Interaction and Stray-current Corrosion "(MS 156)" for the **Shreir's Corrosion**

Foreword

1 – The phenomenon of a.c. corrosion

The primary factor in alternating current electrolysis is current density. This statement was made in The Engineering Journal, the journal of the Engineering Institute of Canada, and was made in 1927.

A long time has passed since then and a.c. effects have been experienced and investigated in depth.

More recently, since 1986, some instances of corrosion on gas pipelines due to alternating current (16 2/3 and 50 Hz) have been reported in Europe and elsewhere. In all these cases, the cathodic protection values, measured with conventional techniques and instruments, satisfied the conventional criteria. It is most probable that some previous corrosion failures have not been recognised as being caused by alternating current because cathodic protection personnel have not been made aware of a.c. corrosion risk.

The a.c. influence is referred to as "inductive», «resistive» or «capacitive» interference in technical literature.

In the last decade, quite a number of corrosions have been clearly attributed to a.c. corrosion.

a.c. corrosion is a concern for owners operating long structures (mostly pipelines) running parallel or close to overhead high voltage transmission power lines (typically 15 kV and higher) or a.c. traction systems. The problem also exists in municipal areas (structures near buried a.c. power distribution systems), in reinforced concrete structures (e.g. road bridges also sustaining electricity power lines) and inside tunnels for a.c. electrified railways.

It is not uncommon to measure a.c. voltages in the range of 15 to 100 Vrms on coated pipelines exposed to a.c. influence. This may cause safety hazards to people , malfunction of pipeline equipment and corrosion problems.

In the last two decades, a better knowledge of the a.c. corrosion phenomenon has been gained, thanks to the many studies that mainly gas operators have sponsored or directly performed.

These studies started in the 80ies and are still in progress. Since this period, high quality/high resistance coatings have been used for buried pipelines, thus increasing the effects of a.c. interference.

Very often in the past, a.c. corrosion was not correctly diagnosed because usually Cathodic Protection instrumentation rejects industrial a.c. frequencies and the knowledge of the a.c. corrosion phenomenon itself is still growing every day.

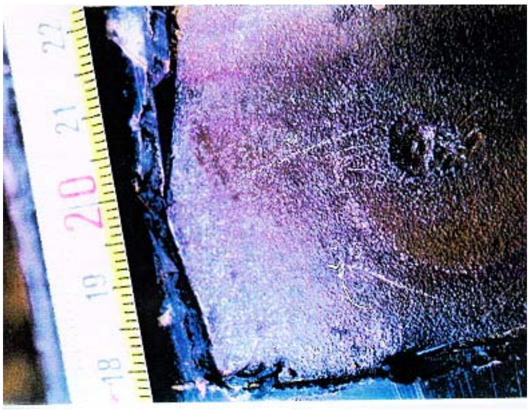

Figure 1 - Typical a.c. corrosion on a PE coated pipeline (Reference 5)

Figure 2- Typical a.c. corrosion on a bituminous coated pipeline (Reference 5)

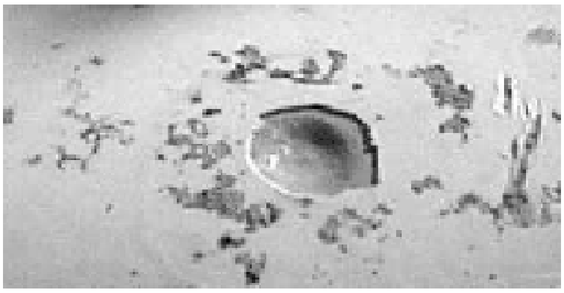

Figure 3 - Typical a.c. corrosion on an FBE coated pipeline (Reference 7)

2 – Sources of a.c. interferences

Main long term a.c. interfering sources on buried metallic pipelines are:

- a.c. overhead or underground electricity power lines;
- a.c. traction systems, fed by a parallel high voltage feeding line (50 Hz or 16 2/3Hz).

Long term a.c. interference on a buried pipeline may cause corrosion due to an exchange of a.c. current between the exposed metal of the pipeline and the surrounding electrolyte at coating holidays.

This exchange of current depends on the a.c. voltage whose amplitude is related to various parameters such as:

- the configuration of a.c. power line phase conductors and shielding wires;
- the distance and the length of parallel path between the a.c. power line / traction system and the pipeline;
- the current flowing in the a.c. power line / traction system phase conductors;
- the average insulating resistance of the pipeline;
- the thickness of the coating;
- the soil resistivity.

3 – Interference effects

When an a.c. voltage is present on a cathodically protected pipeline and defects in the coating are present, an a.c. current will flow across the metal/soil interface. This current depends on the impedance of the system.

During the negative half wave the combined a.c. and d.c. current will result in the reduction of any reducible species that is in contact with the metal, e.g. the formation of hydrogen and hydroxyl ions according to equation (2b). During the positive half wave the current may cause charging of the double layer capacitance, possible oxidation of hydrogen and reduced corrosion products due to the cathodic protection, and oxidation , i.e. corrosion, of the pipeline steel. Since this current leaving the metal surface is consumed by several non-corrosive processes, generally voltages higher than between 4V and 10 V are required to result in a significant corrosion attack to the pipeline steel. Various additional parameters influence this process; among others the most important ones are the leakage resistance of the defect, the level of cathodic protection and the chemical composition of the soil.

- The leakage resistance R_L is generally due to the geometry of a defect that is in contact with the soil (resistivity ρ). Considering a circular defect with diameter *d*, the following formula yields:

$$R_L = \frac{\rho}{2d} \tag{1}$$

Equation (1) is useful for a rough estimation of R_L, however, it should be considered that soil resistivity may vary significantly in the vicinity of a coating defect, and both the soil resistance in the defect (considered within the thickness *s* of the coating) and the polarisation resistance have been neglected.

- Cathodic protection generally creates electrochemical reducing conditions at the steel surface and results in the formation of hydroxyl-ions according to:

  $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ (2a)
  and/or
  $2H_2O + 2e^- \rightarrow 2OH^- + H_2$ (2b)

  This is combined with an increasing alkalinity (up to pH 11 – 12 and even more) and a significant decreasing of the resistivity of the soil close to the steel surface.

- From soils containing Calcium (Ca^{2+} or other earth alkali ions) it is known that non soluble calcareous layers ($CaCO_3$) are formed on the cathodically protected steel surface. This is due to the highly alkaline conditions and reactions with CO_2 in the soil. The result is an increasing leakage resistance of the defect. In alkali ion (Na^+, K^+) rich soils however, similar reactions produce soluble bicarbonates (e.g. $NaHCO_3$) thus resulting in a decreasing leakage resistance (Reference 9).

The processes taking place can be schematically resumed as follows [Reference 8]:

During the positive half wave the bare metal surface is oxidized, resulting in the formation of a passive film. This is due to the current that leaves the metal surface. During the negative half wave, when both a.c. and d.c. current enter the metal surface, this passive film may be reduced to iron hydroxide. In the following anodic cycle a new passive film grows. Upon reduction of the passive film the amount of iron hydroxide is increased. Hence every a.c. cycle results in some oxidation of the metal. In the long term this can result in a significant metal loss.

4 – Calculation of a.c. induced voltage

An a.c. voltage that may cause corrosion can result from resistive or inductive interference from high voltage power lines and/or electrified railways; induction is the most frequent interference mode. The a.c. voltage Uac should be calculated in accordance with CIGRE Technical Brochure N°95 published in 1995 “Guide on the Influence of High Voltage A.C. Power Systems on Metallic Pipelines”.

The evaluation of Uac is generally based on the calculation of the induced longitudinal field strength E for a segment of the pipeline.
The field strength E depends on:

- the value and the frequency of the inducing current;
- the mutual inductance – related to the unit length – between the conductor(s) of the high voltage line and the pipeline, i.e. a function of their clearance and of the soil resistivity;
- the reduction factor, allowing for the protective effect of adjacent earthed conductors.

For simplified conditions (e.g. parallel routing between high voltage line and pipeline, uniform coating resistivity of the pipeline, constant soil resistivity and both ends of the pipeline being terminated by a low resistance to earth, an analytical solution for Uac as a function of pipeline length may be evaluated. In practice, however, calculations are generally carried out by using computers, taking into account the relevant parameters of the high voltage line and the pipeline.
These calculations are, among others, based on the following information and documentation:

- Drawings showing the right of way of the high voltage lines and the pipeline together with the location of power stations, substations, transformer stations, overhead line towers and pipeline CP stations;
- Rated voltage and type of earthing of the high voltage system;
- Nominal or operating and peak (inducing) current of the high voltage line;
- Configuration of the towers and the conductors;
- Diameter and insulation resistance of the pipeline;
- Location of isolating joints and leakage resistance of any structure that provides grounding of the pipeline;
- Reduction factor of the high voltage line and, the case being, of other reducing conductors.

Ua.c. as a function of pipeline length, l, is then obtained from the vectorial sum of the induced voltage from each considered individual pipeline segment.

As an example, Figure 4 shows the results of calculated Uac for a pipeline, DN 500, laid in 1999. Isolating joints are installed at km 0 and km 62. The pipeline is inductively interfered by four 50Hz high voltage lines (110kV/220kV); the level of operating currents is between 520 and 960A. The coating insulation resistance is 1 MΩm2 and 100kΩm2 according to results from cathodic protection measurements. By installing two grounding electrodes Uac may be kept below the safety threshold for people even though for avoiding a.c. corrosion further measures are still to be adopted.

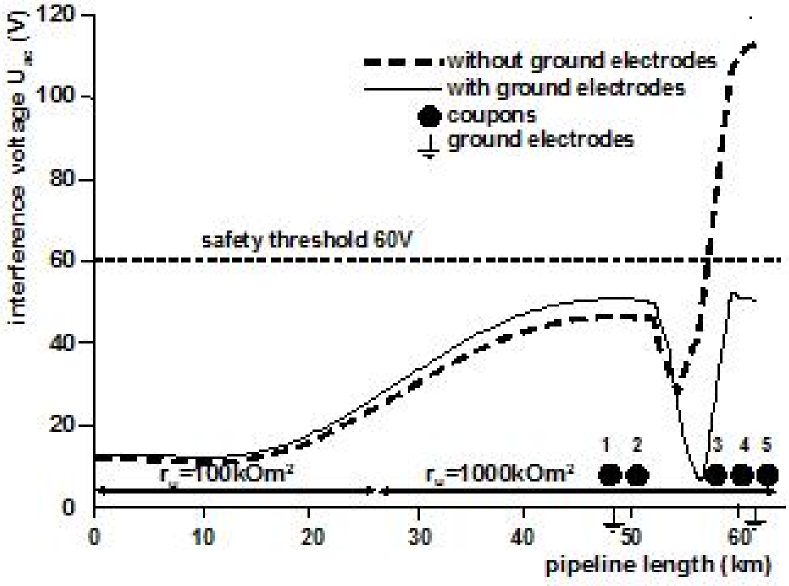

Figure 4: Ua.c. along a pipeline, DN 500, built in 1999

5 – Evaluation of the a.c. interference effects

On pipelines suffering from a.c. interference, pipe-to-soil protection potentials satisfying the requirements of the relevant Standards DO NOT GUARANTEE efficient protection against corrosion. A specific approach to assess the likelihood of a.c. corrosion should be adopted.
The a.c. voltage induced on a pipeline is considered as the most important parameter to be taken into account when evaluating the adverse influences of an a.c. system.

The factors which mainly influence the a.c. corrosion phenomena are:

- induced a.c. voltage;
- a.c. current density on the exposed metal;
- d.c. polarisation;
- size of coating faults;
- local soil resistivity;
- local soil chemical composition.

In order to assess the actual risk of a.c. corrosion on a pipeline interfered by a high voltage power line the following methods can be used:

- Indirect assessment by installing coupons along the right of way of the pipeline where the corrosion risk is expected to be highest. Appropriate locations may be found at pipeline sections where the a.c. voltage reaches the highest values (see Figure 4) .
  These coupons (typically having a bare steel area of 1cm^2) are bonded with cables to the pipeline, thus allowing to measure the voltage and the current density (d.c., a.c.).

  According to EN TS 15280 issued in March, 2006 (Reference 14), the following limits apply:
  The pipeline is considered protected from a.c. corrosion if the rms a.c. current density (Jac) on the coupon is less than 30 A.m^2.
  In practice, the evaluation of a.c. corrosion likelihood on a broader base can be made as follows:

- Ja.c. lower than 30 A/m^2	: no or low likelihood;
- Ja.c. between 30 A/m^2 and 100 A/m^2	: medium likelihood;
- Ja.c. higher than 100 A/m^2	: very high likelihood.

If electrical resistance (ER) coupons are used, the corrosion rate can be measured instantly. The coupon sensitivity should be carefully chosen in such a way that corrosion rates in the order of 0,01mm/year can be measured with sufficient accuracy over a period of some months.

- Indirect assessment by measuring the a.c. voltage along the pipeline and correlating the results with the actual operating conditions of the interfering high voltage system.

According to the CEN TS 15280, the following limits apply:

To reduce the a.c. corrosion likelihood on a buried pipeline, the pipeline a.c. voltage, measured at selected test points, should not exceed at any time:
- 10 V where the local soil resistivity is greater than 25 Ohm.m;
- 4 V where the local soil resistivity is less than 25 Ohm.m.

These values should be considered as threshold limits which significantly reduce a.c. corrosion likelihood; they are based on a long term practical experience of many European pipeline operators.

- Direct assessment by performing potential gradient measurements along the pipeline followed by excavation of sites where results indicate small defects in the coating. In case of pipelines that can be inspected with intelligent pig and after a sufficient duration of the interference (e.g. 2 or more years) the loss of wall thickness may also be detected by ultrasonic or magnetic flux leakage intelligent pigs.

6 – Mitigation of a.c. interference effects

In order to reduce the a.c. corrosion risk of an existing pipeline, generally the a.c. voltage between pipeline and soil and the level of the cathodic protection system can be modified and adjusted by the operator.
The a.c. current density in a defect of the pipeline coating is directly proportional to the a.c. voltage thus any reduction of the voltage reduces the likelihood for a.c. corrosion.
The following Table 1 summarizes some possible mitigating measures and shows advantages and the associated, possible drawbacks:

Table 1 – Summary of measures to reduce the a.c. voltage on interfered pipelines

Mitigation measure	Advantages	*Possible drawbacks*
Increasing the distance between pipe and high voltage line/electrified railway	-	- very efficient solution but only possible for new designed pipes or interfering systems - not possible for existing systems
Arrangement of phase and earth wires of high voltage line	-	- only possible for new designed high voltage power lines - the solution only depends from the electricity company
Earthing of pipeline through a.c. discharge devices	- generally good technical solution and cost efficient	- problems may occur in high resistivity soil due to high resistance of groundings
Compensation of ac-voltage	-	- difficult to settle - high cost of installation and operation
Installation of isolating joints	- good possibility to vary an optimum configuration by calculation and design	- installation of joints involves direct interference with pipeline operation
Earthing of pipeline by using earthing wires	-	- high cost and poor efficiency

- The level of the cathodic protection should also be considered. Some laboratory tests have shown [Reference 8] that excessive d.c. current densities (e.g. exceeding 5 A/m^2, measured on bare coupons), may increase the a.c. corrosion rate, due to the accumulation of hydroxyl-ions close to the metal/soil interface. The subsequent reduction of the leakage resistance at the defect may lead to an increasing a.c. and d.c. current densities and an increased likelihood to reduce the passive film that is formed during the anodic half wave of the a.c. current (References 13,15).
  According to the above said reactions, in order to further reduce the likelihood of a.c. corrosion, besides the reduction of the a.c. voltage on a pipeline, its On-potentials (which are the driving force for the cathodic protection current) should not be much more negative than the ones needed to satisfy the cathodic protection OFF-potential criterion of the pipeline (Reference 15).
  However, in case of d.c. interfered pipelines with high quality coatings (which are more prone to a.c. corrosion), it is difficult to practically cope with the reduction of the On potential and the simultaneous control of the d.c. corrosion risk.

MAJOR EVIDENCES FROM FIELD STUDIES AND LABORATORY TESTS

1 - a.c. Corrosion is more likely to happen on buried pipelines coated with high resistance coatings (e.g. 3 layer polyethylene) than on pipelines with elder bituminous coating types. (even though some case histories have been reported where a.c. corrosion also happened on pipelines coated with bituminous coatings).

2 - a.c. corrosion usually appears in the area along the pipeline which is highest interfered.

3 - a.c. Corrosion likelihood could further be reduced by carefully adjusting the Uon potential of pipelines to values no more negative than the ones needed to satisfy CP OFF-potential

Criteria (e.g. EN 12954). Nevertheless, this mitigation measure is to be considered quite difficult in its practical application and sometimes (e.g. presence of d.c. interferences) not possible.

References

[*1*] - *CCITT : Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines. Vol III - "Capacitive, inductive and conductive coupling: physical theory and calculation methods" – ITU Geneva 1989*

[*2*]- *F. Stalder, D. Bindschedler; Wechselstromkorrosion – Einfluss der Bodenzusammensetzung; CEOCOR, Jahrestreffen, Lugano 1992*

[*3*] - *IGU (International Gas Union) 1994 Milan - Fault Location on Pipeline Coatings*

[*4*] - *CIGRE Report: Guide on the influence of High Voltage AC Power Systems on Metallic Pipelines – 1995*

[*5*] - *Corrosion due to a.c. on metallic buried pipelines: Background and perspectives – L. Di Biase APCE, 2nd National Conference 21st -22nd Nov. 1996 – Rome*

[*6*] - *CeoCor (Comité d'etude de la Corrosion et de la Protection des Canalisation), A.C. Corrosion on Cathodically Protected Pipelines – Guidelines for risk assessment and mitigation measures - 2001*

[*7*] - *AC induced corrosion on onshore pipelines, a case history – Published in 2001*
Roger Ellis Shell UK, Stanlow, Pipeline Manager
UKOPA (United Kingdom Onshore Pipeline Operators' Association)

[*8*] - *A new electrochemical method for the detection of AC corrosion" CEOCOR Dresden-Sector A, Paper N.07 - 2004.*
M. Büchler, F. Stalder, H.G. Schoeneich, SGK, Swiss Company for corrosion protection Technoparkstr. 1, CH-8005, ZÜrich, Switzerland; Ruhrgas AG, Essen, Germany "

[*9*] – *Detection of a.c. corrosion*
A. Pourbaix, Ph. Carpentiers (CEBELCOR, Brussels), R. Gregoor (DISTRIGAZ, Brussels), CEOCOR Conference , BIARRITZ / FRANCE Oct. 2001

[*10*] - *L.V. Nielsen, B. Baumgarten, P. Cohen, „On-site measurements of AC induced corrosion: effect of AC and DC parameters" – a report from the Danish Activities- CEOCOR Dresden – Sector A - Germany, Paper N.03 – 2004*

[*11*] - *L.V. Nielsen, K.V. Nielsen, B. Baumgarten, H. Breuning-Madsen, P. Cohn, H. Rosemberg; a.c. induced corrosion in pipelines: detection, characterisation and mitigation; NACE Corrosion 2004*

[*12*] - *M. Yunovich, N.G. Thompson; a.c. corrosion: Corrosion rate and mitigation requirements; NACE Corrosion 2004*

[*13*] - *L.V. Nielsen; Role of alkalization in AC induced corrosion of pipelines and consequences hereof in relation to cp requirements; NACE 2005, paper #05188*

[14] - *CEN/TS 15280 - Evaluation of a.c. corrosion likelihood of buried pipelines - Application to cathodically protected pipelines - March, 2006*

[15] - *M. Büchler, C.-H. Voûte and H.-G. Schöneich; Evaluation of the effect of cathodic protection levels on the a.c. corrosion on pipelines; EUROCOR-2007, Freiburg, Germany*