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Methods for Cathodic Protection of FPSO's. Where do we go?

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ABSTRACT

For many years Impressed Current (ICCP) has been the most common Cathodic Protection (CP) solution for ships. Examples of Floating Production Storage and Offloading (FPSO's) units are converted tankers or new build ships produced by the same companies building the tankers. The same CP design concept as the ship specifications regarding anode number and anode shield sizes has been adopted for the FPSO's despite the significant longer operational life with no dry docking. Design evaluations and actual experience have shown that the long design life up to 30 years for an FPSO has created requirements for more detailed evaluations (CP modeling) of the potential level over the entire life. In most cases an increase in the number of ICCP anodes is found necessary to avoid excessive potential level. The regulation system has to secure activation of the ICCP system even if the CP system is combined with sacrificial anodes or if the FPSO CP system can be influenced by other connected structures with sacrificial anodes. Not intended excessive consumption of the sacrificial anodes can occur and this is important when evaluating cathodic protection solutions. This paper compares the two methods and their limitations based on the last years experience.

INTRODUCTION

Floating Production Storage and Offloading (FPSO) units have been in operation for many years. In the North Sea the first Floating Production units were installed around 1990. At a later stage tankers were converted to FPSO's and further on new build special ships were made for this purpose. The Cathodic protection system on all these first FPSO systems were all based on standard ship design; which means ICCP system with 4 to 6 anodes with relatively small ICCP shielding arrangement. These corrosion protection systems (standard ship design) were based on dry docking and repair of coating system each 3 to 5 years.

In the offshore operation history based on FPSO's there are not many passed 10 years in operation. From previous performed studies results have shown that the actual overprotection problems can start from around year 10. For some of the converted tankers, the coating degradation may be worse caused by the previous repair work.

ICCP systems do all include a shielding around each anode to avoid too negative potential on the hull coating. Over the years it has been defined that overprotection (coating disbonding) is avoided at potential more positive than -1100 mV vs Ag/AgCl /1/ . The last version of DnV RP B401 /2/ this limit is adjusted to -1150 mV vs. Ag/AgCl. Can even more negative potential limits be accepted?

This paper highlights positive and negative sides of ICCP system and sacrificial anodes on an FPSO.

All potential in this paper refers to Ag/AgCl.

COMPARING ICCP SYSTEM AND SACRIFICIAL ANODE SYSTEM

ICCP system compared with a sacrificial system

Below functions and elements for the two systems are presented.

An ICCP system includes the following:

- Rectifiers (2 to 4 per FPSO)
- Regulation system usually built into the rectifiers
- Reference cells – minimum one per rectifier.
- ICCP anode for hull penetration
- Penetration through hull both for ICCP anode and for reference cells
- Cables from rectifiers and regulation system to ICCP anodes and reference cells
- Shielding around each single ICCP anodes
    - Primary shielding. Sometimes a GRP arrangement around the anodes
    - Secondary shielding. Usually coating system with thickness around 1000 µm
- An ICCP system will require a large safety factor to cover for the risk of short time failure one or more anodes. The safety factor is typical 50%.

Sacrificial system:

- A sacrificial system does not require any active components.
- Galvanic anode of typical AlZnIn alloy
- Weight typically from 100 kg to 200 kg

- Required number of anodes will typically range from 300 to 600 dependent on selected anode weight and required life.
- Each anode with insert steel as flat steel or tube.
  - Typically the anode is welded to the structure each end of the insert steel e.g. two welds per anode.

ICCP anode and sacrificial anodes during installation

The difference between the ICCP system and sacrificial system is shown in the section above. During installation and commissioning the following is required:

ICCP anode system:

- Preparation of penetration through hull wall at the selected positions for both anodes and reference cells.
  - Anodes should be avoided close to material susceptible to hydrogen embrittlement
- Installing anodes and reference cells
- Installing rectifiers and control units
- Installing and connecting cables from rectifier/control unit to ICCP anodes and reference cells
- When possible turn on power and check system.
  - Setup the control system.

Sacrificial anodes:

- Welding anodes on to hull. Typically two welds per anode.
  - Coating has to be removed at installation position

ICCP against sacrificial anodes during operational

The number and type of both sacrificial anodes and IC anodes are based on a detailed CP design securing the required amount through the whole operational life. For both system the actual development of the coating breakdown for the applied coating systems are very important for the performance.

During operation the following is important for an ICCP system;

- When can an ICCP system be activated?
  - If there is a longer period where the hull is exposed to seawater and FPSO topside is not completed and therefore no ICCP activation, preliminary CP has to be installed.
- The ICCP system has to be controlled by a regulation system which is manual, half automatic or fully automatic.
  - The set level for the system is important. Both to secure activation and to avoid over protection. The following is important factors and elements
    - Number and position of reference cells
      - Reference cells close to any sacrificial anodes (e.g. in turret, sea chests, thrusters, fairlead, etc.) will influence the regulation system. Even supply of protection from more remote structures has to be accounted for.
        - With one single reference cell regulation this influence, may cause ICCP system for this area to be turned off and thereby give under protection to part distant to the reference cells
    - Peak regulation or average of several reference cells

        - Failure on reference cells? Do the reference cells give to correct potential levels? CP inspection required to check reference cell potential level
- Required maintenance:
    - ICCP anodes to be changed by diver when they fail; operational life is indicated to be 15 to 20 years
    - Reference cell to be changed by diver when they fail; operational life is indicated to be 15 to 20 years

During operation the following is important for the sacrificial system:

- Sacrificial (e.g. Zn and AlZnIn) anodes have a practical potential window resulting in no risk for cathodic disbonding of the coating system or over protection in general
- The number of anodes is either limited by the total required weight or the final requirements resulting in a high extra boost for fast polarization of the FPSO initially.
- No extra anodes have to be installed to cover up for any special requirements before installation.
- Once sacrificial anodes are installed they will activate and secure protection. CP inspection should be performed initially and on a regular basis (3 to 5 year).
- The extent of protection supplied by one single anode is limited. Therefore the anodes have to be distributed equally around the surface to protect.
- No maintenance is required.

FPSO CP DESIGN AND SIMULATION CASES

In the early stage of the FPSO history, the ICCP design was performed by an average fixed current density not actually considering the coating breakdown as function life (example shown in /4/). The CP design is now in most cases performed according to standards as DnV (the previous /1/ and the latest revision /2/) or NACE standards. For the sacrificial anode design this procedure is fully described by these standards or other equal standards. The ICCP design does have to include estimation of anode shield around each anode combined with size of the anode itself to avoid critical potential on the hull coating.

The examples below are presented to show the large spread in protection level and potential range for ICCP system depending on the selected solution. This is compared with an example based on sacrificial anodes.

The potential distribution on an FPSO can be simulated by use of CP modeling tools as our SEACORR/CP program. One simulation case is a large FPSO with total surface area on approximately 37000 m^2 and initial the proposed number of anodes was 18 with a shield size of diameter 3.5 m. In figure 1 and 2 the potential distribution around the shield are presented for the end of life conditions (25 year). Based on the results from the simulation, the shield diameter size has to be increased to 9.7 m based on an accept potential of -1150 mV and 5.5 m in diameter based on an accept potential of -1500 mV.

Figure 3 to 6 presents potential distribution on a smaller FPSO with surface area of approximately 16900 m^2. A simulation of a classic ICCP ship design with only 4 anodes for the end of life conditions is presented in figure 3 showing very negative potential (-1754 mV) close to shielding.. The shield size for these cases is all 11.3 m^2. Figure 4 to 6 presents the corresponding results for 12, 14 and 20 anodes respectively. In table 3 the results are summarized, also showing the potential distribution window on hull (absolute difference between minimum potential just outside shielding and worst potential on hull). The potential windows are from 219 mV with 20 anodes to 931 mV with 4 anodes.

In figure 7 potential distributions for the end of life conditions is presented for a case with an FPSO with sacrificial anodes. The design life is 30 years and the installed number is 611 each net weight of 82 kg. The coating breakdown is 38%. The potential window is from -909 mV to -991 mV; i.e. 82 mV.

All previous presented cases are based on a seawater resistivity of 0.2 Ωm. Resistivity is an important environmental factor influencing directly the protection capability for a system. A system with a given number of ICCP anodes will require a more negative anode potential to secure protection when there is an increase in the resistivity, but also thereby introducing a significant larger risk for overproduction.

The last example introduces a case with seawater resistivity of 0.34 Ωm. The number of ICCP anodes is 28 and the shield size has a diameter of 4 m. The design life is 20 years and the final coating breakdown is 26%. In figure 8 the development of the potential window over 20 years from close to the shielding to least protected part for a larger FPSO is shown. The potential range starts at around 170 mV and after 20 years this has increased to 900 mV.

The number of IC anodes and the size of the shielding around the anodes can be estimated by use of BS 7361. This formula is mainly applicable for disc-shaped anode.

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

r	=	radius of anode shield (m)
ρ	=	Environmental resistivity (ohm * m)
I	=	current (A)
E_0	=	general potential of the Hull when protected (V)
E	=	the most negative potential that can be withstood by the Hull paint near the edge of the shield (V)

The maximum practical shield radius is found and thereby the minimum number of anodes from the total required current. The essential question is how far down in potential level withstand coating damages. From /1/ this level is recommended to -1100 mV and in /2/ this is changed to -1150 mV.

From paper presented at Corrosion 2004 /3/ formulas for rectangular anodes are presented.

In the formula above, the potential level for over protection is an important factor and will directly influence either on the size of the shield or the required anode number or the size of the shield. This will be covered later.

Cost comparison between ICCP system and sacrificial system

For a given case with a large FPSO with total area around 37 000 m^2 inclusive chains and other appurtenances the required number of sacrificial anodes has been calculated. For the sacrificial anodes the following price basis has been used:

- Sacrificial anode purchase 5.5 USD/kg net anode material
- Installation cost 600 USD per anode

For the ICCP system, purchase cost from suppliers has been used. For installation cost limited direct information are found especially on cabling and anode shielding. As a rough estimate the all inclusive installation cost is defined to be twice the purchase cost. Cost for any future anode replacement is not included.

The costs for three sacrificial anode cases are shown in table 1. A typical larger stand-off anode will result in significantly lower cost than a flush mounted anode. Which anode type to select, will also depend on other elements than economy. This can be factors as e.g. installation aspects, higher risk for mechanical destruction of stand-off anodes in harbors and limitations to influence from drag force during transportations

The initial cost is for ICCP system is lower than a sacrificial system. Depending on the period from first seawater exposure of hull to energizing the ICCP system, requirement for extra cathodic protection might be necessary. This will add on an extra cost of around USD 53 000. This is based on small anodes with an installation cost estimated to USD 400/anode.

The initial costs for ICCP anodes based on the available information are lower than for a sacrificial system.

The cost for electricity for the above case is estimated. The average current is set to 500 A and the guesstimated cost per kWh is selected to either USD 0.1 or USD 0.2. This will result in an electricity cost from USD 261 000 to USD 522 000 over 25 years in operation. Adding these costs to the ICCP anode cost, the sacrificial system is less costly than the ICCP system.

ACCEPT CRITERIA FOR OVER PROTECTION ON COATING SYSTEM

Coating system has to be compatible with CP; i.e. risk for cathodic disbonding has to be within acceptable limits for the operational protection potential. For cathodic protection based on sacrificial anodes several coating system are accepted. The coating systems are tested based on an ASTM standard G8-90 /6/. This specification defines the test samples, test period, test potential level and accept criteria. Typical test period is 30 days. The accept criteria defines the percentage of increased coating damage.

The coating system which requires testing is both the hull coating and the shield coating. The hull coating close to the ICCP anodes on most of the FPSO's in operation today may be exposed to potential level significantly more negative than -1150 mV for periods longer than ten years.

For ICCP systems designed with shield dimensions resulting in a minimum potential of -1500 mV on hull, it is important that the performed accelerated coating tests for defining this accept level are comparable with many years exposure in the potential range from -1150 to -1500 mV.

For the shielding coating system which is typical from 800 μm to 1200 μm, the potential level this part can be exposed to can be significant more negative than -1500 mV. As long as the shield coating system is 100% perfect this will not be problem. If damages occur, cathodic disbonding can be a major problem. Therefore coating tests have to include a realistic potential range and an acceleration effect covering several years of exposure to the actual potential levels.

DISCUSSION

There are several FPSO's installed around the world. The main part is installed the last 5 years. The oldest have now been close to 10 years in operation; reaching an age when it is likely to experience potential levels around the anode shield above the traditional accept level. For those with only 4 or 6 ICCP anodes, this tends to be very likely. It is of importance to collect more data from these older FPSO's in order to get a better design basis for the coating degradation combined with ICCP system.

If the coating system is degrading significant slower than design figures, this will reduce the time period with over protection significantly. If coating breakdown follows the design figures or even higher figures, this can result in an accelerated coating breakdown which will further accelerate the degradation process.

The defined accept criteria for a typical hull coating system has been -1100 mV /1/ and by the latest version of DnV RP B401 /2/ this is changed to -1150 mV. There are design cases where the accept level has been set to -1500 mV. This has been based on coating testing. Both for hull coating and shield coating, the tests performed have to include the knowledge that the coating system can be exposed to very negative potential for several years. When selecting -1500 mV as the accept limit, it is very likely that the area around the shielding will be exposed to potential between -1150 mV to -1500 mV for at least 10 years!. This has to be accounted for in any coating test.

For the shield coating, it is extremely important to make a coating system 100% free from failures and damages. The operational potential window for any damages in the anode shield coating will be exposed to, will be from the potential level of the anode itself to the hull coating accept level. Any damage on the shield surfaces will be exposed to very high current density!! The standard ASTM G8-90 tests /6/ are accelerated tests for coating disbondment and accept criteria are a given percentage of extended coating damage! The test potential is -1450 mV and a test period of 30 days. In an actual ICCP case part of the shielding coating can be exposed to significant more negative potential for the whole operational life of an FPSO; 20 to 30 years!. It is therefore very important that for the shield coating accelerated tests do include realistic potential level and account for the possible long exposure to these negative potential levels.

A sacrificial system the galvanic potential limits the operational potential on the hull, but this also result in an anode requirement of around 300 to 600 anodes. The potential range development for such system will as long as everything is protected not exceed 250 mV. Therefore almost any coating system is compatible with a sacrificial anode system.

The ICCP system is from the initial cost evaluation, less costly than the sacrificial system. Even when including an initial, simpler sacrificial system to cover up for the initial period before the ICCP system is turned on the ICCP cost are lower.

When the cost of electricity for a 25 year period is added this will make an ICCP system more expensive than a sacrificial system. The cost contribution can be questioned. Electricity are produced on the FPSO and the cost impact by adding extra 500 A to 1 500 A has been guestimated based on typically onshore marked prices (USD 0.1 and USD 0.2 per kWh) which can be a conservative approach dependent on the power generation source on an FPSO.

The following future cost for the ICCP system has not been included:

- A significant cost element is anode replacement after 15 to 20 years. This can also be required for the reference cells. This work has to be performed by diver/ROV.
- Monitoring of the system to secure optimum protection window. Needs to be followed up on a regular basis.
- The sections of the hull etc. not covered by reference cells need to be inspected regularly.
- The stability of the reference cells is important. These should be checked regularly for any significant deviation.
- Any failure in single anodes has to be compensated by other anodes, until repair/replacement have been performed. Increases the risk for overprotection.

For the sacrificial system there are few failure modes. The most critical factor for the sacrificial system is the distribution. It is important that the anode are equally distributed, since the protection range for one anode is much more limited than ICCP anodes. If uneven distribution is difficult to avoid, computer modeling is important to verify and optimize. If the anodes are well distributed, an initial survey combined with a survey each 3 to 5 years is satisfactory to secure confidence to the system.

For both the ICCP system, CP surveys to cover the sides of the hull can effectively be performed by drop cell survey around the hull (see reference /4/).

From the uncertainty on the required anode number, shielding size, potential level to withstand disbonding and future cost for the ICCP system, some operators have specified use of sacrificial anodes for their future FPSO's.

CONCLUSIONS

- Initial cost for ICCP system for an FPSO is in most cases lower than for sacrificial anodes.
  - There uncertainties on future cost on maintenance/monitoring for ICCP system
  - The life of ICCP anodes are usually around 15 to 20 years and therefore anode replacement is required for longer operational life.
  - Adding a cost estimate for electricity for 25 years in operation the sacrificial system is the system with total lowest cost.
- Sacrificial anodes have a low level of maintenance and survey/monitoring. The system is self regulating. All typical subsea coatings system will not show any disbonding with sacrificial anodes. Some operators have specified sacrificial anodes for future FPSO's
- Computer modeling is a useful tool for both ICCP system and sacrificial system.
  - For sacrificial system to verify distribution and anode consumption
  - For ICCP system to check anode position, shield size, protection window, position of reference cells and what-if evaluations.

REFERENCES

/1/ DnV RP B401, Cathodic Protection Design, Det Norske Veritas, Oslo 1990

/2/ DnV RP B401, Cathodic Protection Design, Det Norske Veritas, Oslo 2005

/3/ Leif Brattås; Michael B.Surkein, John P. La Fontaine, A Comparison of Impressed Current and Galvanic Anode Cathodic Protection Design fo FPSO Hull, Paper #4095 Corrosion 2004, Houston Texas, 2004

/4/ Are Sjaastad, Harald Osvoll and Francis Duesso, Evaluation of Impressed Current Systems on FPSO's by use of CP Computer Modelling, Paper #4103 Corrosion 2004, Houston Texas 2004

/5/ G. Selboe, H. Osvoll, L. Brattås, Corrosion Protection Based on a Combination of Cathodic Protection (CP) and Coating, Paper #4097 Corrosion 2004, Houston Texas 2004

/6/ ASTM G8-90. Standard test methods for cathodic disbonding of pipeline coatings. American Society for Testing and Materials, Philadelphia, PA 1990

Table 1 Purchase and installation cost for sacrificial anodes

			Cost(USD)		
Alternative	Net weight (kg)	Anode no.	Installation	Purchase	Total
Stand-off	109	444	266400	266178	532578
Stand-off	196	219	131400	236082	367482
Flush	140	305	183000	234850	417850

Table 2 Purchase and installation cost for ICCP anode system

	ICCP system			Cost(USD)		
Alternative	Anode no.	Ref cells	Rectifiers	Installation, cables, shielding, etc	Purchase	Total
ICCP anodes	18	6	3	170000	85000	255000

Table 3 Potential distribution window on an FPSO from outside shield to worst potential as a function of number of ICCP anodes

No of ICCP anodes	Minimum potential on Hull close to anode shield (mV vs. Ag/AgCl)	Potential distribution window (mV)	See figure number
4	-1754	931	3
12	-1212	376	4
14	-1162	324	5
20	-1044	219	6

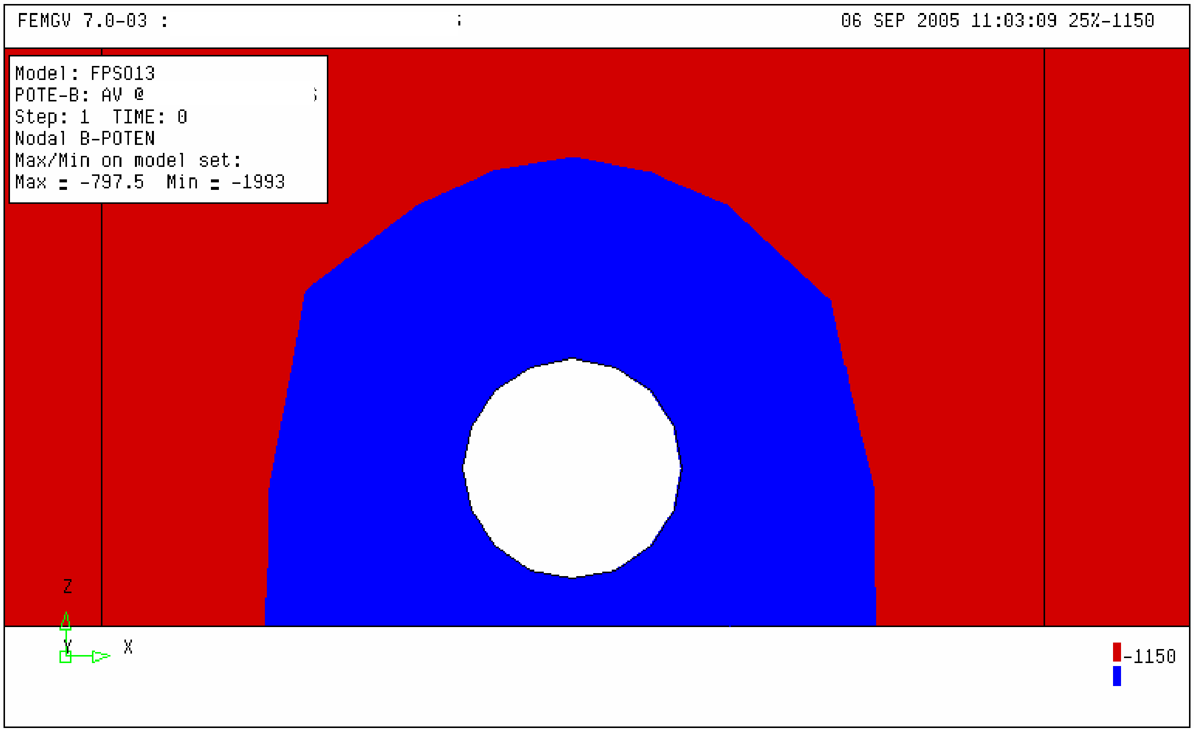

Figure 1 Potential around ICCP anode. The outer of the blue represents -1150 mV. The white circular area represents anode and the initial proposed shield size.

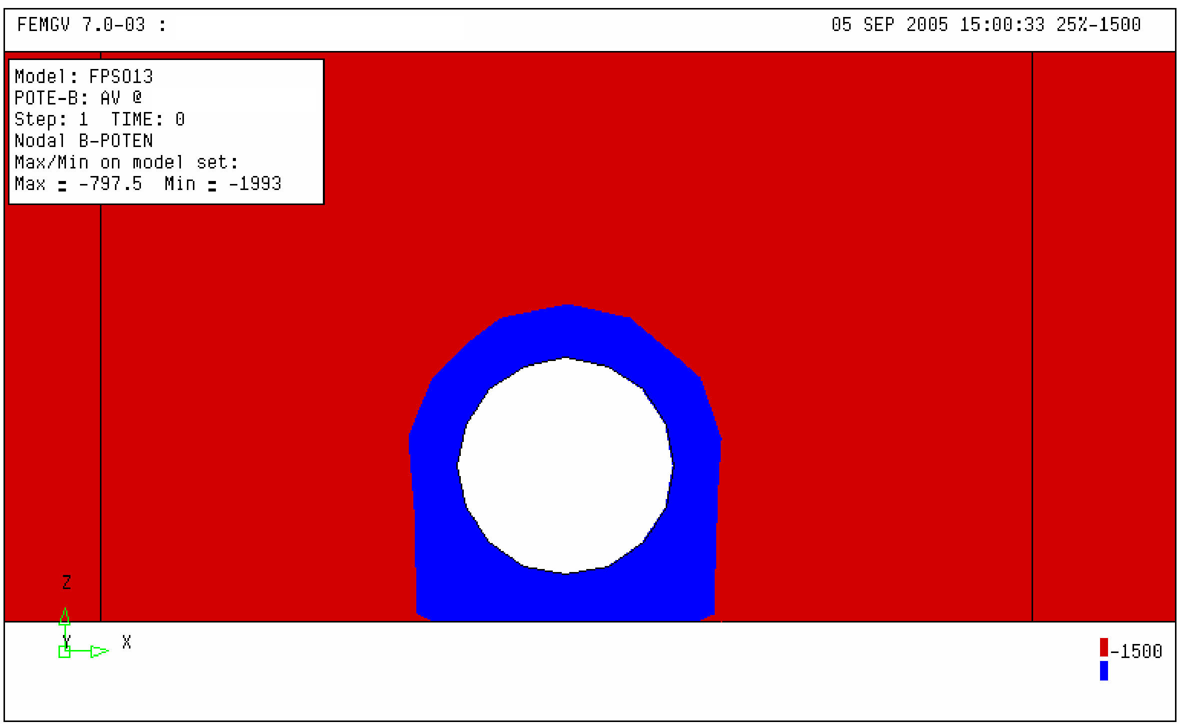

Figure 2 Potential around ICCP anode. The outer of the blue represents -1500 mV. The white circular area represents anode and the initial proposed shield size.

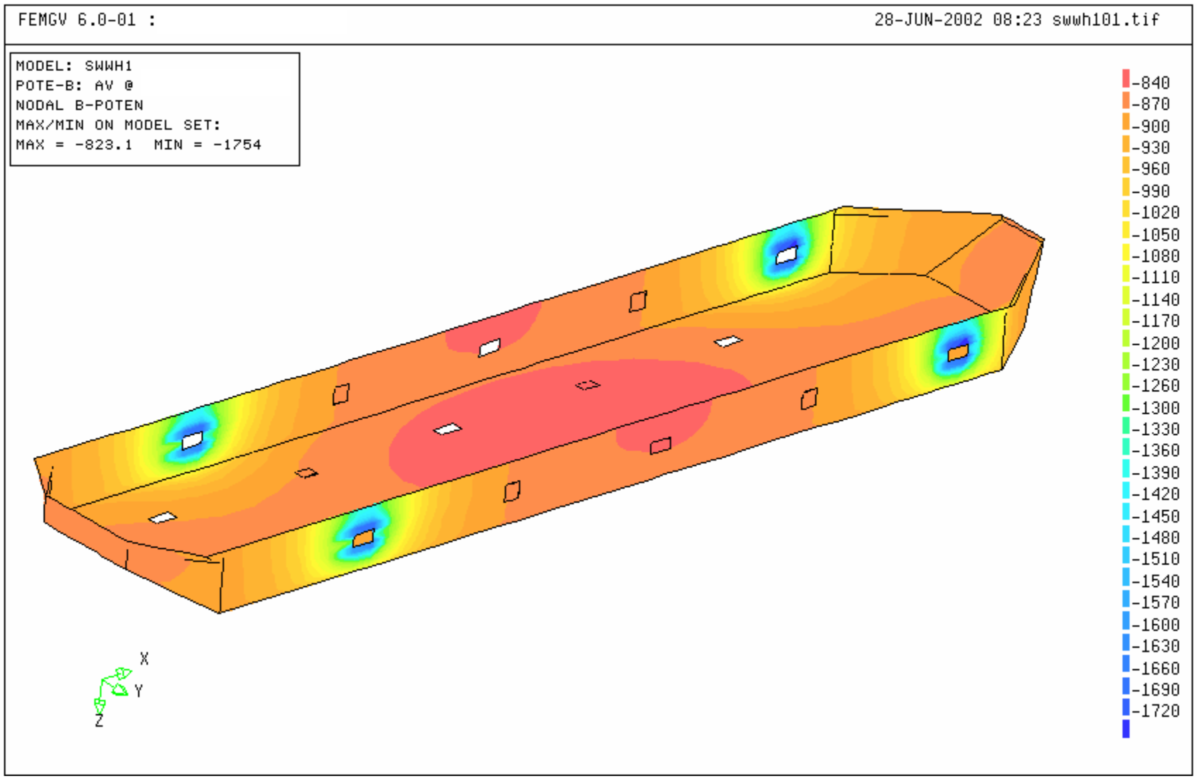

Figure 3 FPSO with 4 ICCP anodes

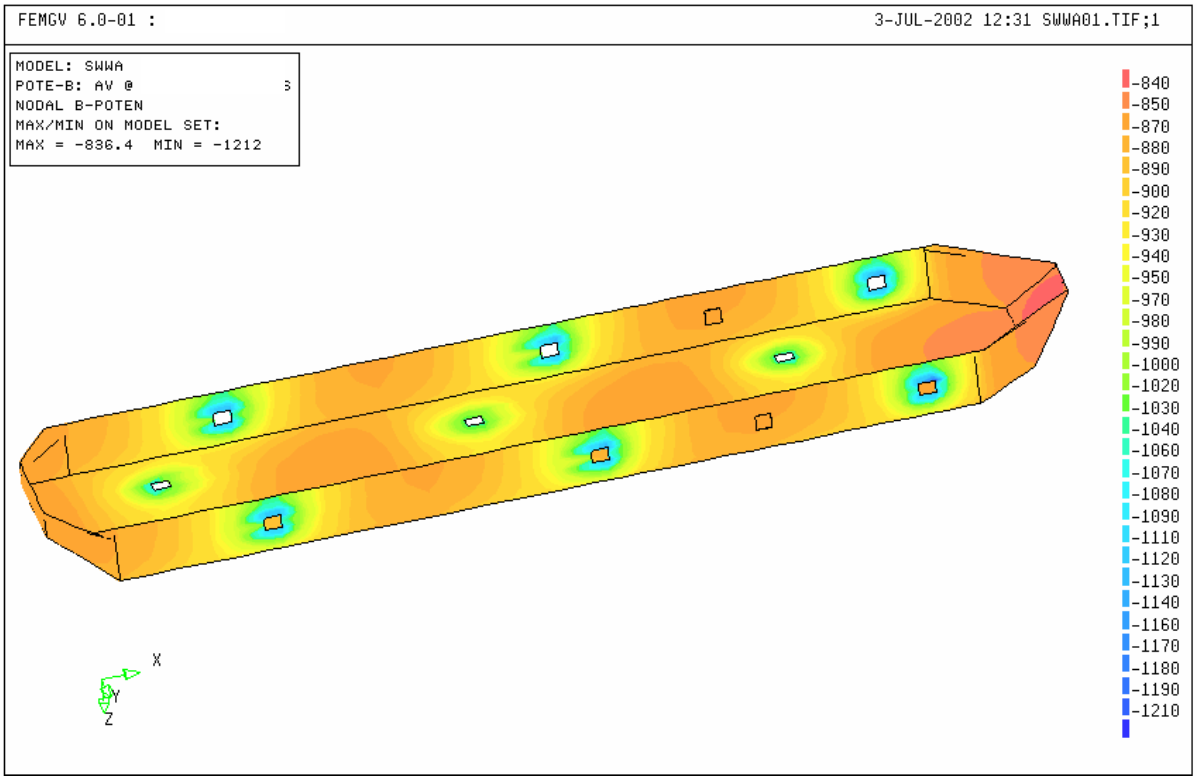

Figure 4 FPSO with 12 ICCP anodes

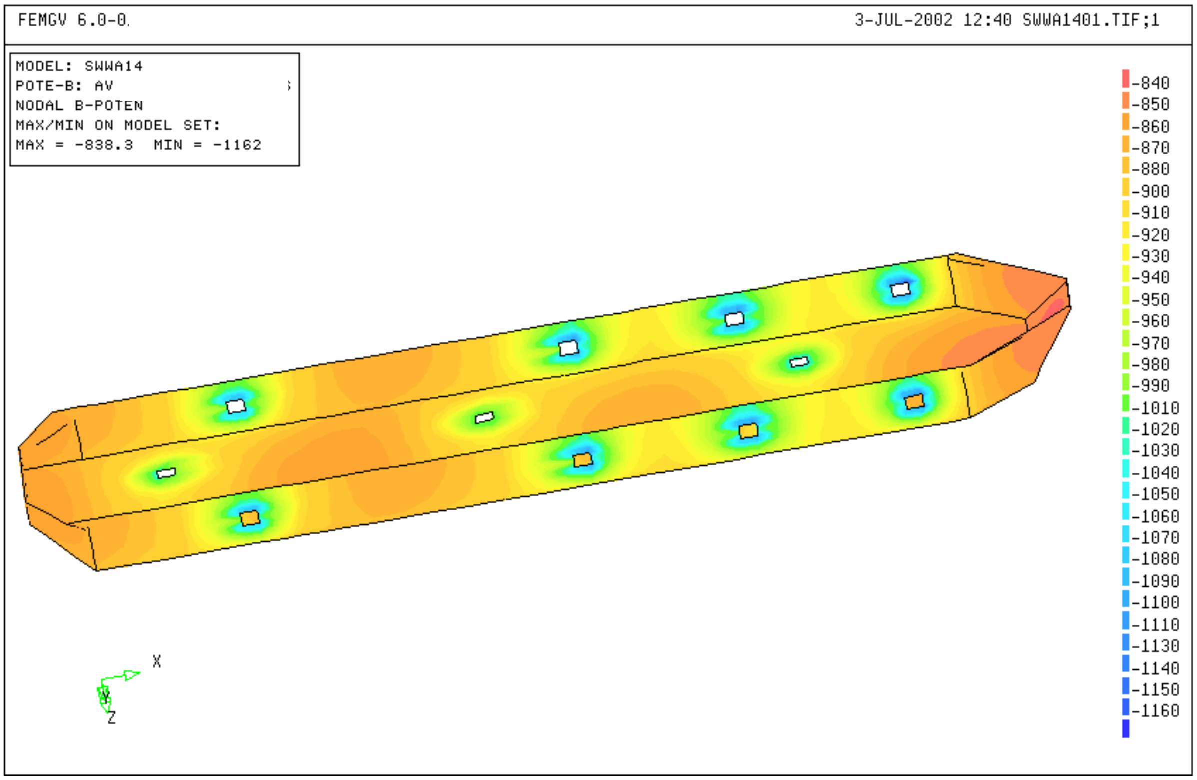

Figure 5 FPSO with 14 anodes

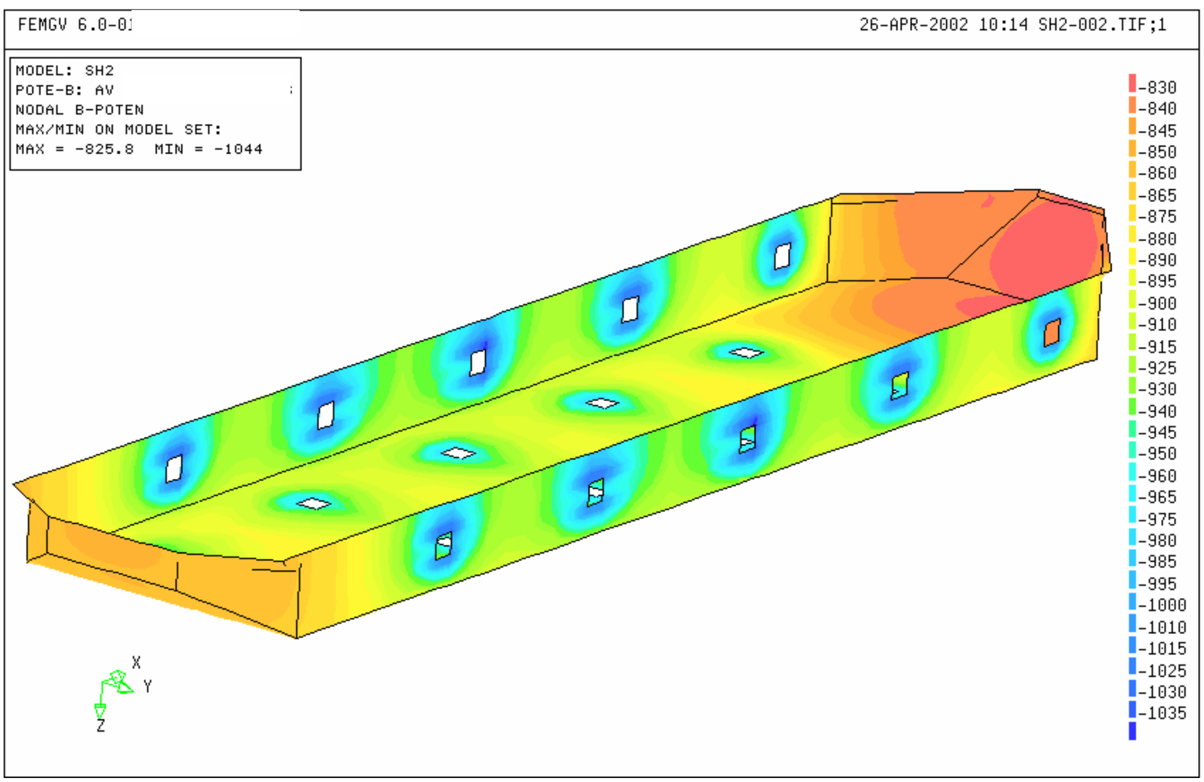

Figure 6 FPSO with 20 ICCP anodes

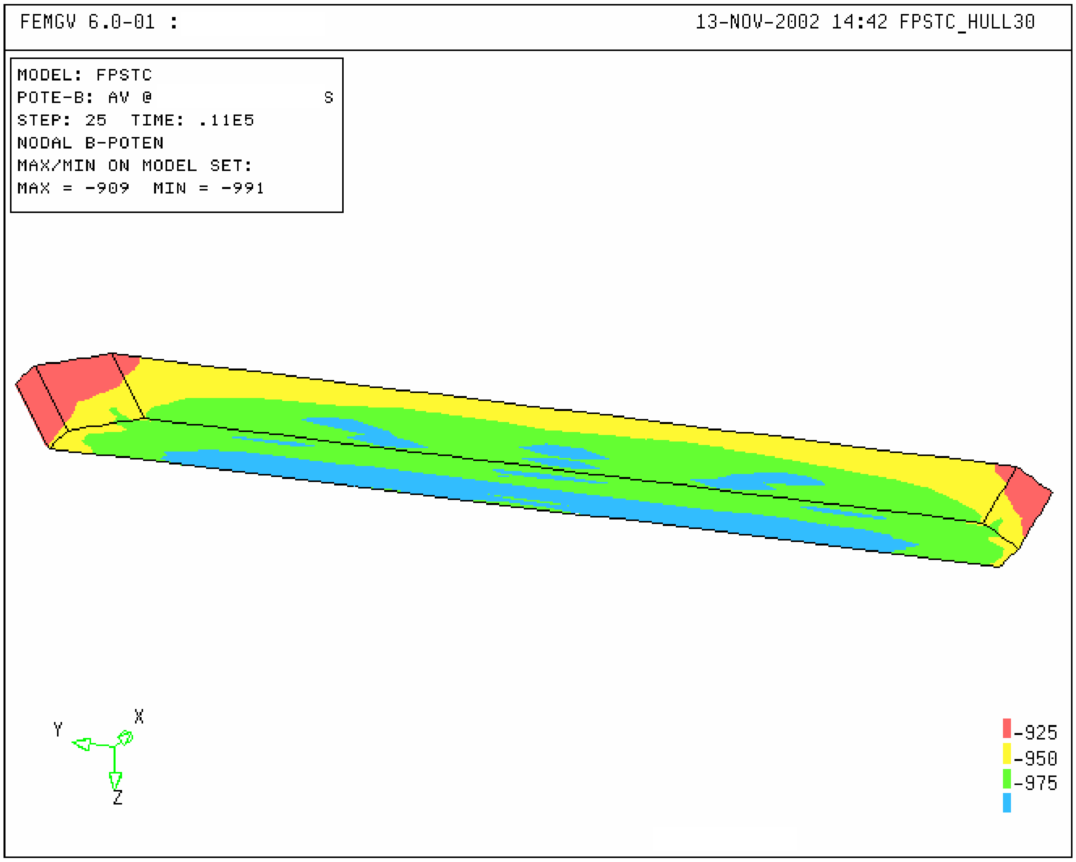

Figure 7 Potential distribution at the end of operational life (30 years) on an FPSO Hull with sacrificial anodes equally distributed on the hull.

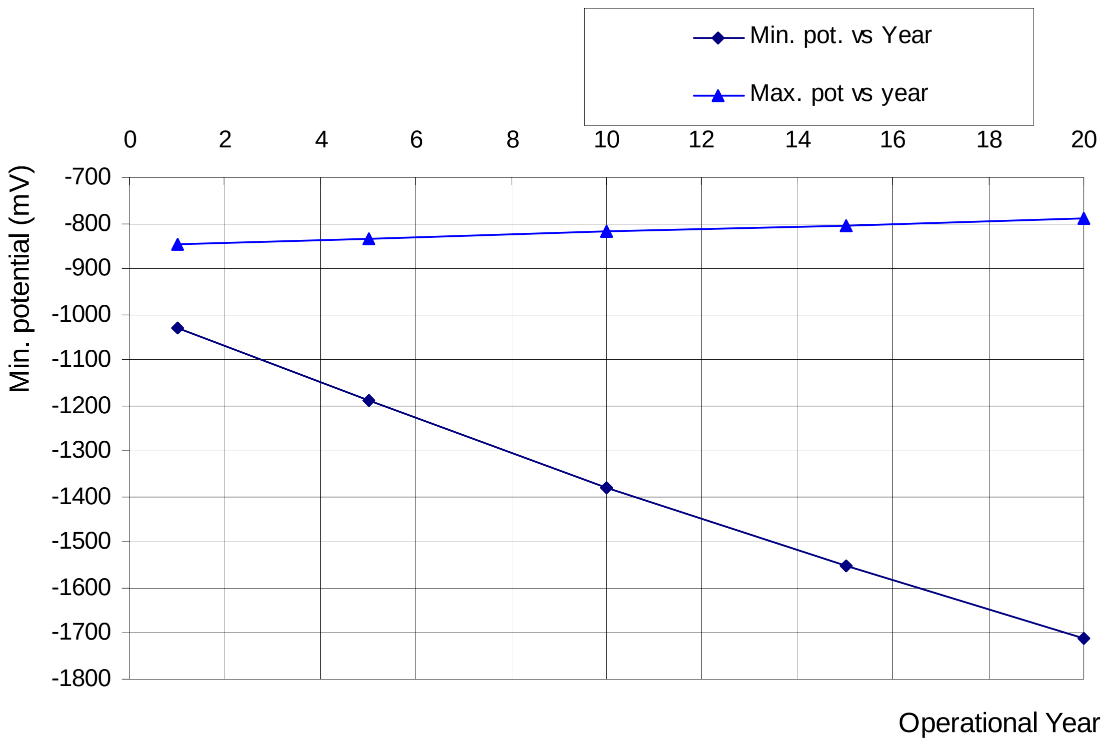

Figure 8 Development of maximum and minimum potential on an FPSO over 20 years. Minimum potential is on the border of the shielding.