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ICCP Retrofit Challenges for an Offshore Jacket Complex

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ABSTRACT

An offshore jacket complex from the late sixties consisting of 5 platforms is protected by a conventional sacrificial anode system. Recent surveys have indicated that extending end service life with a minimum of 20 years requires a significant retrofit effort in the near future. Since replacement of individual anodes on a like-for-like basis would be very expensive, a retrofit option based on remote impressed current anode sleds was considered offering very considerable cost savings.

Remote ICCP anode sleds are relative easy to install but the design of such a CP system is more challenging. Correct positioning of the sleds is critical for obtaining proper protection and avoiding overprotection. In this particular project the availability of target locations was limited because of various subsea pipelines connected to the platforms and two large jack-up zones that should remain accessible.

The feasibility of using an ICCP system was therefore investigated through computational modeling. First the as-is CP status of the complex was simulated taking into account the current condition of the sacrificial anodes as observed during the latest survey. Secondly, an ICCP system was included in the model and different anode sled positions were investigated until an optimal design was obtained. The remaining life of the anodes was re-calculated such that the amount of anode sleds was kept to a minimum. Through modeling the CP effectiveness of the combined system was validated and a cost-effective solution was proposed.

Key words**:** offshore jacket complex, ICCP retrofit, computational modeling

INTRODUCTION

The jacket complex under investigation is located in the North Sea at a water depth of 35 m and consists of 5 uncoated jacket-based platforms, a subsea valve station and 8 subsea pipelines. The structures date from 1967 to 1975 except for one structure that was recently installed. The jacket structures are all bridge linked and thus electrically interconnected. The corrosion protection for all the jacket structures is provided by sacrificial anodes. Figure 1 shows a schematic representation of the jacket complex.

CP potential measurements and anode inspections of the existing platforms have been taken every 5 years and have indicated that a significant amount of anodes have a remaining lifetime less than 20 years. A retrofit system is therefore to be designed that must extend the service life of the complex. Due to the high cost and the high safety risks during installation of a retrofit CP system based on sacrificial anodes, it was decided to evaluate the alternative based on remote impressed current anodes (ICCP).

Elsyca[†] was requested to model the conceptual ICCP retrofit design and validation of the jacket complex by means of CAE technology (Computer Aided Engineering). The work provides a graphical representation of the cathodic protection (IR-free potentials) on the structure, such that the feasibility of the conceptual retrofit ICCP system design can be validated and optimized.

The projected was executed in two phases:

- Phase 1: modeling and simulation of the current as-is situation of the platforms
- Phase 2: modeling and simulation of several ICCP layout options based on remote anode sleds

Finite Element Method (FEM) based software was applied on a 3D CAD model of the structures. In phase 1 the as-is status of the platforms was modeled in separate models, while in phase 2 a single model was created containing all five platforms, eight subsea pipelines, a subsea valve station and several remote ICCP anode sleds.

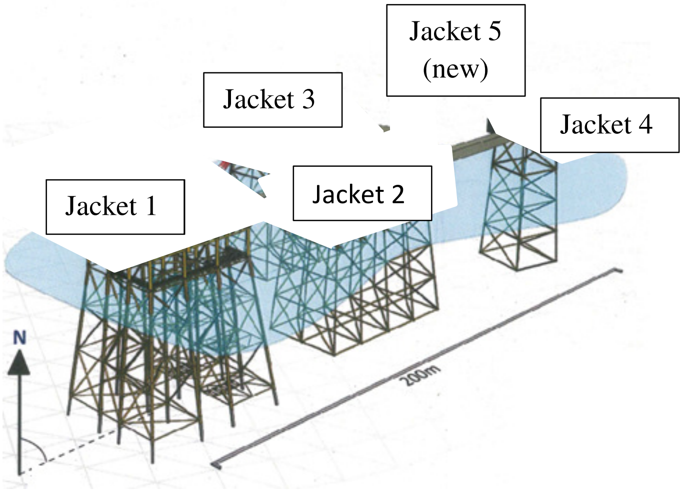

Figure 1: Schematic representation of existing jacket complex

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[†] Tradename

COMPUTATIONAL MODELS

A 3D CAD model was built for the existing and new jacket structure based on the technical drawings as received from the customer. Effort was taken to include sufficient details such as J-tubes, caissons, conductors, boat landings and mud mats that might influence the current demand of the cathodic protection system.

Table 1 gives the resulting surface area of the different structure components in the 3D CAD models.

Table 1
Active Surface Area of Wetted Parts

	Surface area of the structure components [m^2]							
	Jacket		J tubes	Caissons	Subsea pipelines	Conductors		Total surface
structure	Sea	Mud				Sea	Mud	
1	4836	1874	-	32	-	1447	594	**8783**
2	3347	1135	-	16	1467	-	-	**6448**
3	3257	1141	35	104	545	-	-	**5124**
4	1230	335	-	-	-	316	291	**2172**
5	1697	1533	-	-	-	-	-	**3230**

Several retrofits have been taken place in the past resulting in a variety of type (clamped vs welded), size and weight of sacrificial anodes. A total number of 527 anodes was added to the models. The information on the anodes of jacket 3 was not up to date at time of the study and the amount of 29 pcs in Table 2 is probably too low.

Table 2
Anodes Retained based on Survey Data

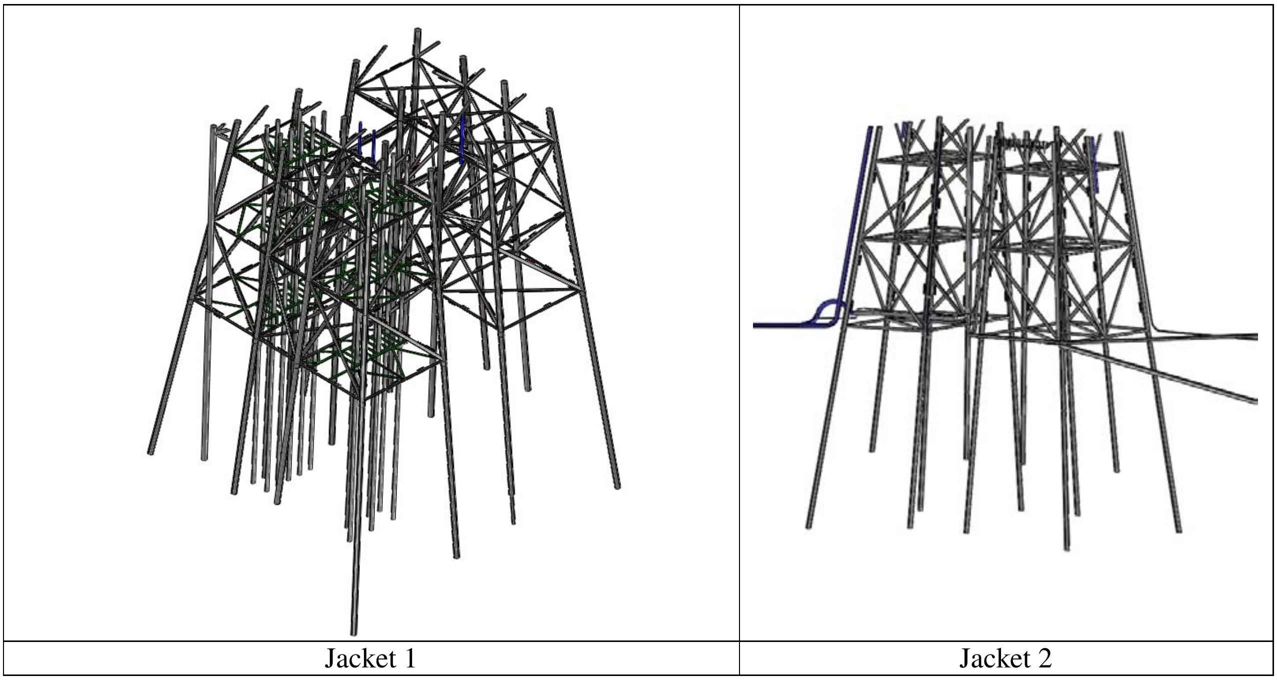
	Amount
Jacket 1	335
Jacket 2	58
Jacket 3	29*
Jacket 4	25
Jacket 5	80

In total 7 subsea pipelines are electrically connected to the jacket 2 and 1 subsea pipeline to jacket 3. An overview of the pipeline characteristics is given in Table 3. The layout of the pipelines is taken from the bathymetry report.

Table 3
Characteristics of Subsea Pipelines

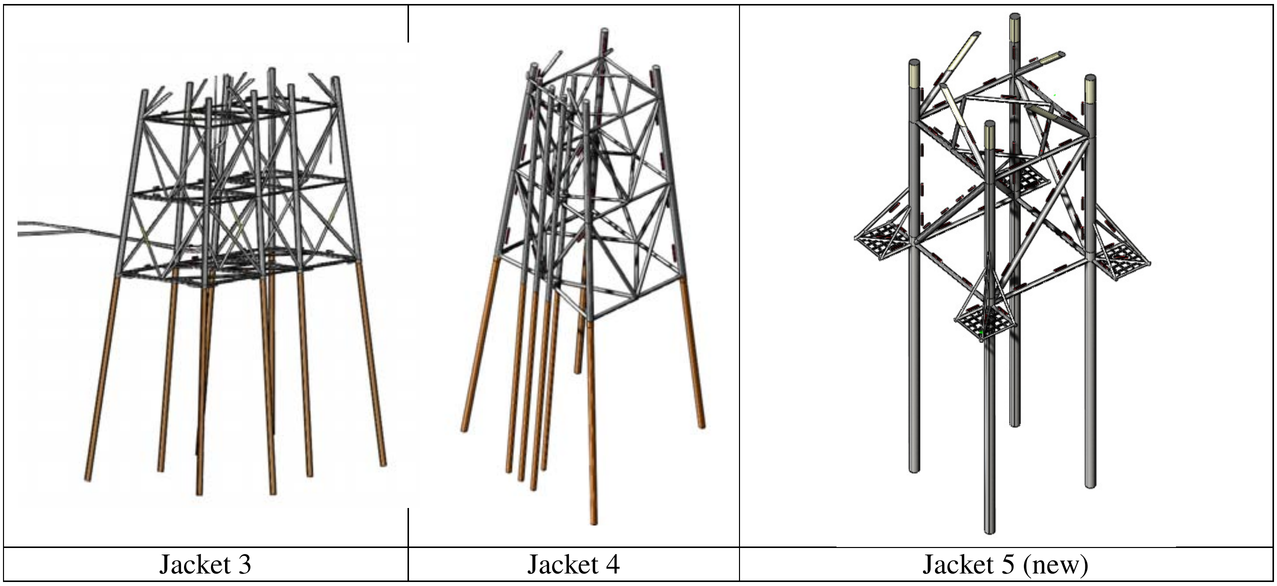
Subsea Pipeline	Diam.	Year	Temp [^{o}C]	Concrete Thickness [mm]	Coating Type
pipe 1 (Jacket 2)	30”	1967	60	80	AE
pipe 2 (Jacket 2)	30”	1971	93	70	CTE
pipe 3 (Jacket 3)	20”	1987	38	40	CTE
pipe 4 (Jacket 2)	4”	1967	60	25	AE
pipe 5 (Jacket 2)	4”	1971	40	0	PE
pipe 6 (Jacket 2)	8”	1970	60	0	PP
pipe 7 (Jacket 2)	4”	1998	1.5/16.5	0	PP
Pipe 8 (Jacket 2)	20”	1998	0/50	0	PP

Note: AE: Asphalt Enamel ; CTE: Coal Tar Enamel ; PE : Polyethylene ; PP : polypropylene


Jacket 1

Jacket 2

Figure 2a: 3D CAD model of the jacket platforms 1 and 2 in the complex



Jacket 3 | Jacket 4 | Jacket 5 (new)

Figure 2b: 3D CAD model of the jacket platforms 3, 4 and 5 in the complex

In phase 2 the layout options for the ICCP retrofit system was studied. The computational model contains the complete complex with the 5 jacket-based platforms with sacrificial anodes, 8 subsea pipelines, an additional subsea valve station on pipeline number 4 in Table 4 and the remote retrofit ICCP sleds. The valve station is partly buried and has sacrificial anodes. The surface area exposed to the seawater was reported to be coated. Because there is no recent data on the coating status the structure is considered to be bare steel in the model. This is worst case condition since the valve station will drain current from the ICCP system. The surface area of the valve station in the model is 755 and 280 m^2 for the part in respectively seawater and seabed.

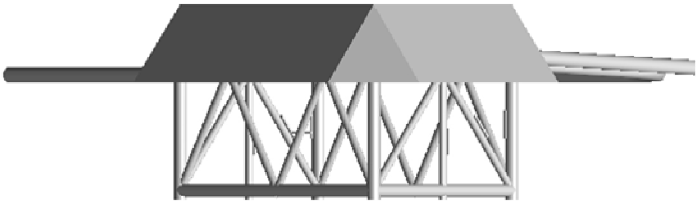


Figure 3: 3D CAD model of the subsea valve station

The concept design of the ICCP retrofit system consists of 3 remote anode sleds. Each sled contains 4 buoys having 3 tubular MMO anodes each with dimensions of 1.25 in x 48 in (31.75 x 1219 mm) as shown in Figure 4. The anodes are vertically positioned at approximate height of 2.6 m from the mud line. Each anode sled is rated at 500 A and 22 V maximum. The anode tubes are represented in the model as rectangular shapes with an equivalent active surface area of 0.06 m^2. The distance between the four anodes was taken as 2.0 m.

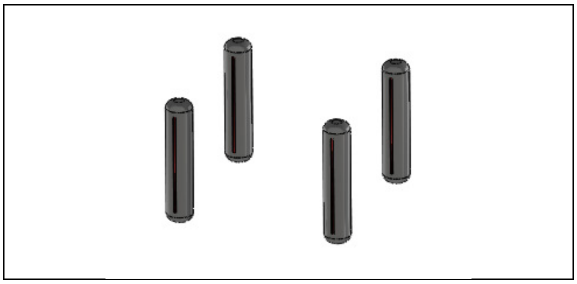


Figure 4: 3D CAD model of the retrofit ICCP sled

The complete model of the jacket complex with subsea pipelines, subsea valve station and 3 retrofit ICCP anode sleds is shown in Figure 5 and 6. The computational domain has a volume of 900x900x500 m^3 such that the current distribution is not disturbed by edge effects. The complete length of the subsea pipelines was not considered. Instead, a characteristic resistor representing the remaining pipe section was introduced at the end of the pipelines.

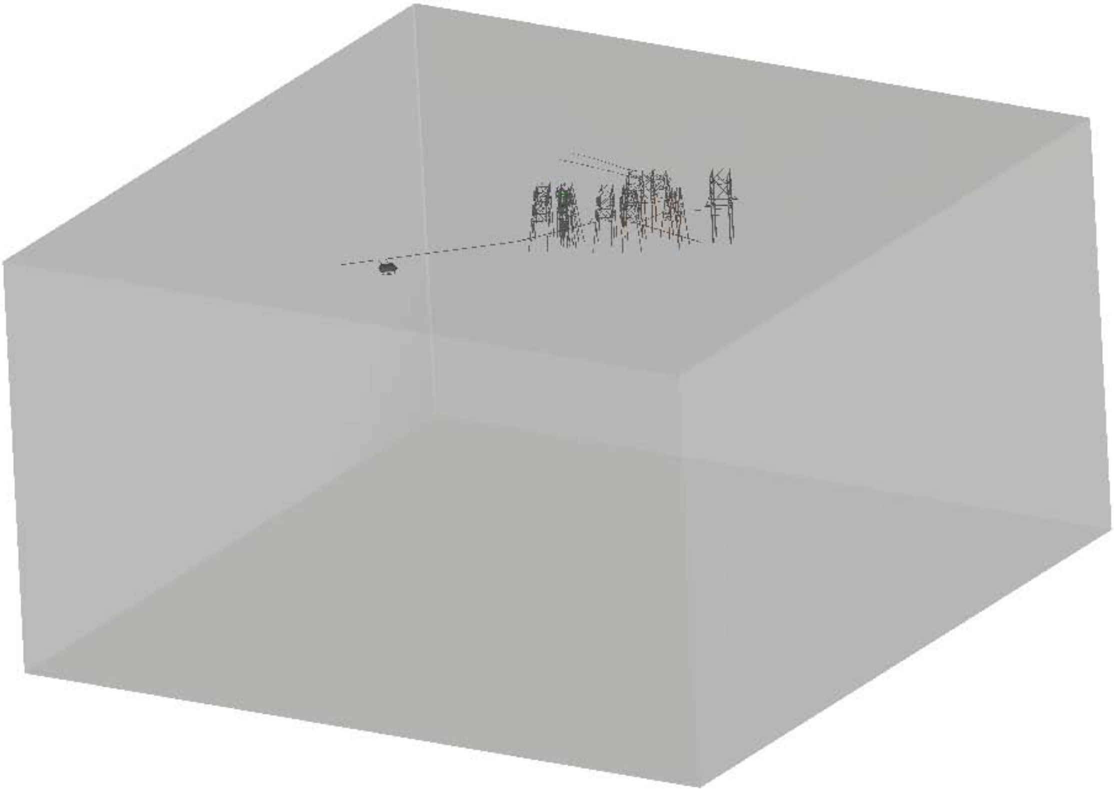


Figure 5: Computational domain of complete complex

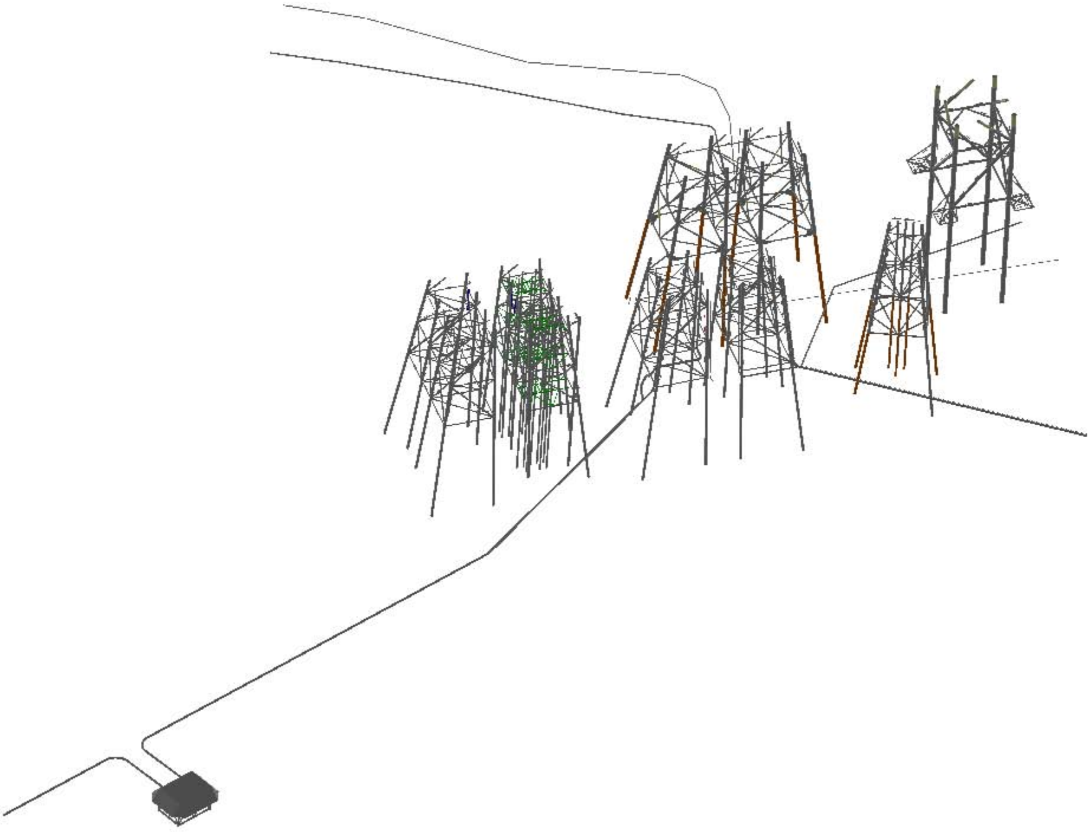


Figure 6: Zoom in of the model near the jacket structures

BOUNDARY CONDITIONS

The protection level of a cathodic protected offshore structure is determined by the current demand of the bare steel at required polarization potential. In general a minimum potential of -800 mV versus Ag/AgCl reference electrode is required for long term protection. The current to achieve this polarization level is originally delivered by sacrificial aluminum zinc indium (AlZnIn) and zinc anodes.

The base case of the modeling is that the existing structures are already polarized by the existing SACP system. The new jacket 5 is recently installed and is assumed to be fully polarized by its SACP system. Therefore it is a fair assumption that at time of installing any ICCP retrofit system, this new jacket will have anodes that are hardly depleted.

Table 4 gives the current density demand of bare steel to achieve -800 mV for different seawater depths, as used in the model. Proper non-linear polarization data has been addressed for each seawater depth (layers of 2 m). If the different values are averaged for a depth of 20 m and below, the averaged current demand corresponds well with the customer's standard for SACP design. Note that the current demand is lower than prescribed in the DNV RP B401 standard[1].

Table 4
Current Density Demand for Maintaining Protection

seawater depth [m]	average seawater velocity [m/s]	current density for -800mV [mA/m^2]
0-2	0.73	71
2-4	0.70	69
4-6	0.66	67
6-8	0.63	66
8-10	0.59	64
10-12	0.57	44
12-14	0.56	62
14-16	0.55	61
16-18	0.55	61
18-20	0.54	61
20-22	0.53	60
22-24	0.51	59
24-26	0.50	58
26-28	0.49	58
28-30	0.47	56
30-32	0.44	54
32-34	0.39	51
34-mud	0.18	31
	Average (0-20m)	**62**
	Average (>20m)	**53**
	Seabed	**20**

In the case that a coating is present (such as on risers and subsea pipelines) the current density in Table 4 is scaled with the coating breakdown factor[2] as given in Table 5. For pipelines operating at elevated temperature the current demand and coating breakdown factor are increased. It is assumed that the coating breakdown is uniformly distributed over the subsea pipeline. The pipelines in the vicinity of the platforms are weight coated or buried. Potential coating damage due to fishing activities is only a risk outside the boundaries of the model. It is therefore assumed that the current from an ICCP anode will mainly flow towards the jackets instead to remote coating defects on the subsea pipelines.

The specific resistivity for the seawater and seabed used for simulations is 0.27 and 1.30 ohm*m respectively. These are averaged values taken from DNV RP B401[1].

Table 5
Calculated Coating Breakdown Factor of Subsea Pipelines

Subsea Pipeline	D (nom) inch	Year	Design Temp degC	Concrete Thickness mm	Coating Type	Coating breakdown factor %
pipe 1 (Jacket 2)	30”	1967	60	80	AE	3.3
pipe 2 (Jacket 2)	30”	1971	93	70	CTE	3.1
pipe 3 (Jacket 3)	20”	1987	38	40	CTE	2.3
pipe 4 (Jacket 2)	4”	1967	60	25	AE	3.3
pipe 5 (Jacket 2)	4”	1971	40	0	PE	1.3
pipe 6 (Jacket 2)	8”	1970	60	0	PP	1.4
pipe 7 (Jacket 2)	4”	1998	1.5/16.5	0	PP	0.8
Pipe 8 (Jacket 2)	20”	1998	0/50	0	PP	0.8

Note: AE: Asphalt Enamel ; CTE: Coal Tar Enamel ; PE : Polyethylene ; PP : polypropylene

SIMULATION RESULTS & DISCUSSIONS

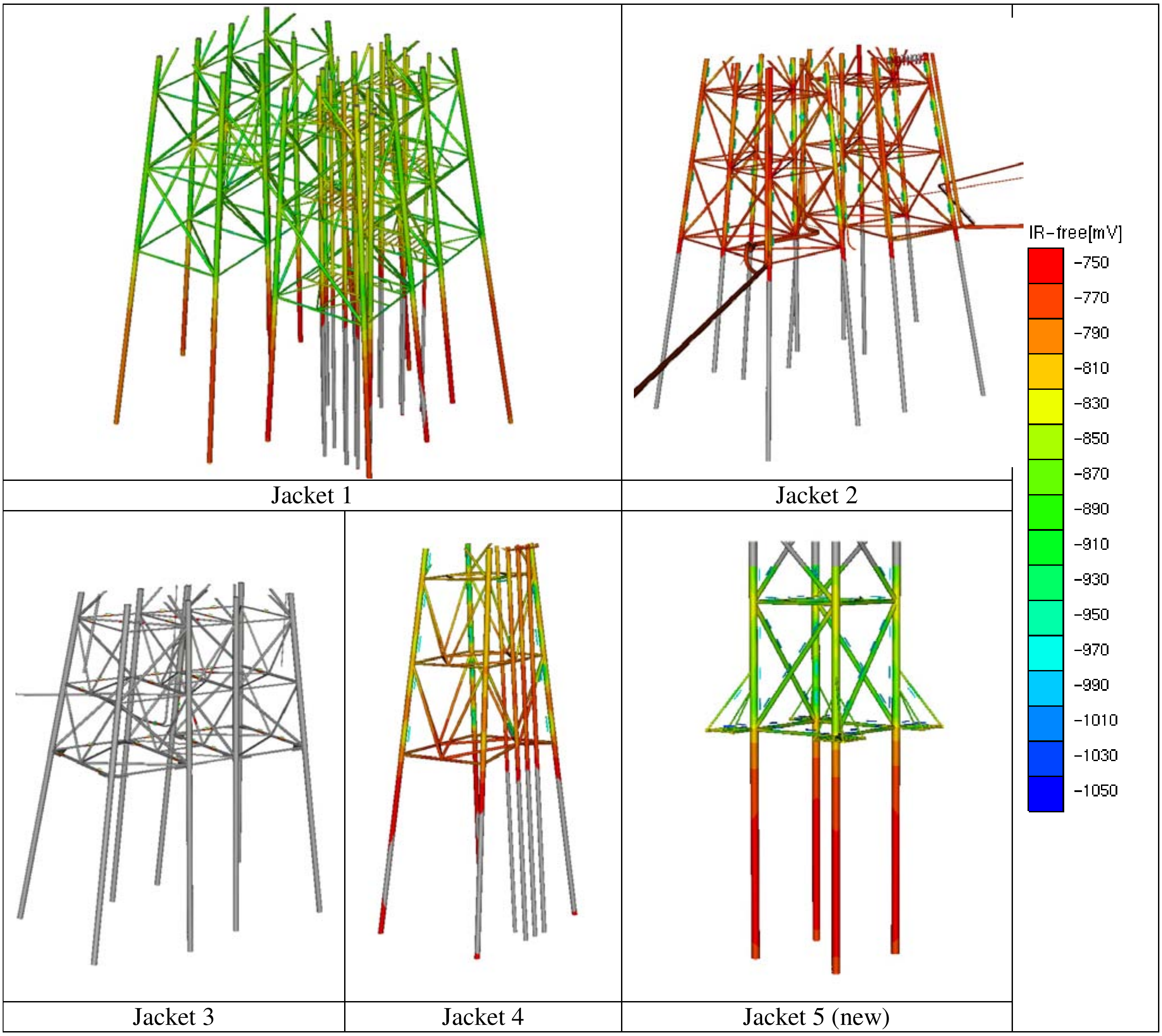
As-is situation with sacrificial anodes (no ICCP)

The purpose of the as-is simulations is to achieve a sound model that reflects the actual protection level of the jacket platforms. A good reflection of the as-is situation will enable a better design of the ICCP and allow a better prediction of the remaining life of the jacket complex.

Simulations are performed for the individual platforms. With this approach it is assumed that the CP systems of the platforms are not interfering on each other because of the local effect of sacrificial anodes.

The anodes are considered not to have any depletion for this first simulation run. In case anode depletion is taken into account the protection level of the structure will be reduced. After the validation, the depletion of the anodes can be considered. In the worst case the anodes will be completely consumed and all current is to be supplied by the ICCP retrofit system.

The simulation results of the IR-free potential are shown in Figure 7. The IR-free is the protection potential of the structure without any IR-drop in the electrolyte caused by flowing CP current. This is the reference electrode reading that would be obtained if the electrode was exactly positioned on the cathode surface. The legend scale is set between -750 and -1050 $\text{mV}_{\text{Ag/AgCl}}$. The greyed parts in the figures indicate protection potentials exceeding the legend scale by means that the IR-free potential is more positive than -750 mV or more negative than -1050 mV.



Jacket 1 | Jacket 2

Jacket 3 | Jacket 4 | Jacket 5 (new)

Figure 7: Simulated IR-free potentials of the individual jackets for the as-is situation

From the simulation results it can be seen that jackets 1, 2, 4 and 5 are well protected in the seawater but that jacket 3 shows large areas of under protection. Jacket 3 is under protected because of a lack of certain anodes that have not been provided as input data for the model. Inspection surveys have demonstrated that this structure is properly protected in practice. A postulated current of 200 A was required to achieve adequate protection in the model.

The inspection surveys have indicated that the measured potentials are more negative than the simulation results. Hence this model is more conservative than the real situation.

In the design of the conductors no SACP protection is required to meet field life and therefore the simulation results shows less negative potentials then the surrounding jacket structure.

From the simulations the total current output of the complete SACP system for all jackets is calculated as 1327 A, anticipated 200 A of jacket 3 included.

Original design with remote ICCP retrofit anodes

In this first case conceptual ICCP layout with activated SACP system is considered. The aim is to determine how much ICCP current could be imposed to avoid overprotection of the subsea pipelines.

The original conceptual ICCP retrofit system contains 3 remote anode sleds. According to the initial layout, the anode sleds are positioned at 95 m distance from the closest jacket structure and subsea pipeline. The sleds are aligned around the Jacket 1 structure having the largest active surface area of steel to be protected. The sleds are represented by blue dots in Figure 8. As can be seen, two sleds were positioned in jack-up footprint areas. Hence, it was requested to reposition these anode sleds outside these areas.

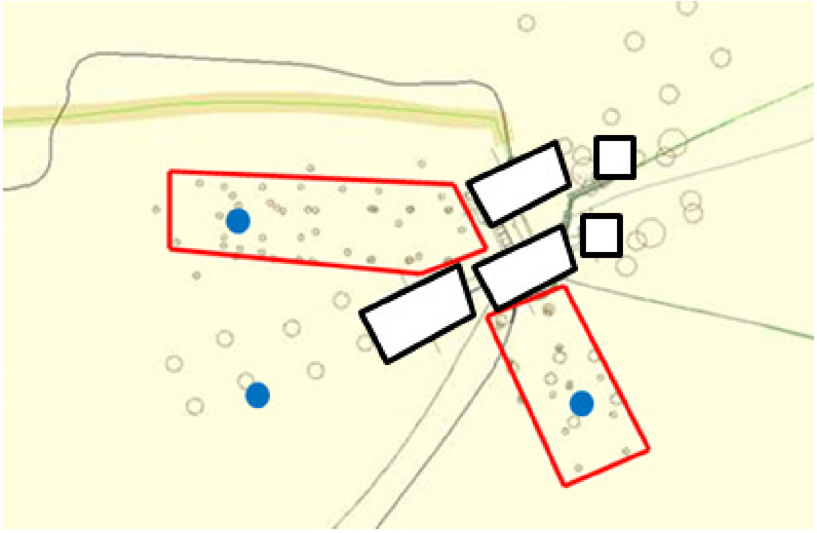


Figure 8: Original location of ICCP retrofit sleds (blue dots) and jack-up zones (red squares)

An evenly distributed total current of 600 A is applied on the ICCP system. Figure 9 shows the IR-free protection level of the structures. The protection level of the jackets is improved compared with the as-is situation (see Figure 7). However the subsea pipelines are overprotected, especially for the sections near the anode sleds. It can also be seen that the protection level of jacket 1(east side) and the subsea valve station is unnecessary high. Moreover the location of the remote anode sleds should be out of the jack-up area. Therefore it was decided to further optimize the ICCP retrofit design by modeling other layout concepts.

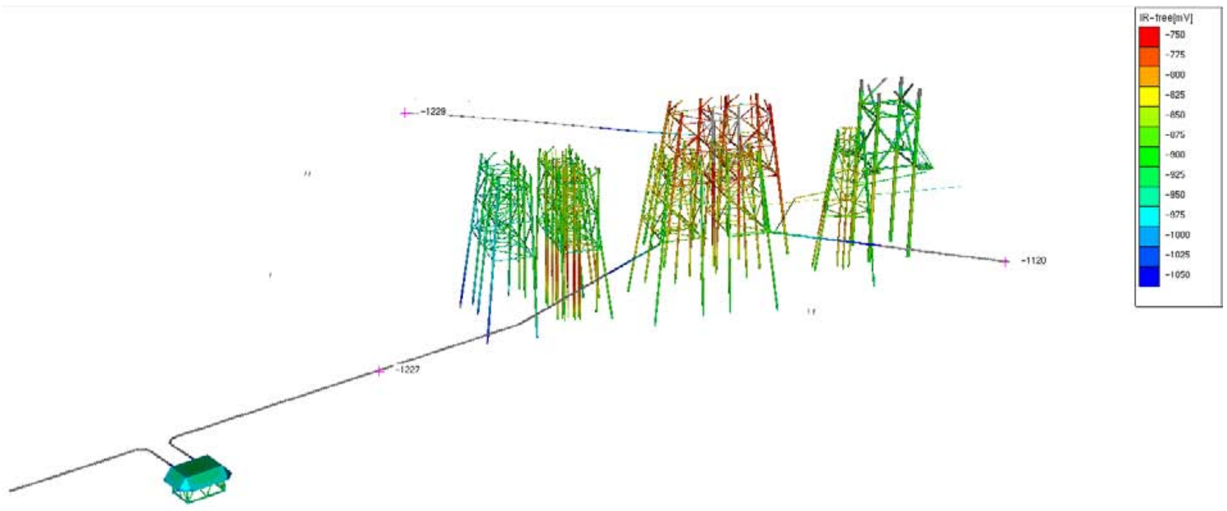


Figure 9: Simulated IR-free potentials of the complete complex with original ICCP retrofit system design and sacrificial anodes

Optimized design of remote ICCP retrofit anodes

The configuration of the ICCP retrofit system was further optimized in order to improve the current distribution over the complex and to avoid overprotection of the subsea pipelines. After several iterations a most optimal ICCP retrofit configuration was proposed taking into account the available target locations. The new ICCP configuration consists of 4 instead of 3 anode sleds as shown in Figure 10. One of them is put closer to the jackets in order to obtain a better protection level in the center of the complex.

A total ICCP current of 1200 A was imposed and the output of the anode sleds was tuned as given in Table 6. The total current drained by the buried piles is 174 A, or 14.5% of the total impressed current.

As can be seen in Figure 11 the simulated IR-free potential is more evenly distributed and the protection level is more uniform. A summary of the minimum and maximum protection level of the structures is given in Table 7. Some critical areas at jacket 1 (especially in the center where a large number of risers/conductors are located) and jacket 3 remains. Note that the sacrificial anode system of jacket 3 was under-dimensioned in the model. Table 7 indicates that the risk of over protection of some subsea pipelines remains.

Table 6
Currrent Output of the ICCP Anode Sleds

	Current [A]
SLD1	300
SLD2	200
SLD3	400
SLD4	300

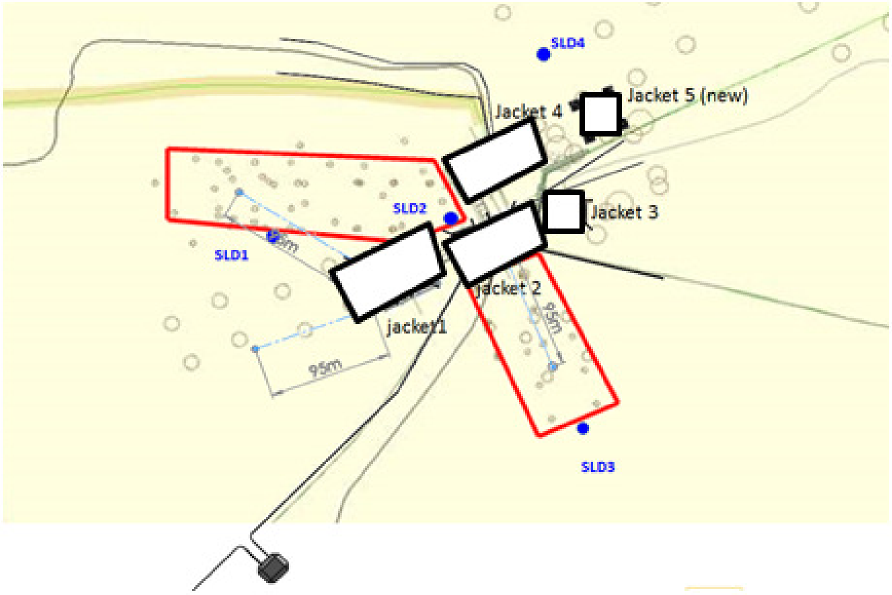


Figure 10: Optimized ICCP retrofit anode sleds

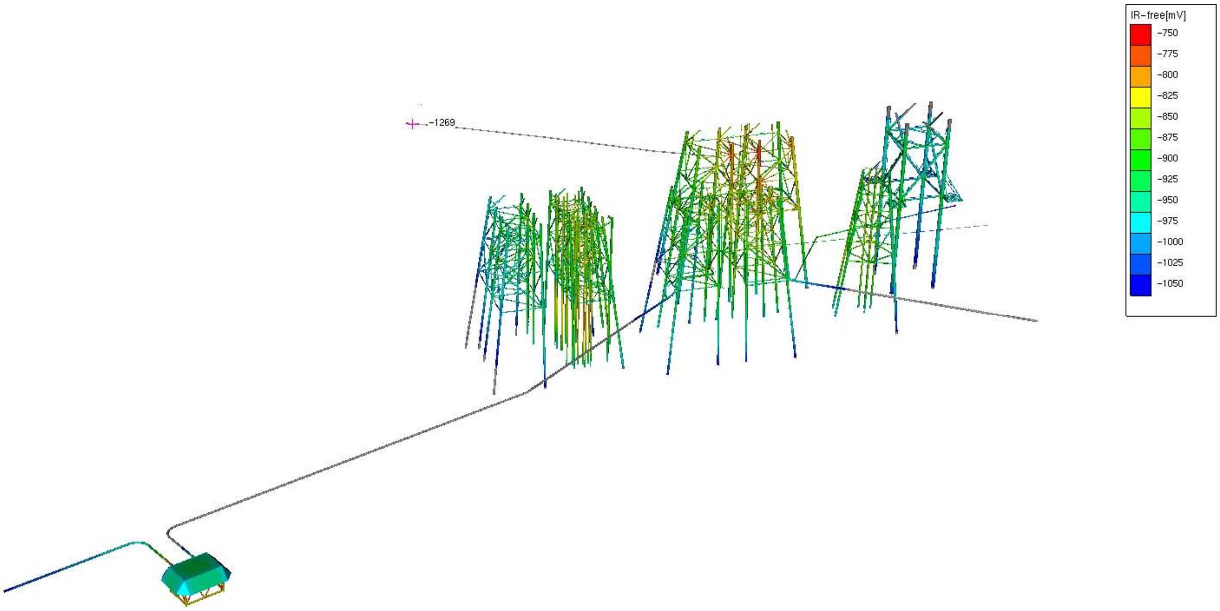


Figure 11: Simulated IR-free potentials of the complete complex

Table 7
Minimum and Maximum IR-free potentials of the structures

		IR-free min	IR-free max
Jacket	1	-825	-1020
	2	-824	-1058
	3	-865	-945
	4	-791	-944
	5	-894	-963
Subsea pipeline	1	-934	-1285
	2	-894	-1038
	3	-893	-1036
	4	-945	-1260
	5	-945	-1268
	6	-878	-1111
	7	-691	-1203
	8	-961	-1225

The remaining life of the existing sacrificial anodes was predicted based on the calculations of their simulated current output and given their percentage depletion rate according to the last survey inspection. The original retrofit design is compared with the optimized design. Table 8 shows that the optimized ICCP system allows the extension lifetime with minimum 20 years for the majority of anode except for those on jacket 1. Note also that the amount of anodes on jacket 3 was not up-to-date.

Table 8
Calculated Percentage of Sacrificial Anodes Reaching a remaining life of 20 y before complete depletion

	ICCP current [A]	anode remaining life >20 years				
		Jacket 1	Jacket 2	Jacket 3	Jacket 4	Jacket 5
original	600	39%	53%	31%	72%	100%
optimized	1200	54%	92%	96%	96%	100%

CONCLUSIONS

A future ICCP retrofit system design of a large jacket complex was validated through numerical modeling with the aim to extend the service life of these offshore platforms with 20 years. Modeling technology allows visualizing the protection level of the jacket structures within the complex and allows anticipating in the retrofit design such that a cost-effective solution is achieved prior to install the retrofit system.

The as-is situation of the jacket platforms of the complex was investigated. The aim was to find the correct boundary conditions before starting the retrofit simulations. Some significant under protection was modeled for the jacket 3 due to lack of data on the SACP system of this jacket. The risers/conductors in the center of jacket 1 are not required to have a SACP system from design and a lower protection level is acceptable. However they will have an influence on the ICCP retrofit behavior. The total simulated current as delivered by the sacrificial anode system was 1327 A and the individual simulated current output of the anodes indicated that the majority of the anodes could not reach an additional service life extension of 20 years. Consequently, the feasibility of an ICCP retrofit based on remote anode sleds was investigated.

First, the conceptual ICCP retrofit layout was modeled with 3 remote anode sleds. Simulations were performed assuming no depletion of the SACP system. A maximum imposed total current of 600 A of design current was applied on the anode sleds. From the simulations this layout may result in overprotection of the subsea pipelines and the remaining life the majority of the anodes cannot be extended to 20 years. Furthermore some sleds were positioned in jack-up areas.

A re-arrangement of the anodes sleds configuration was proposed and the number of sleds was increased from 3 to 4 and one sled was put closer to the jacket. The current per anode sled was tuned and a good overall distribution of the protection was obtained. The remaining service life of the sacrificial anodes was re-calculated and it was concluded that the majority of the existing anodes will be active for minimum 20 years.

Based on the simulation results a retrofit may be required on the longer term for certain areas. However some conservatism was assumed for the boundary conditions. The models have indicated potential hot-spot areas that allowed attention and focused verification during CP monitoring.

REFERENCES

1. DNV-RP-B401 Cathodic Protection Design, 2005

2. ISO 15589 Petroleum, petrochemical and natural gas industries -- Cathodic protection of pipeline transportation systems -- Part 2: Offshore pipelines, 2012