

Corrosion Monitoring for Offshore Wind Farm's Substructures by using Electrochemical Noise Sensors

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Abstract

Electrochemical noise(EN) has been used to analyze the deterioration of coating films of offshore wind substructures. In this study, prototype sensors using EN have been developed to detect the corrosion rate. To verify the reliability of sensors, experiments were conducted both in the laboratory and offshore using probe and standard samples. New analysis and data processing techniques show that the sensor can provide useful information about the corrosion rate.

Keywords: Corrosion Monitoring, Offshore Wind Substructure, Corrosion Management, Anti-Corrosion Guideline, Electrochemical Noise

I. INTRODUCTION

The offshore wind farm has attracted a great deal of interest as a next-generation renewable energy source. The offshore wind farm has obvious advantages compared with the onshore wind farm : constant wind and large scale design [1][2]. However, offshore wind turbines are more expensive and difficult to install and maintain because of the harsh marine environment.

In order to reduce costs, a system for monitoring corrosion of offshore wind structures is required. There are many conventional techniques to measure corrosion. An electrical resistance (ER) or linear polarization resistance (LPR) sensor is mainly used, and after applying a constant level of voltage or current to an electrode, consequent variations in the current may be measured to calculate a corrosion rate.

The techniques are mostly applied to steel and are mainly configured of technologies for analyzing surface states of steel by measuring a corrosion potential. To apply the techniques to coating films to be located underwater, below sea level, may be practically difficult because potential characteristics are varied depending on types of respective coating films.

In this paper, electrochemical noise (EN) has been used to analyze the deterioration of coating films. When local corrosion occurs in a metal or alloy, it is divided into an anode and a cathode locally, resulting in a potential difference. And the current is caused to flow by the potential difference. Measurements of current are accurately measured through a Zero Resistance Ammeter (ZRA), at which point it is possible to determine from which direction corrosion has occurred at which electrode. Using EN is suitable for applying to the offshore because these methods are to analyze corrosion states by only processing voltage and current signals without an external input device. The goal of this work is to provide accurate evaluation of corrosion states compared with other conventional measurement techniques.

II. EXPERIMENTAL PROCEDURES

Anticorrosion measures used on offshore structures such as

offshore wind power generators are a surface coating scheme and an electric anticorrosion scheme. Since such offshore structures may be installed in relatively deep water, as compared to land-based structures or coastal structures, considerably high maintenance costs have been incurred in the use of such structures, due to limitations on factors such as ships, manpower, special equipment, working periods, and the like.

More specifically, for example, since offshore wind farms have significantly large and wide extents, visual inspection thereof using boats, ships and the like may be highly restricted, and the ability to undertake visual inspections of structures located below sea level, that is, in an underwater portion, is extremely limited.

Considering previous techniques for monitoring corrosion, there are provided techniques for monitoring corrosion potential [4]. In the techniques, an electrical resistance (ER) or linear polarization resistance (LPR) sensor is mainly used, and after applying a constant level of voltage or current to an electrode, consequent variations in the current may be measured to calculate a corrosion rate. The majority of the measurement methods have been used in the measurement of corrosion states of steel, rather than in analyzing the deterioration of coating films [3].

In this study electrochemical noise measurement methods have been used. The greatest features of the measurement methods are to analyze corrosion states by only processing voltage and current signals without an external input device.

To make corrosion monitoring sensors two kinds of probes were prepared: a coating film probe and a sacrificial anode probe. A coating film probe was made by processing a body formed of a material the same as a material (for example, a steel or the like) constituting an offshore structure, in a tubular shape or a pillar shape, and forming a coating film through coating a coating film used in the offshore structure on one surface of the body. The coating film probe configured as above may indicate deterioration in the coating film of the offshore structure and at the same time, may determine a corrosion rate of the body to calculate a residual corrosion tolerance thickness at the time of the termination of deterioration of the coating film.

A sacrificial anode probe was also made by processing a

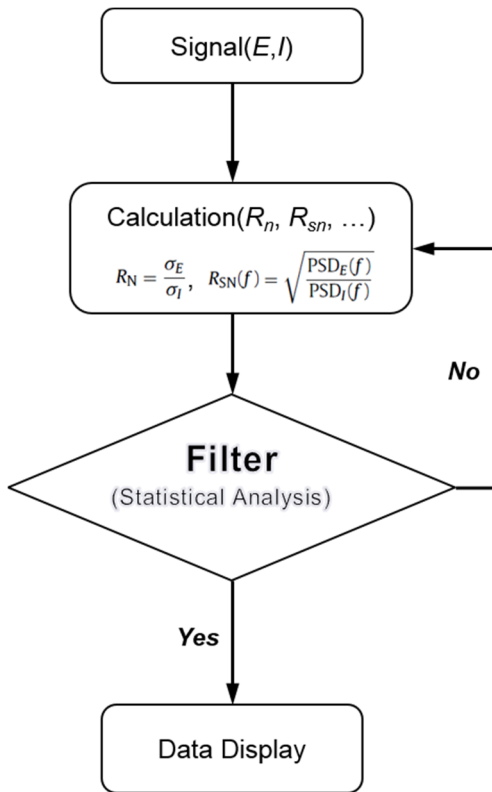


Fig. 1. Signal processing of the corrosion monitoring sensor.

material the same as that used as a sacrificial anode in an undersea portion of an offshore structure, in a tubular shape or a pillar shape. A sacrificial anode is typically formed of aluminum, an aluminum-zinc alloy, and magnesium.

The coating film probe, the sacrificial anode probe, and the reference electrode, separately manufactured, were fixed to a mold, and a molding resin prepared in a resin-mixing bath. And signal lead wires were molded to protrude outwardly from the probe unit, thereby allowing the application of power or the transmission of a signal to be smoothly performed.

Fig. 1 is a block diagram schematically illustrating a configuration of a signal processing of the monitoring sensor. The signal processing included a non-resistance ammeter measuring a current or a voltage of the coating film probe the sacrificial anode probe, and the reference.

In the coating film probe and the sacrificial anode probe exposed to offshore environments, deterioration progresses in the coating film, and the sacrificial anode probe was gradually consumed over time. Variations in voltage and current were generated in the both probes. The variations in voltage and current over time were input to the signal processing.

III. RESULTS AND DISCUSSION

Fig. 2 shows the electrochemical impedance data and degradation evaluation of coating layers. At the frequency of 0.01Hz, the impedance decreased with increasing soaking time. This result may imply that the resistance of the coating layers decreased depending on exposure to corrosive environments. It has been reported that corrosion at a metal-coating interface occurs below the impedance value of $10^7 \Omega \cdot \text{cm}^2$ [5]. And it is recommended to be repaired when it falls under $10^5 \Omega \cdot \text{cm}^2$.

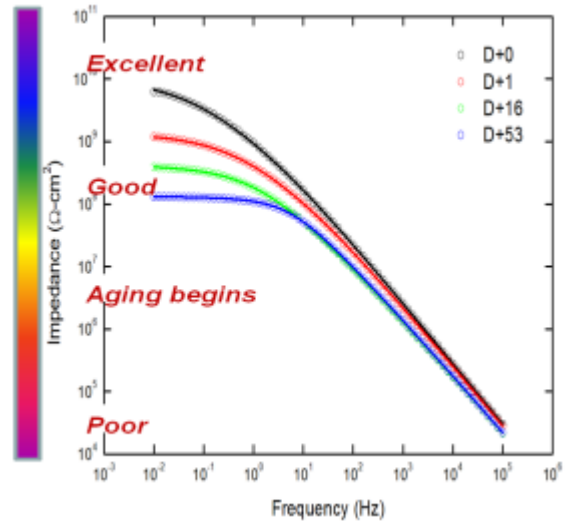


Fig. 2. Degradation evaluation of coating layers by the electrochemical impedance measurement.

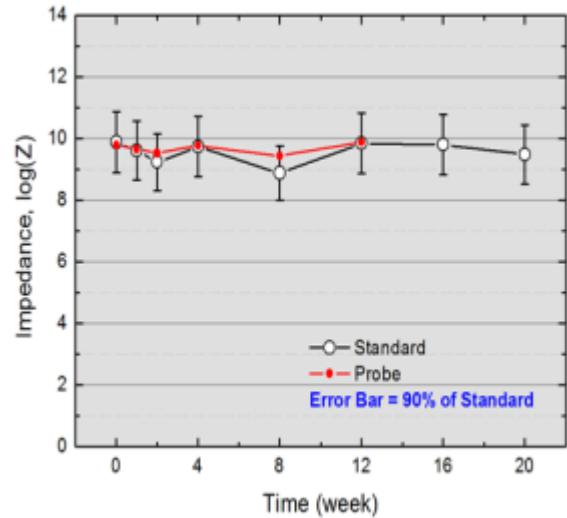


Fig. 3. Electrochemical impedance data of standard and probe samples.

Fig. 3 shows electrochemical impedance data of standard and probe samples. Each data was measured at 0.01 Hz. In order to compare between the two samples, a 90% on the impedance values of the standard samples is shown as an error value. The range of every impedance value of the probe samples can be found within the incoming 90% of standard samples. This result means that the probe is an appropriate representative of the corrosion performance (coating degradation) of the structure. In SEM and EDS analysis, the results were the same as shown in Fig. 4. In particular, it was confirmed that no significant difference in the two samples of the chlorine ions in the metal-coating interface.

Fig. 5 shows data that were measured in both laboratory and field using the prototype monitoring sensor. The voltage and current signals obtained from the sensor after obtaining each of the standard deviation, that is, the noise resistance Fig. 6(b) with the results shown as a blue dot, and the impedance value at 0.01Hz of the electrochemical impedance data obtained in the laboratory it was confirmed that the very well matched.

This means that the noise resistance (R_n), or the coating degradation rate measured at the corrosion monitoring sensor

Table 1. Statistical analysis for the electrochemical noise signal

		Good			Bad		
Potential	Mean	-2.033E-01	-6.156E-01	-6.489E-01	-5.315E-01	-6.714E-01	1.268E-01
	IRMS	2.042E-01	6.156E-01	6.503E-01	5.315E-01	6.714E-01	1.268E-01
	Std. Dev.	1.982E-02	4.246E-03	4.229E-02	5.019E-03	3.451E-03	2.107E-04
	Skewness	-11.516	6.820	7.357	22.674	-0.195	0.183
	Kurtosis	135.181	59.698	93.892	653.045	-0.936	-1.378
Current	Mean	3.318E-11	1.970E-07	-3.055E-11	-2.554E-11	-2.483E-08	5.982E-11
	RMS	3.352E-11	2.025E-07	3.106E-11	3.381E-11	2.490E-08	6.079E-11
	Std. Dev.	4.761E-12	4.693E-08	5.627E-12	2.216E-11	1.934E-09	3.301E-11
	Skewness	-2.942	-1.174	-3.324	-19.279	0.790	1.785
	Kurtosis	23.438	4.554	98.533	471.527	2.140	4.293

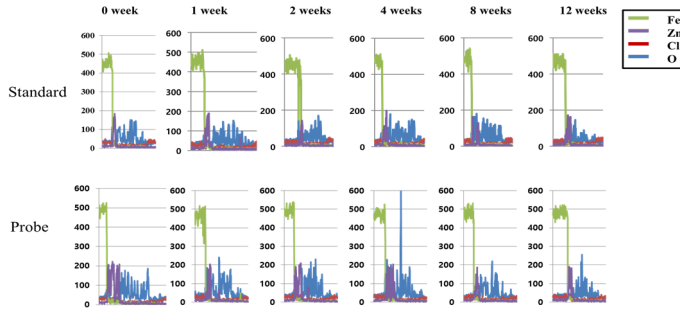


Fig. 4. EDS results from standard and probe samples.

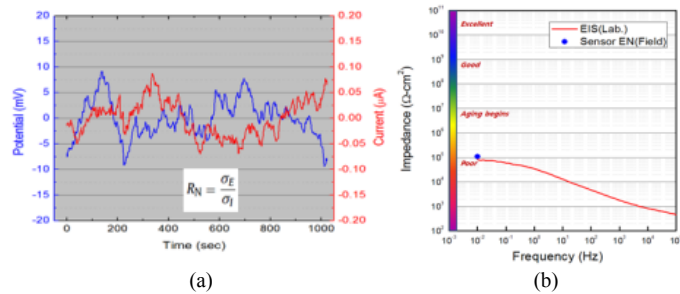


Fig. 5. Test result obtained from laboratory(a) and field(b) using prototype monitoring sensor.

prototype, very well matches the coating degradation rate (Z_i) of the existing electrochemical impedance method. In conclusion, it may indicate that the corrosion monitoring sensor can measure the prototype coatings degradation rate sensors as well.

Fig. 6 shows the degradation rate analysis by electrochemical impedance spectroscopy (EIS) method and electrochemical noise (EN) signal analysis. FIG. 7(a) and 7(b) a relatively high-resistance coating and the state of the low-resistance coating can be seen through the EIS method, for those coating noise resistance (R_n) and FFT spectrum, or noise due to the MEM resistance (R_{sm}) may also be seen that good agreement. However, Fig. 7(c) and 7(d) it can be seen that the noise analysis result is significant difference between the impedance measurements for each of the high-resistance and the low resistance coating.

In order to develop a diagnostic system for corrosion coating degradation rate of the above data for the data in Fig. 7(c) and 7(d) a filtering algorithm, and can indicate the result of the (a) and (b) this development is necessary. For reliability analysis of these data it was performed a statistical analysis of the electrochemical noise signal. The results are shown in Table 1.

Which well matches the impedance measurements from the Table 1. (Good) that do not match well with the noise signal (Bad) results are compared to the noise signal, a Kurtosis value of the

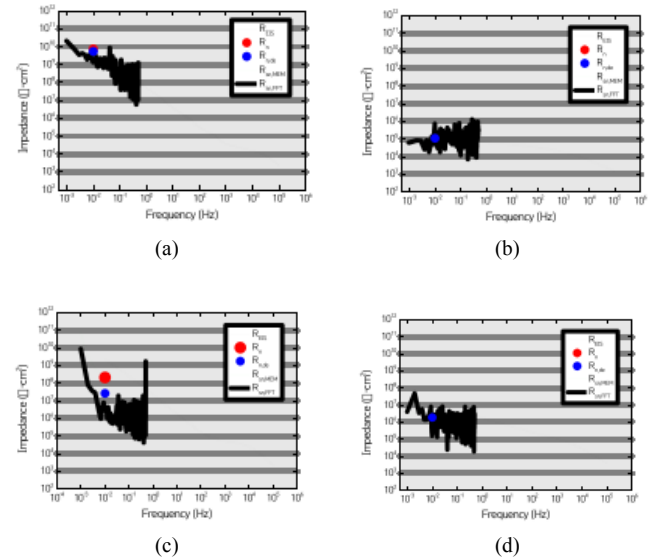


Fig. 6. Relationship between electrochemical impedance spectroscopy (EIS) and electrochemical noise (EN) method results.

voltage can be seen that given the most meaningful. This approximate value Kurtosis value of 50 to 150 through a statistical analysis is estimated to be well matched.

IV. CONCLUSIONS

Development of corrosion monitoring system includes coating degradation rate diagnosis by analyzing the electrochemical noise signals through the zero resistance ammeter (ZRA); sacrificial anode consumption diagnosis by galvanic corrosion current measurement; analysis technique and algorithms.

Electrochemical noise method has been used to to analyze the deterioration of coating films. In this paper, it showed that the degradation rate of coating film which was measured by EN and EIS is very well matches. Furthermore, EN is suitable for applying to the offshore because these methods are to analyze corrosion states by only processing voltage and current signals without an external input device.

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