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DESIGN VALIDATION OF ICCP SYSTEMS FOR OFFSHORE WIND FARMS

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ABSTRACT

The Greater Gabbard Offshore Wind Farm is the world's largest offshore wind farm project (500MW) to move into the construction phase and will be built approximately 25 kilometers off the Suffolk coast of the United Kingdom (UK). The construction work started in summer 2009 and features 140 wind turbines each having a rated capacity of 3.6 MW. The turbines are mounted on steel monopiles and transition pieces in water depths between 24 and 34 meters.

The selection of the optimal cathodic protection system was based on extensive computer modeling. The simulation campaign compared Impressed Current Cathodic Protection (ICCP), Sacrificial Anode Cathodic Protection (SACP) as well as combined approaches against operating parameters taking into account calcareous layer erosion, flow rate dependant polarisation behavior and layers with changing resistivity. In addition, the dissolution effects of the sacrificial anodes and remaining lifetime of the MMO anode pastilles have been simulated.

This presentation details the results of the comparison study of the various cathodic protection systems as well as of the installed design.

Keywords: simulation software, off-shore, wind farm, ICCP, design validation

INTRODUCTION

The project site is located approximately 25 kilometers offshore within the Thames Estuary Strategic Environmental Assessment Area and adjacent to two sand banks known as the Inner Gabbard and The Galloper (Figure 1). The 147-square kilometer project site will encompass the wind turbines and associated infrastructure, including the met masts and offshore substation platforms. Connection to the high-voltage national grid will be made at a new onshore substation located at Sizewell, Suffolk.

The project is expected to provide carbon-neutral, renewable electricity for more than 415,000 homes and will make a significant contribution to meeting the U.K. Government's 2010 renewable energy targets.

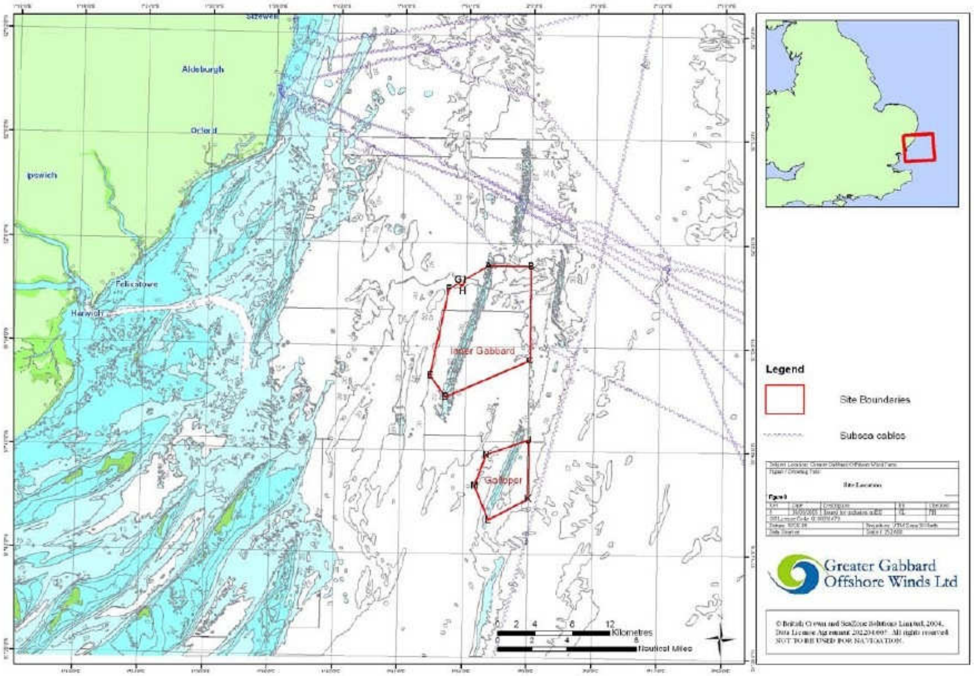

FIGURE 1 - Greater Gabbard Windfarm location

The project will feature 140 wind turbines, each having a rated capacity of 3.6 MW. The turbines will be mounted on a steel monopile and transition piece in water depths between 24 and 34 meters. Three 132-kilovolt (kV) subsea cables will bring the power ashore to the new substation. This project will produce the first offshore wind farm to be built outside the country's territorial waters.

Fluor began onshore construction in 2008; offshore construction commenced in summer 2009. The first turbines will be operational in late 2009, with all 140 turbines to be completed by late 2010.

The project requires 84,000 tons of monopiles (steel tubes) which are on average about 62 meters in length and 600 tons in weight. The monopiles will be driven about 30 meters into the seabed. Connecting the monopiles and the turbine towers are 35,500 tons of transition pieces, each weighing about 230 tons and standing as tall as a four-story building.

The design and installation of the corrosion protection system has been awarded to a Dutch company(1). An extensive comparative study for the selection of the adequate cathodic protection system has been performed with the use of advanced computer modeling technologies.

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[1] Corrosion & Water Control

This paper presents the key aspects of the evaluation study that led to an innovative usage of Impressed Current Cathodic Protection (ICCP) system.

STRUCTURE TO BE PROTECTED

The general scheme of the cylindrical monopile and transition piece are presented in Figure 2.
The bottom of the pile is at z = - 61.00 m, while the seabed (mud line) is at z = - 31.50 m. The top of the pile is at z = 5.15 m. The seawater level is at z = 6.64 m. The transition piece extends 13.36m above sea level.

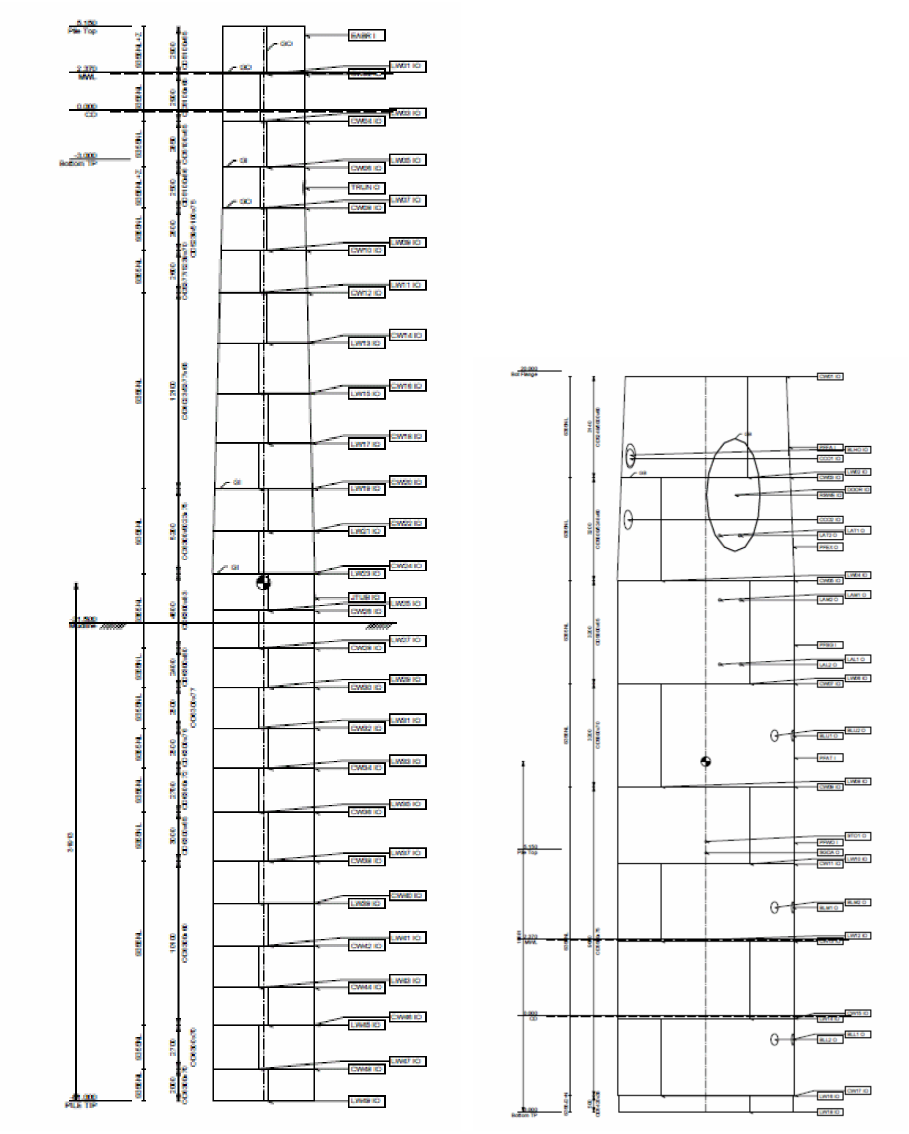

FIGURE 2 - Schematics of the monopile (left) and transition piece (right)

The monopiles are meeting seawater and mud layer, the latter gradually transforming into a clay layer. The transition piece (TP) is protected with an insulating coating, whereas the monopile does not have any coating.

The soil is layered, with a gradual transition between mud and clay as indicated in Table 2.

TABLE 1: RESISTIVITY OF SUBSEQUENT SOIL LAYERS

Medium	Resistivity	Vertical position
Seawater	30 Ω.cm	> z = -31.5 m
Mud	90 Ω.cm	> z = -34.5 m
Transition layer 1	200 Ω.cm	> z = -37.5 m
Transition layer 2	400 Ω.cm	> z = -40.5 m
Transition layer 3	600 Ω.cm	> z = -43.5 m
Transition layer 4	800 Ω.cm	> z = -46.5 m
Clay	1000 Ω.cm	< z = -46.5 m

TARGETED PROTECTION POTENTIALS

When designing a cathodic protection system for a structure, the aim is to obtain a structure-to-electrolyte or IR-free (IR = ohmic drop) potential on the entire structure that is more negative than a certain minimum protection level.

This IR-free potential can only be measured with a reference electrode that is placed directly adjacent to the structure in order to reduce the IR-drop in the electrolyte.

In practice however, due to the hidden character of the structure, it is most of the time impossible to put the reference electrode directly near the structure. In case of the monopole structure, the reference electrode is positioned on the dielectric shield. This will always result in measured potential values that incorporate a significant amount of IR-drop.

Hence IR-free potentials can only be obtained through simulations.

The “Off” potential is measured by interrupting the rectifiers and measuring the instant structure-to-electrolyte before depolarization starts. This measuring technique rules out the IR-drop, but only on condition that no stray current interference with the CP system occurs.

From the above it is clear that making assumptions on the real protection level of a structure based on the IR-free potential is important.

The minimal protection potentials (EP) for steel in contact with respectively seawater and mud as retained in this project are listed in Table 2 below. The protection potential EP is defined as the structure to electrolyte potential (IR-free potential) for which the corrosion rate is acceptable.

TABLE 2: MINIMAL PROTECTION POTENTIALS FOR DIFFERENT MEDIA (VS AG/AGCL)

Medium	EP [V]
Seawater	-0.800
Mud	-0.630
Clay	-0.630

POLARIZATION CURVE SELECTION

Cathodic polarization data for steel in seawater are obtained from references[1-3]. Hack has reported potentiostatic polarization data recorded at different seawater flow rates. The values as obtained after 60 days of exposure correspond to a situation where the steel surface is entirely covered by a calcareous deposit film. The values after 1 day of exposure will correspond in approximation to a situation where no calcareous deposit film has been formed. More recent potentiostatic polarization data are available from the work of Okstad. The values in this paper (figure 3) were obtained after 16 days of exposure and the SEM pictures illustrate that in most cases a thin $Mg(OH)_2$ film exists, combined to a dispersed precipitate of $CaCO_3$, the latter however not completely covering the cathode surface. Moreover, the transient current response has stabilized to a steady state value for the majority of the potentiostatic experiments. This suggests that the data from Okstad can be used instead of the Hack data for long time exposure. But the data from Hack after 60 days of immersion show an even much lower polarization curve, probably due to further growth of the $CaCO_3$ precipitate. An overview of these polarization curves is given in Figure 2.

Due to the shallow water configuration of the installation site, the uncertainty that exists about the erosive impact of the seawater flow on the calcareous deposit was analyzed through three different assumptions. In a first case, the sediment/sand load of the seawater flow is assumed to immediately remove any $Mg(OH)_2$ / $CaCO_3$ deposit that nucleates, hence the steel surface remains entirely bare. In a second configuration, the steel surface is assumed to be covered for 80 % of its surface fraction with a calcareous deposit (microscopic scale), hence the remaining 20 % being bare steel surface due to the continuous erosive impact of the flow. Lastly, the situation where the average lifetime of the calcareous deposit before erosion occurs is 16 days was analyzed.

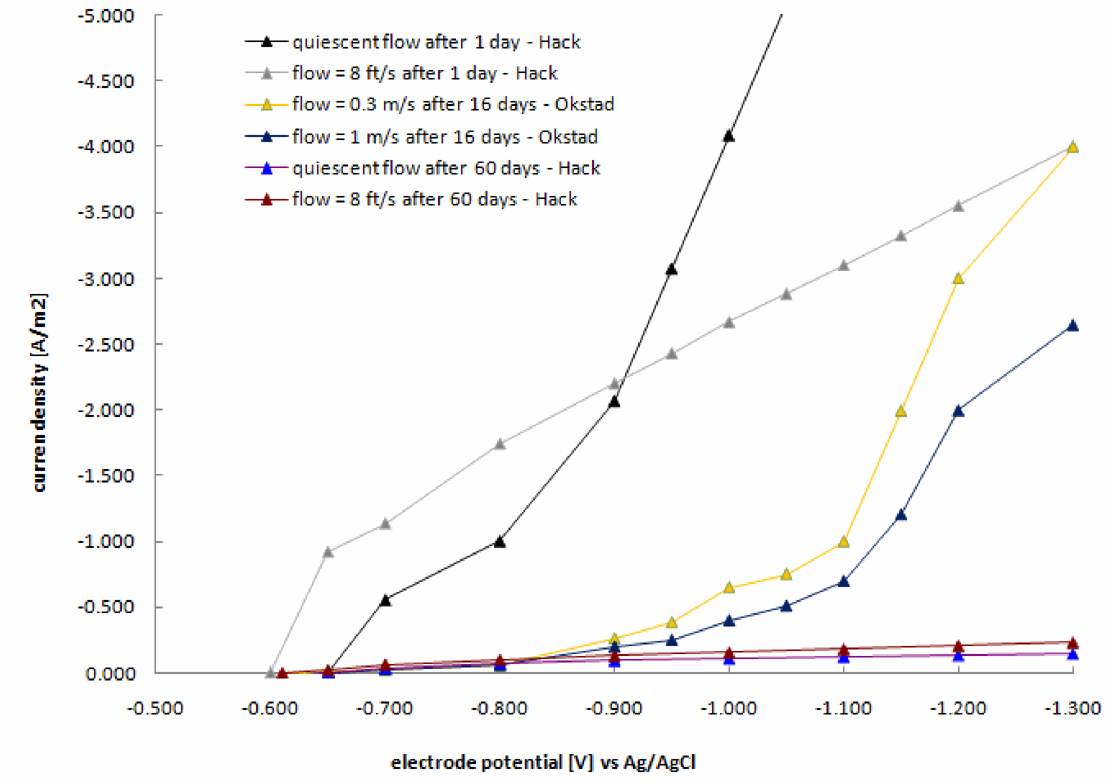

FIGURE 3 - Potentiostatic polarization curves for carbon steel in seawater (some data points have been added compared to literature data for numerical simulation purposes)

Interpolation between the curves for high and low flow conditions is based on Re1/3 (the power 1/3 corresponds to mass transfer limitations for tangential flow along the cathode surface).

The cathodic polarization data for steel in mud and clay were obtained from reference[2]. The anodic polarization data for the dimensionally stable MMO anodes are retrieved from in-house data.

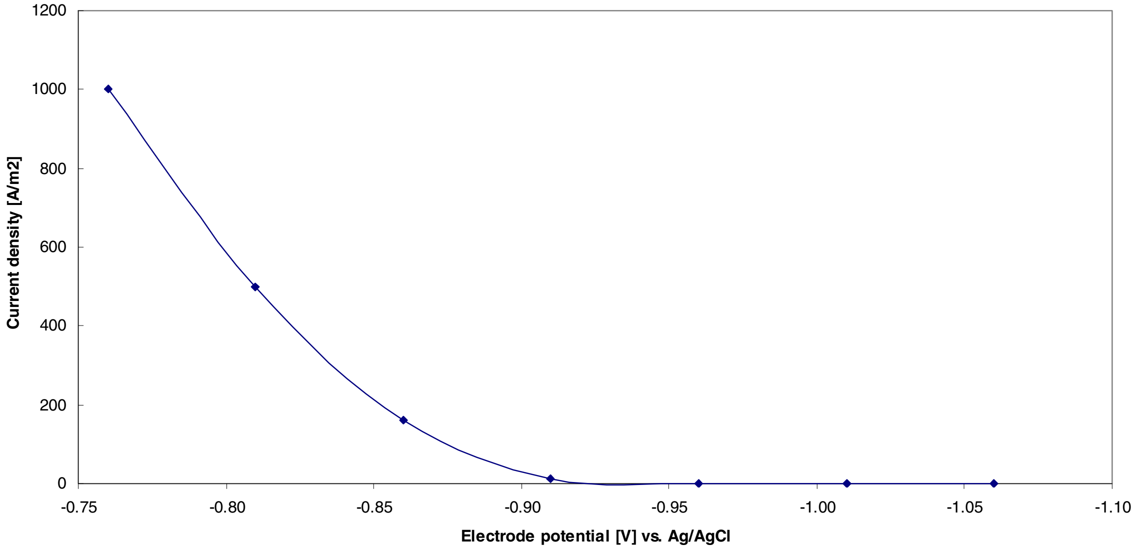

FIGURE 4 - Polarization curves for sacrificial Al-Zn-In anodes

MODELING APPROACH

The numerical simulations in this project have been performed using a software package(2) which is based on the Finite Element Method (FEM) and offers the possibility to calculate potential and current density distributions on 3D structures with complex geometrical features in full detail.

The software solves the potential and current density distribution in the domain that surrounds the structure to be cathodically protected and takes into account the ohmic drop in the seawater, the cathodic polarization including the effect of calcareous deposits and the anodic polarization (dimensionally stable Ti MMO anodes).

The software calculates the IR-free potential values, current density and corrosion rates over the complete structure. Full details on the mathematics behind the model are presented in reference[4]. More information on the software is provided in reference[5].

SIMULATION MODEL

The numerical model is created based on the input as described in the previous sections. A 3D view of the model created in the software is presented in Figures 5 and 6. The model takes into account the seawater and the mud layer, the later extending deeply below the monopile bottom.

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[2] CPMaster – see reference 3

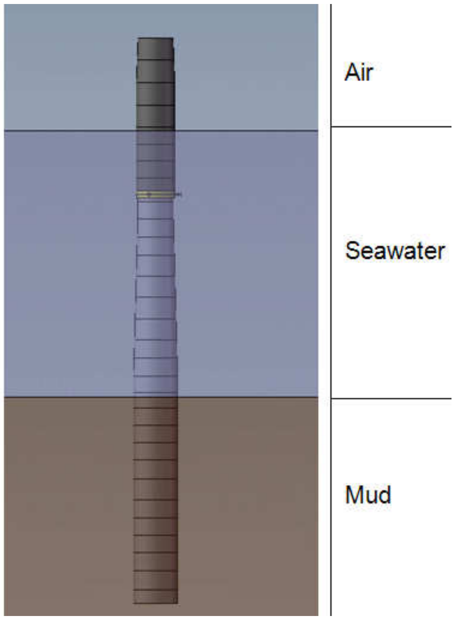

FIGURE 5 - 3D view of model as created in software

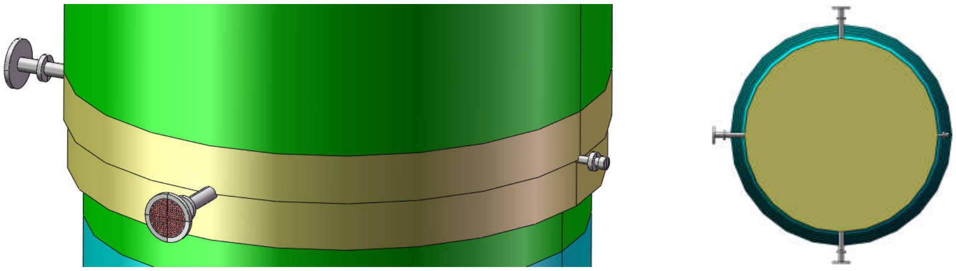

FIGURE 6 - Zoom at ICCP anodes and reference electrode (front and top view)

Cathodic protection design criteria[6] specify that the surfaces in contact with seawater should get an average current density of -200 mA/m^2, and the surfaces in contact with mud an average of -20 mA/m^2. Therefore, the analytical design current for this model is 133 A.

The above value is a general design criteria based on experimental data and experience from the past. In the simulation software used in this report, the complete non-linear polarization behavior of steel in seawater and mud can be taken into account as will be explained below.

The total output current of the anodes is optimized using the simulation software in order to be in line with the minimal protection criteria as listed in Table 1. In addition, the IR-free potential should be more positive than -1200 mV in order not to overprotect the structure (especially in the area near the anodes).

RESULTS AND DISCUSSION

The calculated IR-free potentials are plotted in Figure 7. The same information is plotted along a vertical sample line that runs through the plane at tangential position of 180 degrees (Figure 8). Current density values are plotted in Figures 9 and 10.

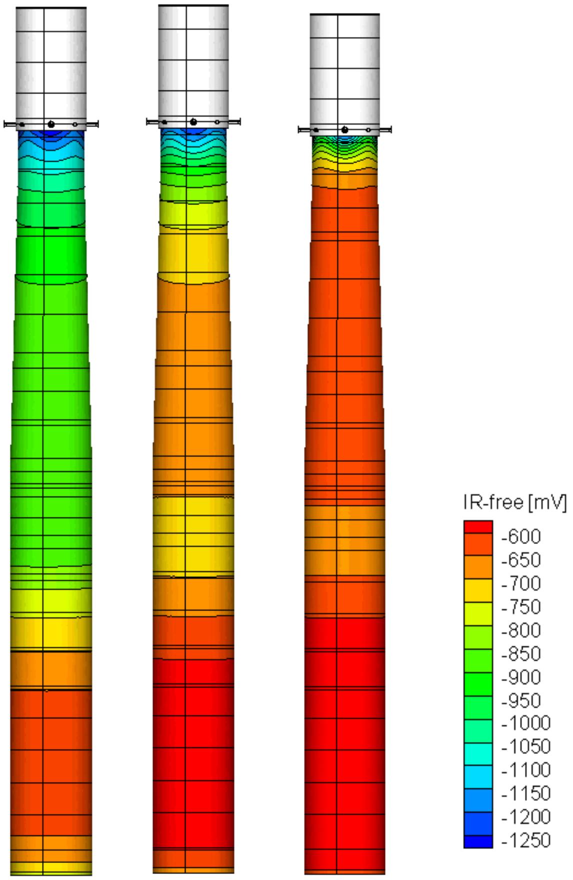

FIGURE 7 - IR-free potentials on the monopile surface for the best, default, worst (left to right)

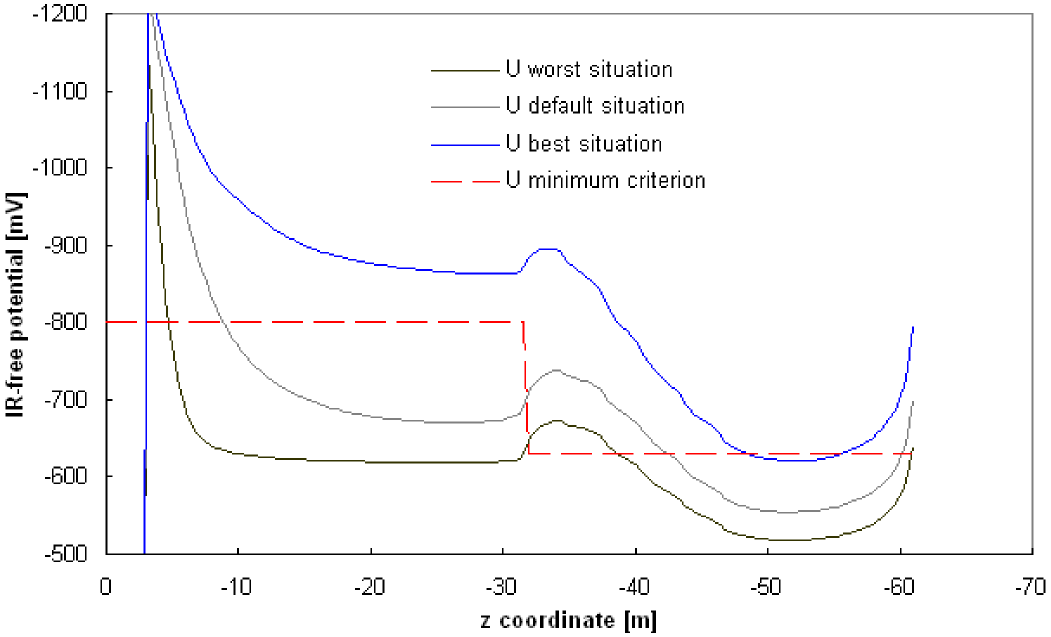

FIGURE 8 - IR-free potential distribution along a sample line

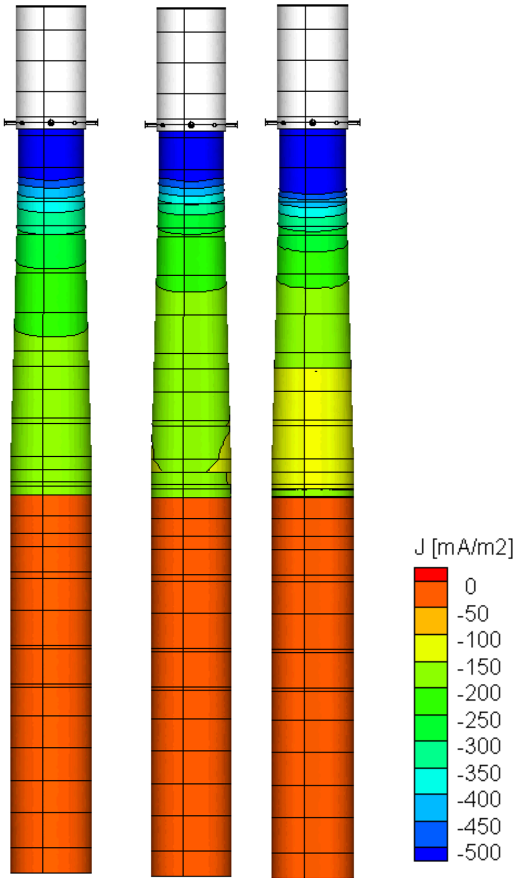

FIGURE 9 - Current density distribution for best, default, worst situation

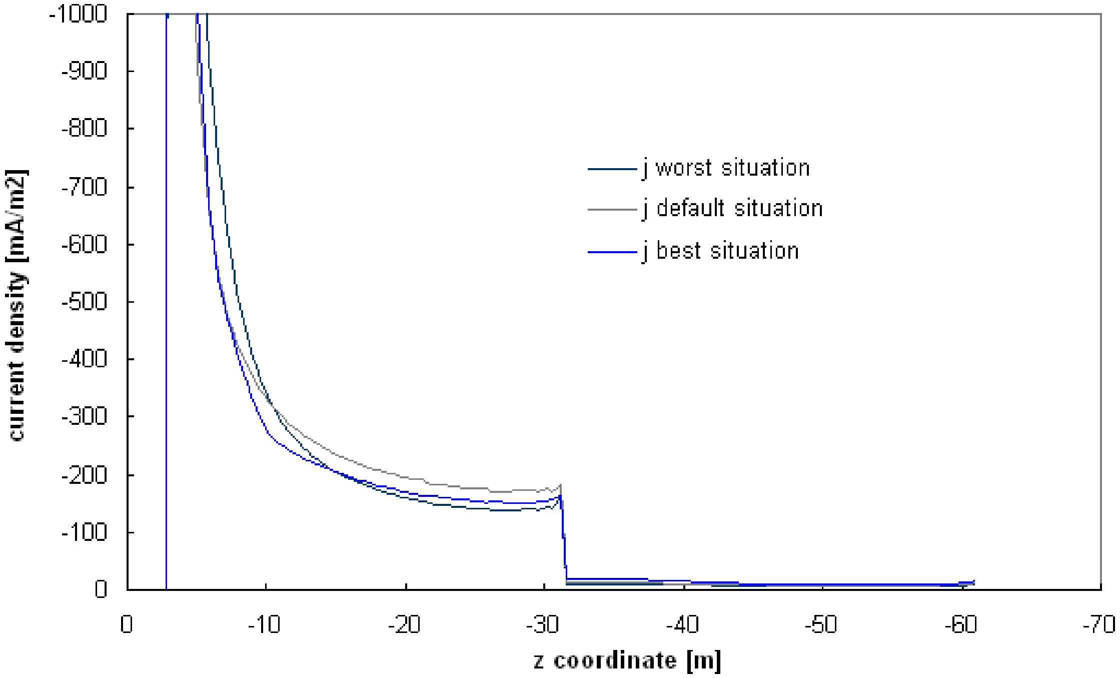

FIGURE 10 - Current density distribution along a sample line

The computer simulations not only provide current density and potential distributions over the surfaces to be protected (= cathodes), but also over the ICCP MMO anodes. This has little relevance for the performance of the ICCP system, but it provides a direct indication on the lifetime of the anodes. Coated anodes typically have a coating deterioration that is inversely proportional to the current density they deliver. As an example, Figure 11 plots the current density for the worst polarisation situation. The average current density on the outer pastilles is about 3 three times larger than that on the central ones. In many cases, the anode manufacturers provide an indication of the life time as a function of applied current density.

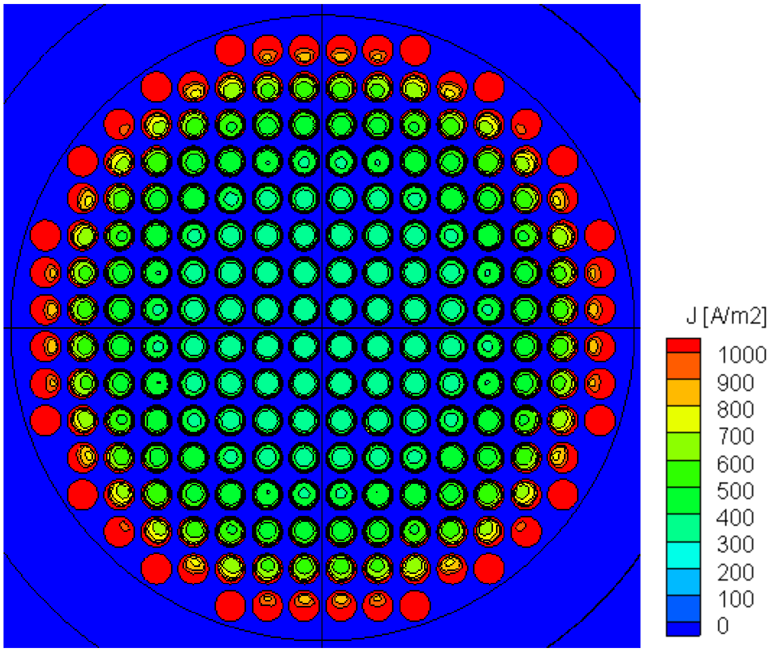

FIGURE 11 - Current density distribution over the MMO pastilles

CONCLUSION

This paper presented the usage of software simulation to help the design of a dedicated ICCP system for an innovative application. The flexibility of the system allows analyzing and comparing various operating conditions as well as environmental parameters.
According the installation plan, the Greater Gabbard Offshore Wind Farm will be commissioned in the course of 2010, allowing comparison between simulated results and field data.

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