Simulation of AC corrosion on pipelines under AC and DC interference

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Cases of close proximity of high voltage transmission lines and metallic pipelines can lead to severe AC corrosion at coating defects. The mechanism of AC corrosion is complex and so far not well understood. Moreover, the cathodic protection and DC interference are generally not considered but their impact on AC corrosion behavior is significant.

A state-of-the-art simulation technology was used to calculate AC corrosion rates at a small coating defect for a given DC and AC signal. The software takes into account the fundamental electrochemical reactions at the metal surface and the chemical composition of the soil surrounding the defect. The AC and DC conditions near the defect are determined by a macro simulation of the pipeline cathodic protection level and AC induced voltage by considering the cathodic protection system, the pipeline network and the overhead transmission line in a single computational model.

Simulation results are compared with the proposed AC criteria in the prEN15280 and other references.

Keywords: AC corrosion, AC and DC interference, cathodic protection, corrosion risk assessment

Introduction

Interference by AC and DC sources on pipelines is a recognized and possibly dangerous phenomenon that can lead to accelerated corrosion. AC and DC interference is of major concern on newer pipelines having state-of-the-art coatings like FBE and PE because the coating defects are generally rather small resulting in a high local current density and by consequence a high corrosion rate.

Interference sources are in general not static in nature but vary with time and might not be fully detected and analyzed using common, established procedures in the cathodic protection field. Indeed, it is possible that the mitigation actions put into place can unknowingly worsen the situation. Therefore it is important to have various techniques available that allows predicting corrosion risks while avoiding expensive excavation work. Using monitoring probes and coupons connected to the affected pipe is a common approach and if applicable, ILI tools are applied. Monitoring probes provide information on the instantaneous and/or accumulative corrosion rate over a relatively short period compared with the lifetime of the pipeline. The ILI tools provide accumulated corrosion loss over the entire lifetime of the pipe but give no information on the conditions that caused this corrosion attack, nor can differentiate the type of corrosion. Both approaches require field interventions and sometimes additional investments.

In this article modeling technology is used to calculate corrosion rates of a pipeline under AC and DC interference. Through modeling the instantaneous and accumulated corrosion rate and the long term corrosion attack can be calculated as long as the correct boundary conditions are applied. Therefore both the cathodic protection behavior and interference level must be determined properly. An important unknown factor is the pipe coating condition. Through modeling appropriate coating properties can be found.

The European Standard prEN15280 on AC corrosion mitigation will be issued soon. The AC corrosion likelihood is evaluated based on electrical parameters that determine the cathodic protection level and the level of AC interference, or on direct corrosion rate measurements on probes or coupons. The DC and AC current densities are the most important electrical parameters in the assessment strategy. Stray current interference is not considered in the standard.

Modeling technology

A time-dependent numerical model was used to calculate corrosion rates under various AC, DC and CP regimes. A description of the software is given elsewhere [1]. The model generates electrical signatures that are very useful for understanding the mechanisms behind AC+DC corrosion. It is a very useful tool for the evaluation of AC corrosion likelihood based on electrical parameters according to the prEN15280 standard.

The software applies a 2D model for the quantification of the corrosion phenomena on the micro-scale level. The electrochemical equations are solved and the electrolyte composition is updated for several AC cycles. Figure 1 is a schematic representation of the computational model.

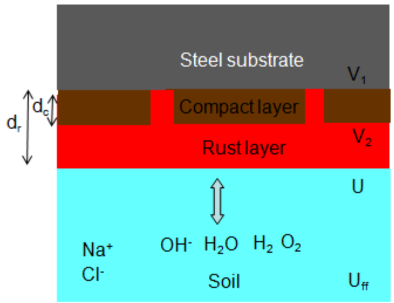

Figure 1 – ACCorSolver numerical model

Given the induced AC voltage, the cathodic protection (and DC interference) level and the bulk soil composition (pH, resistivity, oxygen) the software calculates:

- AC and DC current density
- AC+DC corrosion rate
- the formation and dissolution of the passive film
- the formation of a rust layer
- the change in the spread resistance

The fundamental mechanisms behind the computational model is based on the work of M. Buchler [3]. Note that under moderate cathodic protection the steel surface is passivated and at high cathodic protection level the steel surface is immune. If AC interference is applicable the passive film can be reduced during the negative wave cycle of the AC signal and rust products can be formed or electrochemicaly reduced. During the positive wave cycle of the AC signal the steel metal dissolves forming Fe^{2+} ions and the rust layer is electrochemicaly oxidized. At high pH the metal passivates sponteneously. This process is contineously repeated as long as the AC signal is applied. It is obvious that the cathodic protection and DC stray current will influence the electrochemical behavior of the steel (passivity/immunity). The electrochemical reactions taking place changes drastically the local soil resistivity in the coating defect, which in turn will further influence the AC and DC current density.

In a recent study [4] the computational model was used to predict the onset of AC+DC corrosion on a circular coating defect with a surface area of 1 cm^2. The simulation results were combined with a large field database of ER probe measurements to review the existing AC corrosion criteria as found in literature today. The simulation results of the AC corrosion rates are given in Figure 2. The cases with the highest corrosion rates are mainly found in the region of the highest corrosion likelihood according to the prEN15280 standard. At sufficiently high DC protection current density and low AC current density (JAC/JDC<3) the corrosion rate is minimized. Note that some high corrosion rates are obtained at current densities below the threshold value of 1 A/m^2 DC.

This result was obtained for the case of a high soil resistivity (270 ohmm) and high induced voltage (60V).

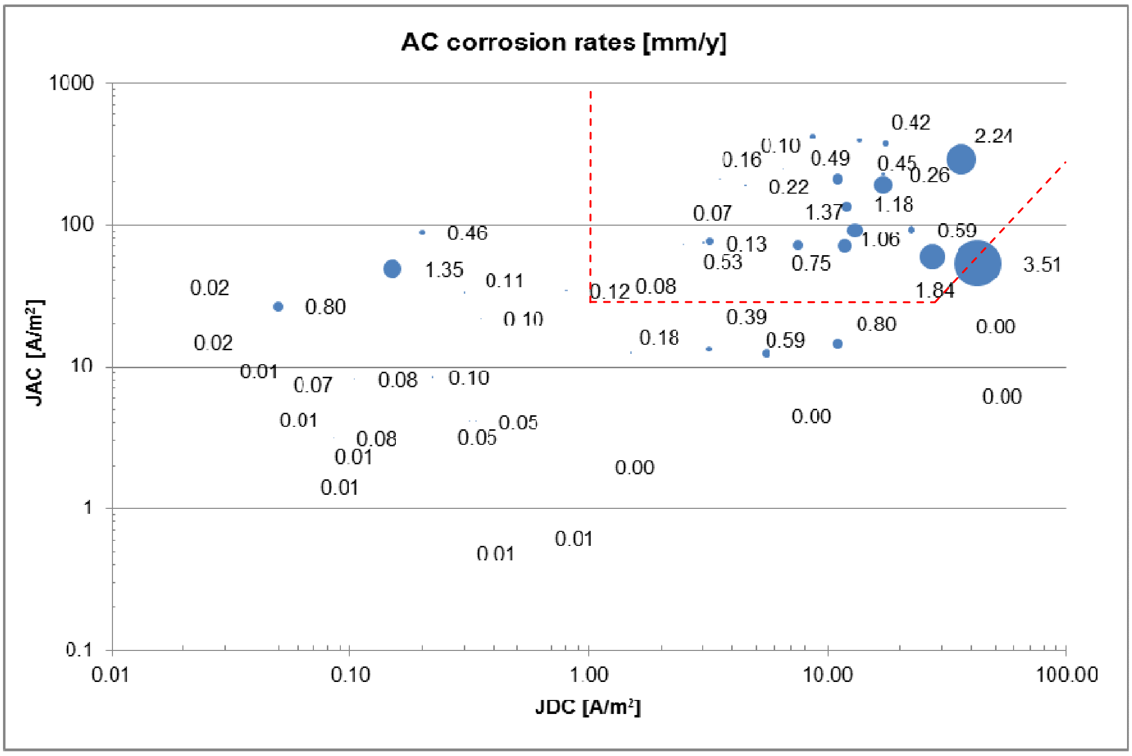

Figure 2 – AC corrosion rates calculated by ACCorSolver numerical model

Case study

A 10 year old 30 inch natural gas pipeline with an insulated section of 46 km is interfered by 9 overhead transmission lines operating mainly at 150 and 400kV.

The pipeline has a 3- layer PE coating with heat shrinkable sleeves at girth welds and polyurethane tar coating at the buried valves. The depth of cover of the natural gas pipeline is approximately 1.5m.

CP was provided with one rectifier in that section. The rectifier operates in a potentiostatic mode, at -1,45V. The total output current typically ranges between 40 and 70mA giving an average current density of 0,5µA/m². Interference from CP systems of foreign lines was considered hardly significant, due to insulation measures taken at crossings with the foreign pipelines.

A macro-scale computational model was made of the pipeline and overhead transmission lines as shown in Figure 3.

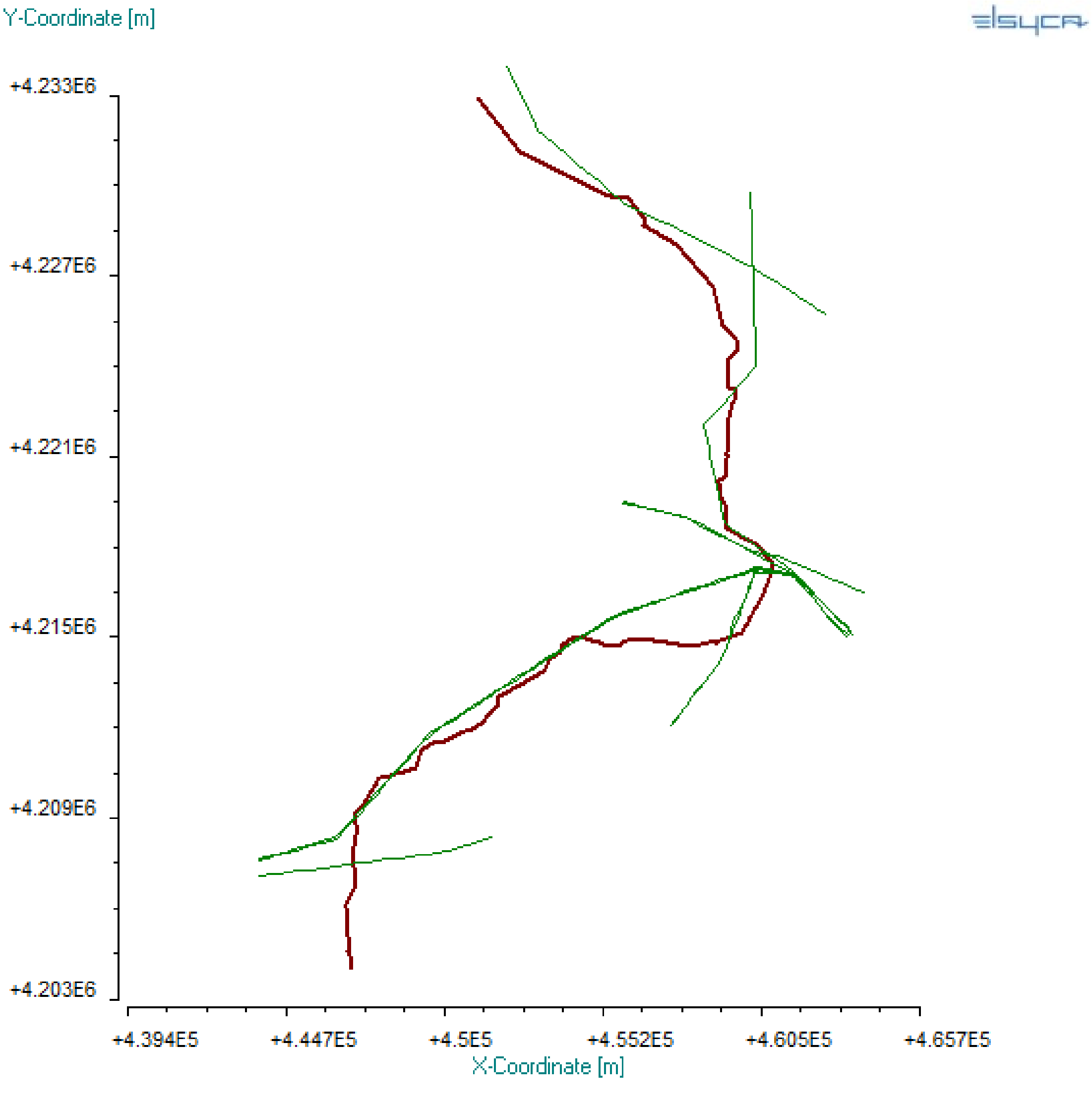

Figure 3 – macro scale computational model of pipeline (brown) with overhead transmission lines (green)

First the cathodic protection performance was modeled given the rectifier settings and the average soil resistivity of 340 ohm.m. The total active pipe surface was 1.077 10^5 m^2. The coating quality was adjusted in an iterative way in order to obtain current densities and rectifier output current that match with the field data. The following averaged coating characteristics were found:

- thickness: 3 mm
- specific resistivity: 1.10^{+08} ohm.m
- holiday fraction: 10^{-5} %

A far field potential of -1.45V was applied on the pipeline at chainage 32 km. This resulted in a simulated averaged current density of 0.54 µA/m^2 and a current output of 54.7 mA at the rectifier. Figure 4 shows the current density distribution over the pipeline. The simulation results match well with the field data as provided by the operator indicating that the general coating properties in the model have been assumed properly.

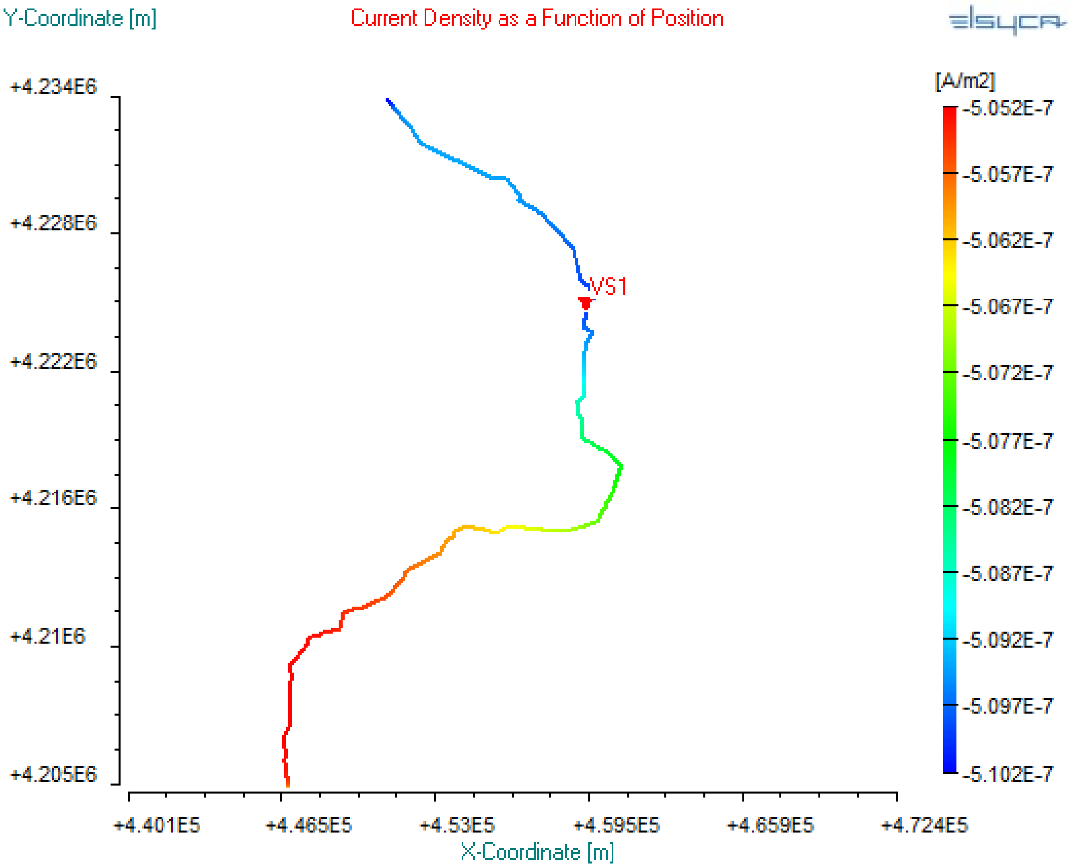

Figure 4 – current density distribution over the pipeline. Potential controlled rectifier is indicated as red VS1 label.

A second macro simulation was performed to determine the induced voltage on the pipeline taking into consideration the coating properties as determined previously.

The majority of overhead power transmission lines operate at 150kV with an average daily current load of 0.53 and 0.78kA respectively. Two out of nine HVAC lines (one running parallel to the pipe in the north and a short section in the middle running perpendicular to the pipe trajectory) operate at 400kV with an average daily current load of 2kA. The exact position of the pipe and the HVAC towers was taken into account since GPS coordinates were provided (see also Figure 3). The tower configurations were known as well.

Figure 5 shows the induced AC voltage on the pipe without any mitigation system. AC voltages exceed largely the 15V and by consequence earth groundings with AC/DC decoupling devices have been installed. The location of these groundings was given by the operator and is shown in Figure 7. An averaged resistance-to-earth value of 2.5 ohm was assumed for the earth grounding systems.

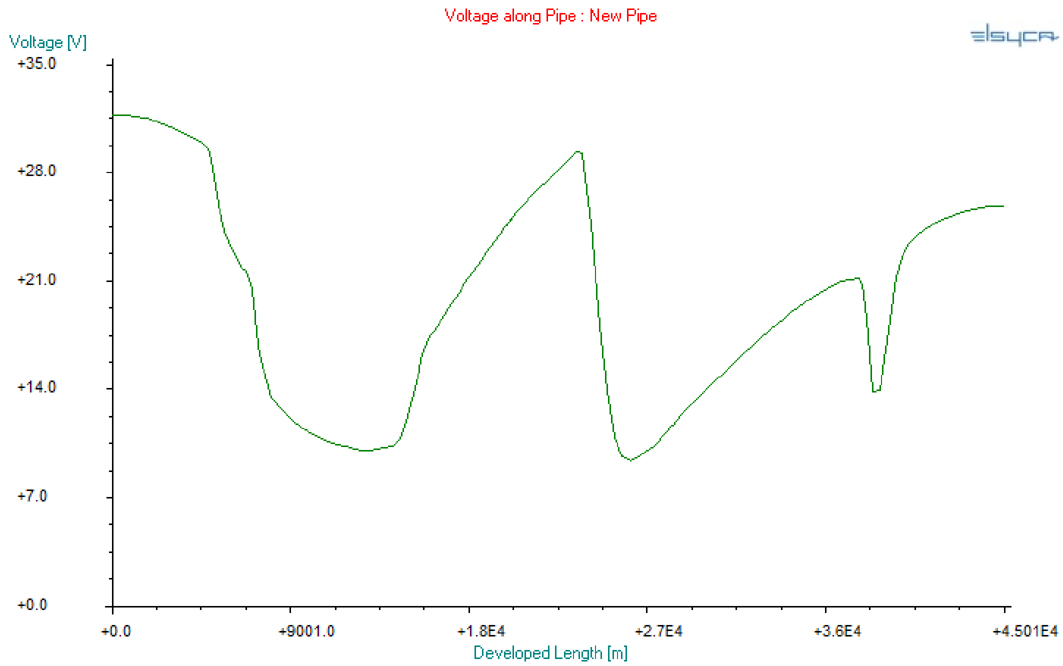

Figure 5 – resulting induced AC voltage over the pipeline before mitigation (the origin of the graph corresponds to the beginning of the pipe in the south)

Figure 6 shows the induced AC voltage after mitigation. The pipeline is compliant to the safety regulations except for a pipe section in the north near the 400kV that still exceeds the 15V.

Figure 6 – resulting induced AC voltage over the pipeline after mitigation (the origin of the graph corresponds to the beginning of the pipe in the south)

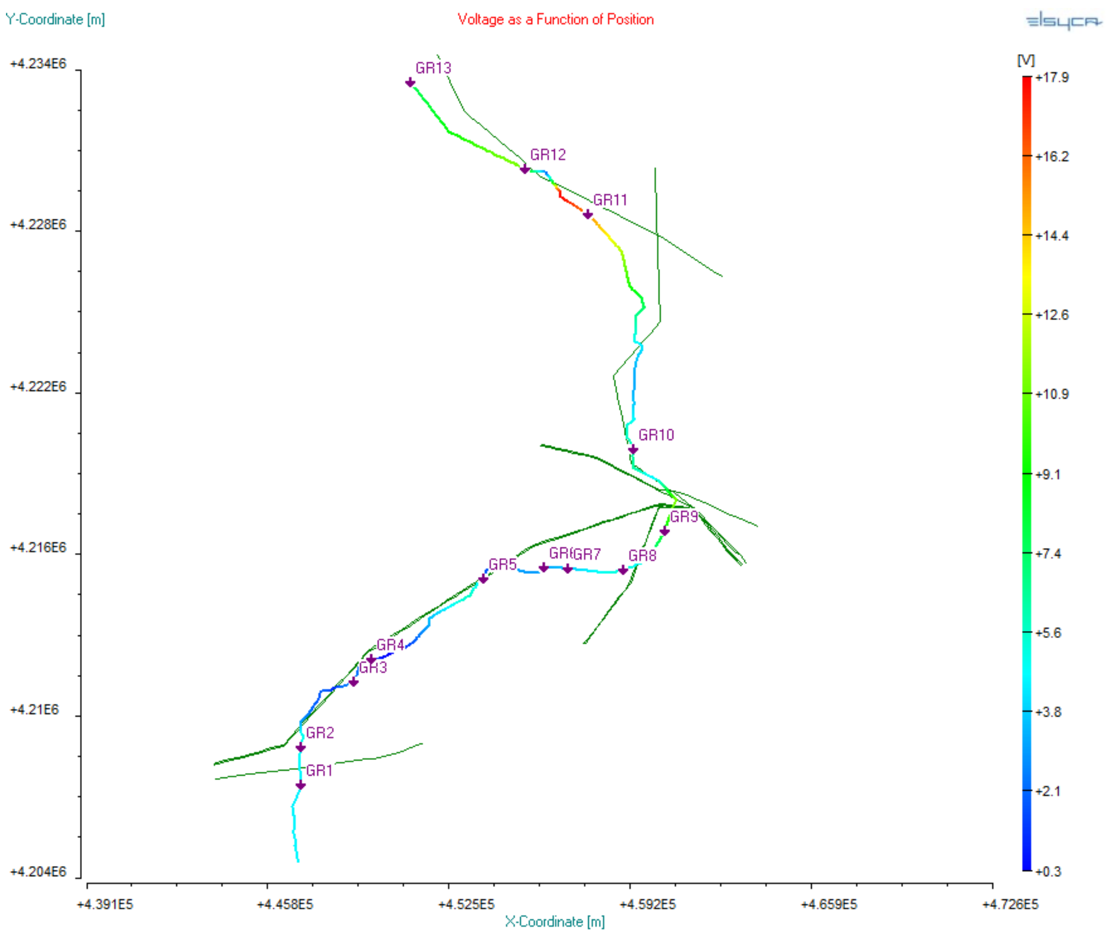

Figure 7 – induced AC voltage distribution after AC mitigation. Different GR labels indicate the location of the earth groundings.

Based on the induced AC voltage and the cathodic protection potential of the pipeline, the AC corrosion risk was calculated with the micro-scale time-dependent model. The following overall CP and soil conditions were considered:

- ON potential: -1.45V
- OFF potential: -1.30 V
- bulk soil resistivity: 340 Ωm
- bulk soil pH: 7
- initial oxygen content: 9 ppm

The onset of AC corrosion was calculated for three different AC voltage levels that were obtained from the simulations as shown in Figure 6.

		JDC	JAC	[mm/y]
Min. V	0.7V	0.22	0.27	0.002
Av. V	5.7V	0.68	1.11	0.053
Max. V	17.9V	0.71	4.80	0.120

Table 1 – calculated corrosion rates and AC and DC current densities for different interference conditions on the pipe for 1 cm^2 defect size

In this case, the AC corrosion rate increases with increasing AC voltage. Note that the DC current density increases as well because of the decrease in spread resistance. The calculated corrosion rates reveal at least the risk of AC corrosion but do not completely quantify long term effects. They might be overestimated since long term effects have not been considered in this study and scaling ions like carbonates are so far not included in the model. These results can be rather considered as instantaneous short term corrosion data as they are retrieved from e.g. ER probes.

Conclusions

In this paper a modeling approach was presented to estimate the AC corrosion risk on buried pipelines under AC interference.

First a macro-scale model was used to determine the most appropriate average coating conditions based on cathodic protection input data from the field. Secondly the induced AC voltage along the pipe trajectory with and without the presence of earth grounding systems was calculated. After mitigation a time-dependent micro-scale model was used to calculate the AC corrosion rate at a virtual defect of 1 cm^2 at different locations along the pipe route. Results were obtained for minimum, averaged and maximum induced voltage.

The micro-scale model is able to reveal the AC corrosion mechanisms, calculate the most important electrical parameters like current densities and AC (and DC) corrosion rates.
The software is a useful tool to estimate the risk of AC+DC corrosion and to better understand the pipeline and interference conditions that might influence the corrosion behavior.

The software calculates the onset of AC corrosion. So far the model does not contain scaling ions resulting in an overestimation of the corrosion rate. Extension of the model is foreseen in the near future in order to better simulate long-term AC corrosion behavior.

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