Iranian Journal of Materials Science & Engineering Vol. 6, Number 2, Spring 2009

A NOVEL MONITORING TECHNIQUE TO DEFINE CP CRITERIA FOR BURIED PIPELINES UNDER AC CORROSION CONDITION

S.R. AllahKaram [1,2] and R. Shamani [1]
akaram@ut.ac.ir

Received: November 2008 Accepted: March 2009

[1] **Department of Metallurgy and Materials Engineering, Faculty of Engineering, University of Tehran, Tehran, Iran.**
[2] **Center of Excellence in High Performance Ultra Fine Materials, Tehran, Iran.**

Abstract: *The risks of alternating current (AC) corrosion and overprotection increasingly demand new criteria for cathodically protected pipelines. To assess the risk of AC corrosion, new cathodic protection (CP) criteria have been proposed based on DC/AC current densities measurements using coupons. The monitoring system designed for this project was based on the instant-off method, with steel coupons simulating coating defects on a buried pipeline. The problems associated with the instantaneous off-potential measurements have been attributed to a non-sufficient time resolution. In present study, it has been possible to determine the de-polarisation of steel coupon within a few milliseconds after disconnecting the coupon from the DC/AC power source, by increasing data acquisition rate. For this, a monitoring system was developed in order to measure the IR-free potential together with the DC/AC current densities. The monitoring system was utilized for both laboratory experiments and site survey to study the mechanism and the condition of AC corrosion, its mitigation and more importantly to define new CP criteria.*

Keywords: *AC Corrosion, Cathodic Protection, Monitoring, IR-Free Potential, Pipeline.*

1. INTRODUCTION

When current flows in an energized conductor, it produces an electromagnetic field at right angles to the conductor. In AC power systems, electric current flowing in the conductor changes direction 100 times per second for 50Hz systems. Thus, the electromagnetic field surrounding the energized conductor is constantly expanding and contracting. Whenever electromagnetic lines of force cut through another conductor, a voltage is induced in that conductor. This is the principle upon which power transformers, alternators, and generators function. A well-insulated pipeline parallel to an overhead high voltage line (HVAC) then becomes the secondary of an air core transformer. With sufficient parallel length, significant voltages can be induced into the pipeline. These voltages can be hazardous to anyone who comes in contact with the exposed pipeline or appurtenances, and potentially may damage the pipeline or related facilities [1-4].

The aim of this paper is to develop new CP criteria based on DC/AC current densities and IR-Free potential measurements using coupons exposed to laboratory tests and on-site measurements. For this, a monitoring system was designed and constructed with a DC/AC power source. The system was capable of data acquisition of between 5 to 10^3 milliseconds (ms) in steps of 2 microsecond sub-divisions.

1.1. Basic Concepts for the Instant Off-Potential

Strictly speaking, the potential protection criteria refer to the structure-to-soil potential. However, in practice, it is clearly difficult to measure the potential of, say, a buried pipeline. In principle, a reference electrode would have to be placed in the soil surrounding the pipeline, at an “infinitely” small distance away from the pipeline surface. When a reference electrode is placed at ground level to measure the potential of the cathodically protected pipeline, this measurement will contain two components: (1) the pipe-to-soil potential and (2) the so-called IR-drop. The IR-drop error arises from the fact that current is flowing through the soil and that the soil between the pipeline and the reference electrode has a certain electrical resistance.

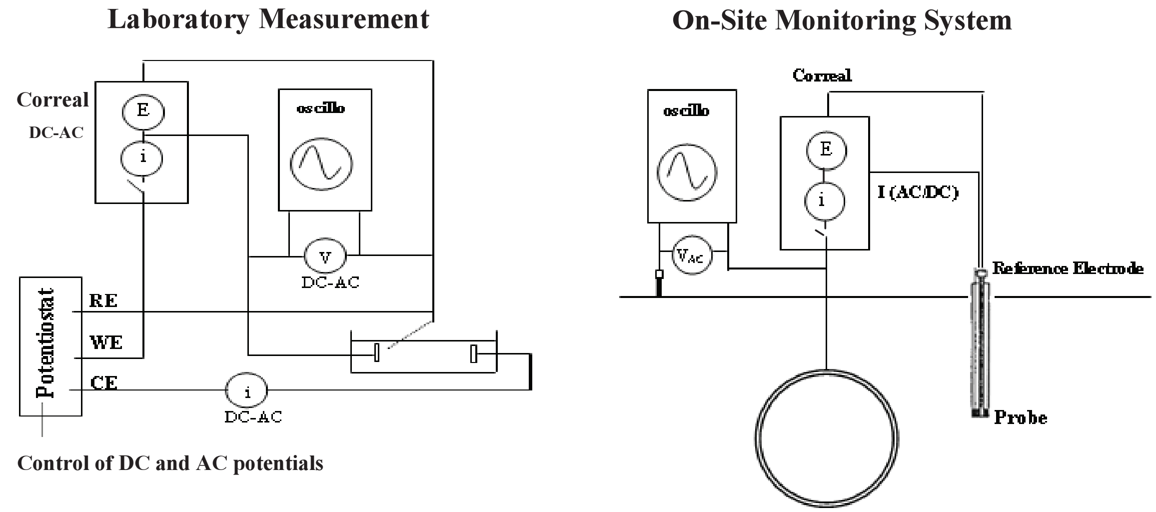

Fig. 1. The monitoring system for laboratory studies and for on-site measurement.

Unfortunately, when a surface potential reading is made, the IR-drop error will tend to give a false sense of security. In the presence of the IR-drop, the pipeline potential will actually appear to be more negative than the true pipe-to-soil potential. It is thus hardly surprising that regulatory authorities in many countries are increasingly demanding that corrections for the IR-drop error to be made in assessments of buried structures [3]. To minimize this fundamental error, it has become customary to conduct the so-called instant off-potential readings, mainly in the case of impressed current cathodic protection systems. In this approach, the impressed CP current is interrupted briefly to theoretically provide a “true” pipe-to-soil potential reading. This momentary interruption of current theoretically produces a reading free from undesirable IR-drop effects [5].

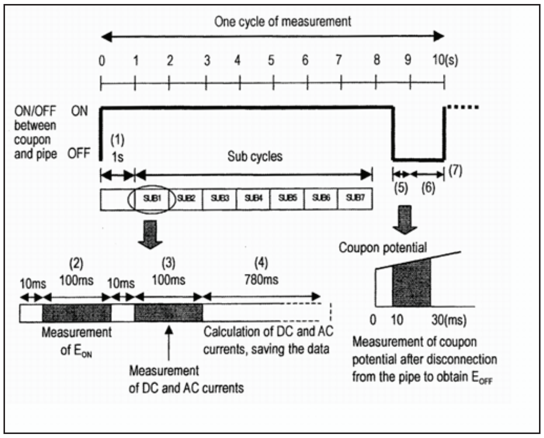

Fig. 2. Schematic diagram for the procedure of one cycle of measurement.

1.2. Monitoring System and Data Acquisition Procedure

In 1999, Pourbaix designed a monitoring system which could detect the potential variations of a cathodically protected pipeline within a few hundreds of a second after disconnecting the power supply [6,7]. This was a completely redesigned system based upon an earlier work in 1996, which could measure the IR-free potential, the current density and the phase angle throughout the AC affected period for both on-site and laboratory condition, as shown in Fig. 1.

For a coupon connected to a pipeline, the measurement starts in a sequence of 8.5 seconds on-period followed by 1.5 seconds off-period.

The first 8 seconds of on-period is then divided into 8 divisions, called sub-cycles. Each sub-cycle being 1 second, corresponds to a particular operation.

The sub-division of each 1000 milliseconds sub-cycle is then divided into a sequence of 10 and 100 milliseconds minute-cycles. Therefore, the measurement sequences as shown in Fig. 2 are as follows:

1. 1st 10 ms for initial waiting
2. 100 ms for the measurement of on-potential
3. 2nd 10 ms for subsequent waiting
4. 100 ms for the measurement of DC and AC

currents

5. The remaining 780 ms for calculation of DC and AC currents, instant-off potential measurement, analysis and storage of data, next cycle of measurement and so on.

In this paper similar principal of data acquisition was developed using Hosokawa procedure [3]. For this a specially designed potentiostatic system was developed based on Pourbaix 1999 laboratory and on-site instrumentations.

2. EXPERIMENTAL PROCEDURE

The experiments were conducted under both laboratory and field conditions. For laboratory experiments two soil samples were selected from two different sites next to a buried pipeline. Each soil sample was mixed with equal volume of distilled water to prepare a pulp. The field tests were conducted in two regions of buried pipelines; one with crossed overhead 400 kV power line and the other with a similar high voltage parallel transmission line.

For laboratory studies a specially designed potentiostatic regulation system for both the DC and AC polarisations with DC/AC output voltages ranging from 0 to 34V at 50-60 Hz (AC) was developed. The idea was to keep the DC+AC polarization condition constant for a period of time, long enough to measure corrosion rates and corrosion patterns. In practice, the effect of AC and DC polarisations produces some potential shift with time. But the results of the laboratory study permit the worker to correlate each of these evolving conditions to a specific type and a certain rate of corrosion.

The specimens were cut from a sheet of carbon steel (St37) in various sizes. The areas of these electrodes were 1, 5 and 10 cm^2 for laboratory studies. For field studies, coupons with exposed steel surfaces, simulating a coating holiday of 10 and 20 cm^2, were connected to the buried pipeline, at the test station. Before the exposures, the specimens were polished using 1200 SiC papers. The aspects and the depth of corrosion attack, compared to a reference metal surface covered by a coating similar to that of the pipeline (i.e. polyethylene), were investigated in the case of both laboratory and field coupon electrodes. To study the AC corrosion and protection criteria, a large number of tests were conduced in a real soil sample from the field. The DC+AC polarization conditions were selected according to the following criteria:

- The potential is permanently in the immunity domain,
- The potential oscillates between the immunity domain and a domain of stability of an oxide film (passivity),
- The potential oscillates between the immunity domain and the corrosion domain at high pH.

The strong dependency of the obtained data on the soil composition and the very fast depolarisation of the metal surface make the instantaneous off-potential measurement a non-suitable technique for the characterization of the AC corrosion of cathodically protected structures [8]. The electrolytes used in this research study, were artificial soil solutions with and without calcium content.

3. RESULTS AND DISCUSSION

a) E-I Curves under AC Polarization

The monitoring system measured the electrode potential (without any IR-drop), the current density and the phase angle at any given moment during a period of time. These field measurements were conducted on a coupon connected to the pipeline with a reference electrode placed directly over it [7-9].

The targets were as follows:

- To break down the E-I diagrams into individual ellipses and identify the ellipse that relates to corrosion (by doing so, the contribution of hydrogen evolution is eliminated from the total current),
- To measure the maximum amount of the anodic current which corresponds to corrosion, bearing in mind the resistivity and capacitivity components (phase angles).
- To calculate the corrosion rate based on this current.

A situation that occurs frequently in soils is shown in Fig. 1.

In Fig. 1, the E-I diagram have been broken down into 2 ellipses, with the upper one relating

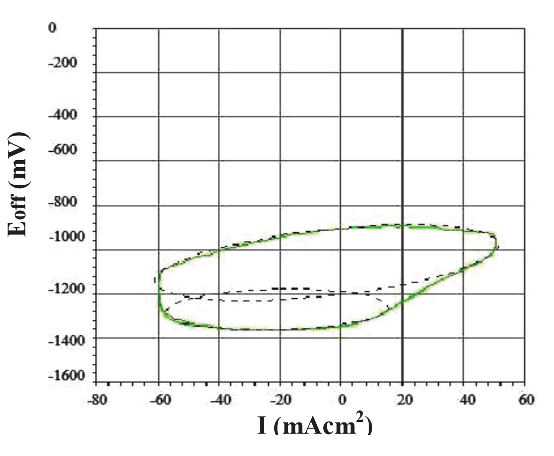

Fig. 1. The E-I graph can be broken down into 2 ellipses, where the upper one relates to corrosion. The corrosion rate is 0.65 mm/year. For an equal AC current density.

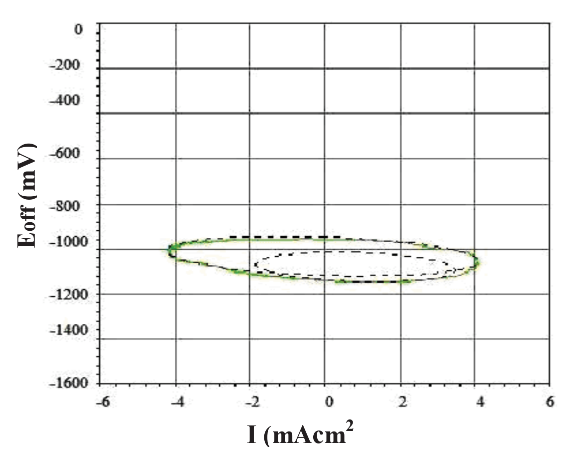

Fig. 2. The potential range between the corrosion and passivating domains produces 1 or 2 ellipses, each with phase angle greater than 90°.

to corrosion. It is located below -800 mV$_{SCE}$ and above -1150 mV$_{SCE}$. In such cases, the estimated corrosion rate is between 0.02 to 0.1 mm/year per each 1 mArms/cm² of an alternative current density. In the case of Fig. 1, the corrosion rate is 0.65 mm/year. For an equivalent AC current density, the corrosion rate gets higher as the lower ellipse extends further into the immunity domain.

Another situation that appears to relate to the potential range between the corrosion and passivating domains produces 1 or 2 ellipses, each with phase angle greater than 90° (Fig. 2). In this case the corrosion rate is less and it will reduce even further over the time. At the same time, the curve changes to a single ellipse.

Depending on the soil composition, the alkalization produced by cathodic protection may precipitate insoluble compounds, depending on the presence of Ca and Mg ions. In contrast, the same test run in artificial soil solution containing calcium ions resulted in a totally different behavior. Clearly, the critical value was exceeded indicating the occurrence of AC corrosion. The characterization study of the sample after the test indicated corrosion attack on the exposed surface, as it was expected for current densities of over 100 A/m².

The analysis of the potential development taken at the maximum off-potential is shown in Fig. 3. It is clear that the sample in the solution without calcium ions resulted in a very rapid decrease of the potential within the first few microseconds. Hence, the values recorded in the first few microseconds cannot be attributed to the depolarization of the metal surface; they are rather linked to the capacitance behavior of the precipitated products. Over the entire data acquisition range, no further change in potential was observed. Very similar results were obtained for coupons with various exposure times, solution pH values and current densities. Moreover, the results were in good agreement with the data obtained with a time resolution of 2 ms [9].

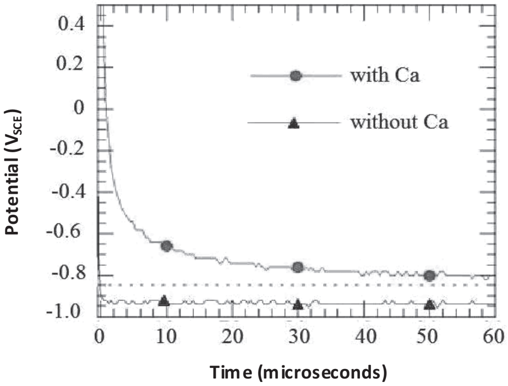

Fig. 3. The analysis of the potential development taken at the maximum off-potential in two solutions (with and without Ca ions).

Solutions containing calcium ions strongly affected the depolarization behavior of the metal surface and showed an exceeded threshold. This is presumably attributed to the formation of a chalk layer on the metal surface that alters the electrochemical behavior. Based on this finding it could be concluded that the instantaneous off-potential measurement allows the prediction of the corrosion behavior in soils containing calcium ions. However, an exceeded threshold was also observed with current densities that do not cause AC corrosion.

b) Criteria for the Elimination of AC Corrosion Risk

On the basis of laboratory and field test results, two important conclusions can be drawn:

-Whenever the maximum true peak DC potential is higher than –1150 mV_{SCE} (or –1200 mV $Cu/CuSO_4$), there is a risk of corrosion. This risk is significant when the peak potential exceeds -800 mV_{SCE}.

-Where the maximum peak DC potential is more negative than –1150 mV_{SCE}, there is no corrosion, regardless of the environment and the values of the induced AC currents.

This protection criterion is explained by the fact that non-protective films are usually formed by the AC polarisations, oscillating between the passivating domain, where the oxides form and the immunity domain, where they disperse. It can also be concluded that the electrochemical reactions rapidly follow the change in potential.

The criteria to assess the importance of AC corrosion are diverse. One criterion used in Germany suggests that there would be no AC corrosion when the rms AC current density is smaller than $2mA/cm^2$ ($20\ A/m^2$) and that corrosion is highly suspected above 10 mA/cm^2 ($100A/m^2$). Between these two values, it depends on the nature of the soil [9].

Nakamura and Kajiyama [2] suggested that a) up to 70 $Arms/m^2$ of AC current density, AC corrosion is reduced to less than 0.01 mm/y, and b) at AC current density in excess of 70 $Arms/m^2$, AC corrosion is probable despite of a high level of applied cathodic polarization.

Based on all discussions above, new cathodic protection criteria can be proposed on the basis of DC and AC current densities shown in Fig. 4. DC current density is determined as the average current density on a coupon. Positive value of DC current density indicates that the current is flowing from the soil to the coupon. AC current density is determined as the components of 50-60Hz power lines, which are commercially used and have the most significant influence on the AC corrosion [5].

DC corrosion is defined as the corrosion due to the lack of CP current, stray currents from DC powered transmission systems or other DC interferences. The lowest limit of DC current density to prevent DC corrosion was determined at 0.1 A/m^2 with reference to the recommendations made by Hosokawa [5]. The upper limit of DC current density to eliminate the risk of overprotection was determined at 20 A/m^2 tentatively from the results of field survey conducted by the authors. The level of 20 A/m2 is twice that of the level recommended by Hosokawa et al [5].

Criteria based solely on the AC current density probably have a limited significance. The ratio of DC/AC current densities considers a balance between the induction effects and the cathodic protection level, which is more reasonable. However, it is scientifically much more accurate to establish the criteria on both the current density and electrode potential, as proposed within the protection domain in Fig. 4.

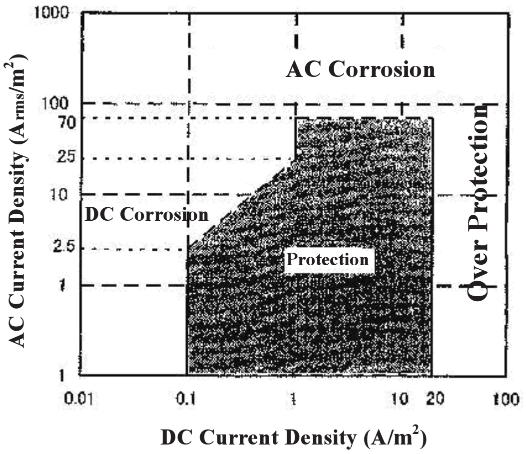

Fig. 4. New cathodic protection criteria proposed on the basis of DC and AC current densities.

4. CONCLUSIONS

Based on the laboratory and field studies, new CP criteria have been developed based on DC/AC current densities and IR-free potential measurements, using coupons, in order to eliminate the risks of AC corrosion and overprotection.

- AC current densities can increase the probability of pitting corrosion on the pipeline in chloride containing soil, due to an increase in non-uniformity of DC potential distribution on the pipeline.

- In fact there is no initiation limit of AC corrosion for the affected zones. However, the corrosion rate will increase substantially at current densities greater than 20 mA/cm^2. That is, at every 1 mA/cm^2 above this amount, the corrosion rate will be increased by roughly 1 mpy, depending on the soil composition.

- Ohmic drop (IR-drop) errors on AC influenced pipelines can be far greater than IR errors (mainly to do with DC cathodic protection currents). Thus, IR-free potential measurements are essential in the presence of AC affected zones.

- Soil composition strongly affects the AC corrosion risk. Identical electrical parameters can result in significantly different AC current densities for different soil compositions.

Finally, the protection criteria for pipelines under AC influence is established in accordance with the following statement; the maximum IR-free potential must remain in the immunity domain at all times for which high pH values must be considered to define such conditions. Protection criteria may thus be much more sensitive in the presence of AC. Because, superimposed AC currents can destroy passive films that would be perfectly protective in the absence of affected AC induced zones.

REFERENCES

1. E. L. Kirkpatrick, “Basic concepts of induced AC voltages on pipelines”, MP, July 1995, pp.14-18.
2. F. Kajiyama, Y. Nakamura, “Effect of induced alternating current voltage on cathodically protected pipelines paralleling electric power transmission lines”, Corrosion, Vol. 55, No. 2, 1999, pp.200-205.
3. F. Hosokawa, F. Kajiyama, Y. Nakamura, “An innovation instrument for evaluating CP levels liaison with enhanced CP maintenance database”, Corrosion 2002, 7-11 APR 2002.
4. J. Dabkowski, A. Taflove, “Mutual design considerations for overhead AC transmission lines and gas transmission pipelines”, Vol. 1: Engineering analysis, Report EL-904, AGA. and EPRI., September 1998.
5. F. Hosokawa, F. Kajiyama, Y. Nakamura, “New CP criteria for elimination of the risks of AC corrosion and overprotection on cathodically protected pipelines”, Corrosion 2002, 7-11 APR 2002.
6. A. Pourbaix, Ph. Carpentiers, R. Gregoor, “Current problems with buried pipelines: monitoring cathodic protection, local condition at coating defects, stray current, AC corrosion, stress corrosion cracking, hydrogen stress cracking”, ICC 2002.
7. R. Gregoor, A. Pourbaix, “Detection and assessment of AC corrosion”, CEOCOR 2000, Sep.
8. A. Pourbaix, R. Gregoor, “Detection of AC corrosion”, CEOCOR 2001.
9. M. Buchler, C.H. Voute, H.G. Schoneich, F. Stalder, “Characteristics of potential measurements in the field of AC corrosion”, Eurocorr 2003.