ASSESSMENT OF THE IMPACT OF UNDERWATER WORKS AND ANODE REMOVAL ON THE CATHODIC PROTECTION STATUS OF AN OFFSHORE PLATFORM THROUGH FEM MODELLING

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ABSTRACT

DP4 Platform in Bouri Oil field is located in the Offshore Libyan Mediterranean Sea and operated by Mellitah Oil and Gas B.V. Libyan Branch. The Platform Jacket was launched in 1987, protected against corrosion by galvanic cathodic protection system, constituted of slender cylindrical anodes made from aluminium-zinc-indium alloy. The design life of the CP system is 35 years.

Owing to recent installation works of I and J tubes on the jacket, the removal of some anodes was foreseen in order to allow free space for the installation of clamps on bracing elements.
For these reasons, an assessment of the protection status of the platform jacket with and without anodes removal was required. The aim of the assessment was to verify that protection conditions can still be achieved in all areas of the jacket, despite of the modification of the original galvanic anode system.

Furthermore, with the platform approaching the end of its original design life, and the intent of the Operator to extend the life, it was fundamental that the actual protection status be established in order to ensure the integrity and durability of the structure. Investigation was carried out mainly with the use of Finite Element Method (FEM) modelling, applying various scenarios based on expected current density at different levels of cathode polarization and anode consumption. The model was also compared and validated through real CP inspection data collected during a recent inspection campaign after the installation of the “I” and “J” tubes.

Results of the modelling confirmed that protection conditions are still being achieved all over the jacket structure, with minor variation of polarization. Consequently, installation of additional galvanic anodes in the modified regions was not necessary, leading to significant cost saving.

INTRODUCTION

Platform DP4 is located in Block NC 41 (Bouri Field) offshore Libya in the Mediterranean Sea, at a water depth of 169 m. It was launched in 1987. Jacket of the DP4 is protected against corrosion by galvanic cathodic protection system, comprising of 2,344 slender cylindrical anodes, made of aluminium zinc indium alloy with initial net mass of 600kg. The design life of the system at the time of 1987 was 35 years.

New I-tube and J-tube have been installed in 2016 on the east side of the jacket of DP4 platform.
For the fixing system, based on clamps, thirteen (13) existing galvanic anodes has been removed. The removal of 13 galvanic anodes in the zone where clamps of I/J-tube have been installed could result to a lack of protection current sources in that area, then less negative potentials, with simultaneous effect on the surrounding anodes, that shall provide protection current for a higher cathodic surface area.

The maximum distance reached by protection current is related with the driving voltage, i.e. the difference of potential between anodes and cathode, that in the case of a galvanic system is limited to about 250÷300 mV, leading to low throwing power compared with impressed current systems.

Formulae for determining the maximum distance reached by cathodic protection are available for a very limited geometries, and not applicable for a complex geometry such as the jacket of a platform. In such a case, FEM modelling is a powerful tool to determine the electrical field between anodes and cathode, producing the potential and current distribution [1].

For the application to DP4 platform, it was therefore decided to simulate the removal of the 13 anodes, to verify if protection conditions are maintained in the area of installation of I/J-tubes and if detrimental effects are produced in the surrounding areas and the overall jacket.
A study assisted by modelling was performed, and in summary aimed at:

- Conducting a study with Finite Elements Modelling (FEM) in order to evaluate potential and current distribution on the structure due to removal of 13 anodes; based on the extended life time of Cathodic Protection system and in compliance with design life of DP4 Platform, currently expected to expire in 2037 (model consider the as built structure and most recent CP inspection data);
- Verifying the absence of under-protected zones and the impact of installation work with anode removal on protection conditions of DP4 jacket.
- Evaluate the CP impact of the new I/J-tube’s sacrificial anode on DP4 Jacket, including recommendations.

Fig 1: DP4 platform (red arrow: I-J tubes installation zone)

METHODOLOGY

DP4 Platform and relevant anodes have been modelled with the Comsol Multiphysics® software. The platform jacket has been represented as three-dimensional wireframe drawing in a 3D CAD software and imported in the model with the specific CAD import module in Comsol. FEM model considers a three-dimensional domain. At each tubular element the relevant radius has been associated.

Galvanic anodes assembled on the jacket have been modelled as cylinders, 2.264 m long (90% of original length) in the positions indicated by the project documents. 6 cm radius, corresponding to end-life size, i.e. residual mass equal to 10% of original mass, was considered as worst-case scenario (anode at end life and repolarization current required). 11cm radius was also considered for the present-day scenario (2015), based on real inspection data. Also, I/J tubes, protection frame, clamps and relevant anodes have been included in the model and have been analysed separately. Conservatively, all surfaces were considered as bare metal and the same cathode boundary conditions of DP4 jacket have been considered.

The boundary conditions considered for solving the electric field were the following:
- Electrical insulation at the free surface of the sea
- Potential and current density defined by the Tafel equations and oxygen limiting current:

$$i = i_{corr} \cdot e^{\frac{-2.303(E-E_{corr})}{b_a}} - i_L - i_{H_2} \cdot e^{\frac{-2.303(E-E_{H2})}{b_{H2}}}$$

where the first term is the anodic curve, the second one represents the oxygen limiting current density and the third is related with hydrogen evolution by water dissociation.

The values of the parameters in the above equation are as follows:
i_{corr} is the metal dissolution rate, and since oxygen reduction is the dominant cathodic process, this value is equal to i_L
i_L = oxygen limiting current density, i.e. maintenance or repolarization current density.
i_{H2} = 0.02 mA/m^2 (hydrogen exchange current density on steel)
E_{H2} = -0.8 V vs Ag/AgCl (hydrogen equilibrium potential)
b_{H2} = 120 mV/dec (hydrogen Tafel slope)
b_a = 60 mV/dec (anodic Tafel slope)

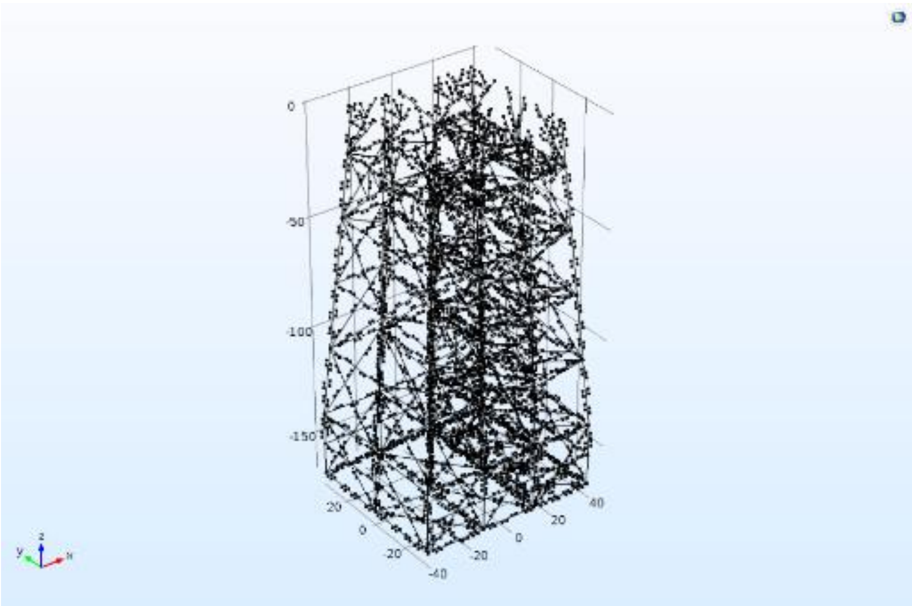

Fig 2: Model domain

Water resistivity at site is equal to 23 ohm·cm. Additional details of methodology and applied parameters are provided in other papers [4-7].

Two scenarios were considered:
- Present-day scenario (2015): Expected maintenance current density of 25 mA/m^2; this value is based on real data collected on DP4 Platform and described in [2]; current density value is very low due to the formation of a protective calcareous deposit on cathodic surface at potentials lower than -900 mV vs Ag/AgCl.

- Worst case scenario: Anodes at end life and repolarization required; expected current density of 50 mA/m^2 according to [3]. In repolarization conditions, the cathodic surface is assumed to have lost or damaged protective layer of calcareous deposit and the potential approaches -800mV vs Ag/AgCl owing to depolarization (corresponding to the maximum current density at -800 mV vs Ag/AgCl as shown in Fig. 3. Current density increases by two times, from the expected realistic value of 25 mA/m^2 up to 50 mA/m^2, i.e. the expected repolarization current density.

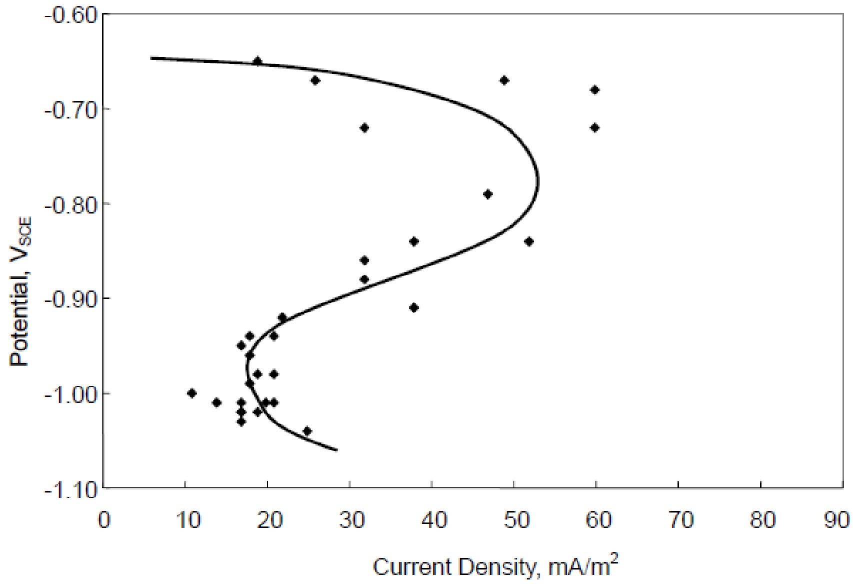

Fig 3: Long-term potential versus current density data according to Hartt et al [3]

RESULTS AND DISCUSSION

Results of analysis for present-day scenario before anode removal, i.e. with anode size corresponding to that measured during 2015 inspection campaign and with 25 mA/m^2 maintenance current density are summarized in Table 1. Figure 4 shows the main results of potential and current density distribution along the platform jacket.

An optimal status of protection was found for the jacket, with potentials in the full protection range. The less negative value of about -0.965 V vs Ag/AgCl was found on a node at el. -48 m. The most negative potential value is -1.050 V vs Ag/AgCl, found at elevation -20 m. All results were in accordance with the results of the inspection campaign, performed between December 2014 and March 2015. According to current density distribution graphs, not shown here, the protection current on the jacket varies between 25.5 and 27.5 mA/m^2.

Results of analysis for worst case scenario, corresponding to anodes at end life and repolarization current of 50 mA/m^2 required, are summarized in Table 2. Figure 5 shows the main results of potential distribution along the platform jacket.

Status of protection was found for the jacket, with potentials in the full protection range. The less negative value of about -0.880 V vs Ag/AgCl was found on a node at el. -48 m. The lowest potential value is -1.050 V vs Ag/AgCl, found at el. -107 m.

Tab. 1: Summary of results of FEM analysis for present-day scenario

Parameter	Value	Unit
Max potential on jacket	-0.965	V vs Ag/AgCl
Min potential on jacket	-1.050	V vs Ag/AgCl
Max current density on jacket	27.5	mA/m^2
Min current density on jacket	25.5	mA/m^2

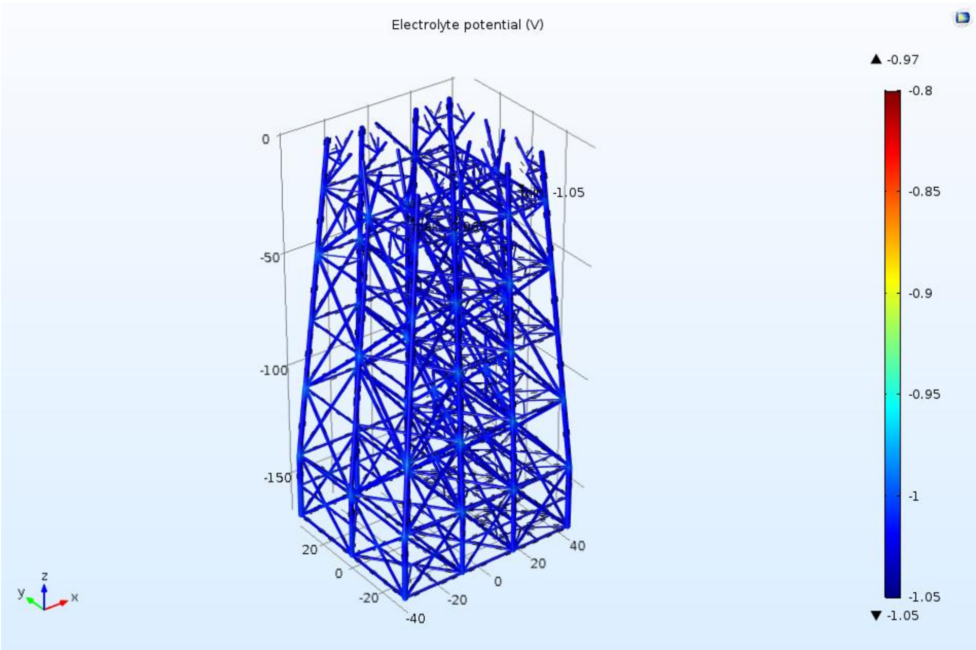

Figure 4: Potential distribution on DP4 jacket (present-day scenario)

Tab. 2: Summary of results of FEM analysis for worst case scenario (anodes at end life and repolarization required).

Parameter	Value	Unit
Max potential on jacket	-0.880	V vs Ag/AgCl
Min potential on jacket	-1.050	V vs Ag/AgCl
Max current density on jacket	52.4	mA/m^2
Min current density on jacket	50.1	mA/m^2

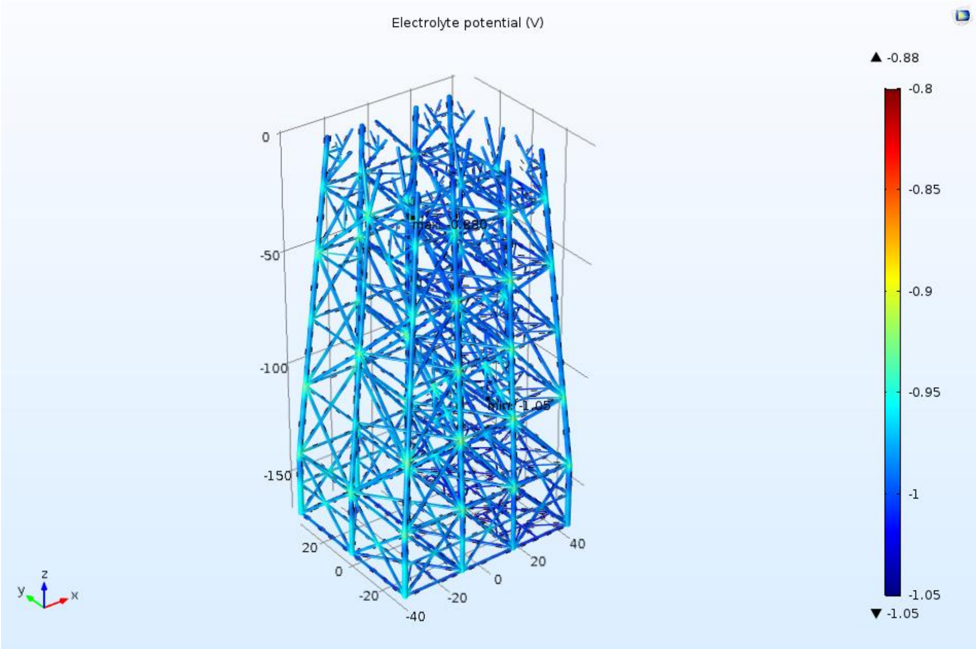

Figure 5: Potential Distribution on DP4 Jacket (Worst-Case Scenario: Anodes at End Life and Repolarization Required).

According to current density distribution graphs, not shown here, the protection (repolarization) current density on the jacket varies between 50.1 and 52.4 mA/m^2.

Simulations after anodes removal were carried out for both the expected scenario with 25 mA/m^2 protection current density and the worst-case scenario, i.e. with anodes at end life (90% consumption) and with expected repolarization current of 50 mA/m^2 required. To allow for a simple and direct comparison, Fig. 6 shows the portion of the jacket where the I/J tubes have been installed, for the worst-case scenario. The image on the left shows the potential distribution in the section of the jacket before the removal of the anodes, while the image on the right is the same section after anodes removal.

According to results for the scenario with 25 mA/m^2 expected maintenance current density, the protection potential range is -0.977÷-1.035 V vs Ag/AgCl (i.e. +0.073÷+0.015 V vs Zn), almost coincident with the range for the case before anode removal (-0.978÷-1.035 V vs Ag/AgCl). At the bracing and leg elements, far from nodes, i.e. where measurements have been taken after anode removal and I-J tubes installation, potential by FEM modelling is approximately within the range -1.01÷-1.03 V vs Ag/AgCl, practically coincidental with the measured data, -1.011 ÷ -1.025 V vs Ag/AgCl.

Also, according to results for the worst-case scenario with 50 mA/m^2 repolarization current density, the protection potential range is -0.909÷-1.021 V vs Ag/AgCl (i.e. +0.141÷0.029 V vs Zn), almost coincidental with the range before anode removal (-0.910÷-1.022 V vs Ag/AgCl).

The overall impact of anode removal on the cathodic protection conditions of the jacket is therefore negligible. Based on the results, the decision not to install additional anodes was taken, leading to significant saving in terms of cost for materials and underwater installation works.

Additional modelling was performed for verifying correct protection conditions of I and J tubes with dedicated galvanic anode system, validating the design and confirming full protection conditions and no impact on the status of the jacket.

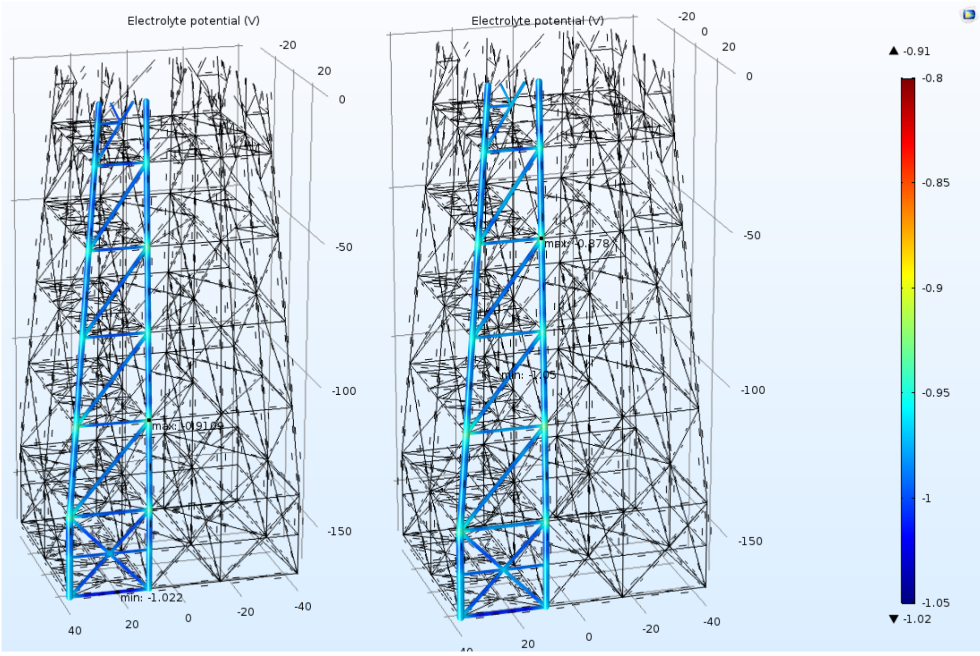

Fig 4: Potential Distribution on DP4 Jacket - Left: Potential Distribution for the Original CP System. Right: Potential Distribution after the Removal of 13 anodes (Repolarization Current Density of 50 mA/m^2).

CONCLUSIONS

In this paper the analysis of potential and current distribution of the jacket of platform DP4, protected with galvanic anodes, has been carried out by Finite Element Method (FEM) modelling.

The scope of this study was to gain an insight into the protection conditions achieved with the actual CP system, evidencing the zones of the jacket, if any, with partial under-protection conditions. After this preliminary study, the main purpose was to perform a FEM study to assess the occurrence of any variation in the protection conditions upon the removal of thirteen (13) anodes from the jacket, a necessary operation before installation of the new I/J tubes on the jacket.

FEM results indicated that the platform structure is currently in good protection conditions, in accordance with the results of the inspection campaign performed between December 2014 and March 2015.

Under the worst-case modelling scenario, i.e. with original anodes depleted at 90% at the end of their operating life and expected repolarization current of 50 mA/m^2 required, the jacket of DP4 platform still remains under protection conditions.

The installation of new I/J tubes on the jacket with consequent removal of 13 anodes does not have significant impact on the overall protection conditions of the platform. In fact, according to modelling results for removal of 13 anodes to create space for the installation of new I/J tubes, the protection potential range is almost coincidental with the range for the case before anode removal.

Potentials at bracing and leg elements far from nodes is coincident with measurements performed in October 2016 after anode removal and I- and J tubes installation. Results of this activity lead to significant cost savings considering that no additional anodes were procured and that no additional subsea installation activity has been carried out.

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