RELIABILITY IN A SEA OF RISK

Training Requirements

June 2018

Wello WEC at Billia Croo wave test site, Orkney © Colin Keldie courtesy of CEFOW

Project Information

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1 Introduction

1.1 RiaSoR background

The goal of the RiaSoR project is to consistently learn from the physical interactions between the devices and their environments, while embedding this understanding and building robustness into marine energy technology designs to improve reliability.

Marine energy devices operate in harsh environments but still need to perform reliably and produce an expected amount of energy, which gives rise to huge engineering challenges.

The OceanERANET-funded RiaSoR 2 project will use the theoretical reliability assessment guideline for wave and tidal energy converters (WEC/TEC) developed in RiaSoR1 and apply it to the field.

This will enable WEC/TEC developers to validate their findings, and establish a practical condition based monitoring platform to prepare for future arrays where big data handling and processing will be vital to drive down operational expenditures (OPEX).

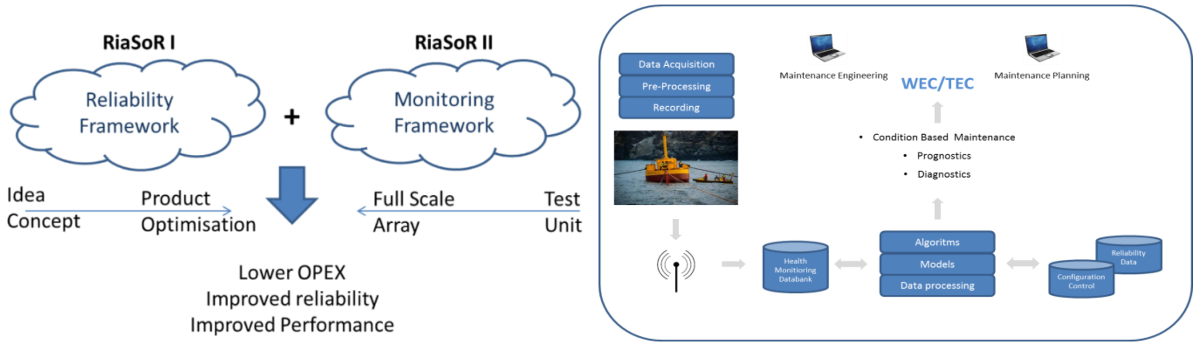

Figure 1 RiaSoR 1 & RiaSoR 2 overview

The RiaSoR 1 reliability guideline built upon established practices from the automotive industry where a monitoring framework is applied to a fleet of test-vehicles. Through design iterations, the reliability is improved and a final reduced set of sensors are deployed in the commercial vehicle.

For RiaSoR 2, the chosen components for monitoring are equipped with several sensors to collect the required data, which will then be fed into the reliability process to reduce uncertainties. Sea tests act as case studies to feed the methodologies and training into the guideline. The findings from this will then be trialled with the other developers.

The key objective of the RiaSoR 2 project is to offer a comprehensive suite of testing methodologies to wave and tidal developers that will enable a systematic approach to achieve optimal reliability and performance, while minimising cost and time-to-market.

2 General

2.1 Introduction

A condition monitoring system (CMS) will measure the vibrations, failures and structural fatigue of the wave energy converter (WEC). The CMS will detect any abnormal behaviour in different components of the WEC, for example the structural, electrical or hydraulic sub-systems and other operational parameters such as pre-tension and entanglement of moorings.

Data from sensors is assessed against the pre-installed limiting values for the comparable component. If the CMS detects that the limiting value has been exceeded the monitoring system will then proceed to alert the appropriate body. CMS systems are sufficient to perform the monitoring function without the need for any additional device. The CMS can also be semi-integrated or fully integrated into the control system.

The performance of the condition monitoring will strongly depend on the translation and assessment of the data collected. The CMS for the WEC must translate and assess the measured values in a view of providing the most accurate high-quality results.

2.2 Training Requirements Overview

This documentation provides various sections which will provide a statement of requirements for a User Training Package. The sections will be as follows;

1. General information on wave energy CMS and the general requirements for relevant CMS certification. Relevant condition monitoring standards and guidelines which can be used in WEC design are provided in this section. These standards are often referred to in the offshore wind sector.
2. A list of proposed requirements will be provided regarding operators, manufacturers and the CMS.
3. Information regarding suggested relevant training for the installation, operation, commission and maintenance of WEC CMS.

2.3 Work Package 5 Aim and Scope

This training package (TP) provides a breakdown of the requirements for a CMS for WECs providing the foundations of the design and installation of WEC CMS and provides an outline of conditions regarding measured data. Areas include assessment of data, interpretation of signals and data storage. The TP will also refer to procedures that will take effect as and when the system detects the breach limiting values.

The aim of this work package is to provide a common developer training platform which will describe the scope and extent of activities performed by a CMS for a wave energy device and the relevant requirements for the design and operations of the CMS.

2.4 References

The TP makes use of various relevant international and European documents. This section provides a list of documents used regarding requirements and certifications.

General procedures which must be considered when setting up condition monitoring within sub-assemblies of machines like the WEC are also included. The following tables are presented as references and documentation of relevant standards and procedures for the condition monitoring framework which will be produced in RiaSoR 2.

ISO Code	Description
ISO/IEC 17020	Conformity assessment – requirements for the operation of various types of bodies performing inspection
ISO 17359	Condition monitoring and diagnostics of machines – general guidelines
ISO 4406	Hydraulic fluid power – fluids – method of coding the level of contamination by solid particles
ISO 5348	Mechanical vibrations – vibration and shock – mounting of accelerators
ISO10816- 1	Mechanical vibrations by measurement on non-rotating parts – guidelines/evaluation
ISO 13373-1	Mechanical vibrations - Condition monitoring/ diagnoses of machines.

Table 1 ISO Standards

IEC Code	Description
IEC 61400-13	Wind turbines -Mechanical load measurements/verifications
IEC 61400-22	Wind turbines -Conformity Testing and Certification
IEC 61400-25	Wind turbines -communications for monitoring and control of wind power plants. General procedures

Table 2 IEC Standards

VDI Code	Description
VDI 3832	Structure-borne sound – rolling element bearings within the machine for evaluation of state condition.
VDI 3834- 1	Wind turbines - Mechanical vibrations – turbines and components
VDI 3834- 2	Typical vibration patterns for electrical machines

VDI 3839- 1	Mechanical vibrations of machines- measuring and interpreting
VDI 3839- 2	Mechanical vibrations of machine – unbalance, bearing faults, incorrect assembly and damage to rotating components
VDI 3839- 5	Mechanical vibrations of machine – typical for electrical machines
VDI 3824-2	Quality Assurance of PVD and CVD hard coatings.

Table 3 VDI Standards (Association of German Engineers)

Other	Description
DNV-GL-0439	Certification of condition monitoring technical requirements *DNV GL standards*
DIN 31051	Fundamentals of maintenance *German Institute for Standardisation (Deutsches Institut für Normung)*

Table 4 Other Standards

3 General Requirements

This chapter refers to the general specification of the WEC, such as the type, speed and control system of the WEC. The following is a list of the minimal number of components that must be documented.

- Gearbox
- Generator
- Blades Bearings
- Hydraulic system
- Coupling

Each component requires documentation of the model type, manufacturer, designation, design, model type, manufacturer, mesh frequencies of all mating gears and any other specific structural features which must be considered during the diagnosis for the purposes of this service specification (DNV-GL-0439).

The WEC operator is responsible for performing the monitoring tasks, this data from the CMS should be made available to the WEC operator. The corresponding manufacturer is then responsible for stating, on enquiry, whether sensors can or cannot be applied to the positions in question. The signals produced from parameters such as the speed, output and oil temperatures which are necessary for the CMS and the later analysis of the measured values shall be provided when required.

Any replacements of the WEC components must be alerted to the operator accordingly and the required data of the components should be provided and any necessary calibration should be performed. Manufacturers providing technical replacements should have industrial application know-how of the offshore renewable sector.

4 Condition Monitoring Requirements

4.1 General Requirements

There are multiple requirements which must be addressed when discussing the purpose of the CMS. The main requirements are presented below:

1. The monitoring of the WEC with a CMS should be a permanent employment. Individual measurements are not effective for analyses and trends.
2. The CMS should be designed to work under extreme environmental constraints such as extreme temperatures and offshore rough terrain.
3. CMS components should be industrial standard.
4. The CMS must feature at least 8 measuring channels for appropriate coverage of the WEC. The possibility of increasing the number of measuring channels should be available.
5. Appropriate storage media shall be used and a backup data storage facility should be provided.
6. A constant power supply shall be provided for the CMS. In the event of a power failure, procedure shall be taken to ensure that the measured data is buffered within the CMS until the data can be transferred safely.

4.1.1 Safety Requirements

1. The CMS will not replace the maintenance and inspections of the WEC if requested by the manufacturer of the WEC.
2. The existence and design of the CMS may be considered during the developing and execution of the maintenance plan of the WEC.
3. A CMS is not to be used as a replacement for independent safety systems. A CMS will not be a replacement for standard systems for the acquisition of operational data of the WEC.
4. When equipping WEC with a CMS, it must be ensured that there is no interruption of the safety and control system of the WEC.

4.1.2 Limiting value

1. The breach of the limiting value (LV) will be delivered automatically by the CMS to the main body computer of the CMS in form of two alarm messages- warning alarm, and then the main alarm.
2. The breach of the LV will not be interpreted by the control system, no data can be lost in translation.
3. There must be a clear definition of what data is from generic operation-dependant sources and condition-dependant measured sources.

4.1.3 Access

1. The CMS should be safe against any unapproved third parties. Due to the risk of unjustified access, access rights must be allocated.

2. Help/ instruction functions and menus will allow simple access without specialist IT skills.

4.1.4 Diagnoses

To prevent the failure of the CMS going undetected, an integrated diagnosis system should be integrated which will oversee all components regarding their durability and operation.

4.2 Wave Energy Converters

There is a wide range of wave energy technologies, each using different solutions to absorb energy from waves depending on the water depth and location. Wave energy devices can be categorised into six main types:

1. Attenuator - relative motion between each pontoon can be converted to mechanical power in the power module, through either a hydraulic circuit or some form of mechanical gear train.
2. Point absorber - structure can heave up and down on the surface of the water or be submerged below the surface relying on pressure differential.
3. Oscillating wave surge converter - arm oscillates as a pendulum mounted on a pivoted joint in response to the movement of water in the waves which then moves in a back and forth motion, exploiting the horizontal particle velocity of the wave.
4. Oscillating water column - trapped air can flow to and from the atmosphere via a turbine.
5. Overtopping device - devices capture water as waves break into a storage reservoir.
6. Submerged pressure differential - motion of the waves causes the sea level to rise and fall above the device, including a pressure differential in the device.

Figure 2, presents the concept of the different main types of wave energy converters which were defined by the RiaSoR I project.

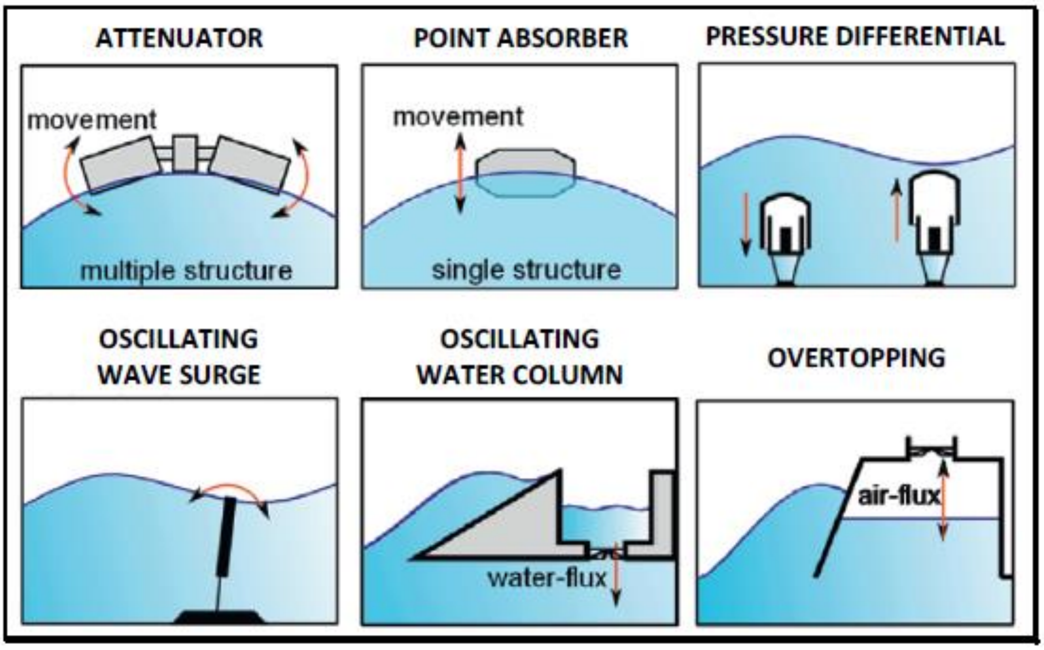

Figure 2 Wave energy converters design concept (Titah-Benbouzid & Benbouzid, 2015)

4.3 Failure Modes

Common monitored parameters in offshore renewable generation are humidity, oil moisture content, speed and vibration. Each parameter depends on both the sub-system and corresponding failure mode.

Condition monitoring to be deployed in the WEC should be able to monitor the condition of the following critical equipment:

- Structure
- Power take off
- Mooring
- Electrical power transmission and distribution
- SCADA and control

The most common wave energy converters can be divided into 5 main sub-systems to be measured by a CMS:

- Moorings
- Structural
- Hydraulic
- Electrical
- Instrumental

There must be clear documentation on which areas are monitored and what types of damages the sensors are capable of detecting.

4.4 Detection Methods

When a function test is to be performed on the WEC, the arrangements made according to the measured values and sensor technology (such as frequency ranges, position of vibration sensors and type of coupling) must be specified in detailed documentation for the WEC and must be justified.

Any condition monitoring system used must require the most state of the art developments of early fault detection.

Each sensor/method of detection must be able to meet all the following criteria to provide effective failure detection:

- Accuracy: The signal is closely representing the actual measurand that is being monitored, while also detecting the smallest of changes in value.
- Repeatability: Consistent reproduction of the same output signal for repeat application of the same value of measurand.
- Cost effective: Using sensors which are effective for early detection, while keeping the cost low. Consider that the most expensive sensors may not be required for certain measurements.

- Long term stability: Long term monitoring in controlled conditions. Likely that experienced manufacturers and knowledge of the components will increase the quality and the lifetime of the sensor.

4.4.1 Vibration Analysis

The appropriate frequency ranges must be selected for the vibration sensors, depending on the component to be monitored.

The number of sensors used for vibration monitoring of the WEC depends on the structural design. Certain circumstances will make it necessary to perform trial measurements to optimise the positions for the sensors.

The sensor should be attached as near to the component as possible and in the loading area, in the direction of the maximum loads. The sensors must be mounted with ceramic glue, screwed or coupled on to the device (DNV-GL-0439).

It must be considered that some high-frequency ranges will result in disruption of the measured signal results (VDI 3824-2).

4.4.2 Oil Analysis

The cleanliness of the gearbox must be constantly monitored (ISO 4406). Parameters such as time, operational situation of the WEC, oil temperature, and the cleanliness values shall be stored accordingly.

4.4.3 Humidity Sensors

For a humidity sensor to be robust it must be able to recover from condensation and be resistant to chemical and physical contaminants. It must be considered that designing with a capacitive humidity sensor is limited by a distance allowance from the corresponding circuitry, with a practical distance less than 10ft.

4.4.4 Water-leak Detection

To detect any change in the watertight seal water level detection systems are used. The condition monitoring system can detect any leakage to avoid water damage to the WEC generator and circuitry.

4.4.5 Strain Gauges

Each new installation of a strain gauge a new calibration must be set depending on the parameters of the WEC.

The fibre optic strain gauge is in times better in comparison to the original strain gauge as the sensors are completely passive and immune to issues like electromagnetic interference.

4.4.6 Electrical sensors

Eddy current inspection can be applied for the detection of fatigue cracks on the WT towers and could be used in WECs. However, encircling coils have been lately applied for detection of debris in the lubricant as mentioned earlier in this section. Any metallic debris ferrous or non-ferrous passing through the encircling coil will change its impedance response.

Motor Current Signature Analysis or MCSA is used to detect unusual phenomena in electrical components.

4.5 Signal Properties

The data acquisition system for the WEC must be compatible with the chosen detection methods and the corresponding analogue circuits. For the analogue signals to be processed by the computer the analogue signals are converted to digital signals. When working with analogue signals sufficient screening shall be provided.

CMS uses detection methods with analogue signals which must be manipulated before being digitised. For measuring these signals various documented requirements are relevant and must be recognised (ISO 5348, VDI 3839-1, 2 and ISO 13373-1)

The sampling theorem for the detection signal must have the sampling rate at least twice as high as the highest signal frequency (VDI 3839-1 and 2).

4.6 Data Acquisition

DAQ measures electrical and mechanical changes, from the failure modes with a computer system. The DAQ system consists of the detection methods, the actual DAQ device and the computer system.

The Analogue to Digital converter is within the DAQ system hardware and will convert the conditioned signal to a digital output which will be accessible by the computer system of the CMS.

To detect the smallest of changes in the input signals the highest resolution must be used. Resolution is the unique binary levels an ADC uses to represent the analogue signal.

The DAQ must be accurate to detect early stages of failure. The accuracy will never be greater than the chosen resolution of the device. An ideal measurement of accuracy would of course be 100% although real-life practical factors mean that devices will record uncertainties.

4.7 Signal Processing

When processing signals in the CMS, it is required to amplify and filter the collected signals. The processing will determine between normal operation-dependent signals of the WEC and any damages or unbalances.

Due to the high speed and accuracy requirements of the CMS, a special purpose digital signal processing (DSP) chip may be required to perform certain signal processing procedures. In current technology signal processing is achieved digitally. Digital circuits are becoming progressively cost-effective and faster, with characteristics such as repeatability and consistency compared to analogue signals.

4.8 Data Storage

To maintain appropriate failure rate data analysis of the CMS a collection of data will be collected and stored to form accurate conclusions regarding failure modes and the integrity of the WEC.

4.8.1 Reliable Data

The data must be stored even if there is no exceeding of the limiting value to create a large database of data. Depending on the importance of the data, the data could be stored once a day.

The storage of reliable data is dependent on the avoidance of data reduction. It is crucial to store only data which is comparable and which contains consequential constraints which will be stored together with data. By regular transfers of data to an industrial PC the data storage on site can be kept small.

4.8.2 Raw Data

During the first measurement phase the raw data from the original sensor signals must be collected and stored with data involving the external physical conditions.

The raw data should be stored at least once a day.

4.9 Communication Architecture

For data transfer in some cases, only telephone lines are practical choices. The installation of a server in the WEC site could carry out the analysis and then transfer the analysed data to the industrial PC.

IEC 61400-25 addresses all aspects of communication architecture for the monitoring and control of wind power plants. Wave energy developers can make use of this standard for the development of an established communication architecture. There are also other different standards for the communication network requirements of power system, including IEEE C37.1 for SCADA and automation systems, IEEE 1379 for the interoperability of IEDs and RTUs, and IEEE 1646 for communication internal and external to the electric substation.

4.9.1 Wave Energy Converter Area network

WEC devices consist of different parts, such as the prime mover, generator, structure, etc. Each part is equipped with different types of sensors, actuators, and measuring devices.

IEC 61400-25 provides information on the critical parts within the generating device identified by logical nodes (LN). e.g. wave device prime mover information (WDPM), wave device generator information (WDGE), wave device structure information (WDST), etc.

4.9.2 Farm Area Network

The wave energy park may consist of several WECs, a meteorological buoy, and control centre. WEC devices will usually include local SCADA systems as a part of the wave energy park where the SCADA function is to communicate with the different WECs, send and receive information, and execute start/stop commands.

4.9.3 Control Area Network

The main function of the control centre is to continuously and efficiently monitor the wave energy park. The local control centre is dedicated to a single wave energy park and is responsible for collecting information from the WECs, meteorological buoys, and substations.

5 Suggested Training

The following overview is a selection of suggested training for those involved with the installation, commissioning, operation and maintenance of a WEC CMS.

5.1 Installation of the condition monitoring system

Training should be provided on the procedure of the installation of the CMS at the location of installation. This will be on site of the WEC and will provide safe operation when installing the CMS. The training will be relevant to the type of CMS chosen and may be appropriate on other types of CMS depending on the various types.

The installation training must be so that the technical personnel involved and in charge are able to understand.

For the training to be successful it must include precise classification of the of the type of CMS to be used. The condition of the installation must be clear along with each step to be performed in the install. Health and safety must be addressed with all involved and all must be warned against all hazardous situations.

5.2 Commissioning of the condition monitoring system

Training should be provided on the procedure of the commissioning of the CMS to provide safe work and operation of the CMS. The training will track each individual working step during commissioning.

The commissioning training must be so that the technical personnel involved and in charge are able to understand.

Safety and regulation training to prevent accidents should be provided and highlighted for those involved to clearly note. The work and safety checks required for commissioning should be provided to staff through training.

5.3 Operating of the condition monitoring system

Training should be provided for the operator to give knowledge of the operation of the CMS and should be at the level of detail that a skilled worker with technical know-how can understand.

This training should provide a description of the CMS, notes for using the CMS and advise for any problems that are likely to occur.

5.4 Maintenance of the condition monitoring system

Maintenance training should contain instructions and guidelines for maintenance, inspection, various repairs, safety measures and accident prevention methods.

A breakdown of each components and replacement instructions should be provided as well as inspection and assessment procedures.

A detailed list should be given with all required tests and required frequency tests. Training should be also provided for documentation/logging of all results collected.

RiaSoR 2 project partners

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