Cathodic protection condition in the presence of AC interference

A. Brenna, L. Lazzari, M. Pedeferri, M. Ormellese

To assess cathodic protection criteria in the presence of alternating current (AC) interference, weight loss tests on cathodically protected carbon steel specimens were performed in soil-simulated conditions in the presence of AC densities ranging from 10 to about 500 A/m^2. Tests last for four months. Carbon steel potential was periodically monitored by means of a Luggin capillary in order to eliminate the ohmic drop contribution and to record the true polarization level of the polarised carbon steel samples. At the end of the test weight loss was evaluated. On the basis of the results, a corrosion risk map is proposed. Main conclusion is that overprotection is the most dangerous condition in the presence of AC interference.

Keywords: Cathodic protection - Alternating current - Protection criteria - Interference

INTRODUCTION

Buried pipelines used to transport hydrocarbons and dangerous fluids are provided with corrosion prevention systems, namely an insulating coating, such as polyethylene or polypropylene type and a cathodic protection (CP) system [1]. CP reduces the residual corrosion rate due to soil corrosiveness below 10 µm/y, which is the maximum accepted damage regardless the pipe wall thickness, according to international standard EN 12954 (Cathodic protection of buried or immersed metallic structures - General principles and application for pipelines).
Nowadays there is general agreement upon the criteria to be used for corrosion mitigation in the presence of stray currents from DC systems, like a third party CP system as well as electric traction system, and international standards are available since many years (e.g., CEI EN 50162 [Protection against corrosion by stray current from direct current systems] and NACE SP0169 [Control of external corrosion on underground or submerged metallic piping systems]).
AC-induced corrosion of cathodically protected pipelines became a problem in the last 25-30 years, due to the growing number of parallelisms between buried pipes and AC sources (as high voltage power lines and AC high speed rails), which caused problems both for the electrical safety and for the management of corrosion and CP systems. Laboratory investigations [2] have confirmed that: 1) at industrial AC frequencies (50 or 60 Hz) corrosion can occur even if CP is correctly applied; 2) at the same current density value, the corrosion induced by AC interference is less than the corrosion caused by DC interference. Field AC-induced corrosion failures are reported [3-5] on cathodically protected carbon steel pipes, which matched the -0.85 V CSE[1] protection criterion provided by EN 12954. Uncertainties still exist on protection potential interval and on protection current density to reach acceptable protection when AC interference is present [6-14].
The primary factors for AC corrosion likelihood evaluation are AC voltage and AC density. AC voltage on the pipe is measured as remote earth voltage, it is of easy detection, but it seems to be a less accurate parameter since the measured value depends on soil resistivity, thus no absolute threshold can be adopted. Till now, there is no agreement on reliability to consider AC voltage an influencing parameter and above all on the limit value to consider AC interference negligible. NACE SP0177 standard (Mitigation of alternating current and lightning effects on metallic structures and corrosion control systems) suggests 15 V as maximum allowable AC voltage to remote earth in order to control AC-related corrosion. The European Technical Specification, CEN/TS 15280 (Evaluation of A.C. corrosion likelihood of buried pipelines - Application to cathodically protected pipelines) states that remote AC voltage should never exceed 10 V along the pipe and, in particular, 4 V at points where the local soil resistivity is less than 25 Ω·m.
AC density is a more interesting parameter: the higher the AC density, the higher the risk of corrosion. Based on experimental results [2], AC densities higher than 30 A/m^2 give rise to considerable corrosion rates of carbon steel in free corrosion condition. Even an AC density of 10 A/m^2 may nearly double the corrosion rate with respect to non-interfered specimens in both aerobic and anaerobic conditions. Corrosion rate is greater than 1 mm/year in the presence of AC densities higher than 500 A/m^2. Such values of AC density can be reached at small coating

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[1]CSE, Copper-copper(II) sulphate electrode, +0.318 V SHE.

defects, or porosity, due to the small metallic surface area exposed to soil. Unluckily, AC density measurements are not easy to perform: proper probes are required and should be installed near the pipeline to measure correctly AC density and true potential [15,16].
The technical specification CEN/TS 15280 contains a list of factors, which may affect the AC corrosion phenomena, as DC polarization level, the size of coating faults, local soil resistivity and soil chemical composition. Nevertheless, doubts are revealed about the use of induced AC voltage and soil characteristics as critical parameters for the assessment of AC corrosion likelihood of buried pipes. Threshold values of affecting parameters can only be considered from a probabilistic viewpoint, since there is no deterministic relationship between the values of the parameters and AC-related corrosion rates [17-18].
In order to assess cathodic protection criteria in the presence of alternating current interference, weight loss tests on cathodically protected carbon steel specimens were performed in soil-simulated conditions in the presence of AC densities ranging from 10 to about 500 A/m^2. Potential profile readings and residual corrosion rate measurements allow estimating the critical parameters to be considered to evaluate the risk of AC-induced corrosion and the threshold of alternate current density to assure an acceptable CP condition.

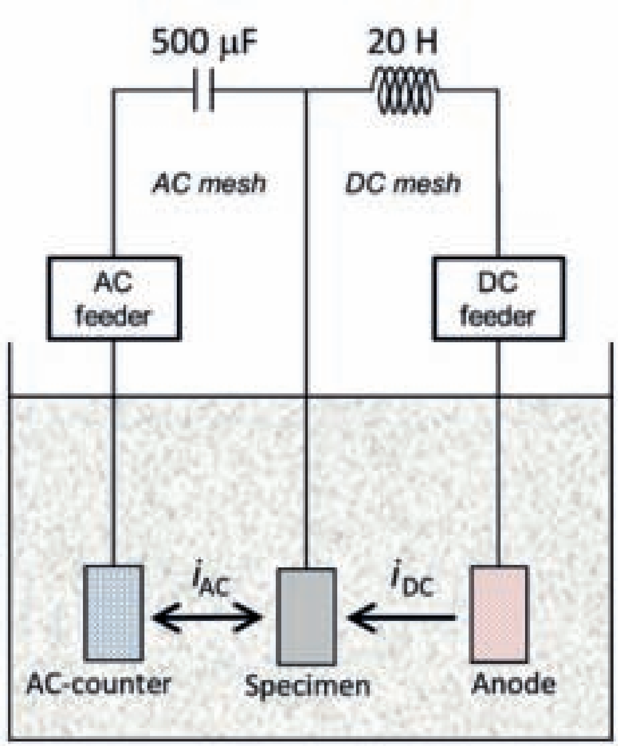

Fig. 1 – Schematic representation of the test cell and the electrical circuit

Fig. 1 – Rappresentazione schematica della cella di prova e del circuito elettrico

MATERIALS AND METHODS

Three series of tests were performed on carbon steel specimens (10 × 20 × 2 mm, Figure 1) cathodically protected and then interfered by AC. Three protection current densities were considered: 0.5, 1 and 10 A/m^2. Even if typically cathodic protection is applied at 10-20 mA/m^2, on real pipeline cathodic current densities as high as some A/m^2 may be reached due to the use of high dielectric coatings (like extruded polyethylene or polypropylene) where pin-holes or small defects are always present. AC interference was applied from 10 to about 500 A/m^2.
Specimens were first degreased in acetone, and then sandblasted; the borders and the back were painted with an epoxy resin-based coating. The exposed net surface (200 mm^2) was then softly sandblasted and the samples were weighed before the start of the tests (tolerance ±0.01 mg).
Tests were carried out in soil-simulating conditions: carbon steel samples were placed in a 3 L cell filled with sand saturated with 1 g/L Na_2SO_4 solution. Soil resistivity was 10 Ω·m. Temperature was kept constant at 20°C (± 1°C).
DC and AC signals were separated by a suitable two meshes electrical circuit, described elsewhere [19]: in the DC mesh, AC was limited to about 1% of the total AC by a 20 H inductance; in the AC mesh, DC was halted by a 500 µF capacitor. AC was applied on specimens by means of an AC feeder (variable transformer), through a carbon steel counter electrode; a MMO-Ti anode was used to apply CP, by means of a DC feeder (Figure 1).

Tests were performed as follows:

- immersion of specimens into the cells (specimens were placed in vertical position);
- application of CP for 15 days, until stable potential was reached;
- application of AC for a proper time of exposure (about 100 days);
- weight loss measurements, according to ASTM G1 (Standard practice for preparing, cleaning and evaluating corrosion test specimens); at the end of the test, specimens were removed from the cells, rinsed and dried; then specimens were pickled by 18% HCl inhibited with 3.5 g/L hexamethylenetetramine and weighted (tolerance ±0.01 mg) after 24 h drying in oven.

Carbon steel potential was periodically measured by means of a Luggin capillary to eliminate ohmic drop contribution. Thus the measured values are the true polarization level of the steel, and are reported in the paper as true potential or IR-free potential. For the sake of uniformity, all potentials are reported against CSE. Even if tests were performed at a constant cathodic DC density and interfering AC density, currents values very measured once a week for verification porpouses.

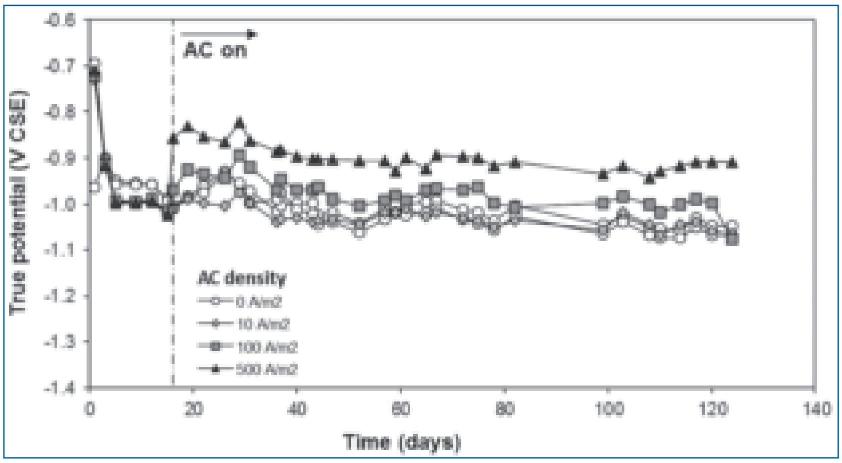

Fig. 2 – True potential of carbon steel (0.5 A/m² cathodic current density) in the presence of AC interference

Fig. 2 – Potenziale vero dei provini in acciaio al carbonio (densità di corrente catodica 0.5 A/m²) in presenza di interferenza da corrente alternata

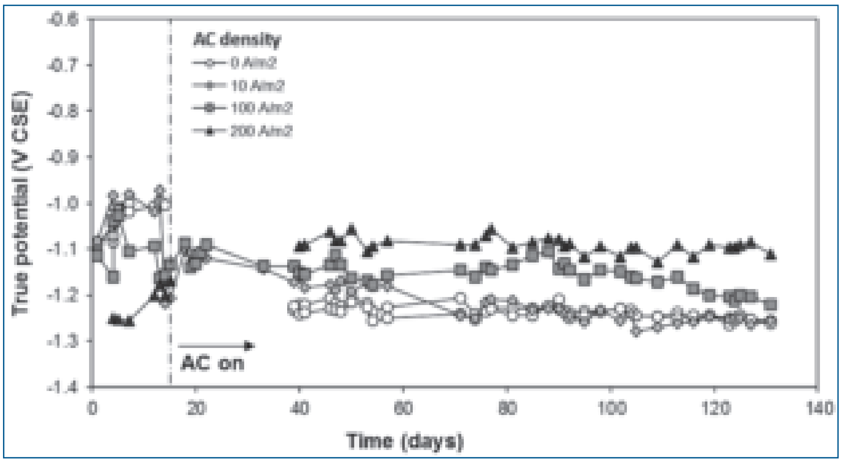

Fig. 3 – True potential of carbon steel (1 A/m² cathodic current density) in the presence of AC interference

Fig. 3 – Potenziale vero dei provini in acciaio al carbonio (densità di corrente catodica 1 A/m²) in presenza di interferenza da corrente alternata

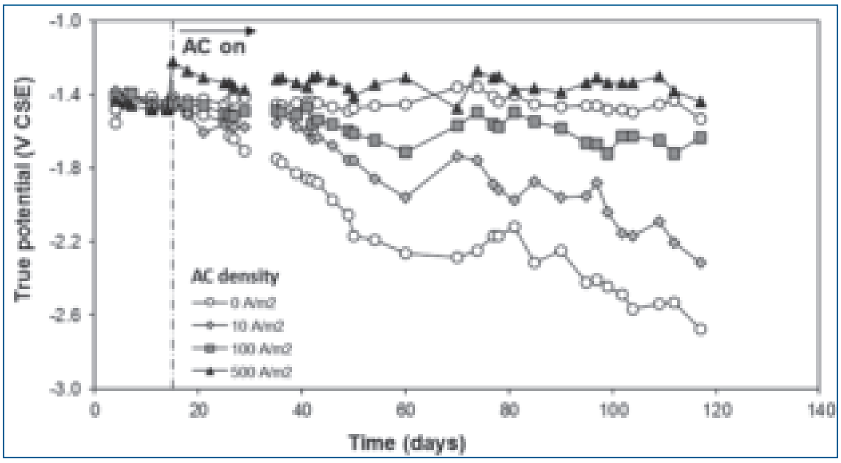

Fig. 4 – True potential of carbon steel (10 A/m² cathodic current density) in the presence of AC interference

Fig. 4 – Potenziale vero dei provini in acciaio al carbonio (densità di corrente catodica 10 A/m²) in presenza di interferenza da corrente alternata

RESULTS

Potential monitoring

True potential, E_{true} (or IR-free potential) readings on carbon steel specimens cathodically protected at 0.5 A/m² and interfered by AC are reported in Figure 2. During the first 2 weeks, only DC was applied: potentials were in the range −0.9/−1.0 V CSE. Then AC interference was overlapped. While no variations of potential were observed at 10 A/m² AC density, an anodic shift up to 0.1 V occurred when 100 and 500 A/m² were imposed.
Figure 3 reports true potential measurements of carbon steel specimens, cathodically protected at 1 A/m² and interfered by AC. Under CP condition, potentials were close to −1.2 V CSE. In the presence of AC densities an anodic potential shift was recorded: at 100 A/m² true potential increased up to -1.15 V CSE; at 200 A/m² AC interference, true potential increased to −0.95/−1.0 V CSE.
Figure 4 shows the true potential measured on the specimens polarised at 10 A/m² cathodic current density. Before AC interference, overprotection condition was established (true potential −1.4 V CSE), compatible with the high DC density. At 500 A/m² AC density, potential shifted to −1.2/−1.3 V CSE, then confirming an AC

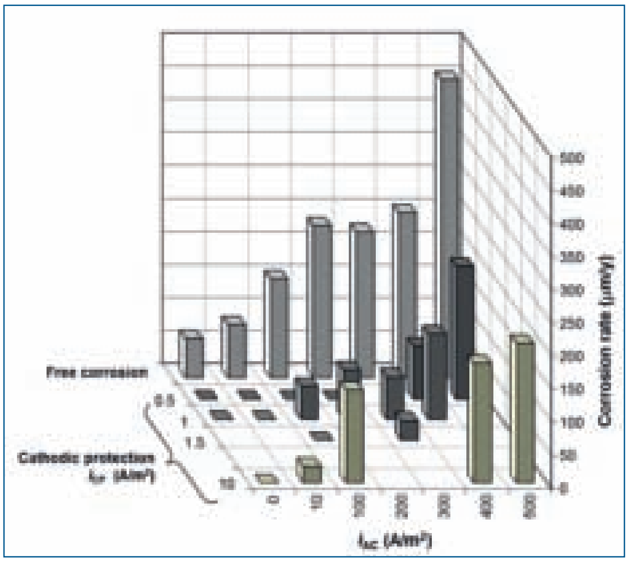

Fig. 5 – Corrosion rates of carbon steel specimens as a function of AC interference and cathodic DC density (CP)

Fig. 5 – Velocità di corrosione dei provini in acciaio al carbonio in funzione della densità di corrente interferente e della densità di corrente catodica

polarizing effect [16, 19]. After 30 days, potentials of two cathodically protected specimens, gradually lowered to −2.2 V and −2.6 V CSE, respectively. These values include a high contribution of concentration polarization due to hydrogen evolution at very high cathodic DC density, therefore they cannot be considered as true protection potentials, since they are not the real polarization level of the carbon steel samples.

Weight loss tests

After four months exposure, specimens were removed from the test cells and the corrosion rate was calculated by weight loss measurements. Estimated corrosion rate values are reported in Table 1 as a function of cathodic current density (i_{DC}) and interfering AC density (i_{AC})
In the absence of AC interference, corrosion rate of

i_{DC} \ i_{AC}	0	10 A/m^2	100 A/m^2	200 A/m^2	500 A/m^2
0.5 A/m^2	< 10	< 10	< 10		210
1 A/m^2	< 10	< 10	60	80	
10 A/m^2	< 10	40	150		220

Table 1 – Corrosion rate (µm/y) of carbon steel specimen under CP in the presence of AC interference

Tabella 1 – Velocità di corrosione (µm/anno) dei provini in acciaio al carbonio in protezione catodica in presenza di interferenza da CA

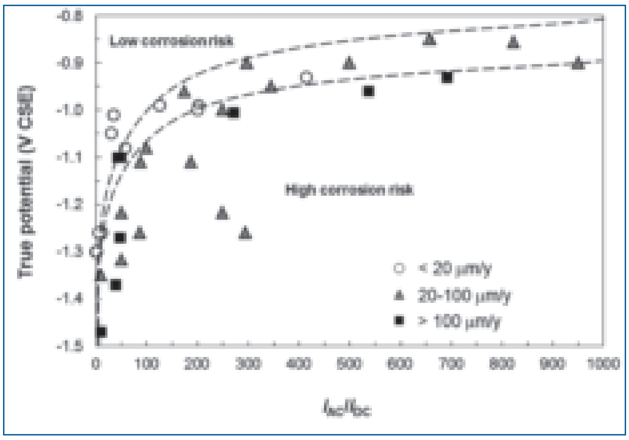

Fig. 6 – AC corrosion risk map: corrosion rate as a function of true potential and i_{AC}/i_{DC} ratio

Fig. 6 – Mappa di rischio di corrosione: velocità di corrosione in funzione del potenziale vero e del rapporto i_{AC}/i_{DC}

specimens under CP is almost negligible (lower than 10 µm/y). AC interference promotes a significant increase of corrosion rate. At low cathodic current density (0.5 A/m2), corrosion rate is higher than 200 µm/y only when AC density is 500 A/m^2. At 1 A/m^2 cathodic current density, corrosion rate increased to 60 µm/y at 100 A/m^2 AC density. In overprotection condition (10 A/m^2 cathodic current density) the increase of corrosion rate occurred at a very low AC density, 10 A/m^2.

DISCUSSION

Experimental tests simulated possible AC interference on cathodically protected coating defects on buried coated pipelines. Results are analyzed and discussed in order to highlight the influencing parameters to be considered to estimate the risk of AC-corrosion and to evaluate the CP criteria in the presence of AC interference.
Figure 5 reports corrosion rate obtained by weight loss test on carbon steel specimens as a function of cathodic DC current densities and AC interference. For comparison purposes, results of corrosion rate measurements performed on freely corroding carbon steel specimens under AC interference are reported. Tests were carried out with the same experimental procedure and detailed results are reported in [2]. Moreover, results obtained on carbon steel specimen polarised with 1.5 A/m^2 cathodic current density are also represented (detailed results are reported in [19]).
In freely corroding conditions carbon steel corrosion rate is about 50 µm/y. Increasing AC density from 10 A/m^2 to 500 A/m^2, carbon steel corrosion rate increased up to about 500 µm/y. Under CP condition, in the absence of AC interference, corrosion rate is always negligible, lower than 10 µm/y. At a constant CP current density, corrosion rate increases as AC interference increases. At constant AC density, higher is the cathodic current density, higher is

the measured corrosion rate. Summarizing, corrosion rate of carbon steel under CP condition increases as AC and DC current densities increase, i.e. corrosion rate depends on both interference and protection levels. The critical value of AC density that may cause significant corrosion rate on a cathodically protected specimen decreases from 500 A/m^2 to 10 A/m^2 as cathodic DC density increases from 0.5 A/m^2 to 10 A/m^2.
AC density and CP current density are not sufficient to establish AC-related corrosion risk, since protection potential must be taken into account.
Figure 6 reports a corrosion risk map which correlates true potential (true polarization level measured by means of a Luggin capillary, then not affected by ohmic drop) and the AC and DC current densities ratio (i_{AC}/i_{DC}). This empirical diagram allows assessing CP effectiveness in the presence of AC interference by means of IR-free potential and current densities measurements. Three corrosion risk levels are identified: low, medium and high, depending on corrosion rate. Medium and high corrosion risk correspond to corrosion rates in the range from 20 to 100 μm/y and greater than 100 μm/y, respectively.
As reported ion Table 1 and Figures 5 and 6, in the absence of AC interference, corrosion does not occur: the metal is protected by the cathodic current. In the presence of AC interference, at a fixed i_{AC}/i_{DC} ratio, corrosion rate increases as true potential decreases. At a constant potential, corrosion rate increases increasing the current densities ratio. Overprotection (potential lower than -1.2 V CSE) is the most dangerous condition as regard AC corrosion risk: few A/m^2 of AC density (i_{AC}/i_{DC} in the range 5 to 20, depending on potential) may cause severe corrosion on protected carbon steel. At -0.85 V CSE (protection potential value according to UNI EN 12954), cathodic protection is not effective if i_{AC}/i_{DC} ratio is higher than 400.

CONCLUSIONS

Weight loss tests on cathodically protected carbon steel specimens were performed in simulated soil conditions (sand saturated with 1 g/L Na_2SO_4 solution) to estimate the effect of AC interference. Main conclusions can be summarized as follows:
- in the presence of AC interference corrosion occurred even in the presence of a cathodic current density;
- corrosion rate increases up to 200 μm/y by increasing AC density, even if CP is applied;
- the -0.850 V CSE criterion is not always safe in the presence of AC interference;
- overprotection (true potential lower than -1.2 V CSE) is the most dangerous condition in the presence of AC.

Therefore, cathodic protection criteria for carbon steel in the presence of AC interference should exclude high protection levels (no overprotection conditions). Moreover, in order to assess the AC corrosion likelihood, AC density, true (IR-free) potential and i_{AC}/i_{DC} ratio must be taken into account.

REFERENCES

1] L. Lazzari, P. Pedeferri, Cathodic Protection, Polipress, Milan, Italy (2006).
2] S. Goidanich, L. Lazzari, M. Ormellese, AC Corrosion - Part 2: parameters influencing corrosion rate, Corrosion Science, 52, 3, 916-922 (2010).
3] R.G. Wakelin, C. Sheldon, Investigation and mitigation of AC corrosion on a 300 mm diameter natural gas pipeline, Int. Conf. CORROSION/2004, Paper 04205, NACE International, New Orleans, LA (2004).
4] R. Floyd, Testing and mitigation of AC corrosion on 8'' line: a field study, Int. Conf. CORROSION/2004, Paper 04210, NACE International, New Orleans, LA (2004).
5] P. Linhardt, G. Ball, AC corrosion: results from laboratory investigations and from a failure analysis, CORROSION/2006, Int. Conf. CORROSION/2006, Paper 06160, NACE International, San Diego, CA (2006).
6] P. Carpentiers, R. Gregoor, A. Pourbaix, AC corrosion: detection, investigations and mechanisms": Proc. Int. Conf. EUROCORR/03, Paper 307, Budapest, September 28 – October 2 (2003).
7] L.V. Nielsen, K.V. Nielsen, B. Baumgarten, H. Breuning-Madsen, P. Cohn, H. Rosenberg, AC-induced corrosion in pipelines: detection, characterization, and mitigation, CORROSION/2004, Int. Conf. CORROSION/2004, Paper 04211, NACE International, New Orleans, LA (2004).
8] M. Yunovich, N.G. Thompson, AC corrosion: corrosion rate and mitigation requirements, Int. Conf. CORROSION/2004, Paper 04206, NACE International, New Orleans, LA (2004).
9] C.Y. Du, B. Cao, Y. Wu, New cathodic protection potential criterion under AC interference condition, Corrosion and Protection, 31, 11, 847-850 (2010).
10] S. Goidanich, L. Lazzari, M. Ormellese, AC corrosion – Part 1: effects on overpotentials of anodic and cathodic processes, Corrosion Science, 52, 2, 491–497 (2010).
11] A. Brenna, M.V. Diamanti, L. Lazzari, M. Ormellese, A proposal of AC corrosion mechanism in cathodic protection, Technical Proc. of the 2011 NSTI Nanotechnology Conf. and Expo, NANOTECH 2011, TechConnect World - Conf. & Expo, ISBN 978-1-4398-7138-6, Vol. 3, 553-556, CRC Press - Taylor & Francis Group, Boston, MA (2011).
12] A.Q. Fu, Y.F. Cheng, Effect of alternating current on corrosion and effectiveness of cathodic protection of pipelines, Canadian Metallurgical Quarterly, 51, 1, 81-90 (2012).
13] D. Tang, Y. Du, M. Lu, L. Dong, Z. Jiang, Progress in the mutual effects between AC interference and the cathodic protection of buried pipelines, Journal of the Chinese Society of Corrosion and Protection, 33, 5, 351-356 (2013).
14] Z. Jiang, Y. Du, M. Lu, Y. Zhang, D. Tang, L. Dong, New findings on the factors accelerating AC corrosion of buried pipeline, Corrosion Science, 81, 1-10 (2014).

15] L.V. Nielsen, F. Galsgaard, Sensor technology for on-line monitoring of AC induced corrosion along pipelines, Int. Conf. CORROSION/2005, Paper 05375, NACE International, Houston, TX (2005).
16] M. Ormellese, S. Goidanich, L. Lazzari, Effect of AC interference on cathodic protection monitoring – Corrosion Engineering, Science and Technology, 46, 5, 618-623 (2011).
17] L. Xu, Y.F. Cheng, A real-time AC/DC measurement technique for investigation of AC corrosion of pipelines and its effect on the cathodic protection effectiveness, Corrosion/13, Paper N. 1012, NACE International, Houston, TX (2013).
18] L.Y. Xu, X. Su, Y.F. Cheng, Effect of alternating current on cathodic protection on pipelines, Corrosion Science, 66, 263-268 (2013).
19] F. Bolzoni, S. Goidanich, L. Lazzari, M. Ormellese, Laboratory test results of AC interference on polarised steel, Corrosion 2003, Paper 03704, NACE International, Houston, TX (2003).

Condizioni di protezione catodica in presenza di corrente alternata

Parole chiave: Acciaio - Corrosione - Elettrochimica

Le tubazioni in acciaio al carbonio interrate, utilizzate per il trasporto di idrocarburi sono protette per legge dalla corrosione da un sistema di protezione catodica e da un rivestimento isolante che permette di limitare la superficie metallica da proteggere alle sole zone esposte al terreno, come i difetti o le porosità del rivestimento (UNI EN 12954 - Protezione catodica di strutture metalliche interrate o immerse - Principi generali e applicazione per condotte). Correnti vaganti di tipo alternato possono causare corrosione delle tubazioni, anche se correttamente provviste dei suddetti sistemi di protezione. In letteratura sono infatti documentati casi di corrosione di strutture metalliche interrate in protezione catodica interferite da corrente alternate, con potenziale di protezione che rispetta il criterio dei -0.85 V CSE. A livello internazionale non sono ancora condivisi dei criteri che indichino quale sia il livello di potenziale di protezione o la densità di corrente di protezione da applicare nel caso in cui la tubazione interrata sia interferita da corrente alternata. In questa memoria si illustrano i risultati di prove sperimentali condotte su provini di acciaio al carbonio in protezione catodica interferiti da corrente alternata, al fine di individuare i criteri di protezione da adottare per strutture interrate. Lo schema del circuito elettrico è riportato in Figura 1. Sono state applicate diverse densità di corrente di protezione (da 0.5 fino a 10 A/m2) e per ciascuna condizione sono state sovrapposte densità di corrente alternata da 10 fino a 500 A/m2 (con frequenza 50 Hz). I risultati hanno permesso di individuare i parametri critici da considerare per valutare il rischio di corrosione da corrente alternata: la densità di CA interferente, il potenziale vero di protezione, la densità di corrente di protezione in particolare il rapporto tra la densità di corrente di protezione e la densità di corrente alternata interferente. In particolare, è confermato che in presenza di condizioni di sovraprotezione catodica, anche soli 10 A/m2 di densità di corrente alternata interferente provocano un attacco corrosivo non trascurabile (Figure 5-7).