Online corrosion monitoring on foundations validating corrosion protection strategy

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Figure 1 Transition piece with monitoring plates with probes installed to the left, to the right an offshore foundation with tower and turbine

Online corrosion monitoring for offshore wind application has been developed and matured jointly by Ørsted and MetriCorr since 2015.

Operation and maintenance of offshore wind is challenging and costly, a challenge which is becoming bigger with bigger sites, bigger structures, and having sites placed further and further offshore, and hence with a limitation on accessibility for any operation and maintenance activity.

Following and documenting integrity of structures has therefore become increasingly important, also as structures are optimized to keep the cost of electricity down, and any unforeseen or unforeseeable maintenance and repair activity may penalize the business case.

Measurements and inspections of structures are performed on a regular basis using visual inspections and using manual equipment. Results from manual measurements are however subject to uncertainty and inaccuracy and in some cases manual measurements cannot provide information on the structural integrity, for instance below seabed or in the tidal zone.

To address the need for design validation and enable planned maintenance activity, Ørsted has become frontrunner in applying online measurements and evaluating unique long-term corrosion measurement data utilizing ER (Electrical Resistance) sensors and loggers. A variety of sensors have been installed internally and externally, above and below seabed at selected foundations on in total nine operating OWF up until 2022, and is planned for installation also on upcoming assets. This paper describes the measurement principle, the rationale behind the monitoring and some of the learnings so far.

Introduction

Ørsteds fleet of offshore wind foundations has since 2016 been equipped with online corrosion condition monitoring. This comprises technical advanced condition monitoring of the foundations using MetriCorr technology. The key objective is to directly monitor and document the performance of the corrosion protection system in place, thereby validating the design, reduce operation and maintenance costs and with a potential to increase service life.

Offshore wind structures represent a growing industry where the foundations become larger in size with increasing in number and with increasing distances to shore. This makes operation and maintenance more and more time consuming and costly when based on physical access to the structures, which is how it is done in most cases.

In comparison to offshore oil & gas installations, which are manned and few in number, offshore wind is unmanned and with approaching 200 foundations per site. Maintenance and access for inspections is costly and challenging requiring extensive logistics. Online monitoring of representative positions can therefore be of significant value, supporting an ambition for planned maintenance but also as a tool to design validate the protection strategy.

Why corrosion protection?

Corrosion is the degradation of metals exposed to a harmful environment such as seawater resulting in loss of material ranging from uniform loss to more localized loss of material.

Structural calculations for fatigue sensitive structures such as offshore wind foundations highly depend on the conditions of the structure. In case corrosion takes place, this is taken into account using so-called “free corrosion SN-curves”, which in many cases are design drivers for the material thickness used in a fatigue sensitive structure. If corrosion takes place during operation and not encountered for; this can adversely affect the service life of the structure, and thereby highly impact the business case going forward.

Optimized structural designs have intensified the need for confirming the applied corrosion protection strategy, which may include some level of corrosion. Being able to confirm the corrosion protection strategy is therefore of paramount importance, for instance to which level full cathodic protection from the anodes is assumed and the no corrosion scenario below seabed.

Value creation

The corrosion protection of the immersed part of an offshore wind structure is a combination of coating and cathodic protection. Corrosion monitoring is installed to provide information on the efficiency of these systems.

Instrumentation is selected with a purpose to create value for the project when providing foundations with a monitoring system. This is short term design validation, but also with a view for long term documentation of the selected corrosion protection system. The online system is considered superior to any manual measurement system you can adapt.

Documenting the level of protection in the tidal zone is directly linked to the structural design and the ability to repair going forward. The tidal zone is the bigger challenge where it comes to coating repair, and is also an area where high flows, especially where large tides are present, provide a challenge to any coating system applied.

For the area below seabed Ørsted has an adapted method of selecting positions for monitoring which represent the highest risk of corrosion. The corrosion risk is evaluated based on soil samples being analyzed for chlorides, sulphates, organic content among other. If the areas with the highest risk for corrosion can be shown to be protected against corrosion, we are confident that other areas on neighbor foundations with a smaller corrosion risk are also protected.

Conventional performance monitoring using drop cells and gravimetric coupons

Performance measurements of cathodic protection systems, as specified in cathodic protection standards, for instance the newly published EN ISO 24656 Cathodic protection of offshore wind structures comprise drop cell measurements. This technique utilizes an electrode being lowered (dropped) into the water and record the potential difference between the structure and the electrode. A potential more negative than -900 mV vs Ag/AgCl is taken as an expression that the structure is protected against corrosion.

Challenges when using Drop cell measurements:

- Measurements only possible when the electrode is in water. This means that a measurement where the electrode is placed at low tide, cannot inform on level of protection at higher tide, and vice versa. Adding to this is the fact that cathodic protection is only efficient when water is present, the drop cell technique cannot inform if the level of protection is adequate for instance at mean sea level
- Measurements with distance to the structure are subject to errors (voltage drop in water and marine growth on steel surface affect the measurements)
- Measurements are not possible at all locations (only in the water column, not at inaccessible areas like below seabed)
- Only information on potential and not if corrosion is actually taking place or has been arrested.

One way of overcoming the limitation with drop cell and errors, is in some cases to use what is named as a stabbing electrode, where the structural connection and the electrode is in one unit and measurements done by stabbing the structure. This can be done using divers or ROV (remote operated vessels), but is expensive, provides a safety risk and will cause damages to the structure, where this is coated.

The common way to investigate the actual material loss due to corrosion is by exposing gravimetric coupons, which requires costly physical retrieval of coupons, elaborate analyses and only gives one point of data on accumulated corrosion rates.

Electrical Resistance Technology

The use of ER (electrical resistance) technology overcomes the above challenges, as reduction in (exposed or coated) steel thickness can be measured directly and continuously utilizing the electrical properties of the material and without an electrolyte (water) being present. This is a major benefit especially in the tidal and splash zones, where it in this way is possible to directly measure if corrosion has been arrested.

Further, below water in the immersed zone, the MetriCorr developments of the ER technology make it possible to document the protective current flow to the sensor installed, and thereby confirm that protection is achieved, regardless of which potential the drop cell measurements show. This enables an evaluation if further actions such as retrofit with anodes are needed, in case drop cell measurements show that the protective potential is not met. If current is flowing and no corrosion takes place, retrofit can be postponed or maybe even disregarded.

ER principle and probes

$$R = \rho_m \cdot \frac{L}{W \cdot d}$$

R: electrical resistance of element

ρ_m: material specific resistivity
L: length of element
W: width of element
d: thickness of element

Electrical Resistance (ER) is a proven technique for measuring corrosion rates in all media, such as water, sediment and air, hence well suited for the offshore application both above and below seabed.

With high accuracy, the electrical resistance of a metal element with defined dimensions is measured by sending a small electrical current through the element, measuring the resulting voltage and thereby calculating the resistance of the element. If the thickness of the element decreases due to corrosion, the resistance will increase. Measuring the change in resistance over time will in this way generate a direct measure for the corrosion rate.

Online Corrosion Monitoring

Since 2015, Ørsted and MetriCorr have collaborated on maturing, developing and implementing online corrosion monitoring in offshore wind foundations typically consisting of ER sensors and reference electrodes, but also adding resistivity sensors.

The continuous data obtained by ER sensors and associated reference electrodes is transferred using a bespoke multi-channel data acquisition system (placed inside the transition piece or tower) into the Ørsted data lake, from where data can be evaluated remotely on a continuous basis.

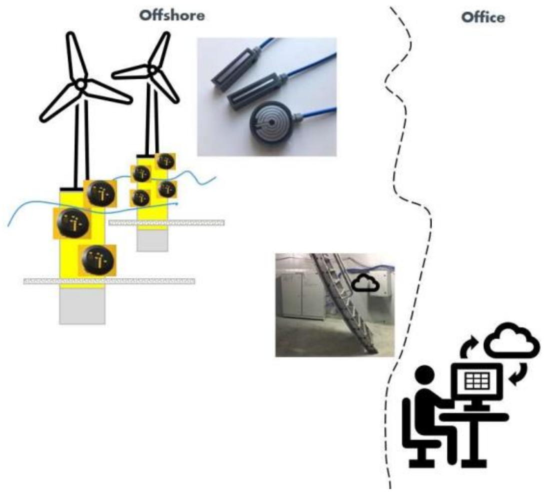

Figure 2 Set up of Online Corrosion Monitoring transferring data from the offshore system to allow for remote analysis from the office

The first online corrosion monitoring system came into operation in 2016 and by 2022 a variety of tailored corrosion monitoring systems have been installed and are measuring at numerous wind farms around the globe. More systems are planned for upcoming Ørsted wind farms in the coming years.

The ER sensors are electrically connected to the structure, thereby receiving similar protection as the structure from a cathodic protection system.

Reference electrodes are installed enabling structure to electrolyte potential measurements. Furthermore, it is possible to support the measurements of ER-sensors by including sensors measuring environmental parameters such as dissolved oxygen (DO), pH, resistivity and water level in the monitoring set-up providing an increased insight into the corrosion environment.

Furthermore

- Pitting corrosion ER sensors (ER-P) can be included in location where the structure is sensitive to fatigue and
- Coated ER sensors (ER-C) can be included for evaluating coating performance

Up to pile toe level below seabed

ER sensors can be applied at pile toe level below seabed to measure the general corrosion.

The data in Figure 3 illustrates that it in this way is possible to monitor the metal degradation below the seabed as deep as at pile-toe level, confirming a design assuming "no corrosion".

Continuous measurements over years can confirm no corrosion, which represents valuable data for Ørsted to validate predictions and corrosion risk evaluations conducted in the design phase, and also if against expectations the situation change, enabling mitigation to be taken, securing the integrity of the asset.

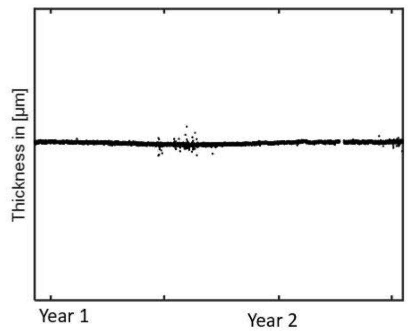

Figure 3. Change of material thickness (derived from the measurement of electrical resistances) over a continuous time of measurement over in total more than a year showing no material loss at pile-toe.

Corrosion in the tidal zone

Validating the corrosion protection by drop cell measurements is especially difficult in the tidal zone with intermittent wetting.

The data illustrated in Figure 4 shows the direct measure of change in thickness for both a general corrosion sensor and a coated corrosion sensor mounted in the tidal zone on an offshore foundation. Even small changes in the trend of corrosion can be identified using the general corrosion sensor exposing bare steel to the environment and with this simulating the impact of a small coating defect on the structure. To allow for a direct comparison with the measurements to the present structure, coated sensors are installed confirming no corrosion and documenting coating as an efficient barrier against corrosion.

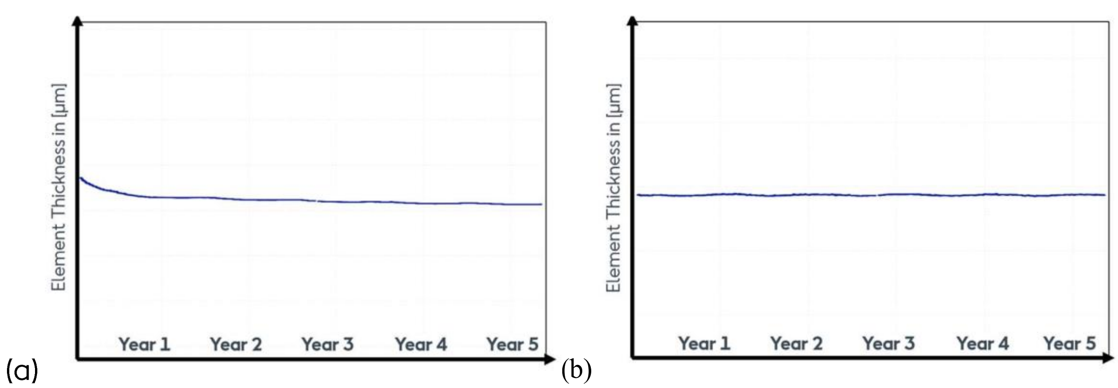

Figure 4. Changes of the thickness (derived from the measurement of electrical resistances) over a continuous measurement time of in total five years for (a) a general corrosion sensor (ER-G) and (b) a coated corrosion sensor (ER-C) in the splash zone around mean sea level. The ER-G sensor can identify small changes in the material loss

as the material is exposed to the environment without any protective layer. The coated ER-C sensor confirms that protection is present below the coating applied to the sensor.

Combining ER technology with potential measurements for the same location enables a direct comparison to measurements of the material condition provided for example by ER-G sensors as shown below. Figure 5 shows the thickness change measured by an ER-G sensor and the corresponding electrical potential measured for the same measurement time by a reference electrode exposed at the same location. In this case early on in the service life of the asset (first 3 years after installation), there is no corrosion and the potential also indicate protection. However, later in the service life, in case the protective criterion is not fulfilled, the thickness and current flow to or from the ER sensors will provide information on if corrosion is actually taking place and mitigation is needed or if no corrosion is taking place and mitigation can be postponed.

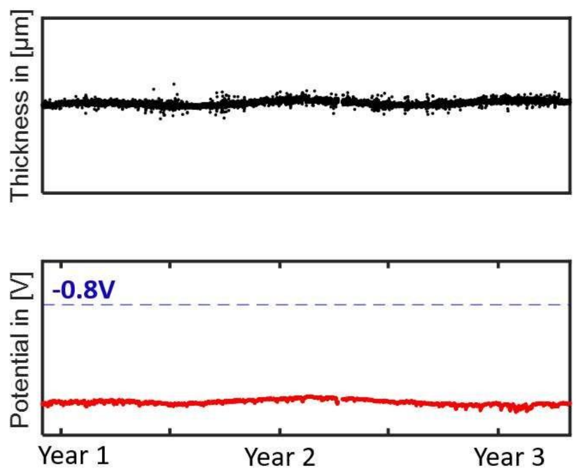

Figure 5. Thickness measured by an ER sensor (top) and potential measured by an Ag/AgCl/Seawater Reference Electrode (bottom) at the same location for a continuous measurement time of in total over two years.

Ørsted jointly with MetriCorr have matured and developed systems for online corrosion monitoring based on ER technology using MetriCorr loggers and sensors.

The general and pitting corrosion sensors are patented by MetriCorr.
Ørsted has patented the use of the coating and pitting corrosion sensor for offshore wind structures

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