PREDICTION OF INTERACTIONS BETWEEN FPSO AND SUBSEA CATHODIC PROTECTION SYSTEMS

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ABSTRACT

Deepwater Oil & Gas developments consist of many more components designed to extract, transport and store the oil when compared with developments in shallower waters. Designing the cathodic protection [CP] systems to protect the individual components is problematic without an appreciation as to how CP systems fitted to the various components will interact with one another once the entire asset is commissioned.

For a recent deep-water project, a computer modeling study was commissioned to provide information on the performance of the CP systems protecting each of the subsea structures and in particular the interaction currents flowing between them. The principal aim was to ensure that the impressed current CP (ICCP) system on the hull of the FPSO would be operated in such a manner as to reduce interaction with the sub sea sacrificial anode CP systems to the minimum possible throughout the operating life of the field and to develop an understanding of the probable behavior of CP systems on the key components (FPSO, Oil offloading lines & Buoy, Riser Structures, etc.) particularly in respect of sacrificial anode lives.

In addition, a further aim was to provide a working tool for Operations that could be used to aid ICCP control beyond the design and construct phases, and to provide input to Risk Based Inspection and maintenance planning.
The paper will describe the strategy and rationale behind the modeling studies and some of the lessons learned and the plans for validation and ongoing maintenance of the model as ROV and field data becomes available.

Keywords: Cathodic Protection, Boundary Element Modeling, Modeling, ICCP

INTRODUCTION

A layout of the field and its major components is shown in (Figure 1). Production, gas and water injection wells and associated manifolds are located in a water depth of approximately 1400 m. The subsea facilities are connected to the surface via a number of risers assembled together to form a single riser tower, anchored to the seabed and held in place by a buoyancy tank. Flexibles are used to connect the risers to a spread-moored FPSO. Oil is off-loaded after processing via two off-loading lines and a SPAR buoy.

All the subsea equipment, and the riser tower and off-loading system, are protected from corrosion by a combination of coatings and sacrificial anodes. The hull of the FPSO is fitted with an impressed current cathodic protection system, again used in conjunction with coating.

In the course of reviews it became apparent that the complexity of the various systems and their possible interactions required employing methods that would allow a detailed analysis be represented in a manner that could be easily understood and if possible readily adjusted. Such a solution was to employ mathematical modeling. In particular, it is known that interactions between ICCP on an FPSO and the associated subsea sacrificial anodes can shorten the lives of the latter, and impact on the operability of the former. Analysis of other FPSO projects has shown the possibility of:
- shortening of sacrificial anode lives by as much as 80%
- current of several tens of amps flowing in risers
- loss of ICCP control early in the design life.

In order to determine the possible magnitude of these interactions, and their likely effect on the longevity of the sacrificial anodes and consequent integrity of the installation, mathematical modeling of the various CP systems and their individual and connected behaviour was considered necessary. The modeling study is intended to provide data which can be used to ensure operation of the ICCP in such a manner as to reduce interaction with the subsea SACP to the minimum possible throughout the FPSO operating life.

This paper describes the approach that was used to develop a mathematical model of the CP systems and describes the results obtained using the design data on which the various CP designs were originally based. Once actual data are available from ROV surveys, the intention is to recalibrate the model and use the resultant output to inform the optimum mode of operation of the ICCP system on the FPSO.
Boundary Element Methods (BEM) have been used to simulate the behavior of cathodic protection systems since the late 70’s (1). As the name implies, the method requires creation of elements, but only on the boundary (ie surfaces) of the problem geometry. The BEM is used to mathematically model the potential drop in the electrolyte represented by the Laplace equation. BEM has been found to be superior to Finite Element Methods [FEM] as only the metallic surfaces in contact with the electrolyte have to be modeled. In addition the differences in the dimensions (Scale) of the components which vary from a fraction of a meter to thousands of meters make the use of FEM almost impossible for a study of this type. In many applications it is sufficient to couple these equations with the equations representing the electrochemical electrode kinetics on the metallic surfaces to form a system of equations capable of simulating the potential fields and current flowing in the electrolyte.

In large scale deep water Oil and Gas developments there are hundreds of individual flow lines and connections each introducing a new electrical connection path which must also be considered in the model. In these situations interactions will occur between the Cathodic Protection (CP) systems, causing significant currents (and therefore voltage drops) in the flow lines connecting the components. Therefore a key component in building the model was the definition and understanding of the electrical resistances of the various components in the development and how they were connected together.

The FPSO is protected by both an ICCP system and there are also sacrificial anodes located in some of the appendages to the FPSO. In addition because there is an electrical connection between the risers and the sacrificial anodes and the subsea systems, they also can make a contribution to the protection of the FPSO and vice versa depending upon the operation of the ICCP system. A particularly useful tool used in the study was the automatic optimization which automated many of the tasks associated with determining the settings of the ICCP system. This enables for example the user to define the minimum protection potential required on the
hull of the FPSO and the software automatically computed the required outputs of the ICCP anodes and the potentials at the reference cells taking into account any interactions with the risers and subsea systems.

**Modeling The FPSO And The Subsea Systems**

The simulation model was developed using the BEASY\(^1\) Corrosion and CP software of the principle components of the system. The major components to be referred to are:

- FPSO (Floating Production, Storage and Offloading)
- Buoyancy Tank
- Riser tower
- Bottom tower
- Electrical resistances
- Flow line termination assemblies
- Oil offloading lines
- Riser tower anchor
- Calm buoy
- Variation of the seawater conductivity

The nature of the infrastructure has necessitated that, to avoid a very complex computer model, a number of simplifications were made. Since the objective was to determine the overall magnitude of interactions between the FPSO and the subsea structures, rather than the detailed distribution of potentials into complex areas, this approach is considered acceptable for the intended use of the model.

Therefore the initial approach included in the model the following:

- FPSO hull & appurtenances
- Riser tower buoyancy tank [equivalent area used for goosenecks]
- Taper joint
- Core pipe and guide frames [guide frames separately modelled to provide simplified input to overall model]
- Risers
- Riser tower bottom [equivalent area used for pipework]

Following evaluation of the interim results, and in particularly in view of a clear indication that significant interaction extended to the base of the riser tower, the following components were added to complete the model:

- Riser tower anchor and suction pile
- Flowline termination assemblies at riser tower base[simplified equivalent area model]
- Oil offloading lines
- SPAR buoy and mooring chains.

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\(^1\) BEASY Software. www.beasy.com
For each component a BEM model was developed representing the surface areas, shapes, coatings, coating breakdown factors, internal resistances and the anodes. The aim was to be able to predict the performance of the CP systems and the protection provided at the initial, mid and final life condition of the structure. The specification of the internal resistances of the flow lines and flexibles was particularly important because of the significant interaction currents for particular settings of the ICCP system.

Other key data used in the model was the polarization properties of the various metallic components and the sea water resistivity.

The FPSO as shown in (FIGURE 2) was modeled in sufficient detail to represent the important features and provide information on the protection provided.

![FIGURE 2 FPSO](image)

An example view of the model is shown in (FIGURE 3) where the representations of the anchors and other appendages can be seen.
The surfaces of the FPSO were coated and appropriate breakdown factors were specified to represent the initial, mean and final life conditions. The results shown in (FIGURE 4) were used to identify the set points for the ICCP control system and to estimate the life of the sacrificial anodes attached to the various appurtenances on the Hull.

An important element in the model was the representation of the tower as this is a complex assembly of flow lines connected together by a number of guide frames. This presented a significant modeling challenge because of the complex geometry of the tower itself, the internal resistance paths of the lines and the height of the tower. It was therefore decided to use two
types of model on the tower. A global model which could be used in conjunction with the FPSO and sub sea systems and a more detailed local model looking at the protection provided to the guide frames and flow lines.

In order to fully understand the level of protection provided by the guide frame anodes and their influence on the FPSO and the surrounding tower structures a detailed model of the guide frame and surrounding structure was developed.

Inclusion of detailed models of all the guide frames in the full model would make the overall model extremely complex, and increase computer simulation times. Since it was not initially clear that the guide frame anodes would influence potentials beyond their immediate vicinity, work was undertaken to establish their combined effect. A separate computer model was, therefore developed for the local configuration at an individual guide frame for comparison with the results in the full tower model. The model can be seen in (FIGURE 5).

The local model (FIGURE 6) shows that the guide frame is well protected by its own anodes (at the mid life conditions) as the potentials are significantly more negative than -900mv vs Ag Ag Cl assuming no interaction with other parts of the structure. However, the potentials are much more negative than those predicted, for the riser bundle, by the full model. This confirms that significant interaction with the guide frame anodes will occur and that they must be taken into account in the fully developed model. The local model was therefore used to create an equivalent anode representing the guide frames and their anodes in the global model.

In the global model the guide frame and the anodes are represented by a cylindrical segment with polarization properties computed from the local model. The polarization properties were computed by running the local model for a number of cases where the seawater potential on the outside edge of the tower was specified and the resulting current flow was computed. By
repeating this study for a range of potentials an equivalent polarization curve was be created for the equivalent cylindrical segment which was used in the global model.

FIGURE 6 Predicted potentials. All the potential are shown to be more negative than -900 mv vs Ag Ag Cl. Note that the foam has been removed from the visualization

(FIGURE 7) shows an overall view of the complete model which clearly indicates the scale of the global model. The variation of the sea water resistivity with temperature/depth was taken into account in the model as well As the resistivity of the sea bed.

FIGURE 7 Overall view of the model showing the riser tower, FPSO, Oil offloading lines (OOL) and the FTA sea bed systems. The sea water resistivity was varied with the depth

The data obtained from the model for the initial, mean and final life includes:

- Potentials on the structure
- Anode consumption rates
RESULTS TO DATE

The completed model was used to predict how the system would perform and the level of protection which would be provided for the initial, mid life and end of the intended design life of 25 years. Of particular interest was the configuration of the ICCP system and the operational settings required to ensure protection of the structures while at the same time minimizing interaction currents. For example predictions were made using the model for the following conditions:

- ICCP on, nominal FPSO set point potential -800 mV
- ICCP on, nominal potential -900 mV
- ICCP on, nominal potential -1000 mV

It is possible to draw some significant conclusions from the model.

Interaction currents

Interaction currents are generated in the flow lines and connections when the CP currents from the anodes find that the least path of resistance is via some associated structure and current flows to metallic structures not originally intended to be protected by that anode. For example if the ICCP system anodes produce too little current then sacrificial anodes on the tower and sub sea systems will supply current to the FPSO thus reducing the life of those anodes. If the ICCP anode output is too high then current will flow to the tower and sub sea systems and may cause over protection. In both cases the additional affect is that significant current flows are generated in the flow lines and connections.

The total protection currents flowing to the FPSO, riser tower and oil-offloading systems, and from the anodes on each of these components, were derived from the model. By comparing the internal anode to cathode current flows in each component, the magnitude of the interaction currents flowing in the flexibles connecting the riser tower to the FPSO, and in the oil-offloading lines, can be derived. The results show that the ICCP potential setting required to eliminate adverse interaction currents becomes less negative with time.

It should be noted that the predictions, in this and following sections, are dependent upon the polarization data and the coating breakdown factors assumed in the model. Changes in these values would result in significant changes in the results. It is intended that the model will be re-calibrated when actual field data become available.

Protection potentials

The ranges of protection potentials were predicted by the model for the various scenarios postulated over the life of the field. It is possible using the model to predict as the coating condition deteriorates, the spread of potentials on the FPSO hull will vary and identify potential overprotection areas. The impact of design changes or late changes during the construction phase can also be assessed.

Sacrificial anode lives

Data exist, within the model, which was used to estimate anode lives for any of the hull appurtenances, URF and OOL components. This area has not been addressed in detail to
date, but will prove valuable as a diagnostic tool if anomalous anode corrosion is detected during ROV surveys.

CONCLUSIONS

Computer modeling has been employed to predict the level of protection provided by the cathodic protection system, to identify interactions and as to aid decision making. The CP systems on the FPSO and riser tower have been modeled for conditions through life and at a number of ICCP control settings. Potential distributions, anode and structure currents and resultant interaction currents have been determined.

The model has provided valuable information on how the ICCP system should be managed and identified changes which may be necessary during the future operation of the field, thus proving valuable data for future planning.

As data becomes available from surveys and on board data collection systems further validation and refinement of the model will be performed. It can then have value as an input to future ICCP operating procedures and as a guide for trouble-shooting any problems revealed by the RBI program.

FUTURE MODEL DEVELOPMENT

The modeling carried out to date has identified the nature and magnitude of interaction effects produced by the complexity of the CP design. It has also indicated the way in which such effects might be mitigated. In order to further validate the model, and increase its usefulness as an operations tool, the following actions are in hand:

- Incorporate into the Project risk based inspection program the facility to produce operating data [ICCP currents and FPSO, URF and OOL potentials, together with currents flowing in flexibles and oil-offloading lines] which are suitable for re-inputting into the model. This will assist in validating the model, and correcting any of the initial assumptions, particularly in respect of relative coating breakdown, which impact on the model output.
- Use the [developing] model to extrapolate, from reference electrode readings, the range of potentials on the hull, in particular to determine if over-potentials conducive to coating damage are likely to be present.
- Ultimately, as FPSO hull potentials become less uniform, and the risk of coating damage increases, use the model to determine alternative control strategies for the ICCP system.

REFERENCES