operates and design acceptance is important for all stakeholders. Management needs to be kept informed to be sure they understand the costs and benefits of the system and how it will solve the functional requirements. This will minimize changes to the design, saving potential extra expenditures during the design and installation phases. **Get Management and Employees Involved and Trained** Management and employees must be involved in the card/badge process. If the card has a picture and other data, management needs to approve the layout, colors and design, and the information that appears on the card. Employees need to be involved to ensure acceptance of the card's appearance and end-functionality. With a proximity or contactless smart card, the distance will vary by the antenna (inside the reader itself) and surrounding interference. **Plan for Growth** The various site security managers should be able to allow access based on each employee's specific needs. These concerns — along with replacing lost cards, card lifetime, employees leaving the company, etc. — should be addressed in a "card manufacturing process and distribution" document. These problems with replacing lost cards, card lifetime, employees leaving the company, etc. should be addressed in a specific document. One way to plan for additional readers is to incorporate a few spare items into the initial installation. Additional space for card input boards and card readers could also be added to the original project scope. A spare inventory of readers and card input boards will help address immediate repair and expansion issues. **Periodic checks** Even after installation, it is critical that any issues that come up are addressed swiftly and with a system-wide solution. An electronic access control equipment failure or card reader issues must be addressed as a top priority. The security staff should be alert and report any issues to their security manager to improve the system operation.
Trouble-shoot	When none is able to successfully log into the platform then there is, probably, a hardware problem. When, on the other hand, there are people working and only some groups have access control problems, it could be a functional problem. **Checking the cables** If the terminal has just been installed and does not communicate, it could be with the ethernet cable that connects the terminal with the router. If, on the other hand, the reader suddenly stops communicating with the server, then it is necessary to check that the cable connecting the terminal to the router has not been inadvertently disconnected. **Firewall and antivirus**

	Firewalls and antivirus must allow free communication of terminals on the network. Therefore, make sure that the IP address of the terminal is enabled for communication and that it is not blocked by particular firewall or antivirus settings. **Streaming Video** Video streaming and any programs that allow strong interactivity with the internet could negatively affect the performance of the network and consequently also the performance of the badge reader. **IP address conflict** Make sure that if the terminal has a fixed IP address this does not conflict with other devices on the same network.

A5. Structural Health Monitoring System

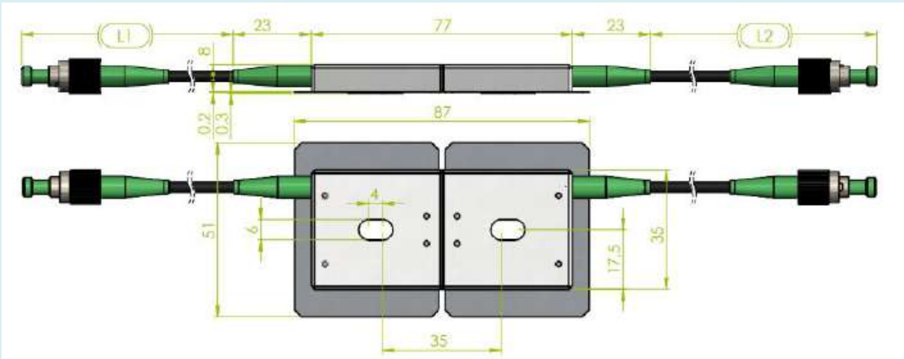
STRUCTURAL HEALTH MONITORING SYSTEM Operation Sheet

FUNCTION

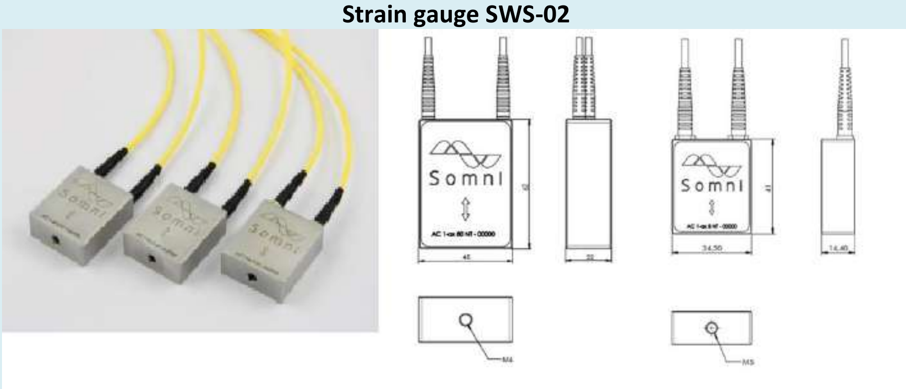
The Structural Health Monitoring (SHM) system is crucial to ensure the proper functioning of structures and infrastructures. SHM allows to perform the maintenance of the BGF infrastructures when it is necessary (discovering as early as possible a potential degradation) and not following a schedule. The SHM system installed at critical areas of the platform enables a continuous monitoring of structural deformation leading to a better knowledge of environmental loading history experienced through the entire life.

Equipment

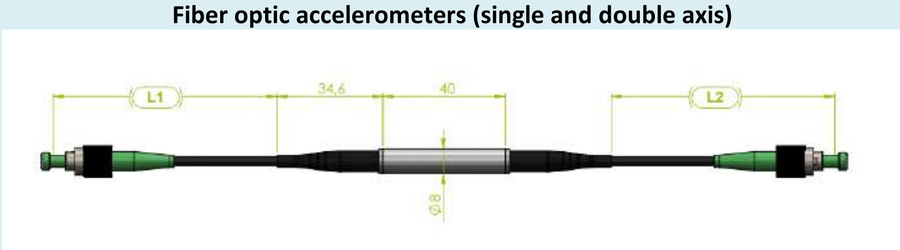
Fiber Optic Sensing (FOS) solution and, in particular, Fiber Bragg Grating (FBG) sensors, has been selected for the SHM system of the Blue Growth Farm. The Structural Health Monitoring (SHM) system is composed by different kind of sensors, as strain sensors, accelerometers, inclinometers and temperature sensors.



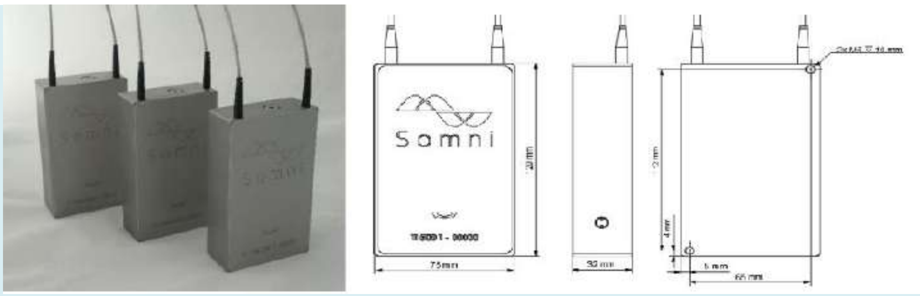
Strain gauge SWS-02

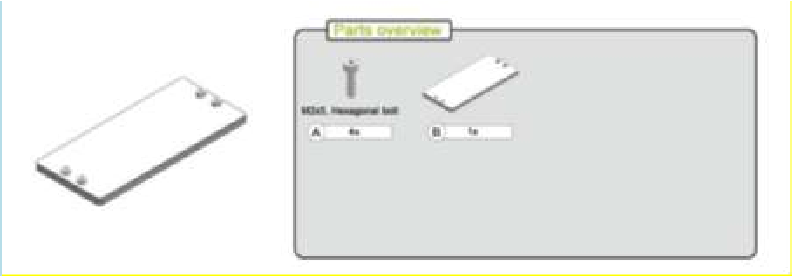


Fiber optic accelerometers (single and double axis)



Temperature sensors

	 **Inclinometers**
Suppliers	Sylex fiber optic, Somni Solutions, LUNA inc.
Layout	----
Key technical aspects	**OPTICAL STRAIN GAUGE SWS-02 INSTALLATION PROCEDURE** The document is focused on the spot-welding method which is the primary and recommended method for achieving a long-term stable bond between the monitored structure and the SWS-02 sensor. Other installation possibilities are mentioned in the last chapter. **Installation requirements** **Instruments & Tools** ▪ Standard spot-welding machine for 0.2mm stainless steel plates. Typically, this works well with regular spot welders used for electrical gauges. ▪ FBG interrogator. ▪ PST-02 Pre-strain set up tool for SWS-02 sensor. **Installation time** Typical spot-welded installation time of SWS-02 sensor: **between 5-10min** (surface preparation not taken into account). **Installation sequence** This sequence is described in the next chapters in more detail. Time indicates estimated time efforts. 1. Removing transportation protection from the sensor [1 minute] 2. Mounting of PST-02 and setting up the desired pre-strain [2 minutes] 3. Surface preparation for spot welding [5 minutes] 4. Spot welding of the sensor to the surface [5 minutes] 5. Removing PST-02 from the sensor [2 minutes] **(1) Removing transportation protection from the sensor** SWS-02 comes with a preinstalled Transportation fixture – this is to protect the sensor during transportation and initial manipulation. This transportation fixture needs to be removed from the sensor before installation. Remove the screws and top plate from SWS-02 as shown in Figure 1– follow the alphabetical order of all parts as listed. All tools are included inside the PST-02 package.



Parts overview of the Transportation fixture

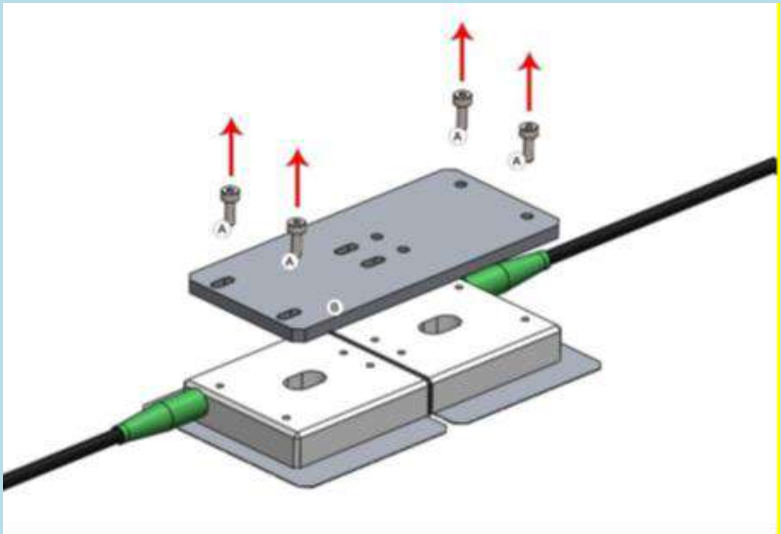


Figure 1 Removing the Transportation fixture

If you are not installing the sensor, it is recommended to mount the transportation fixture back on the sensor.

(2) Mounting of PST-02 and setting up the desired pre-strain

SWS-02 comes with very small pre-strain not applicable for compression measurement therefore it is necessary to adjust the pre-strain on the SWS-02 before installation. For this purpose, the PST-02 pre-strain setup tool is used. It allows setting the desired pre-strain level to the sensor just before the direct installation of the sensor to the surface and it also keeps the defined pre-strain during installation. After installation, the PST-02 is removed from the sensor and can be used for another SWS-02 installation.

PST-02 provides safely pre-straining the SWS-02 sensor up to 4000με.

Mounting the PST-02 to the SWS-02 sensor

Mount the PST-02 on the SWS-02 sensor as shown in Figure 3– follow the alphabetical order of all parts listed in “Parts overview” (Figure 2). All tools are included inside the PST-02 package.

Applying pre-strain to the SWS-02

To apply pre-strain, connect the sensor to an interrogation unit and focus on the higher wavelength. In a standard case, the higher wavelength for strain measurement and the lower for temperature compensation. Use the knob on the top of the PST-02 (Figure 3) and rotate it clockwise to increase the pre-strain[6] and anti-clockwise to reduce it.

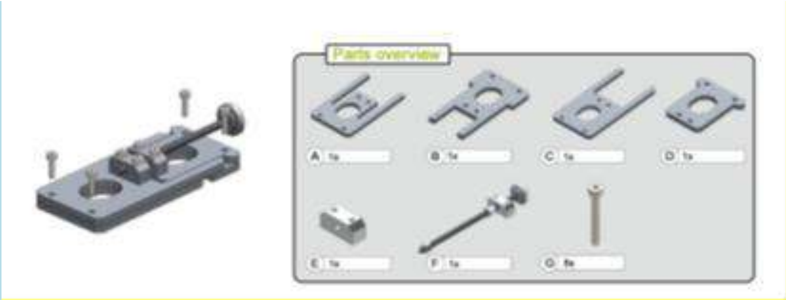


Figure 2. Parts overview of the PST-02

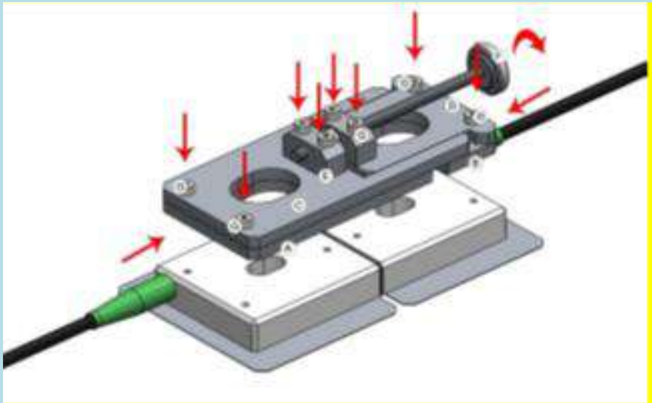


Figure 3. Assembling/Disassembling of the PST-02

(3) Surface preparation for spot welding

Regardless of the installation method, it is advisable and, in some cases, even necessary to properly treat the surface of SWS-02 and the surface to which the sensor should be applied. This process includes mechanical cleaning of the surface using abrasive materials and removing any paint, rust, debris, or similar imperfection from the surface.

Chemical treatment of the surface is advised 20min before the installation to avoid of creation of oxide layers on the mechanical treated surface.

Recommended cleaning solvents (not included inside the packaging):

- Loctite 7061
- Loctite 7063

(4) Spot welding of the sensor to the surface

Primary and recommended installation method for SWS-02 is spot-welding. The SWS-02 is surrounded by a 0.2mm metal sheet (base) allowing to spot-weld the sensor to the monitored structure. The base is made from a 0.2mm thick SS304 material and allows the usage of common spot-welding tools.

The necessary spot-welding area of the sensor is shown in Figure 4 in green color. Follow the number order of spot welds as shown in Figure 3. One side can typically contain 10-12 spot welds as a minimum, so around 20-24 spot welds for both green areas together.

Additional spot-welds are recommended in red areas to ensure the sensor is securely mated over its entire length with measured object. You can apply 2-3 spot welds per red section, so additional 8-12 spot welds for all red areas together.

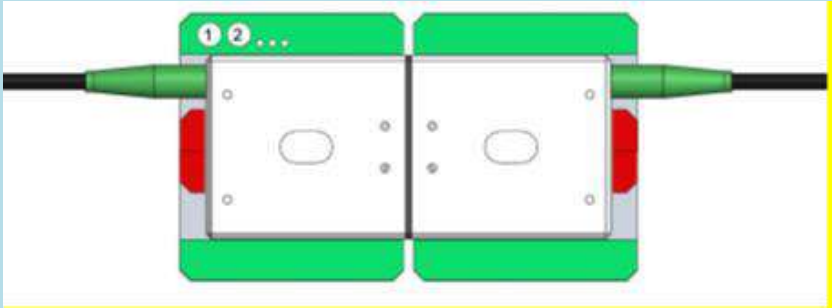


Figure 4. Recommended area of spot-weld

5) Removing PST-02 from the sensor
Dismount the PST-02 from the SWS-02 sensor – follow the reversed alphabetical order of all parts listed in "Parts overview" (Figure 2). All tools are included inside the PST-02 package. After installation, it is recommended to verify the actual WL of the sensor with the interrogator. Small wavelength shifts that can occur during spot welding and PST-02 removal processes shouldn't exceed ±50pm.

Other possible installation methods
While the spot welding is the recommended installation method, other methods can be applied to secure the sensor on the surface of the measured object.

Mechanical installation (screwing)
Mechanical installation is based on using two standard M6 metric screws (one at each side). These screws are not supplied with the sensor. This method could be applicable i.e., to concrete, walls or even metal structures if spot welding is not allowed.

The anchoring distance is 105 +/- 6mm. This has to be respected during drilling the holes.

Set-up the sensor ready and pre-strained before screwing it to the surface. Screws are then fastened on both sides of the SWS-02 sensor. Then the PST-02 can be removed.

After the installation, it is recommended to verify the actual WL of the sensor with the interrogator. Small wavelength shifts that can occur during screwing and PST-02 removal processes shouldn't exceed ±150pm.

1) Suitable thread adhesive or secure washers can always improve the stability of this installation method.

Chemical installation (glue bonding)
Chemical installation is based on using an adhesive that bonds the sensor with the measured surface. The glue is not supplied with the sensor.

The selection of the right glue highly depends on the material of the surface and environmental conditions. Special curing procedures such as elevated temperature, pressure or air humidity can be required by using such adhesives.

Set-up the sensor ready and pre-strained before bonding it to the surface. The glue can only be applied to the metal areas of the SWS-02 and avoid the bonding of the none-metal areas.

After curing the adhesive, the PST-02 can be removed as described in this section. It is then recommended to verify the actual WL of the sensor with the interrogator. Small wavelength shifts that can occur during bonding and PST-02 removal processes shouldn't exceed ±150pm.

FIBER OPTIC ACCELEROMETER MOUNTING INSTRUCTIONS

General purpose Fiber Bragg Grating based accelerometer. The dual ended accelerometer is optimized to have a high sensitivity combined with a large measurement bandwidth. The stainless-steel sensor design is ruggedized and robust such that it can be used in a wide variety of indoor and outdoor applications.

This kind of sensors are available as 1, 2 and 3 axis accelerometer.

For the accelerometers with 2 or 3 axis it is recommended to fasten the sensor on a flat surface using a **M6** bolt as indicated in the Figure 5. Maximum torque to apply is **8 Nm**.

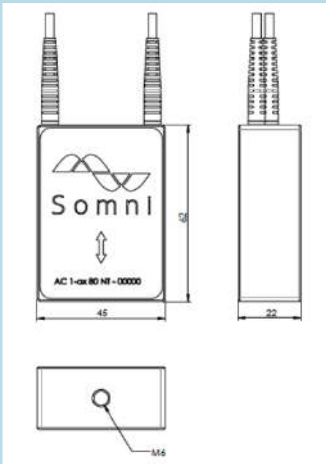


Figure 5. Fiber optic accelerometer

While for the fiber optic single axis accelerometer it is recommended to fasten the sensor on a flat surface using a **M5** bolt as indicated in the figure below. Maximum torque to apply is **5 Nm**.

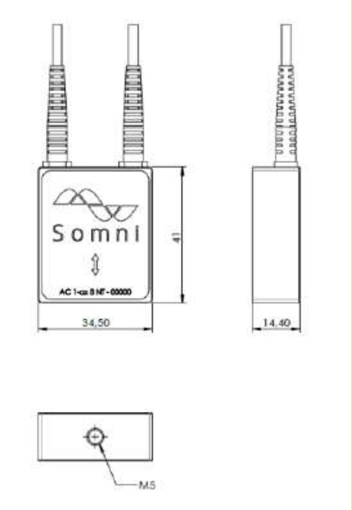


Figure 6. fiber optic single axis accelerometer

TEMPERATURE SENSORS INSTALLATION

The temperature sensors can be mounted on the desired surface or embedded into nearly any structure. These sensors can be connected in a serial configuration with any other sensor.

- Surface-mountable or embeddable into different structures
- Double ended
- Van be used for temperature compensation of other sensors

DATALOGGER INSTALLATION

The Data Acquisition Unit (DAU) employed in that SHM system is the *HYPERION Optical Sensing Instrument - si155* . In the following the installation guide.

Necessary equipment

- Micron Optics HYPERION Optical Sensing Interrogator
- Power Supply
- AC Line Cord
- Ethernet Crossover cable
- Windows 7 or Windows 10 PC
- An LC/APC connectorized 0.25 nm FBG sensor
- Ethernet cable (used when NOT directly connecting interrogator to PC)

Getting started

1. Download and install ENLIGHT from the product page: http://www.micronoptics.com/product/optical-sensingsinstrument-si155
2. Power the HYPERION Optical Sensing Interrogator by connecting the power supply and the AC line cord to the instrument. Toggle the power switch until the red LED illuminates. The instrument is booted and ready when the green LED is illuminated.
3. Connect your LC/APC connectorized 0.25 nm FBG to channel #1 of the HYPERION Optical Sensing Interrogator.
4. Connect your HYPERION Optical Sensing Interrogator to your Windows PC (2 ways):
   a. Direct Connection
      i. Configure your PC's Ethernet NIC to a static IP address of 10.0.0.2, Subnet Mask of 255.255.255.0, and Default Gateway of 10.0.0.1.

	ii. Ensure the HYPERION Optical Sensing Interrogator is set to the static IP address 10.0.0.55. Press the front panel CTRL button until the IP address is displayed. If the IP address screen does display "10.0.0.55 (S)", press the CTRL button for 15 seconds to reset the IP address. b. Network Connection (via network switch or router) i. Connect the HYPERION Optical Sensing Interrogator to the same network as your PC via an Ethernet cable ii. Ensure the HYPERION Optical Sensing Interrogator is set to acquire a dynamic IP address. Press the front panel CTRL button until the IP address is displayed. If the IP address does not end in a "(D)", press the CTRL button for 5 seconds to enable a dynamic IP address. 5. Open ENLIGHT. 6. Select "HYPERION" in the Swept Laser Core drop down menu. 7. Enter in the IP address displayed on the LCD screen of the instrument. 8. Clock OK 9. Start making measurements
Key operational aspects	**SENSORS PROTECTION** When installing a strain sensor, it is important to consider how to insulate and physically protect the sensor in order to improve the accuracy and longevity of the sensor. There are many ways to insulate and protect a sensor depending on the particular installation. One method that may be applicable is detailed here. This method utilizes expanded polystyrene (EPS) foam insulation and a stainless-steel cover shown in Figure 6. This method may not be applicable to all installations due to size or other considerations; however, the general principles demonstrated here can be adapted for the particular installation. Figure 6 also shows a Non-metallic conduit and fitting.  **Figure 6. Expanded polystyrene (EPS) foam insulation and a stainless-steel cove** Figure 7 shows how EPS foam insulation can be used inside the cover. The insulation is designed to thermally insulate the sensor from the effects of wind and sun exposure. Notice the "stepped" interior of the foam insulator. The insulation is designed so that the fiber can be spliced, and excess fiber coiled and stored above the sensor.

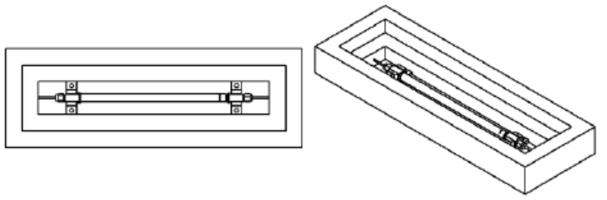


Figure 7. EPS inside the cover

The foam insulation can be cut with a knife as needed to provide fiber access. The EPS foam insulation can be attached to a variety of surface materials using a silicone sealant (such as 3M Super Silicone Sealant, Part No. 08663), or another compatible adhesive. Complete the insulation assembly by attaching an EPS foam cover to the base using silicone sealant or other compatible adhesive. The completed foam insulation is shown in Figure 8.

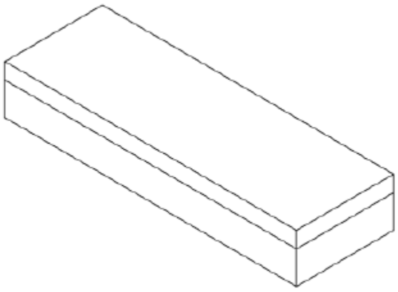


Figure 8. Completed foam insulation

RECOMMENDED GRATING INSTALLATION PROCEDURE FOR TEMPERATURE COMPENSATION SENSORS

A temperature compensation sensor may be attached to a variety of surfaces using screws, spot welding, or epoxy bonding. For all mounting methods, the mounting surface should be clean and flat. If the mounting surface is not smooth and flat, stress may be applied to the sensor frame during the mounting process negatively impacting sensor performance. Surface preparation and cleaning is especially important when epoxy is used to mount the sensor.

In many applications additional protection may be needed to protect the sensor and fiber from the weather and physical damage.

MATING OF FIBER OPTIC CONNECTOR INTO THE ADAPTER

There are situations where the fiber optic connectors need to be mated together via an adapter or to be mated (plugged) into an adapter on a front end of the device (like interrogator, switch, or splitter). Before each such mating, the connectors and adapters need to be cleaned as described in § 4.2.5.2 e § 4.2.5.3. The mating types are:

- Two sensors together → connector to connector via adapter.
- Two patchcords together → connector to connector via adapter.
- Sensor with access cable (pathcord) together → connector to connector via adapter.
- Two cables with WCP-01 (Watertight connector protection) which can appear in any of abovementioned the configurations → connector to connector via adapter.
- Cable with device (i.e., interrogator, etc) → connector into the adapter.

Once connectors are cleaned it is possible to mate them into an appropriate fiber optic adapter.

Below the description of the mating of an FC/APC connector inside the S-line switch although this procedure applies to all above mentioned mating types.

Both the connector and the adapter have an align key which directs the connector into the only right direction. Rotate the connector in your fingers to find the alignment key, insert it into the optical port adapter following the key and screw the threaded body until it is completely screwed.

When removing the connector, always put on the dust cap on both connector and adapter.

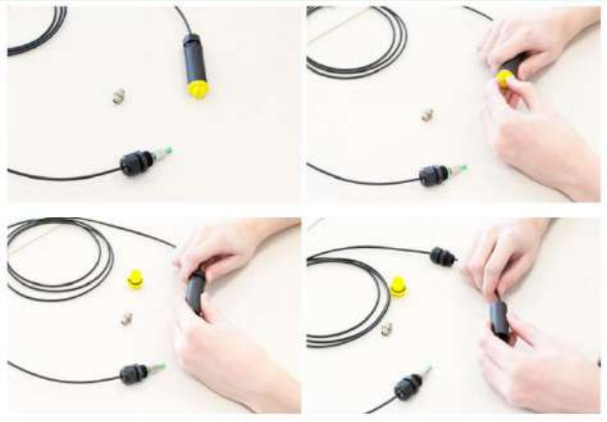
MATING OF TWO WCP-01 PROTECTED CONNECTORS TOGETHER

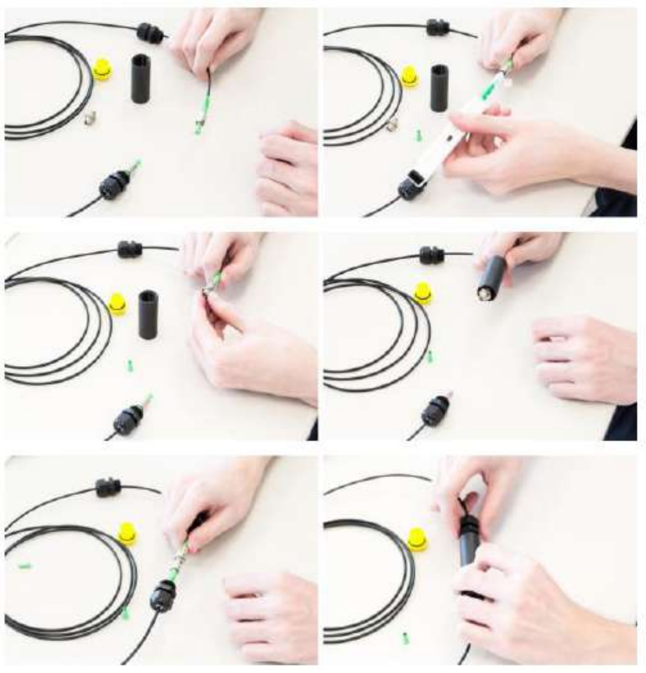
The WCP-01 Watertight connector protection is an optional item protecting the free end connectors or connector connections against dust and water during transportation and installation. The WCP-01 has to be ordered before manufacturing of sensors or access cables (patchcords), it cannot be mounted on the connector afterwards.

WCP-01 consists of three parts: cable gland, protective tube and a protective cap.

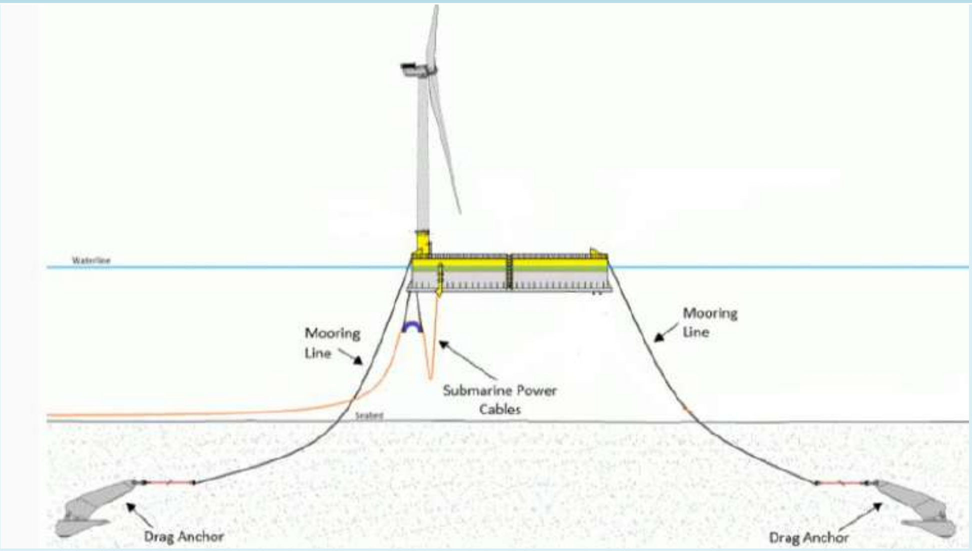
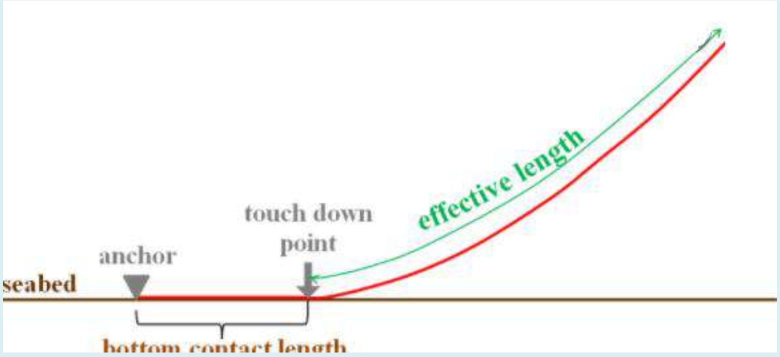
Steps: Remove the protective cap together with the protective tube from both cables. Untighten the cable gland on both cables and slide them slightly away from the connector. Clean first connector as described in the Connector cleaning procedure and mate it inside an adapter. Move the cable gland back in its original position covering partly the connector and tighten it around the cable next to the connector. Slide the protective tube over the second connector and screw it to the cable gland (this cable gland is still freely movable over the cable). Clean the second connector and mate it inside the adapter against the first connector, follow the steps in the Connector cleaning procedure guide. After the connectors are mated inside the adapter, slide the protective tube with the cable gland to the first connector and tighten the protective tube against the first gland and afterwards tighten the cable gland on the second connector.

The steps are shown in the following figure.



	 **FIRST USE/ CHECK AFTER LONG DOWNTIME** At the first use or after long downtimes several checks are required in order to ensure the system proper operating. They include: i. power supply wire installation from general panel to SHM panel ii. ethernet wire installation from general panel to SHM panel iii. power outlet installation in the SHM panel iv. UPS connection to power outlet v. SHM computer and acquisition system connection to UPS vi. Optical strain gauge series connection vii. Connect strain sensors, accelerometers, inclinometers to acquisition system viii. On-the-spot verification of the acquisition system ix. Remote check of the acquisition system ensured by ethernet wire
Trouble-shoot	---

A6. Mooring System

MOORING SYSTEM Operation Sheet	
FUNCTION	The mooring system is a key element of these floating structures. Moorings can significantly affect rigid body motions and, in turn, the performance of a floating system and are solely responsible for station-keeping during extreme weather events.
Equipment	 
Suppliers	Delmar Systems, Offspring International, MacGregor, Sotra Anchors & Chains, Anchor Industries; Dawson Group, Hilifting, Hi-SEA
Layout	 

Key technical aspects	**Installation** Installation methodologies for catenary based mooring system are commonly divided into two phases. First, the mooring lines are pre-installed before the hook-up of the floater. Anchors are also installed in the seabed during this phase. Usually, it is possible to install one mooring line every 8 hours. Once the anchoring points are installed in the seabed it is possible to hook up the platform fairlead to each anchor, leaving the mooring lines wet stored in tension on seabed. Installation and maintenance detailed procedure are implemented once mooring layout is fully defined. This insight is required to accurately assess the necessary information and instructions to perform these activities in a safe way. Reference standards are listed in the following table:

Title	Reference
API, Design and Analysis of Station keeping Systems for Floating Structures	API RP 2SK
DNV, Sea transport operations	DNV-OS-H202
Noble Denton marine services - certification for towing vessel approvability	DNVGL–SE-0122
Marine Operations and Marine Warranty	DNVGL-ST-N001
DNV, Position mooring	DNVGL-OS-E301
Classification of mooring systems for permanent offshore units	BV-NR493
Offshore mooring chain	DNVGL-OS-E302

Generally speaking, mooring installation requires three different vessels: anchor handling tug supply vessel, observation class remote operated vehicle and guard vessel.

Anchor Handling Tug Supply Vessels are used to install mooring lines and anchoring. These vessels are selected mainly evaluating bollard pull, brake horsepower, clear deck space and winch line pull. These vessels incorporate the required electronics navigation tools and specific dynamic positioning system, acoustic devices as well as survey spread to locate mooring and anchoring in accurate positions, monitor vessels on site and provide survey report.

Observation Class Remote Operated Vehicles are used for visual inspection and light intervention tasks during the operation. They are equipped with electronic, mechanics and control systems to implement specific tasks.

Guard vessel is mobilised on site during operation in order to ensure safe and efficient operations and to prevent and alert in such a way that no vessels enter the installation zone.

Key operational aspects	**As-built inspection** The as-built survey is normally planned to verify that the completed installation work meets the specific requirements and to assess for the first the mooring conditions. The survey is primarily conducted to confirm that the anchor legs are connected as designed,

to check for damages that occurred during installation, and to ensure that the twist in the anchor legs is within the design margins. Most as-built surveys are conducted mostly by video-capable ROVs from anchor to fairlead.

General visual inspection

General visual inspection (GVI) is the most common inspection method for mooring lines by carrying out a continuous slow ROV flight. The scope of a general visual inspection is to assess:

- Damage to the structure and components such as dents and deformation(s)
- General wear on the chain links
- Presence of corrosion and or pitting
- Missing or loose parts
- Distorted elements

Detailed Visual Inspections (DVI)

Detailed inspections of critical areas underwater can be done with e.g., scanning methods. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens, endoscope and fibre optic may be used to assist testing. Marine growth often makes it difficult to perform a detailed inspection and preparatory work might be required. The scope of a detailed visual inspection is to assess:

- Material degradation
- Condition of issues from previous periodical inspections
- Connectors, anchors and chain stoppers
- Corrosion
- Pitting
- Cracks
- Indication for weld defect

Critical areas for which more detailed inspections may be beneficial are the fairlead region, the splash zone, the seabed touchdown area, the connectors and the rope terminations. Another area where failures are likely are parts of the mooring line where weight discontinuities occur leading to additional bending and wear.

Planned periodic inspections suggested by Regulatory Bodies
The various regulatory requirements suggest different procedures for the periodic inspections to the mooring main components.

<u>NK Class</u>
Intermediate surveys

- Mooring line stoppers
- Tensioning equipment
- Measurement of mooring line departure angles to check if the line tensions remain within the permitted limits. Other verification methods may also be applied.
- Mooring line above water to identify wear and tear
- Mooring components above water to identify wear and tear
- Turret mooring system bearings if applicable (including the lubricating system)

	− Check of abnormalities in the operation of the mooring equipment (winches, windlasses etc.) *Special surveys* − Connecting points to the platform and the anchor (remove marine growth in advance) − Mooring lines and tendons in their complete length including all connections − Detailed inspection of areas where high corrosion and wear is to be expected (seabed, splash zone) − NDT of chain and chain stoppers above sea level (remove marine growth before testing) − Examination of turrets and related equipment and measurement of thickness due to corrosion − MEP at representative locations in the mooring line − Check of abnormalities in the operation of the mooring equipment Occasional inspections are to be executed in case of loads acting on the structure exceeding the design assumptions and the results have to be reported to the classification society. If essential parts of the substructure are damaged, the operator needs to apply for an occasional survey. DNVGL Det Norske Veritas foresees the time interval for periodic inspections be five years, if the Design Fatigue Factor (DFF) is applied. The interval for periodic inspections can be increased if the DFF is modified according to DNV requirements. BV Bureau Veritas requires the determination of inspection intervals on a case-to-case basis. However, it is recommending a 5-year inspection interval. **Mooring monitoring systems** Monitoring systems may indicate mooring line failures in real time or at least on short term, whereas inspections will only detect mooring line failures on pre-set inspection intervals or after major events. Monitoring systems enable collection of data on fatigue damage (and remaining structural lifetime), extreme loads as well as on specific issues like chain bending characteristics around fairleads and chain stoppers. Monitoring of mooring lines improves reliability and optimizing operation and maintenance of floating support structures leading to reduced costs. Among the commercially available sensing systems, a cheap solution to detect the abnormal changes of the offset of the floating substructure thus possibly indicating the failure of a mooring line is represented by the GPS/ Differential Global Positioning System (DGPS). This solution is proven offshore technology when combined with knowledge of environment and mooring system behaviour. Any anomaly detected can anyway provide indications for a local inspection.
Trouble-shoot	-----

Annex C. Maintenance procedures (BGF Infrastructure Production)

A.1 Aquaculture Production

1. Fish Net System Maintenance sheet
2. Fish Net Cleaning System Maintenance sheet
3. Fish Feeding Maintenance sheet
4. Dead Fish Collecting and Treating System Maintenance sheet

A.2 Energy Production

1. Wind Turbine System Maintenance sheet
2. WEC System Maintenance sheet
3. PV System Maintenance sheet

A.3 Oxygen Production

1. Oxygen System Maintenance sheet

A.4 Microalgae Production

1. Microalgae System Maintenance sheet

A5. Sea Water Desalination Production

1. Reverse Osmosis Maintenance sheet

A.1 Aquaculture production

FISH NET SYSTEM Maintenance Sheet	
FUNCTION	Having the nets system serviced is crucial for maintaining a safest possible fish production. To ensure an optimal service life, it is important that it is checked regularly during the infrastructure life. Furthermore, despite the net system is designed so that the ropes' structure absorbs expected loads, there are some factors to be considered in the risk assessment: ▪ extreme weather conditions or strong currents beyond the BGF platform protection volume; ▪ potential contact between the net and the platform, which may lead to wear and tear; ▪ incorrect placement of attachment loops; ▪ insufficient maintenance of attachments consequent to tearing ▪ insufficient removal of dead fish, which may cause predators to make holes in the netting in an attempt to get to the dead fish; ▪ insufficient net cleaning resulting to overloads. Adequate training of net staff who handle the nets and are responsible for the day-to-day monitoring will in many cases minimise the risk of accidents involving fish escaping.
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised equipment service supply companies.
Layout	Refer to the associated Operation sheet.
Key technical aspects	**Routine Inspections**

CHECKLIST ITEM	INSPECTION
ATTACHING OF THE NET	Check that all attachment loops are firmly attached to the interface supports to the platform, and that there are no abrasions or fraying damage to the visible part of the attaching rope.
TOP LOOP	Check that the loop is intact and does not appear to be under strain. Strain on the top loop can be a sign that the attachment loop has been attached incorrectly.
TOP ROPE, MAIN ROPE, SIDE ROPE (VISIBLE SECTION)	Check that the rope does not have any breakage, crushing damage or other signs of being exposed to abrasion. Check that there is no fraying and no holes in the netting near the ropes.
JUMP NET AND VISIBLE SECTION OF NETTING UNDER MAIN ROPE	Check that there are no holes or obvious fraying. Pay special attention to the area around the attachment points. Check that the jump net is correctly positioned against the railing and is not exposed to an abnormally heavy load.
ADDITIONAL EQUIPMENT	Check that all additional equipment installed in or around the net is attached in a manner that cannot damage the net.
OTHER TYPES OF FISH INSIDE THE NET	If you see other species of fish inside the net, this indicates that there may be a hole in the netting. If this occurs, a proper inspection by ROV is required to inspect the sides and bottom of the netting. Dolphins patrolling cages is a clear signal of net damage.

Special Inspections

Net inspection by ROV at least once every three months is part of the inspection procedures. After installation, the nets are be inspected before adding fish. The same after the net replacement, or when making changes to ropes, or after completing procedures such as delousing. Generally speaking, anytime there is any suspicion that something may be wrong with the net or associated components.

CHECKLIST ITEM	INSPECTION
SIDE ROPE, BOTTOM ROPE, CROSS ROPE, WAIST ROPE	Check that the ropes are not damaged or showing other signs of having been exposed to abrasion in critical places such as around the stretching system, dead fish collector and attachment points.
SPECIFIC AREAS OF THE NET	Pay special attention to the areas around the attachment points and dead fish collector. If you observe any “clean” sections on a net that is otherwise covered in marine growth, this could indicate that the net has come into contact with something. These areas must be closely inspected.
SINGLE WEIGHTS	Must hang so that they are well below the net and not in direct contact with the netting. Distance between net and weight should be equal to significant wave height.
CENTRE BOTTOM	Check that all components in the bottom centre are intact.

Each net is to be logged by its proper label, firmly sewed to the upper side and reporting an indelible code. All inspections and maintenance of a net must be logged. The log must at a minimum describe:

- Net label code
- The action completed (type of inspection, cleaning, maintenance or repair), with reference to a plan and procedure
- The result of the action taken
- The necessary follow-up as a conclusion to the action taken
- Date
- Person/facility responsible
- Signature

Key operational aspects

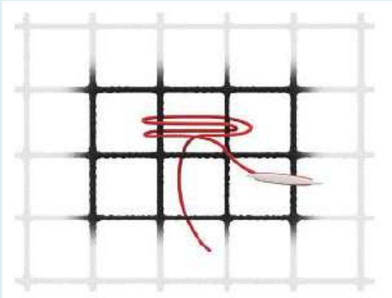
Temporary repair to prevent fish escape

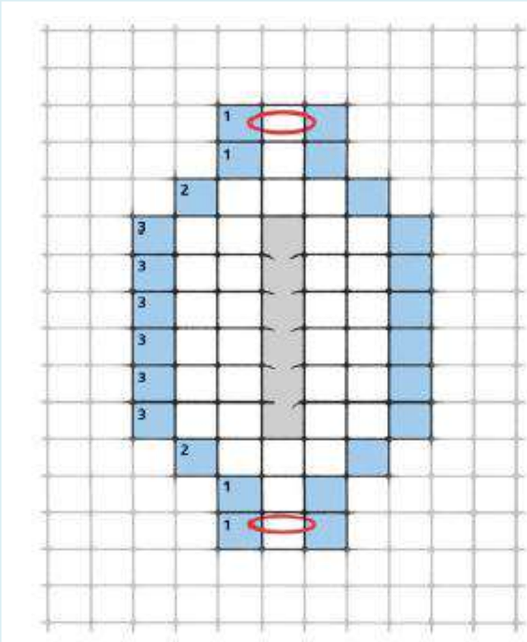
In case of any holes in the netting, temporary repair work must be immediately initiated. First precaution is to use thread with sufficient strength. In case of thread unavailability, use cable ties. Temporary repairs are not considered repairs.

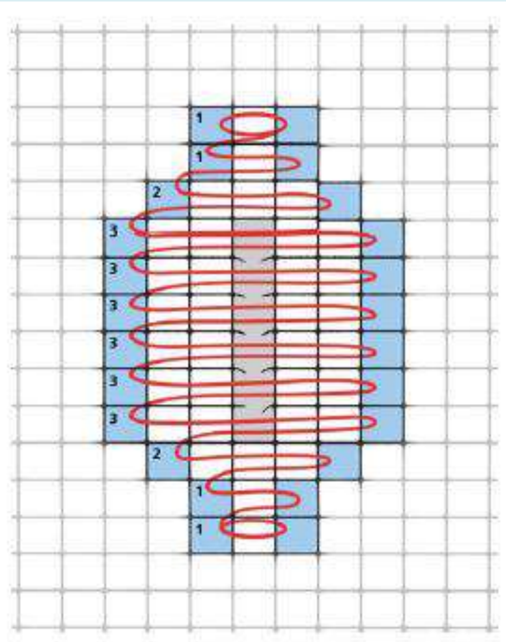
The repair procedure (using thread) is illustrated below:

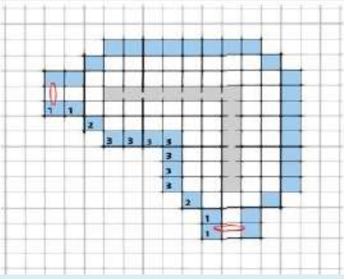
1. Start three rows above the hole and make a double flag stitch to secure the knot.
2. When you are going to sew up a hole, it is important to stitch far enough into the netting (marked 1, 2, 3) to avoid tearing.
3. Make a double half hitch that is as tight as possible, i.e., a maximum distance of 10 cm.
4. Finish sewing up the hole with a double flag stitch.
5. Go back two rows and make a double half stitch to secure the knot.

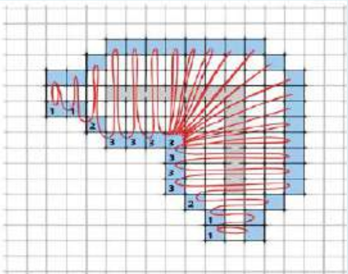
Principle for completing temporary repairs is the following:











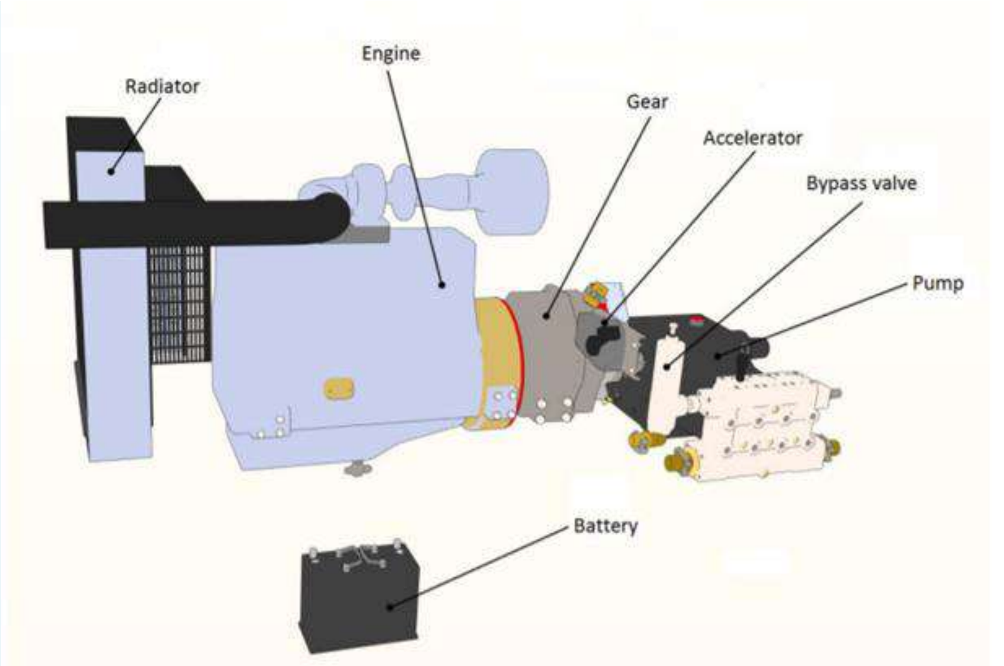
Net certification

A new net must be inspected and checked by a certified service facility in accordance with the requirements set out in the NS 9415, within 24 months of the net being put into use. If the net satisfies the standard minimum requirements for durability of new netting, the net can be approved and used for a further 24 months before the next inspection by a certified service facility.

In order for a net to be used for more than 24 months after it was put into use as new, a valid service history card issued by the service facility certified for this type of inspection has to be produced, confirming that the net still satisfies the requirements for use.

Net disposal / recycling

	A net that no longer meets the minimum durability requirements or is in a condition that makes it advisable to no longer use it to contain fish, is to be discarded. The nets on BGF are made of Dyneema technology, which is difficult to recycle, though this problem is currently being addressed. In the interim the net could be returned to the supplier for disposal or disposed of by incineration. All non Dyneema ropes can usually be recycled. In all cases it is required to return the net to a certified recycling service facility for appropriate management.
Trouble-shoot	-----

FISH NET CLEANING SYSTEM Maintenance Sheet	
FUNCTION	The fish net cleaning system supports the periodic removal of algae growth on the net panel to guarantee fish growing in the optimum growth conditions. It is infact known that marine fouling leads to reduced waterflow through the nets and reduced oxygen levels. In addition, it also causes the net to become heavier, which leads to overstress locally and even globally the net system and its interface.
Equipment	Nets are to be cleaned in situ with the underwater ROV net cleaner. This includes the ROV itself, the hydraulic cable, the hydraulic compressor, net cleaning workboat and any connecting electrical cables. The whole system is composed by a pressure generating unit, divided in engine (electric or diesel) and the pumping system. Both are based on on-the-shelf components, and maintenance schedule refers to the producers' sheet, until differently advised by the assembler (refer to the associated Operation sheet).
Suppliers	OEM service contract.
Layout	 

Key technical aspects	High pressure water represents massive forces, and it is therefore important that critical components are inspected and tested regularly. Safety valves are installed in all high-pressure equipment in order to prevent the pressure inside the system from exceeding maximal pressure endured by the various components. The safety valve is set to open up for water flow in case the pressure exceeds predetermined level. Out of order valves can cause severe damage to the system, as well as endangering personnel safety and damaging equipment installed nearby. The safety valve is set to the maximal working pressure that the equipment manages to endure. Never change this pressure point to a higher pressure. All hoses used in this construction must be able to endure the maximal working pressure of the equipment. Make sure that all hoses endure this pressure, by looking at the labelling on the hose outside. All hoses must be inspected for tears and other external damages. If the hose is damaged, it must be replaced or repaired before use. Service is mainly due to diesel driven engines, following producer indication and not detailed here. High pressure pumps have a limited worktime duration, and the use of clean water dramatically improves hours of service capability.
Key operational aspects	High-pressure water pumps working in marine waters suffer abrasion by sediment; ceramic pistons have then to be replaced together with joints and sealing at the first sign of insufficient pressure. **<u>Oil check</u>** ▪ Both motor and gear box have dipsticks for checking oil level. ▪ Read the oil level from the dipsticks. ▪ Add oil if the oil level reaches the "Add" area. ▪ Drain oil if it reaches the "Overfill" area. ▪ Refill motor oil in the front of the motor. ▪ Gear oil is refilled into the same hole as the dipstick sits. ▪ The pump has an oil level window placed on the side facing the gear, and a refill hole on top. ▪ Hydraulic oils should be replaced by hydraulic fluids approved for the feeding industry and also keeping a bio-degradable capacity, to minimize environmental effects in case of spilling. **<u>Coolant</u>** ▪ Check the coolant level on top of the radiator. ▪ Open the lid and check the level. ▪ Refill in the same opening. **<u>Safety valves</u>** They are mounted on all high-pressure equipment to ensure that the pressure inside the system never exceeds the component's maximum pressure tolerance. The safety valves are set to open for water flow when the water pressure inside the system exceeds the predetermined level. If this does not work as it should, the high pressure will cause serious consequences for both equipment and personnel. If water appears in the hoses connected to one of the safety valves, something is wrong. Either there is something wrong with the

	valve itself – in that case, it must be overhauled or changed before use. Another cause for water in the valve hose, is pressure higher than the predetermined pressure. The most common cause of this is net cleaner nozzle condensations. Check these and rinse them. If they are ok, and the pressure still is too high, check the hoses for bends, and flatten these. **Hoses** All hoses used with high pressure cleaner must be constructed in order to bear the working pressure of the equipment. Make sure the hose used is able to bear this pressure, by reading the labelling on the outside of the hose. Hoses also need to be inspected in case of tears or other damages. In case of damage, replace or repair the hoses before use. High pressure hoses for high pressure water or hydraulic oil have to be regularly inspected at the end of any service for tearing or damages, and immediately substituted at the first sign of damage. **Net Cleaner Frames** Check the hoses on the frames for bends, these must be flattened. Also check for tears and other damages. Any damage must be repaired, or the hoses replaced before use. Check the hose couplings and tighten if necessary. Run the system with feed pressure to check the conditions of all the nozzles. **ROV maintenance** ROV system should be carefully cleaned of any biofouling that may have accumulated from the net cleaning process and all parts of the system in contact with sea water should be inspected and cleaned and washed in fresh water after each use.
Trouble-shoot	----

FISH FEEDING Maintenance Sheet	
FUNCTION	Maintenance activities ensure the ongoing operational integrity of the whole feeding system and associated machineries, including planned maintenance and unplanned service in response to malfunctioning, either proactive or reactive. The feeding system driven by air is suitable for all species feeding on pellets. It can be integrated with camera control, pellet- and environmental sensors, as well with production control software. The system is designed to handle several parallel feed lines and several cage units, using centralized- or hopper feeders or a combination of both. The configuration of the system is based on transport lengths, biomass (feed amount), number of units (cages) and species. The capacity of the feed system depends on the technical quality of the pellets, the feeding regime and the length of the feeding pipe.
Equipment	Refer to the associated Operation sheet.
Suppliers	OEM service contract.
Layout	
Key technical aspects	The system has several connected elements all of which need to work correctly in order to achieve the overall desired function. These elements are: a control computer with purpose designed feed control software (specific to the particular species being reared), feed silos with feed dosing valves, air blower, air drier, feed distribution valve, distribution hoses feed spreaders. Ancillary systems providing input to the feed control software are the water quality sensor array, the fish weighing sensors, and underwater cameras. **<u>Blower</u>** The blower generates the air pressure to transport the feed to each tank/cage. The combination of air control system and frequency regulated blowers makes it possible to optimize the pellet transportation. The air speed can be adjusted to optimize both feed spread and gentle feed handling. The blowers are delivered in high quality silencer cabinets which ensures a comfortable work environment. **<u>Cooling system</u>** The transport air will be compressed from ambient pressure up to a maximum of 1 bar over-pressure. The pressure depends on feed pipe length and feeding regime. Compressed air generates heat (up to 120°C), and it is important to cool down transport air as well as surrounding components to a minimum temperature before it reaches the dosers.

	Preferably down to 25°C, depending on the location. Therefore, always install the air cooler after the blower. **Dosers** Feed doser valves are used to transfer feed into the air flow. This is a critical part of any feed system. Compared to the auger doser, the doser rotor will more carefully and accurately transfer the pellets down to the feed pipe, and they cause minimum pressure contact and pellet damage. The pellets are transported in controlled separate doses from the silos to the feeding pipe below, and then they are blown out to the cages. **Feed selector valves** The Feed Selector Valve is the connection point for the HDPE feeding pipes. They provide the dispatch of pellets to the selected cage. **Air control system** The air control system is installed between the air cooler and feed doser and allows for real time measurement of airflow, back pressure and temperature, ensuring optimal feed handling, as well as significantly reducing the risk of blockage and breakage. - if air speed is too low, the risk for pellet breakage and blockage increases - if air speed is too high, dust and breakage increase. The system will also supervise and log air speed, back pressure and air temperature.
Key operational aspects	All parts of the feeding system are to be maintained according to the schedule of maintenance provided by the individual suppliers involved. Where servicing is included in the suppliers' package then, unless otherwise instructed, maintenance may be restricted to regular inspection and cleaning of the system by the on-board staff and engineers. Key spare parts for those most prone to damage/failure should be stored on the platform. Similarly, the ancillary systems should be maintained according to the suppliers' instructions, though with many kinds f water quality sensors the servicing interval and requirements may be affected by factors such as water quality and the rate of growth of biofouling organisms. In such cases maintenance and cleaning should be carried out by trained on-board staff as an when performance deterioration is observed. **Maintenance tasks** **Blower** - When operating, this component gives a continuous airflow to the pipe-system, and thereby transports the feed through the system in order to feed each unit in the system. 1. Turn off the main power switch and secure in off position to make sure the blower will not start while working; 2. Open the filter box by unscrewing the black handle on top of the filter box; 3. Pull out the air filter and replace it with a new one; 4. Put the lid back on and tighten the black handle/screw by hand; 5. Turn the main switch back on. **Dosers** – it is mandatory to turn the main switch off and secure in locked position before any work is commenced with the dosers. All maintenance parameters for dosers are visual controls and cleaning and is performed by the site personnel. The dosers are to be disassembled in order to perform necessary maintenance of gaskets and rotor. Each doser

requires different disassembling methods, it is therefore very important to follow the correct instructions for the specific doser. If a doser leaks air, the gaskets need to be taken out and checked. Most of the time, a simple vacuuming and soap-wash is enough to stop the air leakage, but if gaskets are broken, they must be replaced. The rubber gaskets must be lubricated with a thin layer of siliconic grease after cleaning. Remember to place the gaskets back into the rotor in the same order as they were originally placed. If there are leakages in pipe couplings, these need to be tightened or replaced. Loose couplings in the electro motor also need to be tightened, repaired, or replaced. If electro motor couplings are loose, these must be tightened. If they are broken, they are to be replaced.

Selector – 1. Unlock the cover-lock; 2. Remove the cover; 3. Vacuum then clean with warm soap water; 4. Rinse well with a normal water pressure hose (never use high pressure washer here, this can severely damage the electro motor); 5. Also be careful not to get water on or into the control box if this is installed inside the selector. Cover it or keep the water away from it during the cleaning; 6. Rinse out the selector drains when necessary.

Feeding pipes - Whether only parts of the feeding pipes need to be repaired or the entire pipe has to be replaced, it is very important to follow these instructions and precautions: Electric shock may appear because of the static electricity appearing between the pellets and the HDPE pipe material. The electricity inside may cause severe shocks when cutting the pipes endangering the life and health of the user. When only parts of a pipe need to be repaired, cut off the broken part according to given instructions, and splice the extra pipe-length to the rest when necessary. Remember that the feeding pipes need enough length that they can follow the motions in the ocean at all weather conditions. Always use adjusted pipe couplings for the pipe splicing.

Feed silos

One high risk maintenance task is the periodic cleaning of the feed silos. This requires work to be carried out in an enclosed and high risk environment and should only be carried out with staff fully trained in the safety equipment to be used and protocols to be followed.

Maintenance intervals - All components each have its own maintenance intervals. Blowers, dosers and selectors have automatic hour-counters. The users must have total control over when the blower oil was changed the last time, and thereby know when the next change must be performed. This simplifies ordering services, parts and other equipment for the feed system.

Expected life cycle for the equipment

- Rotary spreaders Ball-bearing: 600 tons feed. Preventive change 80% (480 tons) to ensure the bearing 100% up time.
- Aluminium pipes: Pipe connected to ball-bearing: Same interval as ball bearing (480 tons)
- Pipe outlet: Preventive change: 1000 tons feed Selectors O-rings for S-pipe (2 inlet and 1 outlet): - Change preventive every 2 years
- Blocking device/wing: - Change every 2 years
- Dosers PEHD gaskets and silicon gaskets: Change every year

	▪ Engines and gear (both for selector and doser) No oil change. Change complete unit every year ▪ Cooler Galvanic anode: Change every 3 years (or when required) ▪ Blower Belts: Preventive change after 12000 hours or every 2 years ▪ Oil change: 500 hours after start-up. After that: 6000 hours or every year ▪ Air filter: Every 2500 hours or every year Lubrication generally No maintenance with grease lubrication shall be performed
Trouble-shoot	------

Maintenance tasks periodicity

ITEM	FREQUENCY
BLOWERS	
Listen for noise	Once a week
Oil level	Every 6th week
Oil leakage	Once a week
Oil change	Twice a year
Filter blockage	Once a month
Tighten belt	Once a year
Check wear	Once a year
Change belt	Every 15.000 hours
COOLERS	
Clean radiator and check for leaks	Once a week
Check fan blades	Once a week
Check engine fan	Once a month
Check hose and pipe connections	Once a month
Check electric engine cables	Once a month
DOSERS	
Check dosers inside and out	Once a week
Check for air leakage and connectors	Once a week
Check couplings in pipes and hosings	Once a week
Electric engine: check cables and couplings	Once a month
SELECTORS	
Clean inside	Once a week
Check for leakage	Once a week
Visual control S-pipe position, accuracy	Once a week
Check engine cables	Once a month
Listen for noise in gear	Once a month
ROTOR SPREADER	
Clean or change bearing	Twice a year
MAIN CABINET	
Change air filter and clean cabinet	Four times a year

<table>
<tr><th colspan="2">DEAD FISH COLLECTING AND TREATING SYSTEM Maintenance Sheet</th></tr>
<tr><td>FUNCTION</td><td>Adequate periodic maintenance tasks are required to enable the efficient use of the dead fish collector in place, thus guaranteeing hygiene condition to the stock, as well reducing attraction from outside cage fish.</td></tr>
<tr><td>Equipment</td><td>Refer to the associated Operation sheet.</td></tr>
<tr><td>Suppliers</td><td>OEM service contract.</td></tr>
<tr><td>Layout</td><td>


</td></tr>
<tr><td>Key technical aspects</td><td>As part of the maintenance periodic tasks, the Collector System necessitates to run on a periodic basis (ideally on daily basis and no more than three days of inactivity) regardless of dead fish in the cone or not. This is important in order to keep the cone basin clean and to prevent clogging.

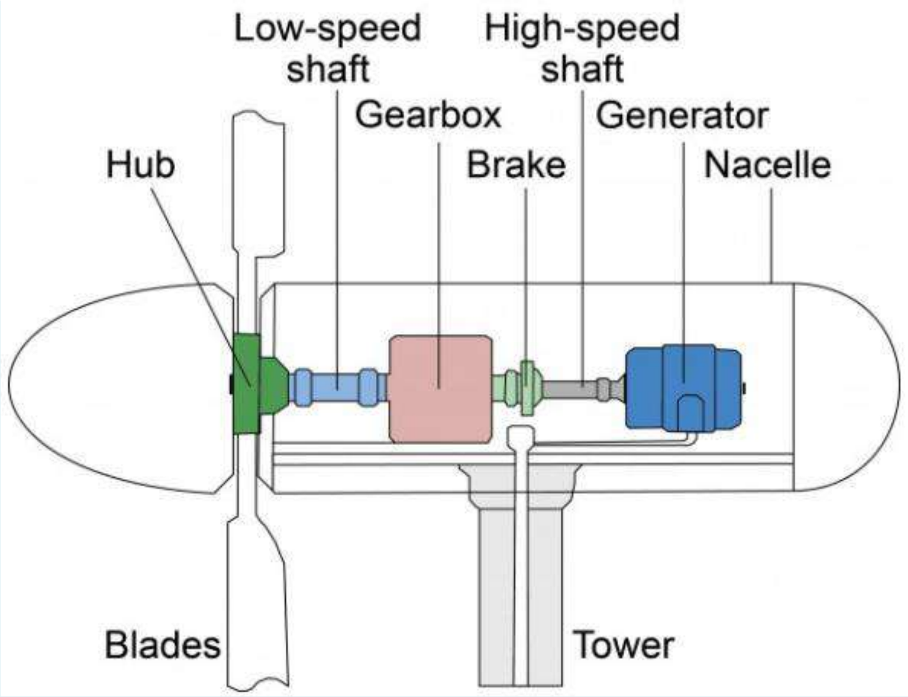
The system must be activated as soon as possible after storms and bad weather, but to be fine-tuned for the specific BGF installation practise, taking into consideration its own protected pool. Every time the system is activated, it must be checked visually. Damages must be repaired immediately.

Every time the system is brought up, hoses and hose clamp protections are to be checked. All plastic parts are verified as well against possible damages. Also check that the wrasse guard may be opened and closed unhindered.

Furthermore, in order to daily counting of dead fish in the production facility, a dedicated camera can support the process thus avoiding time-consuming work of counting dead fish manually. The digital counting process ensures a consistent and correct result - every time.</td></tr>
</table>

	Data and documentation are stored as a basis for analysis and directly reported at the Local Control Room level with indication of the reference net cage.
Key operational aspects	**Regular Maintenance Tasks** The compressor, as well as the dead fish treatment equipment follow, OEM instruction manual for the specific maintenance tasks. Regarding the dead fish collector, upon completion of the production cycle: ▪ Change hoses, hose clamps and lifting rope before re-using the system ▪ Clean and disinfect all parts ▪ Control all parts for damages, change if necessary When taking out the system: ▪ check all hoses ▪ check protection around hose clamps ▪ control all plastic parts for damages ▪ make sure that the grind moves unhindered
Trouble-shoot	------

A.2 Energy Production

WIND TURBINE SYSTEM Maintenance Sheet	
FUNCTION	Maintenance activities ensure the ongoing operational integrity of the wind turbines and associated balance of plant, including planned maintenance and unplanned service in response to faults, either proactive or reactive.
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised equipment service supply companies.
Layout	
Key technical aspects	The initial service agreement typically covers the period of the turbine defect warranty, which is usually five years. During this period, turbine technicians are typically employed by the wind turbine supplier. The service agreement may specify that on expiry technicians' contracts are transferred to the wind farm owner. This ensures continuity of staffing and removes technicians' disincentive to relocate to the wind farm site. Activity is divided into preventive maintenance (scheduled) and corrective service (unscheduled) works. The bulk of preventive works will typically be carried out during periods of low wind speeds to minimise the impact on production, however, in practice, this is not always achievable. Corrective service is performed in response to unscheduled outages and is often viewed as more critical, due to accruement of downtime until the fault is resolved. The primary skills required are mechanical or electrical engineering, with further turbine-maintenance training often provided by the relevant turbine provider. Typical maintenance includes inspection, checking of bolted joints, and replacement of worn parts (with design life less than the design life of the project).

	Unscheduled interventions are in response to events or failures. These may be proactive, before failure occurs, for example responding to inspections of condition monitoring or reactive, that is after failure affecting a single or multiple components.
Key operational aspects	**BLADE INSPECTION AND REPAIR** Blade maintenance and service is an area of specific focus in the offshore wind industry. Issues such as leading-edge erosion have been the source of availability issues in the industry and proactive blade inspection and preventative repair is now widely pursued in response. Blade inspections are typically performed by drones equipped with high-resolution cameras. Accurate visual inspection may be required by rope-access technicians. In some cases, high-resolution camera equipment can be located on the transition piece should it be considered critical to be continuously monitored. Where substantial repairs or blade replacement are required, this is sometimes possible using rope access teams often using a blade platform suspended from the hub. Where a blade cannot be repaired in-situ a jack-up vessel is typically required in order to deliver the swap-out, although smaller vessels than those used during turbine installation can be used. Exchange is carried out in one visit, followed by BGF deck-based repair or an off-site specific intervention. Retrofit programmes are carefully planned to ensure effective vessel utilisation taking into account repair turnaround times. Blade inspection work typically requires the turbines to be stationary, therefore there is a focus on performing inspection work during the less windy periods of the year to minimise lost energy production. Specialist expertise is required to undertake damage diagnostics and repair activities. Automation of blade inspection and damage diagnostics is an active area of innovation. In case a drone is required to carry out the inspection, they are typically provided by specialist operators and are rented with qualified pilots. Most UAVs for wind turbine inspection are multi-rotor copter drones. Drones can perform an inspection in a fraction of the time required for a traditional rope-access inspection. The drone is equipped with a digital camera, a thermographic camera, or a combination, depending on the scope of the inspection task. A digital camera provides proof of the visual failures and damages to the tower, nacelle, rotor blades and bolt jointing. **MAIN COMPONENT REFURBISHMENT, REPLACEMENT AND REPAIR** Modern design methodologies for offshore turbines make easier large component repair and replacement with less external intervention. On-board BGF service cranes can in some cases lift substantial loads. Some components on turbines however need a jack-up barge to enable replacement, although smaller vessels than those used during turbine installation can be used. Exchange is carried out in one visit, typically followed by an off-site refurbishment if nature of the intervention can’t be dealt with onboard BGF. Retrofit programmes are carefully planned to ensure effective vessel utilisation taking into account repair turnaround times.

	Large component repair vessels are typically self-propelled jack-ups that can install or have previously installed turbines. Most large component repair vessels are installation vessels that are no longer able to install current turbine models or are suboptimal for the purpose. Given the large number of such vessels, day rates are competitive, and owners typically seek to negotiate call-off contracts for vessel or charter them for several months for intensive maintenance or service campaigns. **UMBILICAL CABLE INSPECTION AND REPAIR** Umbilical cable is normally inspected by means of adequate ROVs. ROVs have the potential to replace vessel-based surveys. They are launched offshore from parent vessels, but they can be also launched from a CTV, therefore avoiding the need for a larger vessel with the lifting capacity. The frequency of inspections depends on seabed mobility and results of the initial surveys. Surface surveys can be used to detect substantial cable exposure, but ROV surveys will be required for more accurate burial depth data. Insufficient burial or cable exposure is typically resolved by remedial measures including protective structure and rock dumping, normally using a dynamically positioned fall pipe vessel, or occasionally side-dumping vessels. Condition monitoring system is also compatible with ROV inspections, for cabling failure forecast. Parameters such as currents, temperature, humidity, elongation and mechanical strength can be continuously monitored due to Bragg and OCT sensing. Cable damage may come from the mechanical loads of wave and tidal action if the cable is exposed to obstacles, or because of handling during transport or installation that exceeds the cable's specification. Although cables typically come with a two-year warranty, none of the main causes of damage is covered by the warranty. The owner is therefore responsible for monitoring and surveying the cable and repairing it when required. The survey work and remedial work is likely to be subcontracted to a specialist provider. Cable repair will normally require a full cable laying spread consisting of a cable laying barge with cable plough or jetting equipment, with a quadrant to ensure that the minimum bend radius is not exceeded. On deck, the cable is cut, and a new section inserted with cable joints linking the new and old sections. Unlike in subsea telecoms, where cables are largely standardised, subsea power cables may differ substantially. In the past, bespoke joints have been used but there is high interest by transmission operators in developing universal joints.
Trouble-shoot	---

WEC SYSTEM MAINTENANCE Sheet

FUNCTION

Preventive maintenance is of great importance on WEC turbine equipment in order to prolong as much as possible integrity of the asset as well as awaited performance in this heavy environment. Regular maintenance is to be carried out monthly and annually depending on the degree of wear of each component and covers both mechanical and electrical components as well as control equipment and server checking.

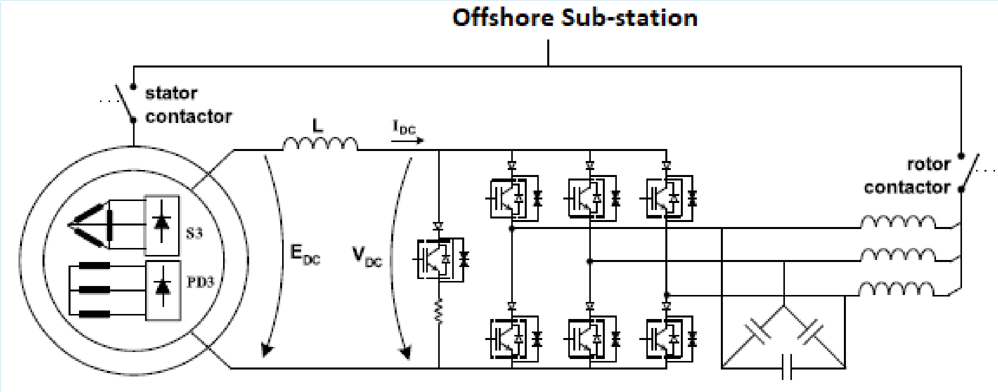
Equipment

Refer to the associated Operation sheet.

Suppliers

Specialised equipment service supply companies.

Layout

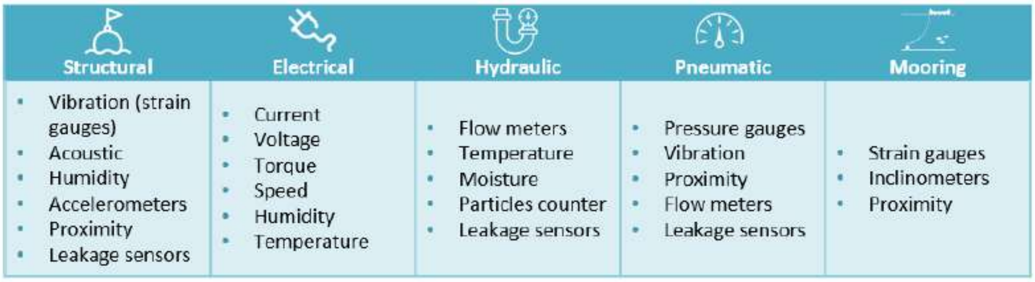


Key technical aspects

Operation and Maintenance (O&M) is considered one of the main technical and economic barriers to the emergence of commercial Wave Energy Converter (WEC) farms, where planned and unplanned maintenance may account up to 29% and 28% of the total OpEx, respectively. This is the reason why Reliability Centered Maintenance (RCM) is usually employed to study ways to preserve the system's functions and ensure its performance through effective optimization and integration of different maintenance strategies applied adequately to each component of the WEC. The RCM is based on a Criticality Analysis leading to different types of maintenance to be used (e.g., reactive, preventive or predictive) or even advising the redesign of the system to solve the potential failure, depending on different factors, such as health, safety, environment, cost and operational risks.

Corrective Maintenance	Preventive Maintenance (Scheduled Inspections)	Preventive Maintenance (Scheduled Replacements)	Predictive Maintenance
• Non-critical items • Low failure rate • High MTTF • Redundant	• Subjected to wear • Failure pattern known	• Consumable replacement • Failure pattern known	• Not subjected to wear • Random failure pattern

Technology improvements and the rise of machine learning and big data have created new ways to optimize maintenance strategies, where traditional reactive interventions are being replaced by preventive and predictive maintenance strategies, avoiding breakdowns instead of reacting to them. Maintenance has evolved to embrace concepts of monitoring and reliability, in order to find a compromise between cost and performance. In particular, sensing technologies and systems able to monitor the integrity of the WEC device are proposed, depending on the nature of the component and failure mode (see image below).



Structural	Electrical	Hydraulic	Pneumatic	Mooring
• Vibration (strain gauges) • Acoustic • Humidity • Accelerometers • Proximity • Leakage sensors	• Current • Voltage • Torque • Speed • Humidity • Temperature	• Flow meters • Temperature • Moisture • Particles counter • Leakage sensors	• Pressure gauges • Vibration • Proximity • Flow meters • Leakage sensors	• Strain gauges • Inclinometers • Proximity

RCM study typically addresses the most critical and relevant items, as well as the components having failure modes leading to critical operational risks, including:

- WEC system inoperable;
- Loss of power production;
- Potential for explosion/fire;
- Catastrophic failure of the WEC system;
- Permanent damage of the conversion chain and/or WEC internals.

Different sensing technologies can be considered in the Condition Monitoring Systems of WECS, as reported in the following table:

Monitoring object	Description (failure modes / consequences)	Sensing strategy
Humidity	Presence of internal water and steam can speed up corrosion and degradation and cause the growth of microorganisms. Humidity sensors must be resistant to contaminants and condensation.	▪ Relative Humidity (RH) sensor: electrode that responds to RH changes ▪ Dew Point sensor: integrated circuit that outputs a voltage signal as a function of humidity
Temperature	Overheating can signal severe problems in mechanical and electrical devices	▪ thermocouple
Strain	WEC can be strained by external influences or internal effects (e.g., pressure, heat, strikes), which can result in an imminent deformation and catastrophic failure.	▪ Strain Gauge: outputs electrical resistance to measure the strain of the device ▪ Fibre Optic Strain Gauge: measures precise wavelengths through optic fiber. Shifts in those wavelengths indicate deformation
Physical Disturbances (movements, vibration)	Accelerometers measure high-frequency acceleration forces, which can be used to predict increases in friction, rubbing, impacting, and other defects. Commonly used as vibration sensors.	▪ Capacitance sensor: outputs voltage as a function of changes in capacitance ▪ Piezoelectric effect: creates voltage from stress and converts it to velocity/orientation
Proximity	Fundamental to detect proximity between critical devices within the WEC that can increase friction and consequent damage.	▪ Proximity sensor: emits electromagnetic radiation and compares the changes in the returned signal.
Electrical variables	Continuous measurement of electrical variables allows a close monitorization of the system's performance and may signal an imminent failure through unusual phenomena in the signals.	▪ Voltage and current transducers ▪ Linear resistor: resistance changes depending on thermal, mechanical or electrical influence ▪ Absolute encoder: records the velocity ▪ Torque transducer: measures constant and varying torques on rotating shaft

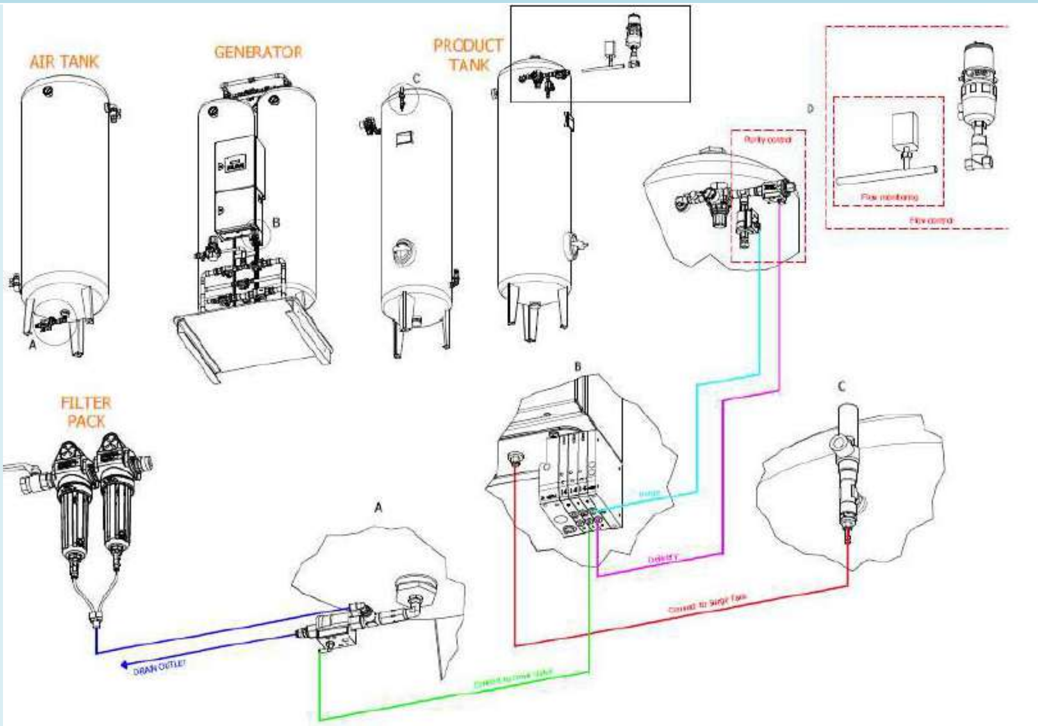
				▪ Inductive proximity sensor: it detects displacements in the device through a high frequency magnetic field.
Key operational aspects	Typical maintenance operations are characterized as being either inspections, services, repairs or replacements. Repairs and replacements usually imply longer periods of downtime, since different systems are being analysed and, potentially, repaired. If a damaged component fails to be repaired before leading to a critical failure and, thus, to the necessity of performing a replacement, downtime can be affected by several factors. **<u>Monthly Maintenance</u>** During scheduled monthly maintenance, a visual inspection of the plant is carried out. The following components are revised: sensors, emergency stop switches, fasteners (i.e., concrete interface, damper, turbogenerator, attenuators, etc.), the generator terminal box, cable trays and cables, freshwater piping and the damper actuator. A general review is also conducted for signs corrosion, including staining on surfaces. The power converter room cooling fan is also checked. **<u>Annual Maintenance</u>** During the annual maintenance, mechanical maintenance is completed with the lubrication of the generator bearings and the electrical inspection, including control system cabinets in the turbine room, the power converters cabinet to detect any sign of overheating and the cables, as well as the SCADA alarm and trip indicators. Removal of accumulated fouling in the WEC chambers must have higher frequency than the removal activity around the submerged volume of the concrete caissons-based platform. This activity must be performed having plugged the WEC chambers opening to avoid water entrance and by sucking the water left in the chamber by acting through a dedicated opening at the level of the platform deck. From there the removal of fouling is facilitated by means of water jets. Final removal of other obstructing objects eventually entrapped in the chamber is feasible by employing adequate on-deck means. **Machine learning approach to predict performance deviation** By collecting data from the facility and applying machine learning techniques, it is possible to develop algorithms that enable predictive maintenance to be performed. The machine learning techniques may be either supervised or unsupervised. In the case of unsupervised techniques, just operating data is used. In the case of supervised algorithms, however, information on when the failure occurred or when the performance dropped significantly that triggered a maintenance action is known. Having detected that a turbine needs maintenance action, or that a particular component is reaching the end of its useful life, regression models can be trained so as to predict the normal response of the entire system or a single component. For instance, vibration is the parameter that usually shows the highest degree of deviation when some components begin to suffer wear and tear.			
Trouble-shoot	----			

PV SYSTEM MAINTENANCE Sheet	
FUNCTION	Correct maintenance of the PV panels is at the base of their production efficiency. The solar PV panels work best when clean. Regular rainfall or washing with a hose will maintain their cleanliness. If they do become excessively soiled, they can be cleaned with cold water. Periodic inspections can be combined to other checks.
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised equipment service supply companies.
Layout	
Key technical aspects	If you need to shut down the solar PV system, please follow these steps in this order – 1. Switch off the Solar Supply Main Switch in the main switchboard or meter box 2. Switch off the AC isolator adjacent to the inverter 3. Switch off the DC isolator adjacent to the inverter Following these steps will safely isolate the solar array. To switch it back on, you simply reverse the procedure. **PV panels cleaning needs** The PV panel installation on top of aft building at sufficient height to prevent green water impacts and inclination on opposite side on roof-type shape is such to prevent frequent cleaning operation. Nevertheless, this routine can be made easier thanks to robotised cleaning system, with commercial capacity of max 1040 m^2/h till 48° inclination.
Key operational aspects	**Maintenance Schedule**

Inspection Item	Maintenance process	Suggested frequency

	Solar array and overall system	Perform visual check of general cleanliness and visual defects of the overall solar PV system. Remove any built-up debris near and under the array and around the inverter location. Report any found defect for corrective maintenance.	Every three months
	Junction boxes	Perform check on the tightness of connections and the integrity of seals and cable entrances for any signs of damage.	Every year.
	Installation wiring	Perform check on all electrical connections for any signs of damage and / or water ingress	Every year.
	Electrical voltages and currents	Measure open circuit voltage and short circuit currents. Suitably record details.	Every year.
	Protective devices	Perform check and verify suitable operation of all DC and AC circuit breakers (CB) and residual current devices (RCD) along with solar array isolators.	Every year.
	Mounting structures	Preform check and verify the integrity of the entire solar array mounting structure	Every year.
Trouble shoot	The inverter displays LED lights and/or screen displays to monitor the normal operation and fault conditions of the system. The occurrence of a problem within the solar PV system will usually be indicated by the inverter.		

A.3 Oxygen production

OXYGEN SYSTEM MAINTENANCE Sheet	
FUNCTION	Monitoring the operation of the unit on a regular schedule is the best way to insure a long life for the oxygen generator. External and internal inspection of tanks/columns and other pressurized equipment must be carried out according to manufacturer procedures.
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised equipment service supply companies.
Layout	
Key technical aspects	**Daily inspection** ▪ Every day observe the operation of the oxygen generator system ▪ Check purity and product consumption ▪ Verify that the temperature displayed on the refrigeration air dryer is correct (+3°C). Check the real dew point value. ▪ Make sure that the automatic drain system and air tank drain system is functioning properly (press DRAIN test button in controller menu to check this function). It is necessary to check if the filter drain port and air tank drain port are clogged. Air should discharge from these ports for 3 seconds every 3 to 7 minutes (depending on time settings) when the oxygen generator is cycling. Clogging of the drain systems causes water/oil carry-over into the absorber columns, and possible damage to the molecular sieve. **Weekly inspection** The weekly inspection of the oxygen generator system consists of a daily inspection point, plus:

- Check oil level and operating temperature on the air compressor
- Check function of your refrigeration dryer
- Check filter elements placed after the refrigeration dryer, pressure differential gauges on the filter elements must not be in red area at any time of operation.
- Air compressor maintenance (clean procedure of air/oil after-cooler)
- Air dryer maintenance (clean procedure of cooler)

After-cooler clean procedure:

- With an air jet (max. 2 bar) blowing from inside towards outside clean the cooler of air dryer and air compressor
- Repeat this operation blowing in the opposite way

Biannual PM– or every 4 000 working hours

- Service of air compressor according to supplier manual (filters and oil replacement, etc...)
- Service of air dryer according to supplier manual (drain and strainer cleaning, etc...)
- Replacement of pre-filter 0,1µm and micro filter element 0,01µm

Annually PM – or every 8 000 working hours

- Air package maintenance according to manufacturer manual
- Coal tower maintenance- replacement of active coal, oil indicator and micro-filter element
- Air tank - Inspection of drain system; each non-return valve is to be cleaned and checked for damage (replace if needed); axial drain valve is to be cleaned and properly re-greased
- oxygen generator - whole system has to be inspected for function, damage, leakage (solenoid valve block, hose/pipe connection, safety valves, etc...); process valves are to be cleaned and properly regreased;
- inspection of strainer and main inlet pressure regulator; gas analyser maintenance / calibration; inspection of the status of molecular sieve - replacement of 2'' O-ring
- Product tank – OMED upgrade filter elements (sterile and active carbon) are to be replaced
- Fan filter

2 years maintenance – or every 16 000 working hours

- Replacement of top brass filters
- Replacement of process valves
- Replacement of main inlet pressure regulator
- Replacement of fan for control cabinet

3 years maintenance – or every 24 000 working hours

- Replacement of HDM solenoid valve block
- Replacement of gas analyser

5 years PM – or every 40 000 working hours

- Molecular sieve replacement is recommended

- Internal inspection of process columns

Key operational aspects

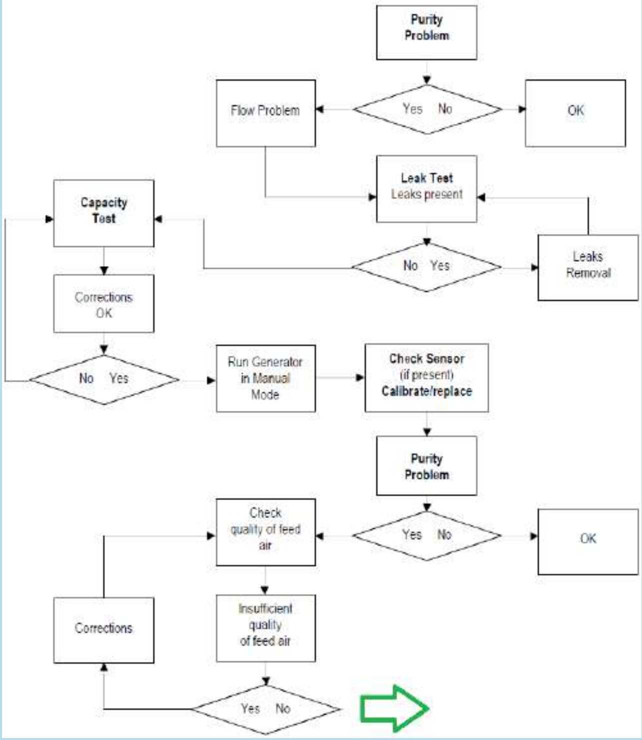
	Service Check List	Installation	every 4 000 hours	every 8 000 hours	every 16 000 hours	every 24 000 hours	every 32 000 hours	every 40 000 hours
1.	Service compressor according to suppliers instructions	x	x	x	x	x	x	x
2.	Check of refrigeration air dryer incl. drain according to suppliers instructions	x	x	x	x	x	x	x
3.	Check of pressure in air tank, column tanks and product tank	x	x	x	x	x	x	x
4.	Check of cycle time and cycle interval	x	x	x	x	x	x	x
5.	Check of product purity	x	x	x	x	x	x	x
6.	Check of product consumption (flow)	x	x	x	x	x	x	x
7.	Check of drain system	x	x	x	x	x	x	x
8.	Replace filters (pre- and micro filter)		x	x	x	x	x	x
9.	***Replace micro-filter after coalescing tower*			x	x	x	x	x
10.	***Replace active coal and oil indicator yearly (recommended)*			x	x	x	x	x
11.	***Replace micro filter and sterile filter/bacterial filter*			x	x	x	x	x
12.	Inspection of pressure regulator		x	x		x		x
13.	Replacement of pressure regulator				x		x	
14.	Cleaning of strainer		x	x	x	x	x	x
15.	***Cleaning and inspection of process valves			x		x		x
16.	Replacement of process valves				x		x	
17.	Check level and status of molecular sieve		x	x	x	x	x	
18.	Replacement of molecular sieve recomended / on demand							x
19.	Leak test	x	x	x	x	x	x	x
20.	Check of safety valves	x	x	x	x	x	x	x
21.	Replacement of top brass filters				x		x	x
22.	Check of manometers	x	x	x	x	x	x	x
23.	Check of pipe and hose connections, cables, plugs etc.	x	x	x	x	x	x	x
24.	Check of solenoid valve block, leakage/function	x	x	x	x		x	x
25.	Replacement of solenoid valve block					x		
26.	Check of purity analyser. Calibrate if required	x	x	x	x		x	x
27.	Replacement of purity analyser					x		
28.	Fan filter replacement		x	x	x	x	x	x
29.	Fan replacement				x		x	
30.	Affixing of service sticker		x	x	x	x	x	x
31.	Hand over copy of service check list to the client		x	x	x	x	x	x
32.	Fill in timesheet incl. spare parts list	x	x	x	x	x	x	x

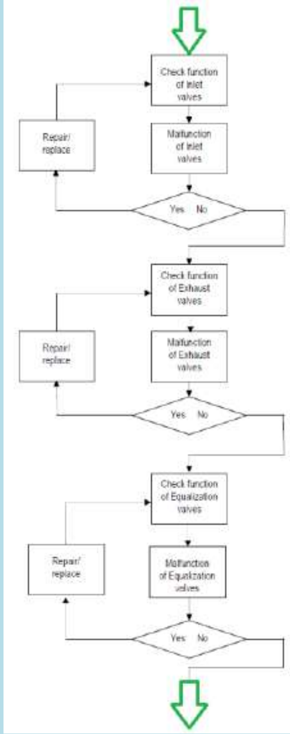
Trouble-shoot

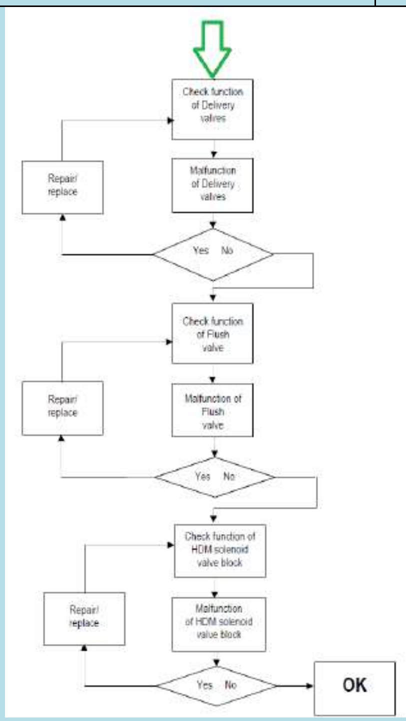
Most common operation failure is thye insufficient oxygen purity due to inadequate flow rate (capacity) caused by too heavy leakage or other capacity problems. If a purity problem occurs, it is strongly recommended at once to uncover these eventually problems before any other initiative is taken (see route diagram below).

The following procedures are available to support the maintenance / trouble shoot activity:

- Leak test procedure
- Air regulator adjustment procedure
- Capacity test procedure
- Pressure set point procedure
- Probe check and calibration
- Purging procedure


Purity Problem
Yes No
Flow Problem
OK
Leak Test Leaks present
Capacity Test
No Yes
Leaks Removal
Corrections OK
No Yes
Run Generator in Manual Mode
Check Sensor (if present) Calibrate/replace
Purity Problem
Check quality of feed air
Yes No
OK
Corrections
Insufficient quality of feed air
Yes No


Check function of inlet valves
Repair/ replace
Malfunction of inlet valves
Yes No
Check function of Exhaust valves
Repair/ replace
Malfunction of Exhaust valves
Yes No
Check function of Equalization valves
Repair/ replace
Malfunction of Equalization valves
Yes No

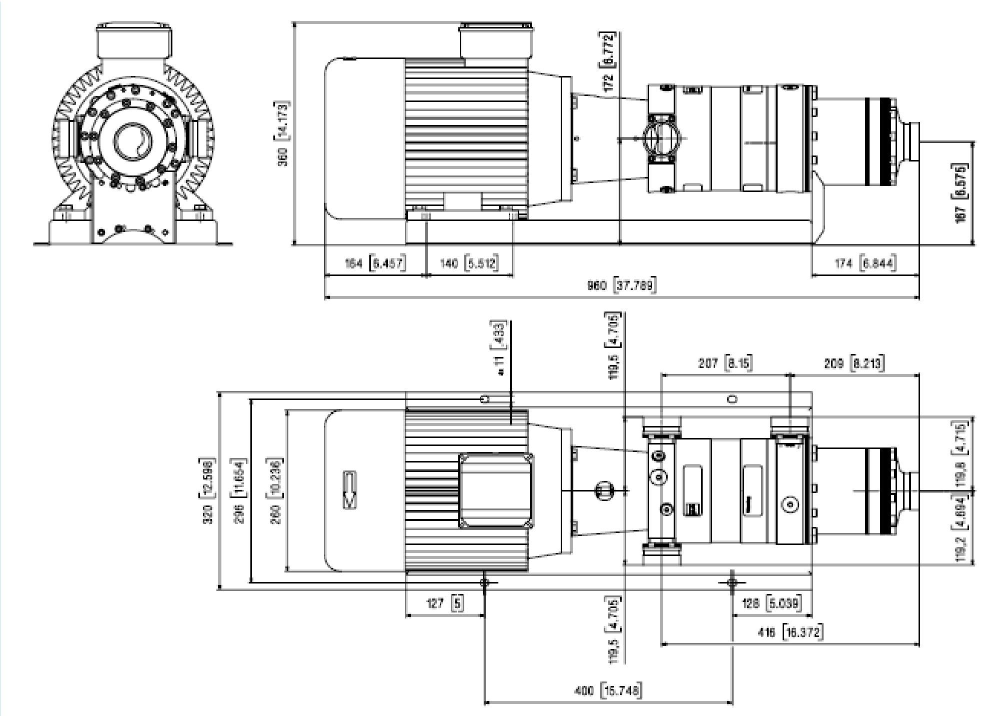

Check function of Delivery valves
Repair/ replace
Malfunction of Delivery valves
Yes No
Check function of Flush valve
Repair/ replace
Malfunction of Flush valve
Yes No
Check function of HDM solenoid valve block
Repair/ replace
Malfunction of HDM solenoid valve block
Yes No
OK

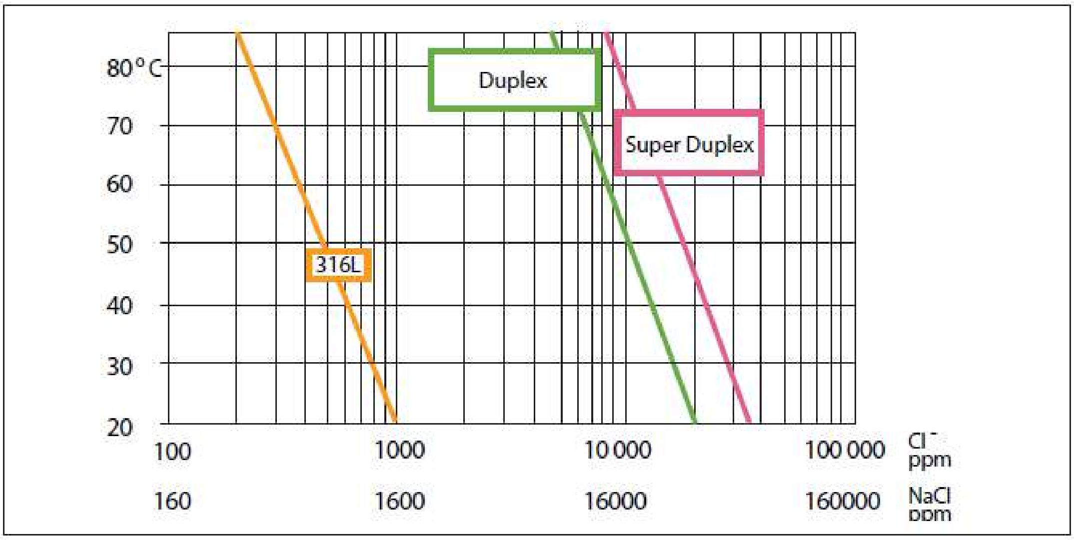
A.4 Microalgae production

MICROALGAE SYSTEM MAINTENANCE Sheet	
FUNCTION	Maintenance tasks in an industrial PBRs installation is reduced to minimum because of the controlled ambient that protect the culture. The system is energy demanding, as it is based on temperature and light control. Maintenance tasks are then those related to such devices.
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised equipment service supply companies.
Layout	
Key technical aspects	The PBR system is housed in a container and comprises the photobioreactor tanks and/or tubes, an LED lighting system, sweater input sterilisation system, circulation pumps, dosing pumps, pH controller, nutrient mixing/storage tank and algae output holding tank, water chiller and air conditioner. The system is designed to be largely automatic. However, it does require a careful maintenance according to suppliers instructions in to perform optimally. **Light management** It is advisable to use an LED lighting system that is designed to emit wavelength within the PAR, for 12–15 h. Also, an unusable wavelength spectrum can be eliminated by adjusting the power supply which in fact lowers the LED power consumption. Additionally, LED lighting systems also produce the same lighting intensity as fluorescent lights but consume less than half of the electric energy used. Another tip to increase the light flux received by the PBR is to attach a reflecting mirror or paint the ground white material at the back of or under the PBR. This is to increase the

	light reflection by creating a continuous weak light background which increases the biomass. **Temperature management** Microalgae can grow at temperature ranges between 15 and 35 °C. Temperatures lower than 15 °C lower the growth rate of the cells while temperatures higher than 35 °C kill the microalgae cells. The optimal temperature for culturing is between 20 and 25 °C. Thus, a temperature control system inside the container requires to maintain such a favourable temperature.
Key operational aspects	Basic requirements are that the incoming water is fully sterilised in order to avoid contamination of the system with bacteria, blue-green algae and algae consuming organisms and hence maintaining that part of the system is critical. Other maintenance includes maintaining the circulation pumps, cleaning of water quality and algal density sensors, emptying and cleaning of the algae collection tank, and checking and replacement of led light arrays. **Inside cleaning procedure** The tubes are made from chemically stable glass. They can be cleaned with various agents. When using a pig (cleaning sponge) make sure it is free from sand or similar abrasive agents to prevent scratching the inside of the tubes. Use sponges that are soft enough to move through the column without getting stuck. **Outside cleaning procedure** When cleaning the outside do not use abrasives and make sure to not accidently scratch the tubes with sand or similar agents attached to the surface. For the outside cleaning as well as for cooling purposes of the PBR tubes, the use of demineralized water (< 1 µS) is strongly recommended to avoid the sedimentation of scale and others that might reduce the transmission of the glass. Cleaning with demineralized water can be supported by high pressure washers. In case of persistent contamination, the use of special adapted industrial cleaners may be required.

A5. Sea Water Desalination production

REVERSE OSMOSIS MAINTENANCE Sheet	
FUNCTION	The iSave 21 consists of an isobaric pressure exchanger (IPE), a high-pressure positive displacement booster pump (BP) and an electric motor. All parts included in the iSave 21 are designed to provide long service life with a constant high efficiency and minimum service required. iSave is a very reliable and low-maintenance performer. With its direct-drive electric motor and its self-lubricating and pipe-free 3-in-1 design, the iSave is not only very easy to service – it can also be done onsite. Expected time between service is minimum 2 years within our specified parameters
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised equipment service supply companies.
Layout	
Key technical aspects	The chart below illustrates the corrosive resistance of different types of stainless steel related to NaCl concentration and temperature. All critical parts of the iSave are made of superduplex 1.4410/UN S32750 or the like. Always flush the iSave with fresh water at operation stop in order to minimize the risk of corrosion

	 The motor as well as possible accessories should always be kept clean, free from dust traces, oil or other grime. As a good rule it is recommended to periodically check whether: ▪ the motor operates without any vibrations or anomalous noises, ▪ the tension of a possible driving belt is correct, ▪ the inlet of the ventilation circuit is not obstructed causing overheating of the windings. All motors are fitted with high-quality, lifetime-lubricated bearings of the manufacturers FAG, SKF, NSK, or INA. The nominal rating life of the bearings used in horizontal mounted motors without any axial load is 40 000 working hours, for power take-off via shaft coupling. If used under maximum load conditions, the lifetime of the bearings is minimum 20.000 working hours.
Key operational aspects	**MOTOR MAINTENANCE** <u>Overload protection</u> In case of direct starting, the motors are to be provided with triple-pole motor protection switches. An additional motor protection switch is also recommended for star/delta starting. <u>Testing of the rotation direction</u> The motor's direction rotation is to be checked before coupling the machine. If necessary, the rotation direction can be altered by changing the connection of two phases. <u>Terminal box</u> Before closing the terminal box check whether: – all terminal box connections are tightened; – the inside is clean and free from any particles; – unused cable entries are closed, and threaded plugs are tightened; – the packing in the terminal box lid is inserted correctly and all packing surfaces are in good condition according to the class of protection. <u>Switching the motor on/off</u>

Before switching the motor on, during motor operation and when switching it off it should be checked whether all safety regulations are followed. In particular, the current consumption under load should be checked to detect possible sudden overloads.

Insulation test

After long periods of inactivity or storage, the insulation resistance of the windings is to be measured. The resistance should be higher than 5 MΩ at 25 °C ambient temperature. If this value cannot be obtained, it means the winding is dump and must be dried accordingly by an expert technician.

The schedule of preventive maintenance below is suggested to ensure a better performance of the system.

One day after commissioning
1. Re-check bolts in the foundation and the baseplate of the iSave and tighten the specified torque if necessary. 2. Visually inspect all pipe connections / couplings for external leakage. 3. Re-check bolts in all pipe connections /couplings and tighten the bolts to the specified torque if necessary.
4. Replace filters if necessary. 5. Clean the filter housing and reinstall filters. Make sure no debris enters the system.
Three months after commissioning
1. Re-check bolts in the foundation and the baseplate of the iSave and tighten the specified torque if necessary. 2. Re-check alignment of iSave baseplate and iSave. 3. Visually inspect all pipe connections / couplings for external leakage. 4. Re-check bolts in all pipe connections /couplings and tighten the bolts to the specified torque if necessary.
5. Replace filters if necessary. 6. Clean the filter elements and install the new filters. Make sure no debris enters the system. 7. Audibly inspect the iSave assembly. If there is irregular sounds or vibrations inspect internal parts of the iSave and replace if necessary.
8.000 hours after commissioning
1. Re-check bolts in the foundation and the baseplate of the iSave and tighten the specified torque if necessary. 2. Re-check alignment of iSave baseplate and iSave. 3. Visually inspect all pipe connections / couplings for external leakage. 4. Re-check bolts in all pipe connections /couplings and tighten the bolts to the specified torque if necessary.
5. Replace filters if necessary.

	6. Clean the filter elements and install the new filters. Make sure no debris enters the system. 7. Audibly inspect the iSave assembly. If there is irregular sounds or vibrations inspect internal parts of the iSave and replace if necessary. 8. Visually inspect pump coupling and replace if necessary. 9. Audibly inspect the iSave assembly. If there is irregular sounds or vibrations inspect the internal parts of the iSave and replace if necessary. 10. Check power consumption and flow out of the iSave. If there are irregular performances inspect the internal parts of the iSave and replace if necessary. 11. Inspect and replace, if necessary, the vanes in the vane pump.
Trouble-shoot	Provided that the iSave has been running according to manufacturer specifications for pre-filtration, pressure and rotation speed, iSave RO solutions guarantees 8,000 hours service-free operation, however maximum 18 months from date of production. After 8,000 hours of operation, an inspection where worn parts, if any, must be replaced is reccomended.

Annex D. Maintenance procedures (BGF Infrastructure Services)

A.1 HVAC

1. HVAC System Maintenance sheet

A.2 Electric Offshore Substation

1. Dry-Type Transformers Maintenance sheet
2. Medium Voltage Switchgear Maintenance sheet
3. Medium Voltage AC Cables Maintenance sheet

A.3 Shipping Operations

1. Automated Docking System Maintenance sheet
2. Electric Recharge System Maintenance sheet

A.4 Surveillance and Security

1. Surveillance Radar Maintenance sheet
2. Long Distance cameras Maintenance sheet
3. Automatic Identification System (AIS) Maintenance sheet
4. Security Systems Maintenance sheet
5. Access Control System Maintenance sheet

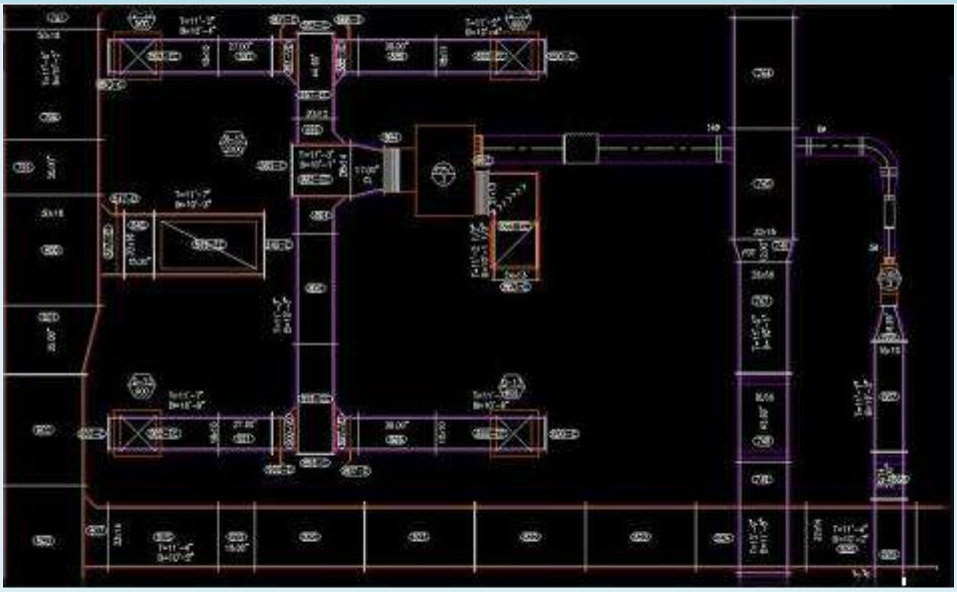
A5. Structural Health Monitoring System

1. Structural Health Monitoring System Maintenance sheet

A6. Mooring System

1. Mooring System Maintenance sheet

A.1 HVAC

HVAC SYSTEM Maintenance sheet	
FUNCTION	HVAC Units are built with control by design in mind, assembled with technically specialized control software to make maintenance tasks easier. Piping and wiring, scroll type compressors, new generation evaporators, air cooled condensers, optional hydraulic components, are components of modern plants, fully equipped with safety and security protections. Units are eco-friendly and operate with R-410A refrigerant. HVAC systems location and accessibility enables adequate routine inspection testing and preventative and breakdown maintenance to be carried out without prejudicing safety of the installation. Suitable access platforms and routes for entry and removal of expendable components or failed equipment is to be provided. Access doors into plant and ductwork would need to be of sufficient size to enable servicing to be adequately carried out. Leading components and utility supplies should be clearly labelled / tagged with appropriate unique identification.
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised HVAC service supply companies.
Layout	
Key technical aspects	Servicing or maintenance of HVAC units is be carried out by experienced personnel with specific training in refrigeration. Repeated check of the safety devices and continuous cycling of control components must be analyzed and corrected before being reset. No maintenance work is needed on the refrigeration circuit as long as the unit is operating normally. Ease of maintenance is taken into consideration during the design stage such that the unit is easily accessible for servicing and maintenance. By accessing from the front panel of the unit, servicing and maintenance operation can be done easily. The electrical components are especially easy to access since they are located in the terminal box on top of the front panel.

	Under normal circumstances, chiller normally requires only a check and cleaning of air intake through the coil surface only. These can be done monthly or quarterly depending on the surrounding environment where the units are installed. For prolonged periods of operation time, the heat exchanger will become dirty impairing its effectiveness and reducing the performance of the units. No major maintenance or servicing needed for the internal water circuit in the unit except the water pump failure. It is advised that regular check on the stainer to be conducted and change the water stainer if it is dirty or choked. Always check the water level in the system, in order to protect the moving components in the hydraulic kit from overheating and excessive wear. It is recommended to energize units 24 hours before the first start up to begin heating the compressor crankcase.
Key operational aspects	**General Maintenance Tasks**

HYDRAULIC MAINTENANCE
Filter cleaning hydronic circuit
Visual inspection of all water pipes for leak detection
Water replacement in the hydronic circuit.

ELECTRIC MAINTENANCE
Retightening of connectors and terminals in the electrical panel, control part, power and junction boxes (Quarterly)
Physical inspection of all contactors and relays on the electrical panel. (Monthly)
Check amperage of all electric motors and compare according to equipment nameplate for detect abnormalities (Quarterly)
Physically verify false contacts (Monthly)
Check the adjusting and state of the electrical protections and fuses, these must be under the manufacturer's specifications (Bimonthly)
Electrical panel cleaning (Monthly)

PHYSICAL INSPECTION
Condenser cleaning with pressurized water (Bimonthly)
Check refrigerant pressures (Quarterly)
Fan blades inspection, blades must be clean (Quarterly)
Check power consumption of compressors to determine refrigerant losses (Quarterly)
Compressor oil inspection (Monthly)
Equipment's internal inspection and cleaning (Bimonthly)
Condensate drain line inspection, must be unobstructed (Quarterly)
Checking alarm history (Monthly)

	Specific equipment maintenance tasks **Chiller**

List of Activities	Weekly	Monthly	Yearly
General			
Reading of operating data	X		
Visual inspection of machine for any damage and/or loosening		X	
Verification of thermal insulation integrity			X
Clean and paint where necessary			X
Analysis of water			X
Electrical			
Verification of control sequence			X
Verify contactor wear – Replace if necessary			X
Verify that all electrical terminals are tight – Tighten if necessary			X
Clean inside the electrical control board			X
Visual inspection of components for any signs of overheating		X	
Verify operation of compressor and electrical resistance		X	
Measure compressor motor insulation using the Megger			X
Refrigeration circuit			
Check for any refrigerant leakage		X	
Analyse compressor vibrations			X
Condenser section			
Clean condenser banks			X
Verify that fans are well tightened			X
Verify condenser bank fins – Comb if necessary			X

Trouble-shoot	------

A.2 Electric Offshore substation

DRY-TYPE TRANSFORMERS Maintenance sheet

FUNCTION

The life of dry type transformers can be improved with proper maintenance. An inspection and maintenance schedule should be established to maximize the life of this equipment. Evidence of rusting, corrosion, and deterioration of the insulation, varnish or paint should be checked, and corrective measures taken. Auxiliary devices should be inspected and serviced during these inspections.

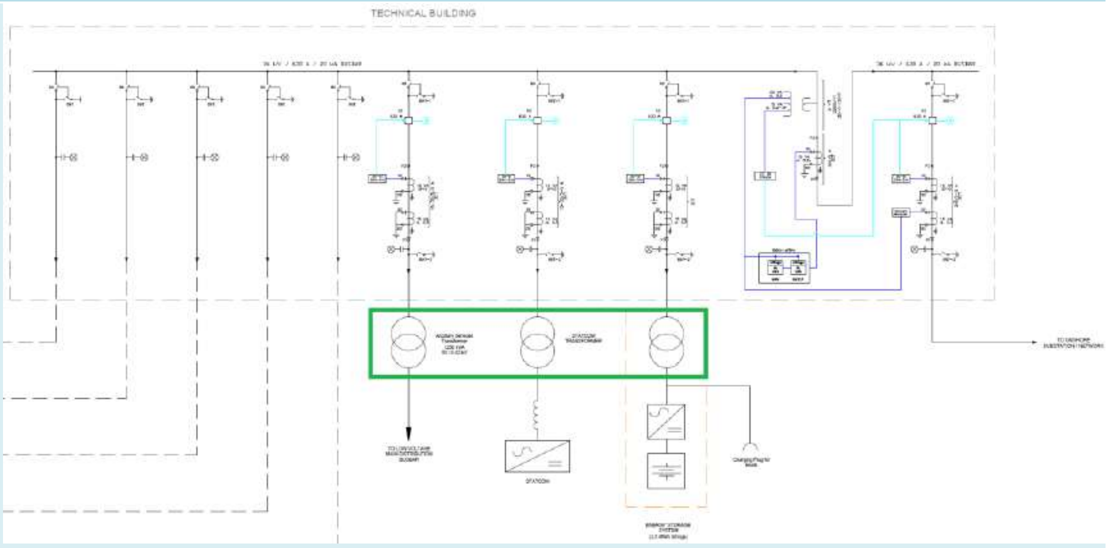
Equipment

Refer to the associated Operation sheet.

Suppliers

Specialised electric service supply companies.

Layout



Key technical aspects

The intervals at which ventilated dry type transformers should be inspected depends on operating conditions. For clean, dry locations, an annual inspection may be sufficient. For harsher environments (saline), a more frequent inspection may be required. Usually after a few inspections, a schedule can be established based on the existing conditions.

Maintenance Work	Interval (months)
Check low-voltage and medium-voltage cable entries for discolorations and damages.	6-12
Check electrical connections for dirt and signs of electric arcs.	6-12
Check surfaces for dirt and damages.	6-12
Check seals for damage	6-12
Check the torques of grounding connections	6-12
Check function of the tap changer	6-12
Check the transformer for paint damage and rust	6-12
Check for temperature rise of coils on normal conditions	Where necessary

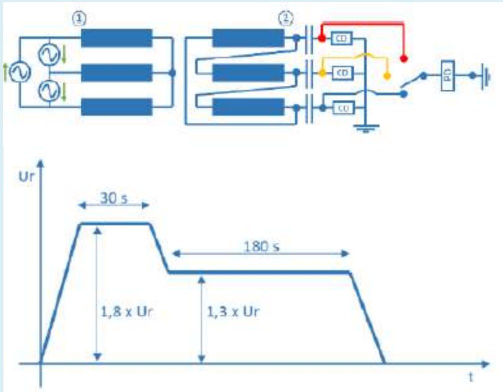
As indicated above, this would be a first approach for a basic inspection; it will be necessary to carry out more specific test to obtain the real condition of the components that are part of the transformer. The testing period can be performed in a time interval of 12-24 months.

Key operational aspects

In a transformer, insulation **breakdown** is the most frequently occurred failure which results in severe faults like earth faults or phase-phase winding. Based on the tests, the condition of insulation for the component parts in the transformer like core, windings, and bushings can be determined.

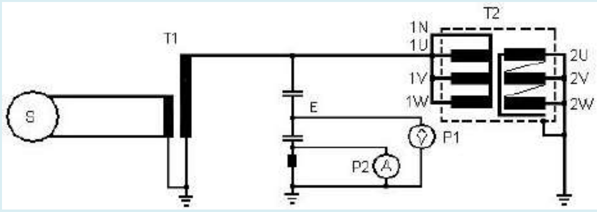
There are different tests for these transformers:

- **Tests for partial discharge (PD):** to proof the quality of the insulation and detection of defects such as missing contact washers and constructive parts that are not grounded. The test object is energized via the Low Voltage windings, while a PD measuring system is connected to the High Voltage windings. It is connected to each of the three phases in succession.



PD measuring configuration and test cycle according to IEC 60073-11

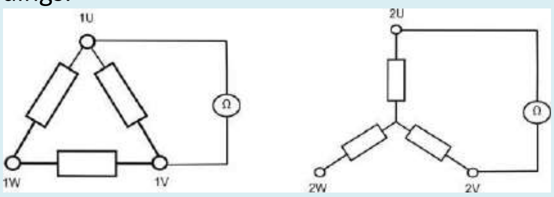
- **Insulation tests:** ensures that the quality of the insulation between the windings and the earthed parts, core, core clamping, is correct.



T1: high voltage transformer with "S" as electricity supply.
T2: transformer to be tested

Check IEC 60076-11:2018 for further details.

- **Resistance of the windings:** this test will help to detect poor or faulty contacts, damage in the windings.



Phase to phase resistance

Check IEC 60076-11:2018 for further details.

- **Transformer ratio and Phase Displacement**: In the process, the High Voltage winding is fed, which leads to the induction of voltage in the Low Voltage winding. This voltage is measured and is compared with the fed voltage. The result is compared with the desired values and the difference in percentage is displayed.

Check IEC 60076-11:2018 for further details.

	In addition to those listed above, it is possible to obtain information of the condition performing a Thermographic survey and Acoustic emission tests.
Trouble-shoot	-----

MEDIUM VOLTAGE SWITCHGEAR Maintenance sheet

FUNCTION

Switchgear should be cleaned, inspected, tightened, lubricated, and exercised on a regular basis. The frequency of maintenance depends on the environment, the condition of the equipment, and its criticality. Moisture and heat combined with dirt, dust, or other contaminates in the environment will deteriorate the insulation, conductive materials, and protective devices in the equipment at an accelerated rate. These factors should be considered in determining whether maintenance should be performed annually, every 5 years or somewhere in between.

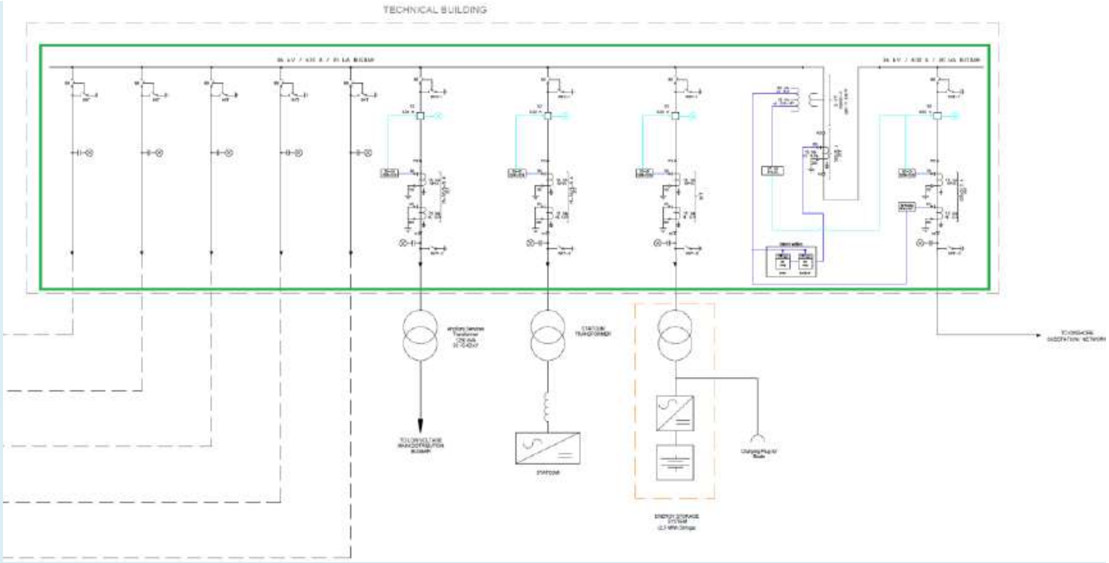
Equipment

Refer to the associated Operation sheet.

Suppliers

Specialised electric service supply companies.

Layout

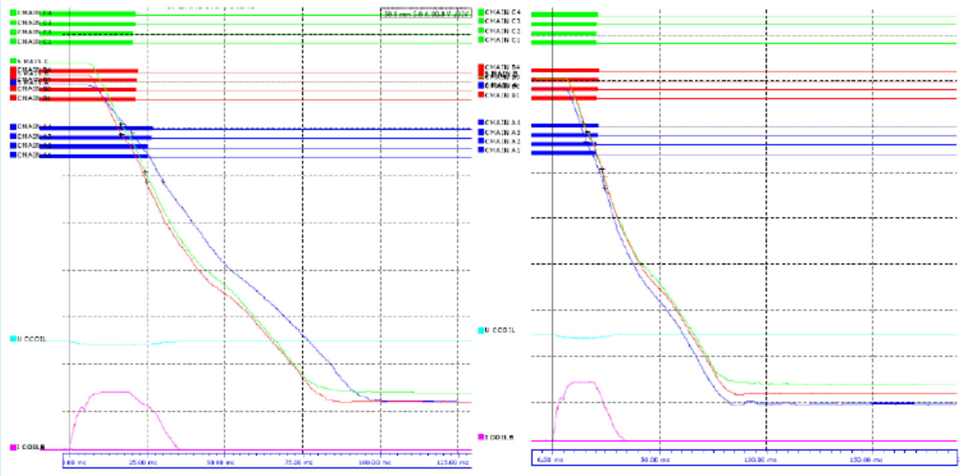


Key technical aspects

Switchgear components require regular maintenance to ensure equipment integrity and proper mechanical and electrical functionality, as well as to optimize the equipment's useful life.

ELECTRICAL/MECHANICAL INSPECTION
Electrical/Mechanical mechanism and interlocks
Bus and support insulators
Proper lubrication
Clean switchgear
Check manual operation of circuit breakers and relays
Check charge/close/trip circuit
Test relays (according to elec. study recommendations)
Check instrument and relay covers
Check circuit breaker insulating parts
Check circuit breaker contact surfaces
Proper phase connection and colour code
Working clearance
All filters and vents clear
Check proper equipment grounding to grounding bus
Check incoming line connections to main bus
Verify proper size breakers/fuses

	Check the counter for circuit breaker operations Verify correct operation of indicating lights, meters, etc Verify correct pressure of the insulation medium	
Key operational aspects	A regularly system preventive maintenance program is intended to detect, repair, or replace affected electrical components, parts, or equipment before they lead to damage, significant power interruptions, and loss of functionality. Air, vacuum or oil circuit breakers require similar maintenance; however, each has unique characteristics and testing procedures. Check IEC 62271:2022 for further information. - **Contact resistance test:** measuring the voltage drop across the line and load terminals for each phase with the circuit breaker in the closed position. Poorly maintained or damaged contacts can cause arcing, single phasing, and electrical fires. - **Insulation Resistance:** useful for detecting major defects in the insulation system, but it can also be used as a final safety check before returning the breaker to service. This test should be performed using a megohmmeter phase-to-phase and phase-to-ground with the breaker in the closed position, as well as across the open contacts for each phase. Use the manufacturers recommended test voltage and acceptance values for this test. - **Dielectric withstand voltage:** used to detect tracking, deterioration, and moisture in the insulation system at a much higher voltage**.** Always use test voltages specified by the manufacturer. Dielectric withstand testing is performed from the line side of each phase, with the breaker open, all other phases tied together and connected to ground. For vacuum circuit breakers, this test will also provide an indication of the vacuum bottle integrity. - **Circuit Breaker operation analysis:** to detect problems in the breaker operating mechanism. There are eight tests that are usually conducted on the breaker with the circuit breaker analyzer: ▪ Closing time and opening time ▪ Contact bounce ▪ Opening and closing synchronization ▪ Closing and opening speed ▪ Trip operation ▪ Trip-free operation: the contacts of the circuit breaker must return to the open position and remain there when an opening operation follows a closing operation, regardless of whether the closing signal, force, or action is maintained. ▪ Close operation ▪ Trip-reclose operation	

<table>
<tr><td></td><td>
Example: Opening operation in the “Blue Phase” slower than the others

- Current Transformers: to check ratio, polarity, burden, winding resistance, magnetization curve and insulation test.
- Voltage Transformer: to check ratio, polarity, winding resistance and insulation.</td></tr>
<tr><td>Trouble-shoot</td><td>-----</td></tr>
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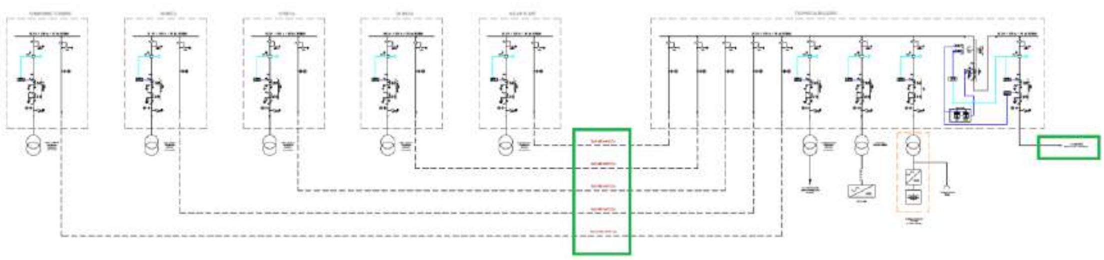
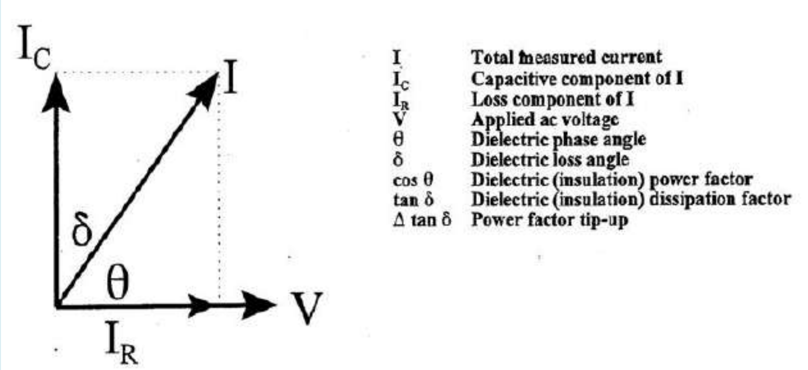
MEDIUM VOLTAGE AC CABLES Maintenance sheet

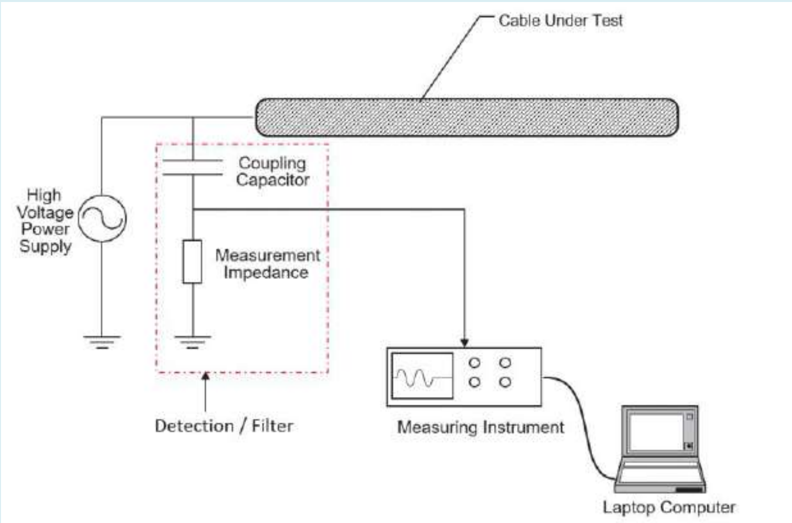
FUNCTION	The preventive/predictive maintenance of power cables includes inspection, test and monitoring of conductors, joints and terminations. The main objective: - Avoid failures - Avoid environmental damage - Avoid expensive repairs - Extend the life of cable and accessories For additional information, the IEC 60502-2:2014 specifies the construction, dimensions and test requirements of power cables with extruded solid insulation from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV).
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised electric service supply companies.
Layout	
Key technical aspects	In order to know the current status of a power cable, there are two main techniques: - Offline Testing: requires the cable to be disconnected from the generator and the grid in order to carry out the tests. - Continuous Monitoring: the cable can be "tested" while electricity is still being transmitted to the grid. Before conducting any offline testing, the following steps should be taken: - All equipment (transformers, switchgear, etc) must be disconnected from the cable circuit. - Provide adequate clearance between the circuit test ends and any grounded object and to other equipment not under test.
Key operational aspects	The electrical properties of a cable generally provide a global measurement of the overall condition of the cable insulation system, such as insulation resistance, polarization index, dielectric loss measurement, and voltage withstand tests. However, some electrical properties tests, such as time domain reflectometry (TDR), line resonance analysis (LIRA), and partial discharge tests, can provide information not only on the magnitude of degradation, but also the location of the problem. **1- OFFLINE TEST** Offline testing and monitoring techniques include: - *Dielectric Loss (tan delta)*: The principle of operation is based on the fact that when a steady-state AC test voltage (V) is applied across a cable's insulation (conductor-to-ground), the resulting apparent total current (I) that flows consists of a charging current (I_C) due to the capacitance of the cable insulation and a leakage current (I_R).



The phase angle θ between the applied test voltage (V) and the total current (I) flowing through the insulation is known as the dielectric phase angle. The compliment of the phase angle is called the dielectric loss angle δ. The ratio (IR/IC) is the tangent of the dielectric loss angle (tan δ) and is a measure of dielectric degradation. It is called the dielectric dissipation factor and is commonly used as a measure of insulation condition.

- *Partial Discharge (PD):* Partial discharge is described as a failure part of an insulation system to withstand the electrical field applied to it. This can be a result of defective materials, contamination, or aging. The result of this failure is a high-frequency, unipolar discharge and accompanying current that flows through and on the insulation from the conductor to ground. This current pulse is low energy due to its short (microsecond) duration, but it can negatively affect the insulation and eventually cause catastrophic failure.

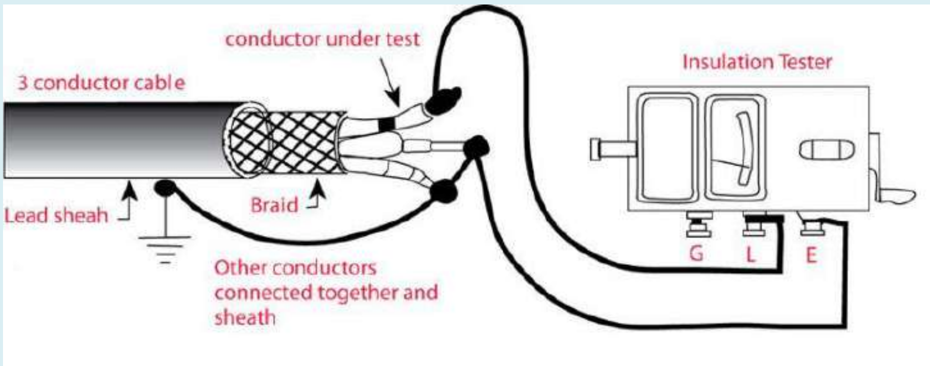
Offline partial discharge testing uses a similar setup to tan delta testing in that the cable should be disconnected from external equipment and connected to a low-discharge voltage source.



While the goal is to measure the PD current pulse, it is not measured directly; rather, it is inferred from the voltage drop when the discharge occurs. For this reason, a known pulse generator is typically required to calibrate the system by relating a measured voltage drop to a Pico-Coulomb amount.

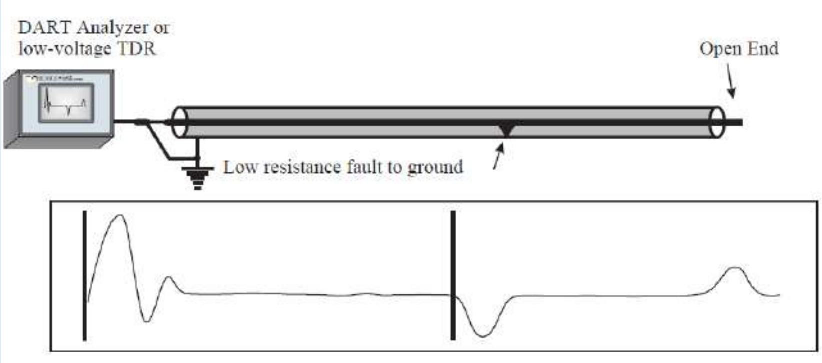
- *Insulation Resistance and Polarization Index:* Insulation resistance measurement is a standard industry technique that is commonly performed to determine the current condition of cable insulation. It involves the application of a voltage between the cable conductor and a ground to determine the resistance of the insulation separating them.

The total current flowing in the insulation from the conductor to ground is equal to the sum of the capacitive charging current, the leakage current and the dielectric absorption current. If the insulation is badly deteriorated, wet, or contaminated, the leakage current will be greater than that found in good insulation and it could continue to increase over time. Insulation resistance is normally measured at one minute and again at ten minutes; then the ratio of the two measurements is calculated. This ratio is called the Polarization Index.



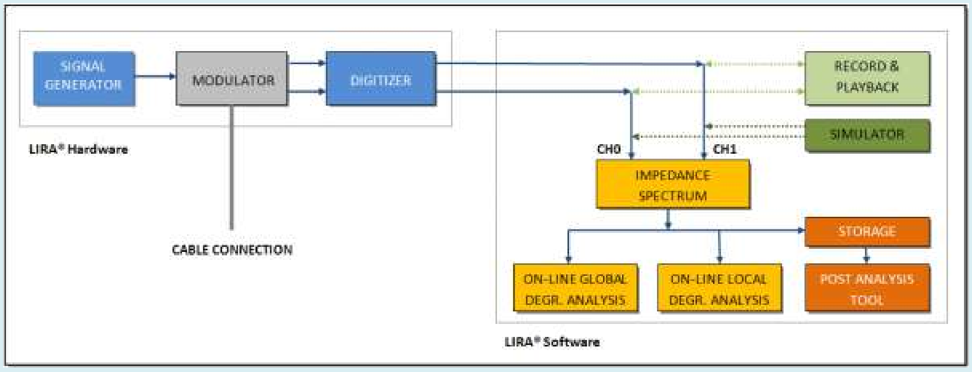
- *AC Voltage Withstand Test:* cable's insulation is exposed to a high test voltage to demonstrate that the insulation can withstand a voltage potential higher than it is expected to see during service. The principle behind the test is that if defects are present in the cable, the high test voltage will force them to fail. Without any failures, the cable is considered to be in good condition and able to continue in service. The test is performed with a high potential test set that applies a relatively high test voltage (2 times rated voltage) for a set period of time between each conductor and ground. The test duration must be in accordance with the safety standard being used. If this test is repeated excessively, the dielectric strength of the insulation could weaken to the point that the cable will fail due to the testing.
- *DC High Potential Test:* similar to the AC voltage withstand test, with the exception that the DC test voltage is less likely to adversely affect the cable insulation. Another advantage to this test is that the test equipment is much smaller and more portable. Some reports from EPRI (Electric Power Research Institute) on medium voltage XLPE- and EPR-insulated cables have shown that DC high potential testing of field-aged cables could potentially damage or cause extruded cables, especially field-aged XLPE-insulated cable, to fail prematurely.
- *Time Domain Reflectometry (TDR)*: commonly used technique for assessing the condition of instrumentation, control, and power cables in inaccessible locations. A non-destructive pulse of energy is transmitted down a cable from one end, and is reflected when it encounters:
  - the far end of the cable
  - a fault along the cable
  - some other problem that causes a change in the electrical impedance of the cable

  The time for the signal to travel to where the impedance change is located and return back is measured by TDR and converted into a distance. This distance is used to locate the impedance change.



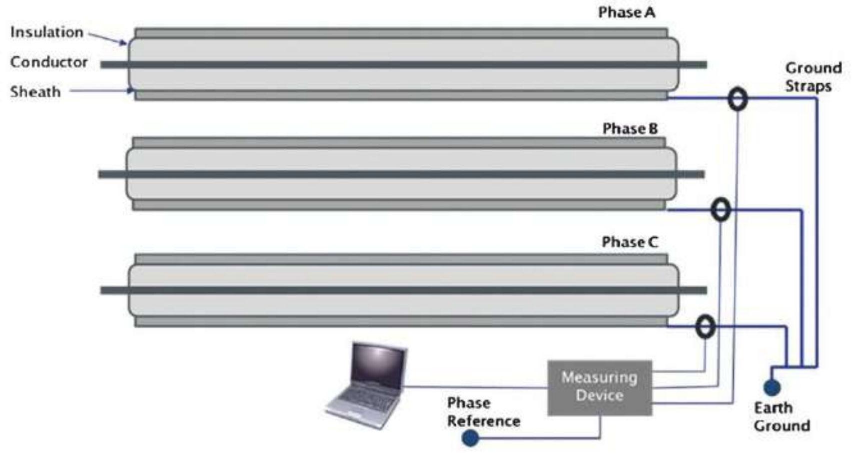
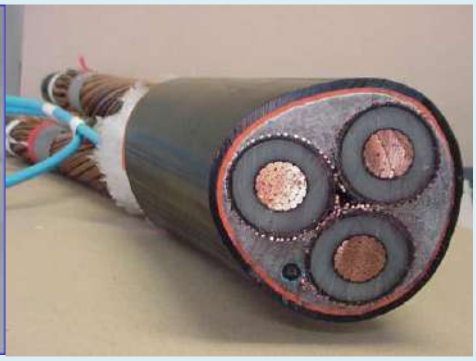
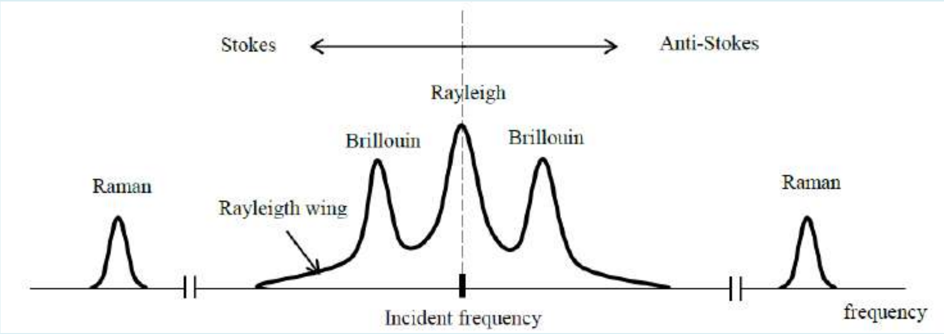
2- ONLINE TEST

- *Line Resonance Analysis (LIRA):* is a relatively new electrical condition monitoring technique that is based on the analysis of electrical test signals input to the cable-under-test using a waveform generator. The technique models a wire system using transmission line theory and uses narrow-band frequency domain analysis of high frequency resonance effects of unmatched transmission lines to detect changes in the cable insulation's properties.

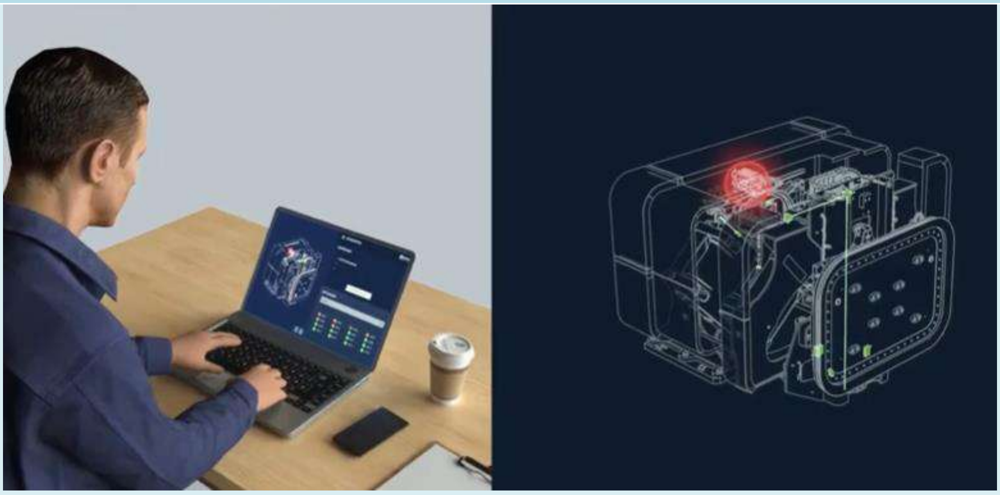


The cumulative phase shift of the input impedance due to the permittivity change in the insulation is used as a condition indicator for aging and small defects. Amplitude change is used to account for larger effects.
The technique is best used to monitor the changes in cable electrical properties over time in comparison to baseline readings. It can be performed in situ without disconnecting the cable and only a single access point is needed.

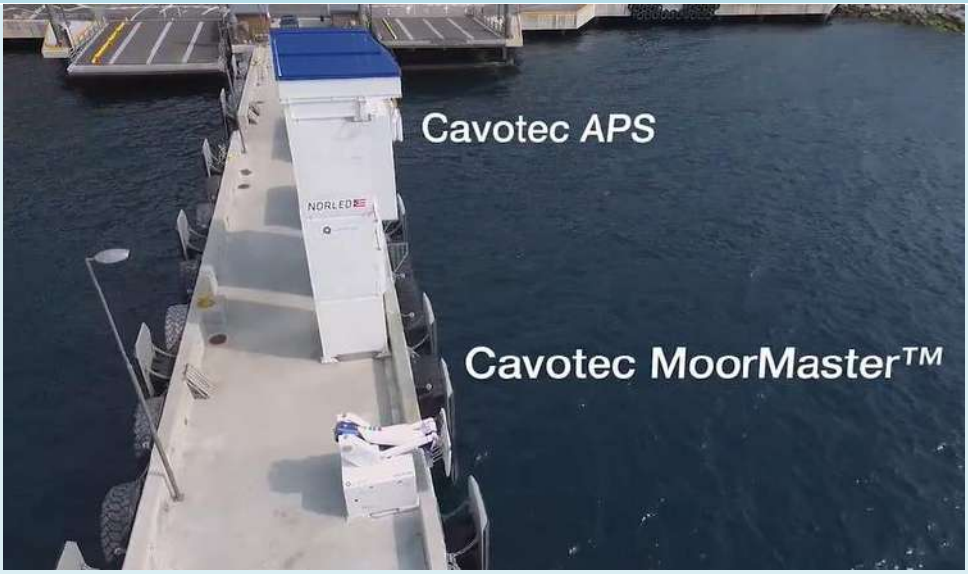
- *Online Partial Discharges:* Online partial discharge testing makes use of the power system voltage and only requires a monitoring circuit. While it is possible to attach a monitoring circuit to the conductor, it is also possible to connect to the ground strap of the conductor since the discharge must travel down it to ground. This ground connection will not adversely affect the electric field at the conductor. By connecting via a high-frequency current transformer (HFCT), a direct measurement can be made, eliminating the need for a calibrator.

	 Tests can be done in a few minutes, as a periodic survey or as continuous monitoring. - *Fibre optic distributed sensing:* A distributed optical sensor is expected to reveal temperature, strain and vibration information from any point along an optical fibre through light scattering. The challenge has been to find a mechanism that would allow the key structural parameters to be determined at any point along an optical fibre with an appropriate sensitivity and spatial resolution, and yet within acceptable time limits for vibration or dynamic strain detection. Experience and development has shown that the inclusion of fibre within the cable is feasible and a small additional expense and available for both single core and multicore cables.  Most Fully-distributed fibre sensing systems are based on scattering, in which the fibre's scattered light is sensitive to external parameters to be measured at any point along the fibre with a certain spatial resolution.  The figure shows the typical spectrum of light scattering. In optical fibres, Brillouin and Raman scattering are 20dB and 30dB weaker than Rayleigh scattering respectively.
Trouble-shoot	------

A.3 Shipping Operations

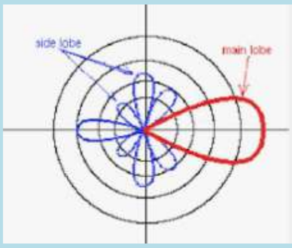
AUTOMATED DOCKING SYSTEM Maintenance sheet	
FUNCTION	Predicted maintenance of the Automated Docking System is achieved through Artificial Intelligence algorithms that elaborate sensors' data in a continuous way, taking care of all forces applied to control the movement of the moored vessel. Routine inspections to HW are made easy thanks to advanced interactive maintenance support SW available to operators.
Equipment	Refer to the associated Operation sheet.
Suppliers	OEM service contracts.
Layout	 
Key technical aspects	Different smart sensors are located in the single robot to enable monitoring of key variables by the Local Control Room operator. Predicted maintenance is based on the artificial intelligence algorithms that elaborate the acquired data from sensors.
Key operational aspects	Only few parts that need regular inspection by the Deck Operations Manager are easily accessible from the main back panel, as depicted in the picture below.

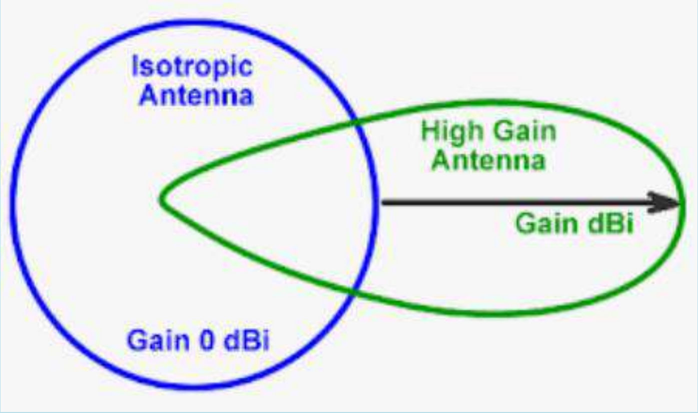
	
Trouble-shoot	----

ELECTRIC RECHARGE SYSTEM Maintenance sheet	
FUNCTION	The Electric Recharge System maintenance are typical of equivalent land based electric energy transfer systems.
Equipment	Refer to the associated Operation sheet.
Suppliers	OEM service contracts.
Layout	 
Key technical aspects	**<u>Industrial connectors</u>** The application implements electrical interlocking of pilot contacts, lamellar, Multi-Way Technology, and Push & Pull systems (IP 66 protected, and with a standard operating temperature up to 80°C, but extendable to higher temperatures). In particular, Multi-Way Technology, (MWT) greatly improves the contact between male and female pins. As the MWT becomes warm, it expands thus increasing contact pressure between the surfaces. This additional contact pressure greatly enhances current carrying capacity relative to the size of the contacts and makes connecting and disconnecting the plug and socket significantly easier.
Key operational aspects	Modern transformers and switchgear are relatively low maintenance items, but they will need periodic monitoring and inspection. Spare main breakers are recommended to minimize downtime in case of a breaker failure.

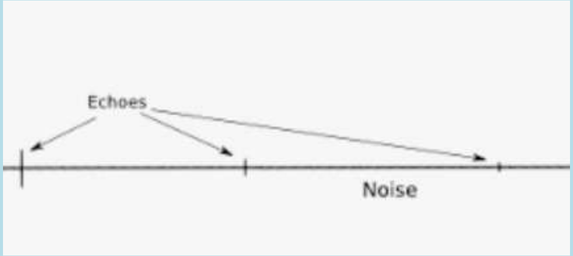
Trouble-shoot	---

A.4 Surveillance and Security

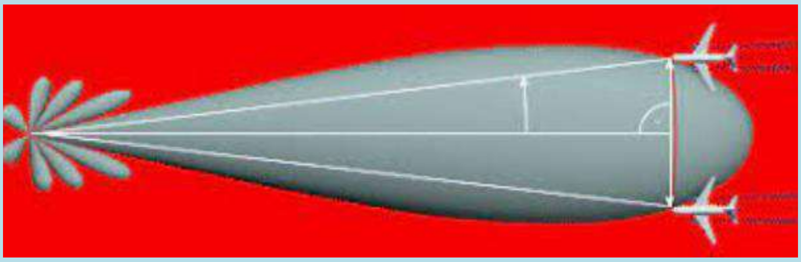
SURVEILLANCE RADAR SYSTEM Maintenance sheet	
FUNCTION	Maintenance of the surveillance radar is essential to keep the device efficient. This allows to maximize the characteristic parameters of the radar (target detection, noise reduction, high signal-noise ratio, low probability of false alarm etc…).
Equipment	Refer to the associated Operation sheet.
Suppliers	OEM service contracts.
Layout	
Key technical aspects	Periodic inspections: • **Receiver calibration (with related signal filtering):** The accuracy of a marine radar, if properly calibrated, is much better. Overall, we can consider it constant for any distance. • **Checking transmitter (total radiated power):** The value of the radiated power must be that of the project (not less). • **Monitoring the infrastructure (such as air conditioning and power systems):** The infrastructure must be in the expected environmental conditions. • **Check of the structure used to protect the radar (Radome):** In addition to the radar equipment, it is necessary to check the radome for leaks, repaired it when needed and, only occasionally, washed and waxed it. The goal is to avoid signal attenuation. • **Antenna's directivity:** The directivity must be that fixed in the design phase. It is not recommended to have excessively high directivity because the radar must have a panoramic view.  • **Antenna's power gain:** This adjustment is used to change the sensitivity of the receiver. If the gain is too low, the echoes are not detected but if it is too high you have signal distortions.



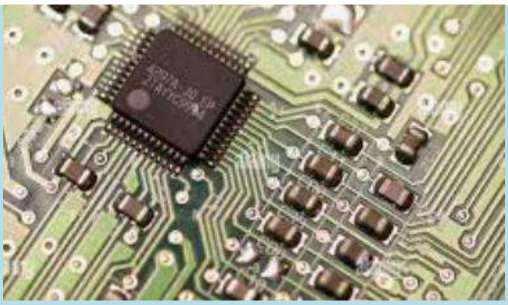
- **Antenna pointing:** In some cases, atmospheric events may cause slight movement of the antenna. It is necessary to correct and, obviously, the operation must be carried out onsite.
- **Radar accuracy in azimuth:** This is a parameter that changes with directivity. The measured values must coincide with the expected ones.
- **Reduction of radar echo caused by obstacles in the path:** There are unwanted obstacles along the signal path. To reduce the echoes provided by them, receive filters are configured. The parameters of these filters can and should be varied to optimize performance.



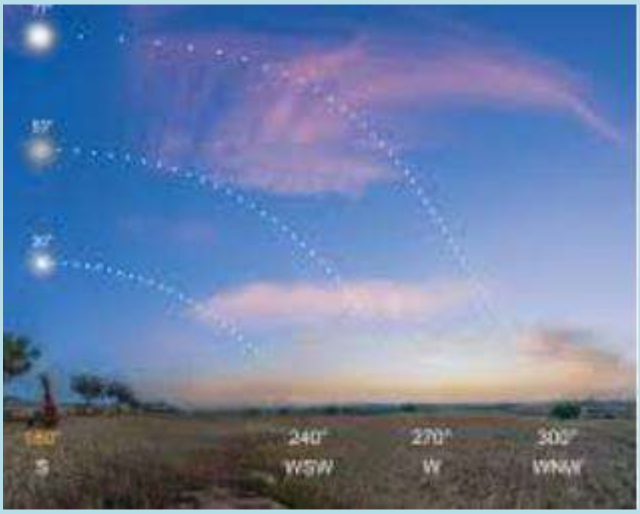
- **Checking the resolution value:** The configuration of the resolution allows to discriminate two echoes if the difference of their delays is greater than the duration of the pulses.

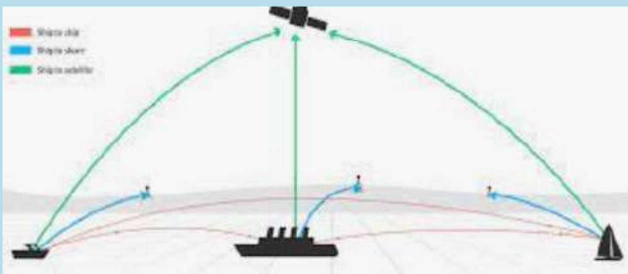


- **Detection speed:** Check the screen refresh rate.
- **Check of internal electrical circuits and components (modulator, oscillator, intermediate-frequency amplifier etc…):** During onsite visits the internal radar circuits must be checked. Eventual failed components must be replaced.

	 • **Scale adjustment (for monitor) and image quality:** Set up for optimal vision.  • **Marine clutter configuration:** The waves generate echoes which can cause problems with the visualization of the targets. However, a strong anticlutter can mask useful signals.
Key operational aspects	An onsite inspection must be carried out at least every 3 months. The radar configuration parameters must be checked at least once a month, but this is also possible remotely. Usually, manufacturers publish the expected lifetimes (mean time between failures) of key components. For radar operators is necessary keep a stock of spare parts; in fact all components can fail at any time. Real-world experience of the durability of different components is exchanged between radar operators. As a radar gets older and the frequency of component failure increases, the operator may start to plan for an upgrade or replacement.
Trouble-shoot	---

LONG DISTANCE CAMERAS Maintenance sheet	
FUNCTION	Periodic maintenance tasks are due to the expected performance in terms of viewing targets and integrating radar information.
Equipment	Refer to the associated Operation sheet.
Suppliers	OEM service contracts.
Layout	
Key technical aspects	Even on long-distance cameras it is necessary to carry out periodic checks. In particular, it is necessary to understand if configurations have changed. The recommended technical checks are: • **Footage quality:** In some cases, footage is blurrier than normal. If the footage that your cameras are capturing is a little out of focus, that's a sign that you need maintenance. It might be the result of damage to the camera or numerous other factors that prevent your camera from displaying a clear picture.  • **Camera lens:** Periodically, it is necessary to adjust the camera lens. This is to ensure that the lens is clean and capable of capturing clear footage. • **Pan-Tilt-Zoom:** It is necessary to test that this function works correctly. • **Remote camera access:** If remote monitoring goes down, probably other key functions of the security camera system may not be operating effectively. In this case the system would require a general check. • **Signs of wear and tear:** It is necessary to do a visual check. • **Recording and storing:** Check that the camera is recording and also storing the footage. • **Weather event:** Check that the camera is working after any major weather event. You can also check the footage that is being recorded to make sure that the camera didn't get shifted during a storm. • **Motion sensing:** If the motion sensing capabilities on the camera stop working or become less sensitive, maintenance intervention is required.
Key operational aspects	Maintenance on the cameras can be done remotely. It is advisable to check the settings at least once a month. There are few operations that need to be carried out onsite. These checks can be done on a quarterly basis. It is necessary to verify: • Any movement of the cameras due to atmospheric agents

	• Broken pieces • Cables correctly connected.
Trouble-shoot	Different nature problems that can affect a long-range camera. They may include: **HEAT REFRACTION** When warm air rises up, it mixes with the cool air above and that creates a difference in air densities. This makes the auto-focusing system of the camera go haywire. There's rarely a solution to this problem except that you need to find a spot where the ground between you and your subject is cooler.  **DIRTY LENS** The contacts between your lens and your camera channel information back and forth between the lens and the camera. If they're dirty, their ability to focus accurately is impaired. **NOT SATISFACTORY VIDEO RECORDING TECHNIQUE** If your technique isn't precise, you're going to get image blur or out of focus results often. Poor technique could be anything ranging from using a slower than optimal shutter speed to an inaccurate tracking movement. **WRONG SENSOR** Incorrect sensor selection can result in poor autofocus performance. When working in low light and low contrast subjects, you will find that this problem is exacerbated by the wrong sensor choice.

AUTOMATIC IDENTIFICATION SYSTEM (AIS) Maintenance sheet	
FUNCTION	Automatic identification systems (AIS) transponders require periodic inspections to guarantee being capable of providing, automatically, position, identification and other information about the platform to other ships and to coastal authorities.
Equipment	Refer to the associated Operation sheet.
Suppliers	OEM service contracts.
Layout	
Key technical aspects	Regular maintenance is required to optimize the performance of the equipment. It is necessary to establish a monthly maintenance program that includes, at least, the following elements: • Connectors: Check regularly that all transponder connectors are firmly connected. • Wiring: Check that the cables are not damaged and replace them if necessary. • Ground terminal: check for rust and, if it is present, clean. • Ground wire: Check that the ground wire of the monitor unit and the transponder are firmly connected. • Monitor: Dust needs to be removed frequently with a soft, dry cloth. Use a detergent to remove salt residues. • It is advisable to encrypt AIS data because cyber-attacks are possible. It is possible to encrypt AIS data. However, if nearby vessels don't have the ability to decrypt the data, the safety benefit of AIS is lost. If all AIS transceivers supported encryption, AIS would be more reliable. However, the problems with key distribution and backward compatibility is significant. Finally, even if all transceivers featured and used encryption, a rogue user could simply purchase a legitimate transceiver from which to transmit tampered data. AIS signals have already been blocked for ships from sanctioned countries. The transmission of unauthorized data can allow those who are subject to sanctions to evade detection. 

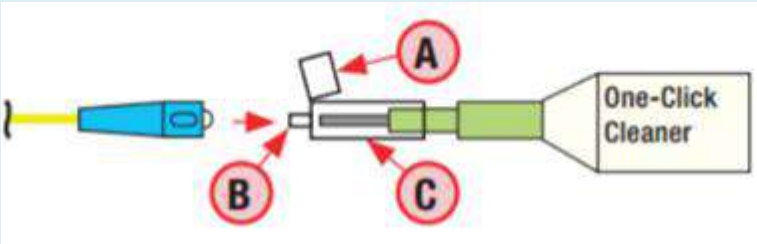
Key operational aspects	With the exception of cable disconnections, access to the AIS can be done from the Local (Remote) Control Room. This means that any reconfiguration, parameter changes etc... can be carried out at any time by accessing the device remotely.
Trouble-shoot	---

SECURITY SYSTEMS Maintenance sheet	
FUNCTION	Maintenance tasks are those typical of standard cameras operating outdoor.
Equipment	Refer to the associated Operation sheet.
Suppliers	OEM service contracts.
Layout	
Key technical aspects	Being cameras, it is possible to extend the previous considerations about long distance cameras.
Key operational aspects	Even the times related to maintenance and the operations to be performed are completely similar to long distance cameras.
Trouble-shoot	---

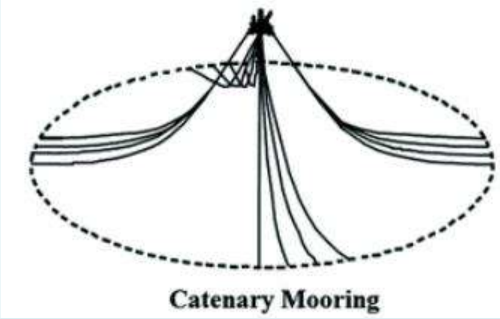
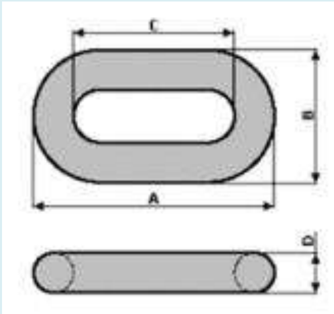
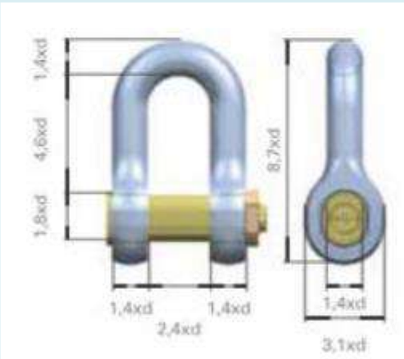
ACCESS CONTROL Maintenance sheet	
FUNCTION	Ensure that only authorized people can access the platform rooms is fundamental for the security of the BGF platform. Robust technology design guarantee long time performance with the scheduled maintenance activity, even in harsh environments.
Equipment	Refer to the associated Operation sheet.
Suppliers	OEM service contracts.
Layout	
Key technical aspects	Checks that must be carried out regularly are the following: • Spare parts replacement (in case of problems). • Possible replacement of old hardware. • Check for lost connection with the cloud or for any configuration changes. • Software and application update installation. • Repair activities, in a laboratory or on the platform, of broken components. • When authorized people change, devices need to be reconfigured.
Key operational aspects	Technical checks on the access system must be carried out onsite at least every two months. Remotely it is possible to make a monthly review of the entry / exit procedures. It is also necessary to ensure that these procedures are effective and followed.
Trouble-shoot	---

A.4 Structural Health Monitoring System

STRUCTURAL HEALTH MONITORING Maintenance sheet	
FUNCTION	Maintenance of Structural Health Monitoring (SHM) system ensure its proper functioning. Cleaning procedure of the single component it is important to guarantee the correctness of the collected data.
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised SHM service supply companies.
Layout	
Key technical aspects	**DATALOGGER MAINTENANCE** The entire performance of the Structural Health Monitoring system is closely linked to the performance of datalogger. For this reason, the datalogger maintenance has a crucial importance. The maintenance routine concerns small but really important steps, that are summed up below (the list is not exhaustive). ▪ Keep the software updated ▪ Replace the worn components (with particular attention to wiring) ▪ Check that datalogger is in a low humidity environment ▪ Remove dust from the inputs of datalogger **STANDARD MAINTENANCE PROCEDURE** Because of IP 66 characteristics of the accelerometers box (watertightness proven under heavy rain and partial submersion, but not in case of entire submersion for different minutes) it is important to check regularly the eventual presence of water within the box, especially after high sea / tidal level conditions. In case of an anomaly, it is possible to recover the system by emptying the box, polishing and drying the equipment. At the end of the procedure, it is crucial to perform a good functioning test in order to test the absence of any damage to the instrumentation as being immerse for the concerned period. If one or more sensors are found to be inoperative, those sensors must be replaced.
Key operational aspects	**OPTICAL STRAIN GAUGE SWS-02 CLEANING PROCEDURE** All fiber optic connectors either inside an adapter or on a sensor's ends or patch cord ends are featuring a protective cap, a.k.a. "dust cap" protecting the end face of the connector from damage.

	To minimize the damage of the fiber optic connector it is recommend cleaning the end face with appropriate tools always before mating them inside the fiber optic adapter (coupling). The steps below demonstrate the cleaning procedure of fiber optic connector using FCS-01 One-click cleaner (or similar). The FCS-01 One-click cleaner (Figure 1) can be used both: ▪ for cleaning the connector inside the adapter (like in the interrogator), and ▪ for a free end connector (like in the sensor's end or a patch cord).  **Figure 1. FCS-01 One-click cleaner** To switch between these two modes, adjust the protective dust cover cap located on the tip of the FCS-01 One-click cleaner (Figure 2).  **Figure 2. Adjusting the protective dust cover cap on the One-click cleaner** **CLEANING THE CONNECTOR INSIDE THE ADAPTER** In order to clean the fiber optic connector inside the adapter it is necessary to remove the protective cap from the adapter (typically a small white plastic screw-able cap). In particular, it is recommended to follow the steps summed up below (refer to Figure 2): ▪ Remove the protective dust cover from the tip of the One-click cleaner ▪ Insert the tip of the One-click cleaner into the optical port adapter and gently press the body of the One-click cleaner until an audible "click" is heard ▪ Remove the One-click cleaner **CLEANING THE CABLE AND CONNECTOR (i.e., sensor's end or patch cord)** In order to clean the fiber optic connector inside the adapter it is necessary to remove the protective cap from the adapter (typically a small white plastic screw-able cap). In particular, it is recommended to follow the steps summed up below (refer to Figure 2): ▪ Flip open the protective dust cover cap. ▪ Slide the connector into alignment sleeve of the One-click cleaner and gently press the body of the One-click cleaner until an audible "click" is heard. ▪ Remove the One-click cleaner.
Trouble-shoot	---

A6. Mooring System

MOORING SYSTEM MAINTENANCE Sheet	
FUNCTION	The purpose of mooring inspections is to check for deviations along the line, around the moorings, and at the sea bottom in order to establish any preventive or corrective actions to be deployed. Assistance based on monitoring systems, as described in the Operation sheet, further contribute to timely detect problems and then drive maintenance actions.
Equipment	Refer to the associated Operation sheet.
Suppliers	Specialised mooring service supply companies.
Layout	  
Key technical aspects	**Data available for maintenance tasks planning** The Condition Based Maintenance (CBM) provides the technical instruments to intervene upon the condition of the mooring system and not with a fixed time intervals. The challenge is to predict the remaining lifetime of the mooring component concerned, visit after visit. Useful entry points are the observations at inspection points and also data from mooring system´s condition monitoring activity. These tests are not “fail or pass” measurements like at the as-laid inspections, but their purpose is to follow the evolution of the mooring system and to plan appropriate maintenance activities. Mooring inspections are typically carried out by ROVs. Several ROVs can go down to 500-800 meters. They can cover a larger area since their operational time is unlimited by the umbilical. The ROVs are powered by the boat and therefore can operate for days at time. Checking items are given in the following table:

Item under analysis	Potential location	Eventual barriers / difficulties
CHAIN		
General inspection	All over chain	Need to clean chain and access difficulties at and below mudline
Tension-tension fatigue	Half-crown intrados (most common location)	Very difficult to see or get any access to the area as it obstructed by the adjacent link
	Crown extrados (another relatively common location)	Reasonable access, particularly in studless chain when the adjacent link is not as obstructive
	Flash butt weld (occasional location for fatigue)	Good access to outside, but more difficult on intrados.
Out-of-plane Bending Fatigue	Chain link at the bell-mouth	Access impaired by bell-mouth in most cases.
General corrosion	All over chain	Visual gives some information. Measurements can be taken if needed.
Pitting corrosion	All over chain	Visual normally adequate
Interlink wear	Contact point between links	Need to measure the double diameter of the two links at the contact point.
Dimensional anomalies	Length over a number of several adjacent links	Measure of relatively large distances with sufficient accuracy can be difficult.
Mechanical or installation damage	All over chain	Visual normally adequate
Twist in chain	All over chain	Need reasonable visibility to be able see twist over number of links
CONNECTORS		
Misalignment	Between connector and connected components	Visual normally adequate
Corrosion	All over	Similar to chain
Inter-component wear		Similar to chain interlink wear
Loose pins, lost retainers, etc	Visual	----

Different chain configurations

In deeper water, an all-chain system may become too heavy. The weight of chain causes the catenary shape to dip, then the angle at the top of a mooring line becomes steeper. The result is a less-efficient mooring system that provides a reduced restoring force to the floating platform. In these cases, wire ropes can be utilized in a mooring system. Because of its lighter weight, wire rope alleviates the weight challenge found with all-chain designs, meanwhile offering a higher restoring force at the same given pretension because of the less-steep catenary shape of lighter mooring lines. Specific inspection requirements are also available for wire ropes.

Key operational aspects

Mooring line replacement

A mooring line failure during operative life of floating structure is not unlikely. Design is such to keep the probability of a mooring line failure as low as economically possible by considering redundancy or safety levels. However, if one mooring line breaks, design is to ensure that the remaining mooring lines and anchors are not overloaded and that the structure will not break free completely. After a mooring line failure, it is reasonable to replace the mooring line at site. Mooring line replacement feasibility using Anchor

	Handling Vessels (AHV) allows for an effective and economic line replacement option. A potential procedure for mooring line replacement depends on installation site characteristics and it is very often matter of contract assistance with the supplier who deployed the mooring system for the first time.
Trouble-shoot	---

Annex E. Responsibility profiles description

N°	Role	Responsibility profile description	Professional grade
1	Control Room Operator	Whole infrastructure management by supervising a dashboard of signals and commands available at console and displays level.	Engineer
2	Fish Production manager	Fish welfare through a lot of data recorded from sensors in real time and duly processed to produce continuous fish state awareness and then to drive relevant actions, based on both manned and automatic means.	Biologist
3	Energy Systems Manager	Planning of electric energy consumption to maximise consumption energy efficiency on site and stabilising the output release to the grid.	Engineer
4	Deck operations responsible	Operations carried out in floating conditions (crane movement, O&M of combined wind, wave and PV electric energy stations, etc.), follow up procedural protocols and safety practises.	Expert Technician
4	Automated ship docking & recharge control manager	Automated operations of service vessels dedicated to the BGF infrastructure logistic process	Expert Technician
6	Aquaculture biologist	Fish welfare and curing. Microalgae efficiency monitoring	Biologist
7	Husbandry staff	Aquaculture activities	Skilled Worker
8	Mechanical staff	Contribute to mechanical O&M activities	Skilled Worker
9	Electrical staff	Contribute to electrical O&M activities	Skilled Worker
10	Divers	Carry out underwater inspections	Skilled Worker
11	Remote Control Room Operator	Whole infrastructure management by supervising a dashboard of signals and commands available at console and displays level at remote control room	Engineer