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A Comparison of Impressed Current and Galvanic Anode Cathodic Protection Design for an FPSO Hull

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ABSTRACT

Ocean going vessels have long employed impressed current cathodic protection systems to minimize corrosion on hulls. In recent years, improvements in offshore oil and gas recovery have led to the development of Floating Production & Offloading vessels and Floating Storage and Offloading vessels (FPSO's and FSO's). This new class of vessel is moored in a stationary condition over the production field. The difference in operating conditions between FPSO's / FSO's and regular transport ships has initiated a debate over cathodic protection requirements for the hulls of this new class of vessel. A review of offshore vessel and structure CP design is presented, contrasting the effectiveness of impressed current (IC) and galvanic anode designs for the hull. The ability to satisfy industry design codes and recommended practices is presented. Results from design calculations, as well as boundary element modeling (BEM) indicate that galvanic anode design is the optimal method.

INTRODUCTION

The use of floating production, storage and offloading (FPSO's) vessels has rapidly increased in recent years. The advantage of FPSO's over other floating production facilities is the ability to store produced fluids, which can be later offloaded to a shuttle tanker. The components of an FPSO include the vessel (which is either a new build or a tanker conversion), the mooring system, the processing facilities, and the storage tanks. FPSO's differ from ships in that they are positioned in a stationary condition over the production field for years at a time. The hulls of FPSO's and mobile ships are protected from corrosion by a combination of coatings and cathodic protection. The current required to cathodically protect a ship hull varies due to factors such as speed, water velocity, and changing water chemistry. To account for the sometimes rapidly changing current requirements, impressed current cathodic protection (ICCP) systems are most often applied to these vessels. Hull mounted ICCP systems can employ mixed-metal oxide (MMO), platinized titanium (Pt-Ti), and lead-silver (Pb-Ag) anodes, in varying shapes. Typically these systems are potential controlled by a feedback loop system by which the hull potential is measured against strategically located reference cells, allowing the T/R to automatically increase or decrease the current output to maintain a set potential. ICCP systems are preferred for ocean going vessels particularly because the system can adjust current output for changing water chemistry and water velocity. Hull mounted ICCP systems are also designed with a low profile, which minimizes drag on the hull. Galvanic (or sacrificial) anodes provide an alternative to ICCP. In open seawater, Aluminum-Zinc-Indium (Al-Zn-In) standoff anodes are commonly used for cathodically protecting stationary marine structures such as jackets and the hulls of SPARS and TLP hulls. Anodes of this type provide 2-4 amps of current per anode at potentials of approximately -1.1 to -1.05 Volts vs. Ag/AgCl. The advantages of a galvanic anode system include, low or no maintenance requirements and durability over long design lives. FPSO's are stationary vessels, which have many appurtenances, for these reasons the requirements for cathodic protection of the hull differ from that which are required of mobile vessels.

DESIGN CONSIDERATIONS

In seawater, the primary cathodic protection criteria requirement is that steel must be polarized to a minimum of -0.800 volts vs. Ag/AgCl[1]. However, excessively negative potentials (greater than -1.1 Volts) can damage the hull coating systems by means of hydrogen evolution[1]. Additionally, hydrogen can decrease the life of fatigue sensitive items and initiate cracking in certain alloys which have excessive hardness. To avoid hydrogen damage, the CP system must supply enough current to the exposed (uncoated) steel so that it achieves this minimum potential (-0.800 V), without surpassing -1.100 Volts. As previously mentioned ship builders have normally utilized ICCP systems to achieve these requirements on mobile vessels. However there are key differences between FPSO's and normal mobile ships. FPSO's can have many fatigue sensitive appurtenances such as transfer lines and steel catenary risers (SCR's). FPSO's cannot be dry docked once placed in service. As such, the coating effectiveness can continually deteriorate through the life of the vessel. To evaluate the effect of these differences a case history is presented to determine the suitability of hull mounted ICCP and galvanic anode systems.

CASE HISTORY

Background

The case history presented herein involves a new-build FPSO with a 25-year design life and the physical parameters in Table 1. The FPSO in question is the production and storage facility for a large, deepwater field, which includes numerous subsea wells and associated risers. The original design concept for the hull CP system consisted of a standard ocean going vessel ICCP system configuration. The system consisted of 22 Pt-Ti anodes mounted in a cofferdam with a diver-replaceable connection. The system would be monitored by eight, high purity recess mounted zinc reference electrodes, similarly mounted in a cofferdam with a diver replaceable connection. Anodes and references cells are shown in Figure 1. To verify the performance of the system the design was analyzed using boundary element modeling (BEM) and a parametric analysis of dielectric shield sizing based BS 7361 criteria[2] and work by Sunde[3]. The design-input criteria are based on DnV RP B401[1].

BEM Results

The BEM analysis considered the effect of decreasing coating performance over the life of the FPSO. The hull requires approximately 1800 amps based on DnV RP B401 criteria. Figure 2 shows the potential distribution on the hull in year 20 based on the 22 ICCP anode proposal. The results of the modeling clearly show that large areas of the hull will be polarized more negative than -1.100 Volts vs. Ag/AgCl, to potentials as low as -3.0 Volts. Conversely other areas of the hull, both exposed sections and locations shielded by the hull appurtenances will be under protected at potentials at or near -0.700 Volts.

Given the poor results of the original design proposal, a second concept was modeled based on increasing the anode quantity to 32. The concept included the original 22 side mounted anodes, with an additional 10 anodes located on the bottom the hull. This approach was based on the fact that increasing the quantity of anodes decreases the current output from each individual anode while providing improved current distribution to the hull. Modeling revealed that the additional anodes would in fact provide improved current distribution (Figure 3). The minimum potential predicted was improved to -0.817 V. However it also revealed that large areas of the hull would still be over protected to potentials greater than -2.0 V.

Parametric Analysis

Hull-mounted ICCP systems require the installation of a dielectric shield to protect the hull paint system from excessively negative potentials in areas immediately adjacent to the anode. A parametric study was performed to determine the relationship between anode current output, coating breakdown and polarization criteria. For a disc-shaped anode the minimum required shield radius as required by BS 7361[2,3]:

$$r = \frac{\rho I}{2\pi(E_0 - E)} \qquad (1)$$

Where:

E_0 = general potential of the hull when protected (in Volts)

E = the most negative potential that can be withstood by the hull paint near the edge of the shield (in Volts)

ρ = water resistivity (in Ohm-meters)

I = anode current (in Amps)

For rectangular or strip anodes the shield must extend to a distance b on either side of the anode, where b is equal to the minor radius of the ellipse:

$$b = \frac{L^{\sqrt{\frac{2\pi L(E_o - E)}{\rho I}}}}{\frac{2\pi L(E_o - E)}{\rho I} - 1} \qquad (2)$$

The major axis (L_o) of the ellipse is given by:

$$L_0 = \frac{L\left[\frac{2\pi L(E_o - E)}{\rho I} + 1\right]}{\frac{2\pi L(E_o - E)}{\rho I} - 1} \qquad (3)$$

From these relationships, the potential on the ship hull at the edge of the shield can be derived as:

$$E_{edge} = E_o - \frac{\ln\left[\frac{L + L_a}{L - L_a}\right]\rho I}{4.605\pi L_a N_{anodes}} \qquad (4)$$

Where,

N_{anodes} = Number of Anodes

I = Total current required for cathodic protection of the hull

Based on these relationships and the current requirements of the FPSO, an analysis was performed to determine the effect of a range of anode current outputs on the shield size.

Two shield sizes were analyzed, the standard 1.5 X 1.2-meter rigid shield (which was proposed in the original design), and a 3.5 X 3.2-meter shield. The results of the analysis, based on equation 4 are shown in Figure 4. The larger shield size was selected based on using the largest dimensions that could be installed on construction block for the hull (Figure 5). Shields that are larger than 3.5 X 3.2 meters will cross the block-erection joints, making installation costs prohibitive. The results show that 1.5-meter and 3.5-meter shields can tolerate a maximum current output of 9 amps and 24 amps respectively while shielding the hull from potentials greater than -1.1 Volts. Based on these current limitations, a total of 200 and 75 ICCP anodes would be required respectively based on the 1800-amp current requirement. Similar results can be found using disk-shaped or elliptical anodes (Figure 6).

Galvanic Anode Design

The large number of required ICCP anodes in turn require an enormous amount of cables and associated wiring. In addition, cables would have to be routed through storage tanks. Fewer anodes would require prohibitively large dielectric shields to protect the hull paint from cathodic disbondement. For these reasons it was determined that a Al-Zn-In galvanic anode system should be considered. Based on the same design criteria as the ICCP system, a total of 424 standoff and 80 flush mount anodes of 127-Kg and 92-Kg net weight each would be required for a 25-year design life. Flush mounted anodes were selected for locations that require a low profile, such as behind the I-tubes. The closed circuit potential of an Al-Zn-In anode is approximately -1.05 to -1.10 V, hence dielectric shields are not required.

DISCUSSION

Current Requirements

The cathodic protection current requirement of an FPSO is several orders of magnitude higher than a typical mobile vessel. The difference in this requirement is attributed to the continued coating degradation over the life of an FPSO. Conversely, mobile ships are dry-docked periodically (perhaps every 5 years); at which time repairs are made to the coatings and CP systems. Coating repairs during dry-dock maintenance results in a high coating efficiency throughout the life of the vessel. The resulting current requirement for such a vessel is several orders of magnitude less than a FPSO that will experience continued coating degradation without the opportunity for repair.

Compatibility with other CP Systems in the Field

FPSO's are the central facility for large subsea developments. In such a field an FPSO hull may be electrically continuous with many items including: FPSO Suction Anchors, Risers, Offloading Buoy and associated mooring, flex Joints, floating steel offloading lines, subsea flowlines, manifold, subsea trees, rigid pipe jumpers. In most cases all of these items are cathodically protected with Al-Zn-In galvanic anodes. To satisfy polarization requirements, ICCP control systems for ship hulls must be set at approximately -0.900 Volts in contrast to Al-Zn-In anodes which have a potential of -1.05 to -1.1 V. Hence, coupling an ICCP protected hull to risers and lines protected with galvanic anodes will create a potential differential that will force draining of current from the galvanic anode systems.

Construction Considerations

Installation of the quantity of ICCP anodes required to avoid hydrogen damage to the hull coatings is not practical or commercially favorable. In normal ship construction anode cabling is typically run from the rectifier to the anode via void spaces. However the distribution of ICCP anode quantities of 30 or more will require the routing of cables through ballast and storage tanks. This scenario in turn will require the construction of special conduit and piping in these areas. Use of a smaller quantity of anodes, each at increased current output, would require very large dielectric shields. However shield size is limited by the size of the hull construction modules. Shields larger than 3-meters are will cross the block erection joints on new-build FPSO hull modules. This scenario will result in higher installation costs and possible schedule impacts. Galvanic anodes require neither shielding or cable routing, resulting in very low installation costs.

CONCLUSIONS

Cathodic protection with Al-Zn-In galvanic anodes is superior to hull-mounted ICCP for FPSO's. The primary reason for the increased CP requirements is due to the stationary nature of FPSO's. Stationary structures require larger current requirements than mobile ships that can rehabilitate hull coatings during periodic dry-docks. In summary, the advantages of a galvanic anode system are:

- Compatibility with the CP systems of other items in the field;
- Galvanic anodes (other than Magnesium) do not disbond coatings and do not require dielectric shield installation;
- Galvanic anode systems require little or no maintenance over the service life of the vessel. Hull mounted ICCP anodes typically require replacement within 15 years of service.

However galvanic anode systems should not be installed without considering several factors which are unique to floating structures:

- Anodes should not be located at the towline where the fenders will contact the hull. This is only a concern during fit up of the topsides after the ship has been launched. The fenders can easily damage stand-off anodes located in this area (Figure 7);
- Ballasting details should be reviewed to determine the minimum water level during service. Anodes should be located on the on the sideshell such that exposure to the atmosphere during service is minimized or eliminated.
- Anode location should be considered early in design, so that damage during construction and launch can be minimized.

REFERENCES

1. Det Norske Veritas - Recommended Practice B401, "Cathodic Protection Design", 1993.

2. British Standard 7361-1:1991, "Cathodic Protection Part 1 - Code of Practice for Land and Marine Applications".

3. Sunde, E.D.,"Earth Conduction Effects in Transmission Systems", 1949.

Table 1. FPSO case study parameters.

Type	New Build FPSO
Destination	West Africa
Design Life	25 Years
Hull Coating (submerged surface area)	3 Coats of Abrasion Resistant Epoxy
Coating Breakdown Factor	DnV RP B401 Category IV - 32.5%
Total Wetted Surface Area	40000 m^2
Current Required for Cathodic Protection	1800 Amps

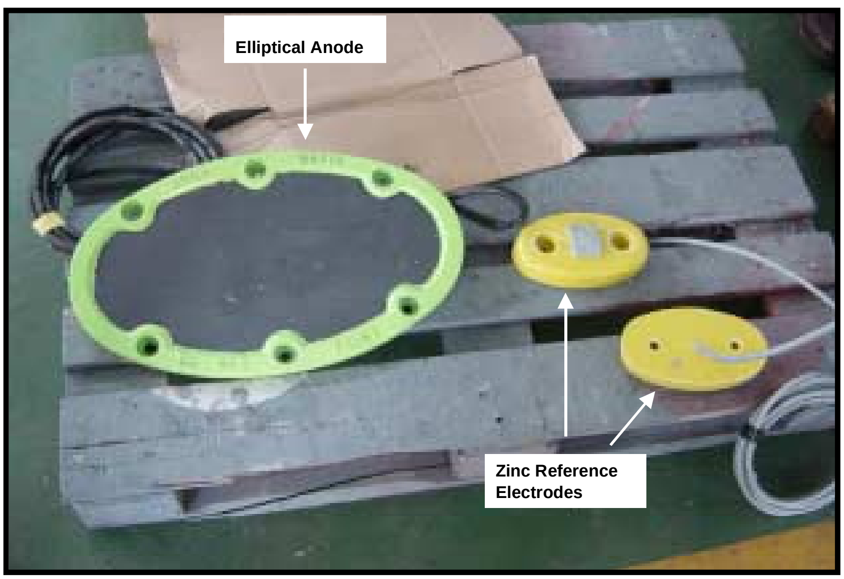

Figure 1. Hull mounted elliptical anode with Zinc reference electrodes.

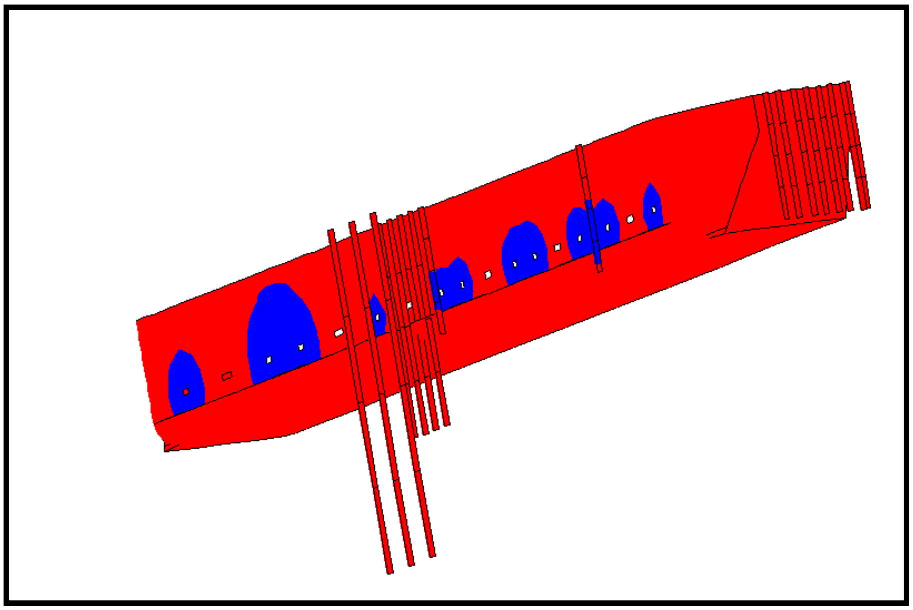

Figure 2. Potential distribution in year 20 on an FPSO hull utilizing and ICCP with 22 anodes. Areas in blue represent potentials more negative than -1.2 V vs. Ag/AgCl.

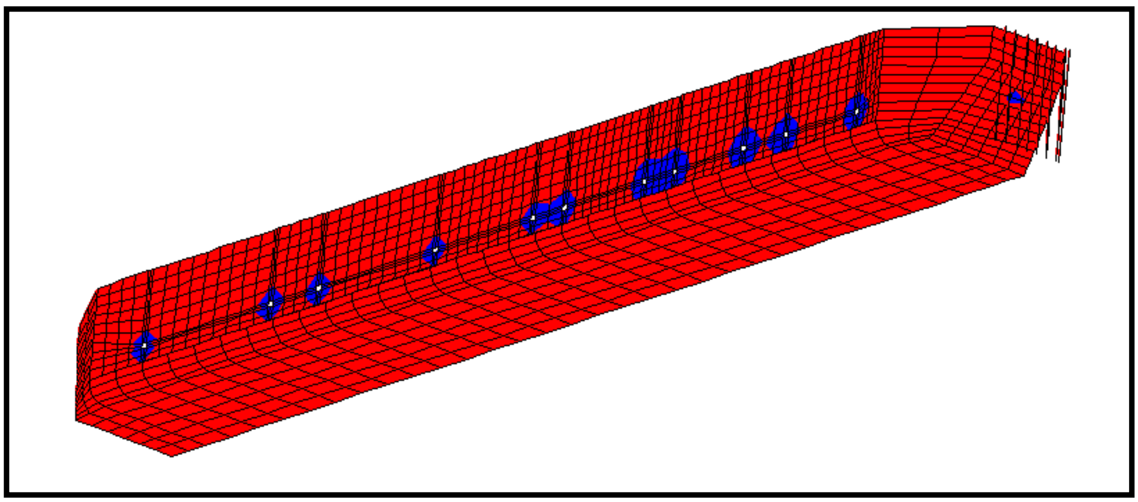

Figure 3. Potential distribution in year 20 on an FPSO hull utilizing a 32-anode ICCP system.

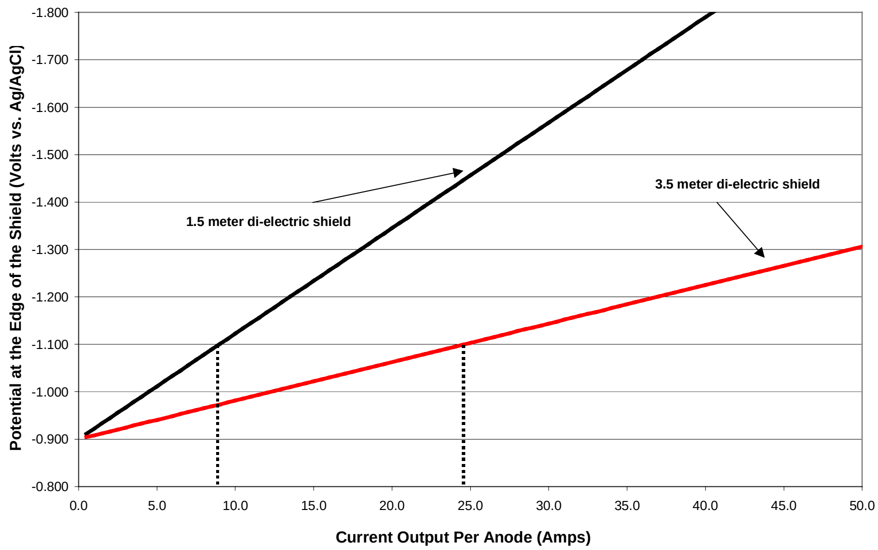

Figure 4. Change in potential on hull adjacent to the edge of the dielectric shield of an individual anode.

Figure 5. Mid-body bottom construction block.

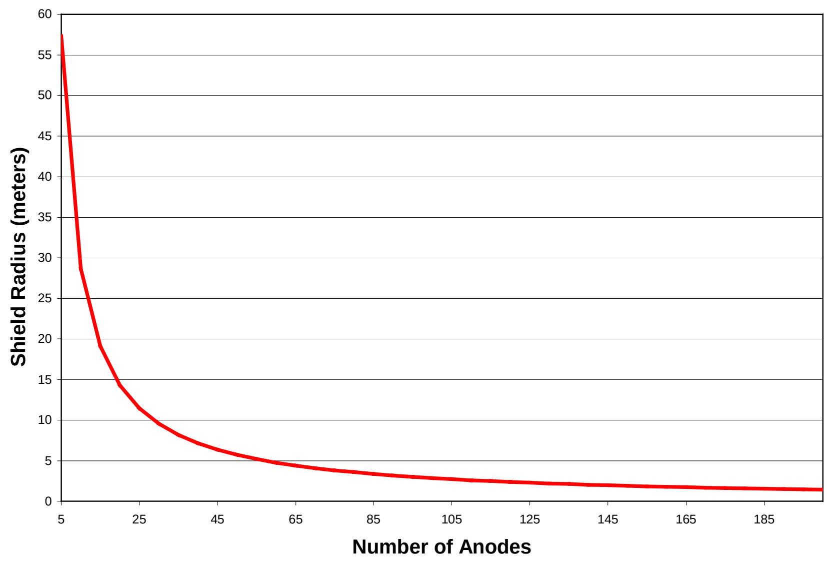

Figure 6. Variation in required shield radius in relation to the number of anodes. The results are based on a 1800-amp current requirement and hull potential limitation of -1.100 Volts vs. Ag/AgCl.

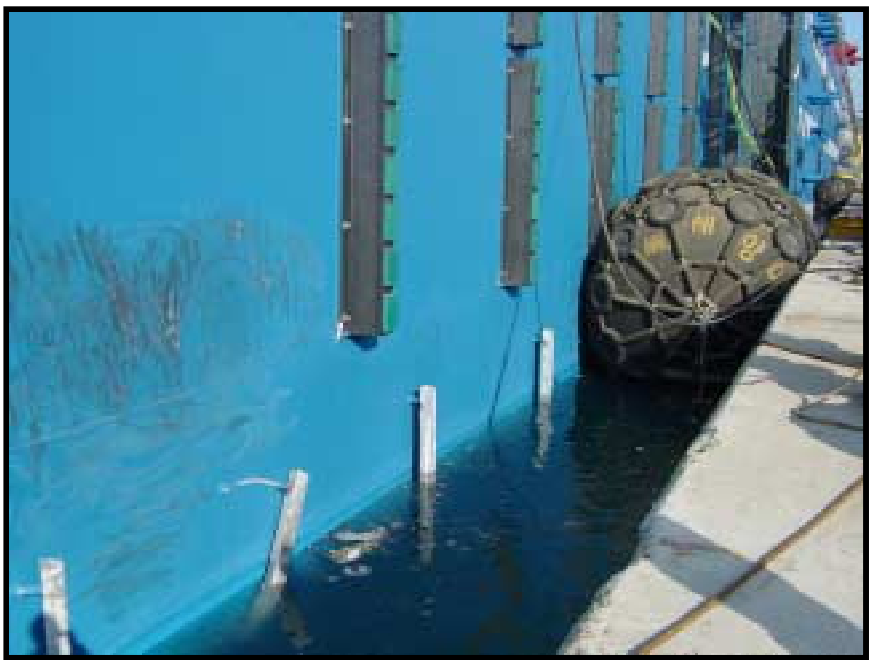

Figure 7. Anode damage resulting from contact with fenders during topside installation.