Paper No.
12985

NACE INTERNATIONAL
CORROSION Conference & Expo 2019

VARIANCES IN PIPELINE AC INTERFERENCE COMPUTATIONAL MODELING

Gerald J Haynes
Elsyca Inc.
TBA
Denver, Colorado, 80112
USA

Christophe Baeté
Elsyca NV
Vaartdijk 3/603
B-3018 Wijgmaal (Leuven)
Belgium

Tyson Manning
Structural Integrity Associates, Inc.
10731 E. Easter Avenue, Suite 100
Centennial, Colorado, 80112
USA

Lance Barton
Structural Integrity Associates, Inc.
10731 E. Easter Avenue, Suite 100
Centennial, Colorado, 80112
USA

ABSTRACT

The AC interference between High Voltage AC (HVAC) power lines and pipelines has been modeled with various software programs, all of which have a variety of input data which creates various results and outputs. Important aspects such as the soil resistivity along the pipeline route can have a significant impact on the pipelines coating resistance. This in turn can affect both the computed AC voltages and more specifically the current densities, both of which can significantly affect personal safety and corrosion of the pipeline. The spacing of the soil resistivity measurements can have a significant effect on the accuracy of the modelling results, which in turn can affect the mitigation design and integrity. For example, measurements at 1,000 ft vs. 5,280 ft can have dire consequences on the accuracy of the modelling, the understanding of the interference, and therefore how an owner/operator responds to the threat. However, the measurements themselves do not affect the corrosion threat.

Other aspects such as the power line Longitudinal Electric Field (LEF) or Electro-Magnetic Force (EMF) may also be used to “calibrate” the AC Interference computational model, especially where power-line load data is absent. This paper addresses the critical importance of collecting adequate data for the AC Interference studies, to prevent costly installations and to mitigate the incorrect positioning of AC Mitigation systems, due to inadequate information.

Key words: AC interference, soil resistivity, Longitudinal Electric Field (LEF), Electro-Magnetic Force (EMF), AC corrosion, grounding, computational modeling

INTRODUCTION

AC corrosion on pipelines has been well documented and researched for a number of decades.[1,2] More recently, standards like EN 15280-2013 “Evaluation of a.c. corrosion likelihood of buried pipelines applicable to cathodically protected pipelines”.[3] This standard addresses the effects of AC on cathodically protected pipelines and has recently been superseded by advances in AC corrosion with the development and publication of ISO 18086 “Corrosion of metals and alloys - Determination of AC corrosion. Protection criteria”.[4] Commercially available computer modeling of the AC interference effects on buried pipelines has been around since the 1980’s, and with the recent hardware and software improvements over the last few years, computational modeling of AC interference has vastly improved and has become an engineering best practice for the pipeline industry, especially for complex pipeline and HVAC right-of-way’s (ROWs).

Despite all of these advances in AC corrosion and computational modeling, significant variances and potential integrity issues can still arise due to the variances in input data and input measurements.

Computational Calibration Process

There are many aspects that can affect the overall accuracy of the computational model for the AC interference, such as drains via direct or indirect bonds with other structures, actual pipeline coating resistance versus theoretical values, existing AC grounding, and other potential anomalies like extraneous earths. There are also instances where the electricity companies will not supply the power-line loads for the steady state or peak state computational study. In these instances other methods are required to be employed in order to determine and “adapt” the power-line loads, based upon specific field measurements, as detailed below.

There are also no standards, codes or guidelines that require any computational “calibration” to take place, in order to ensure that the modeling actually replicates actual field conditions in the specific AC collocation, while taking the entire pipeline infrastructure (CP rectifiers, bonds, etc.,) into account.

However, specific field measurements can be collected such as AC pipe-to-soil potential measurements (AC PSP); Longitudinal Electric Field (LEF) measurements; Electro-Magnetic Force (EMF) measurements; current drains at any cross bond(s); AC current drains and AC PSP measurements at existing AC Mitigation locations; can be collected along the AC interference corridors, in addition to required soil resistivity measurements. The accurate collection of this field data can be used to significantly improve the accuracy of the computational modeling, thereby permitting the interference collocation to be “calibrated” for the “As- Found” or “As-Is” situation. This data may then be used for the balance of the computational modeling and will ensure a greater overall accuracy of the modeling.

Soil Resistivity Input Process

There are several international codes and/or specifications pertaining to AC interference on metallic buried pipelines, such as NACE SP0177-2014-SG “Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems”[5] and EN 50443 “Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems”,[6] which is now also linked to ISO 18086.

However, none of these standards or specifications specifically detail the minimum required interval at which the soil resistivity measurements should be collected and more importantly how they are collected as part of the survey and investigation for the AC interference study.

While the soil resistivity measurements may not have a significant impact on the coating resistance for well coated pipelines, the current density calculations required to be computed in terms of the AC corrosion risks, are greatly dependent upon the prevailing soil resistivity at pipe burial depth.

Soil resistivity measurements for the current AC interference computational modeling appear to be focused upon obtaining a two-layer or multiple layer soil model for the actual AC grounding requirements. These values are often only measured at a few selected sites and often to great depths. Both the locations and depth to which these measurements need to be made are not governed by any guideline, standard, specification and/or code of practice relating to pipeline AC interference. Standards like ANSI/IEEE Standard 80-2013 “Guide for Safety in AC Substation Grounding”[7] and ANSI/IEEE Standard 81-2012 “Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System”,[8] while valuable for grounding design, the data has very little to do with AC corrosion. These soil resistivity measurements seem to be collected predominantly for the AC mitigation grounding and power-line fault analysis requirements, and are currently less focused on the actual AC corrosion risks, which can have a greater overall pipeline integrity risk to the client, pipeline owner and/or operator.

As there are no standards or guidelines regarding the collection of the soil resistivity data and other important field data as detailed above, this can cause large variations in terms of the computational modeling outputs. Software is capable of providing accurate results, however, these results are dependent upon the accuracy and relevance of the inputs, and therefore models may not deliver the accuracy required, or implied. This paper explores the computational calibration process and demonstrates how sufficient field data collection is required to improve the computational modeling results, and further illustrates the importance of making the collection of adequate soil resistivity data a pre-requisite. The paper also explores the potential variances one may obtain in terms of insufficient soil resistivity data, based upon the same AC interference collocation using the same High Voltage AC (HVAC) power-line operating conditions.

FIELD MEASUREMENTS FOR THE COMPUTATIONAL PROCESS

Field Measurements for the Computational Calibration Process

The field measurement process undertaken in order to perform the “As-Is” calibration, commences with the following key site data measurements. The AC PSP, EMF, and LEF measurements are utilized to calibrate the computational models for the AC interference and mitigation studies. These measurements are executed in the field and reflect only the power line conditions at the time of the actual measurements and therefore it is important to synchronize all of these measurements, as they are all a function of the power-line load. The field measured AC PSP, EMF and LEF values, are then compared with the computed values obtained during the computational modeling and this is broadly termed “computational calibration”.

An EMF is generated by the power lines when in operation, and the EMF may be directly measured with a Gauss meter. In general, the magnetic field decreases as the distance from the power line increases. The typical values obtained from a 150kV power line are no more than 10 to 20 milliGauss (mG). A true 3-axis AC field magnitude meter should be utilized, and one which is capable of measuring in the milliGauss range. The meter must be able to accurately measure the EMF magnitude in the XYZ direction. It is important to note, that these measurement should be taken as far from the tower structure as possible and outside of the AC interference collocation, to avoid any outside interference.

The EMF measurements should be collected from the centerline of the power-line(s) in the corridor and at a defined perpendicular trajectory with several measurements collected in both directions. The Gauss meter should be maintained in a stable position and nominally at a height of one meter and the measurements made typically every two (2) to three (3) meters taking the required GPS coordinates (positions) for each reading until the EMF readings reaches a constant value or zero. The measured values should be date and time stamped for future analysis.

The LEF, should be measured using a well insulated copper conductor wire. LEF values are measured independently to the EMF measurements. However, the results obtained from the LEF can be compared with the EMF measurements and used to validate the computational model. The LEF value is calculated by dividing the voltage measured on the wire by its length, as per Figure 1 below, and it must be noted that the measurement is sensitive to the wire alignment with respect to the power-line. Therefore, it is very important to ensure that the LEF probe is parallel to the power line centerline and conductors. Typical LEF values are few hundred millivolts for a 100m length of horizontal wire. During the measurement process, the GPS coordinates of the centerline of the (outer most) power line(s) in the corridor is measured. The insulated cable is then uncoiled and the two reference electrodes or Stainless Steel (SS) pins are installed parallel to the centerline of the towers conductors.

The process and procedure is slightly different for the horizontal and vertical conductor arrangements on the towers. For horizontal towers, the measuring conductor and measurements are made directly below the outer most conductor of the tower. For vertical circuits, the insulated measuring conductor and reference electrodes or SS pins are installed directly below the power-line conductor that is furthest from the tower centerline. It is important to note, that these measurement should be taken as far from the tower structure as possible, and like the EMF measurements, outside the AC interference collocation, to avoid outside interference.

The exact GPS position of the reference electrodes / SS pins must also be collected. The AC voltage is then measured in millivolts (mV) and for the correct frequency (50Hz/60Hz). Measurements are then repeated on the opposite side of the power-line corridor, as values measured on one side serve little purpose. The setup as described above may also be setup for both sides of the power-line corridor, and this is especially recommended on more complex right-of-ways. The AC mV readings should preferably be logged for a specific period to ensure that the measurements coincide with the abovementioned EMF data collection process, and in order to ensure that the data is synchronized or to at least ensure that the data may be compared to the other data collected at very similar times.

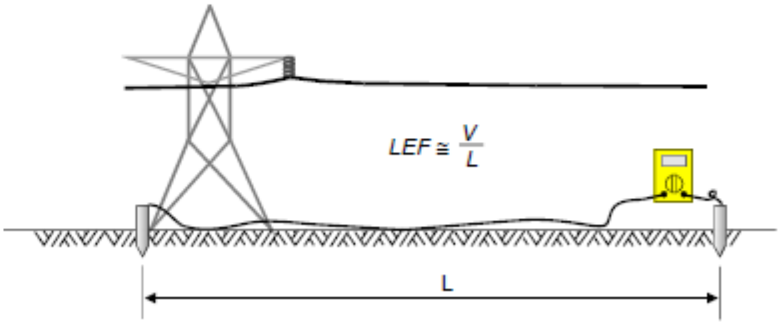


Figure 1: Schematic LEF Measurement Arrangement

AC PSP values should also be collected at as many test points and aboveground appurtenances within the AC interference collocation as possible, as well as a few test points upstream and downstream of the AC interference collocation.

These AC PSP values should also be time and date stamped to compare with the aforementioned EMF and LEF data. In more complex HVAC corridors, it is advised to record or log the AC PSP as it is quite possible that one or two of the towers line loads could fluctuate during the period in which the measurements described above are being collected.

It is well established, that the soil resistivity along the AC interference collocation affects both the magnitude of induced AC potential, and the AC current density along a given pipeline route. It is important to note, that both the specific layered soil resistivity and the apparent soil resistivity must be measured, if one is to accurately determine the potential and severity of the AC interference. The apparent pipeline soil resistivity value is measured up to the pipeline invert depth. This data is then combined with the specific pipeline coating resistance, in order to accurately determine the induced AC potentials along the pipeline route. One is also required to measure the specific resistivity pertaining to the soil layer, that is directly adjacent to the pipeline surface, and this value needs to be measured if the corrosion current density at specific coating defects (holidays) is to be accurately determined. The matter is exacerbated by the fact that the calculation of the AC current density peaks, is extremely sensitive to sudden changes in the soil resistivity, particularly where the soil resistivity changes from average values of 50-100Ω.m (or higher) to much lower resistivity values (especially less than 5-10Ω.m). If these specific high-low changes in the routing soil resistivity are not accurately delineated, then high-risk corrosion areas can be over-looked and the associated AC grounding placed in the incorrect positions. Seasonal soil resistivity variations must also be accounted for in areas, especially where it is drier in one season and wetter in the other season.

The field measured soil resistivity data needs to be measured using a calibrated Soil Meter, and one that is capable of the required noise rejection when working in the vicinity of HVAC power lines and other sources of interference (noise). All of the cables linking the various electrodes need to be well insulated and all connectors need to be low resistance connections. As a minimum the measurements should be conducted at both pipe invert and overt depth nominally every 1,000ft along the pipeline route, using ASTM G57-2012 Wenner-Four Pin-Method.(1) Where the soil resistivity is lower than 20Ω.m then the 1,000ft interval should be decreased to a smaller measurement interval, in a similar manner that areas are correctly delineated for the design and installation of sacrificial anodes. Where the soil resistivity is constant or the changes are not significant, then the intervals may be increased, until the low resistivity areas are re-encountered. Upfront planning can also be undertaken by using the US Web Soil Data Base (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm). The soil resistivity measurements should be conducted, where possible at 90 degrees to the pipeline, especially on poorly coated pipelines.

In addition to all of the above soil resistivity data, the deeper earth soil resistivity needs to be measured at selected areas along the route and to a reasonable depth (300ft or more), to permit the 2 Layers soil to be computed, and the inversion depths to be accurately determined. These measurements are required in order to ensure that; the Step and Touch Potentials can be accurately computed at pipeline appurtenances; to ensure that the resistive coupling between a faulted tower and pipeline is accurately accounted for; to accurately account for the Ground Potential Rise (GPR) which affects the Coating Stress Voltage (CSV); and finally the data is also used to ensure that the AC grounding system can be correctly designed. The challenge being that these specific locations are not covered by any standard, guideline or code of practice and the location of the grounding is not always known until the computational modeling is completed.[1]

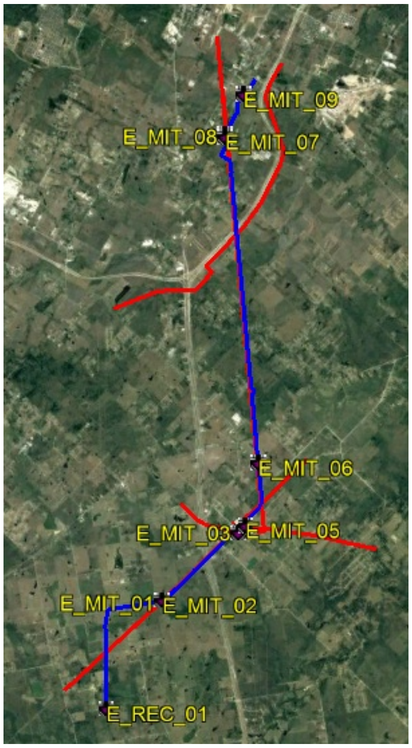
---

(1) American Society for Testing and Materials (ASTM) 100 Barr Harbor Drive, West Conshohocken, PA,19428-2959, USA

THE COMPUTATIONAL AC INTERFERENCE COLLOCATION STUDY DETAILS

In the following case study, the importance of collecting sufficient soil resistivity data along the AC interference collocation will be demonstrated, as well as how the calibration process may be used to calculate power-line loads when data has not been provided, as well as the importance of calibrating the computational model prior to the steady state and fault state analysis. An overview of the first section of the 1inch (0.25inch wall thickness) pipeline used in the computational model, which is buried at an average depth of 4ft is detailed below.

The pipeline section under consideration collocates with eight (8) HVAC power-lines is detailed below in Figure 3 and the associated Google Earth profile is detailed in Figure 2.



🟦 **Pipeline section** 🟥 **Power lines**
🟨 **Existing mitigation**

Figure 2: Google Earth view of the 16" pipeline

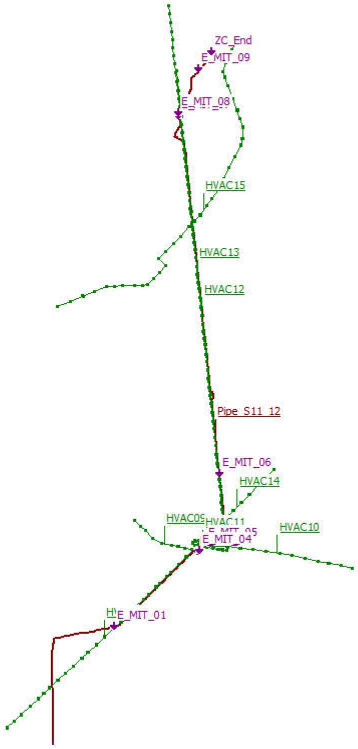


Figure 3: Computational model overview

The section of the pipeline under consideration also has existing AC mitigation systems consisting of nine (9) locations in total. These existing AC Mitigation stations are comprised of four (4) mitigation ribbons, two (2) grounding mats and three (3) grounding cells. The associated AC PSP measurements and AC grounding current measurement were also provided for each of the AC mitigation sites. There are two (2) existing valves and one (1) existing CP rectifiers along the route.

The pipeline external coating was indicated to be a liquid coating which was then overwrapped with a tape system. The pipeline was indicated to have a uniform coating resistance of 54 kΩft^2 along the complete pipeline length. The following power-line details were provided, but no average/operating load details were provided and the current loads had to be computed based upon the measured EMF, LEF and AC PSP as part of the calibration process.

A summary of the HVAC power lines details are provided in below;

Table 1
Summary of HVAC Power-lines

HVAC id.	Power line no.	Circuits	Nominal Voltage [kV]
HVAC08a	T246	2	345
HVAC09a	T382	2	138
HVAC10	T255	2	345
HVAC11	T534	1	138
HVAC12	T100	1	138
HVAC13	943	1	138
HVAC14	T352	2	345
HVAC15	T250	2	345

As part of the calibration process, the induced AC pipe voltage under steady-state power-line conditions is computed. This computed AC voltage is then compared with the measured AC induced voltages measured in the field, for a specific power-line load. The power-line loads and phasing are then adapted iteratively, and compared with the field measured LEF, EMF and AC PSP data. The resistance-to-earth of the existing AC mitigation systems were also iteratively adapted based upon the computational simulations in order to align both the AC pipeline voltage measurements and the AC current drained at the grounding locations, with the simulated induced voltages and simulated AC current drained. In order to further optimize the “calibration”, the coating resistance is also adapted along the route as required.

The soil resistivity data was collected in accordance with the Wenner 4-Pin method as per ASTM G57-(06) 2012 “Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method” and values were measured at pin spacing’s of 2.5ft, 5.0ft, 7.5ft and 10ft. The soil resistivity measurements were collected nominally every 0.12 miles. However, for the purpose of the paper and to highlight the different results one may obtain, the modeling was conducted using soil resistivity measurements at three (3) locations, six (6) locations, every 1 mile and then nominally every 0.12 mile along the AC interference collocation and/or affected route.

COMPUTATIONAL RESULTS

The first aspect pertains to the matching of the power-line loads, based upon the measured EMF and LEF data, as well as the correlation regarding the measured AC PSP. As may be seen from the measured and computed LEF and EMF data, after several iterations of optimizing the circuit loads and phasing, a very good correlation has been obtained between the computed and measured data.

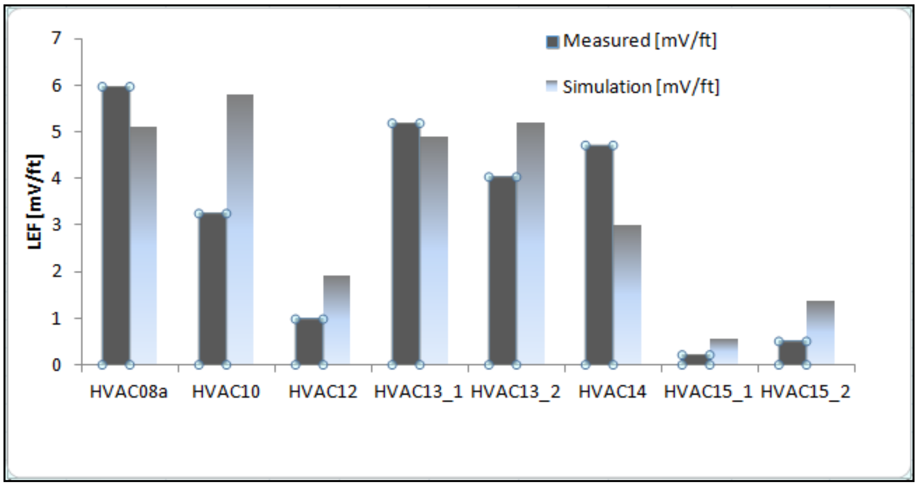


Figure 4: Calibration of the computed LEF and measured LEF

In Figure 4 above, it may be seen that there is a slight mismatch between the computed and measured data, which is to be expected. There will always be slight load fluctuations, and the cable routing will not be perfectly parallel to the conductors. The largest mismatch occurred at HVAC10, which is a double circuit power-line system and therefore a more complicated "calibration" exercise is required for these circuits.

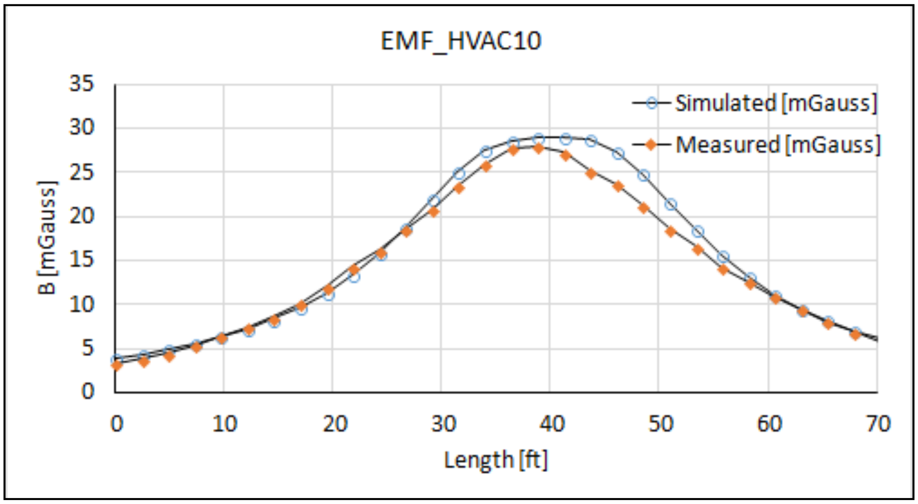


Figure 5: Calibration of the computed EMF and measured EMF

There is excellent correlation between the measured EMF and computed EMF, as may be seen in Figure 5 above. It must be noted that the EMF correlation is generally slightly easier, as the EMF data is measured at right angles to the power-line and is therefore less susceptible to interference and noise.

The induced AC pipe voltage, for the various soil resistivity scenarios which includes for 3 sets of soil resistivity measurements, 6 sets of soil resistivity measurements, a set of soil resistivity measurements each mile and then a measurement every 0.12 miles along the route, are detailed below in Figure 6.

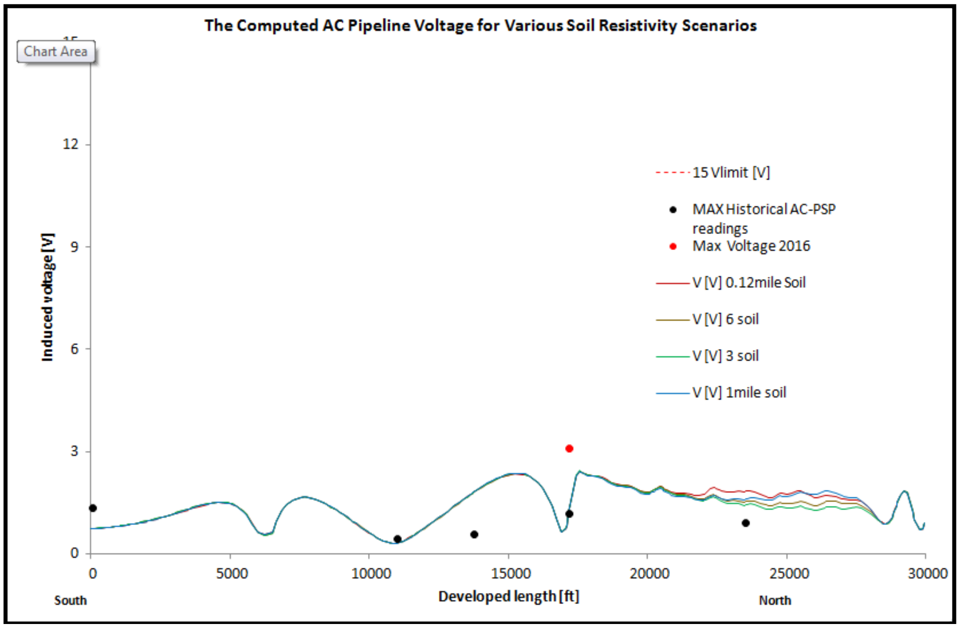


Figure 6: The computed AC pipeline voltage and measured AC PSP

The computed AC voltage shown in Figure 6 indicates that the soil resistivity changes from around 22,500ft, affects the overall AC voltage. The changes in soil resistivity towards the beginning of the section did not have the same effect on the computed AC voltages. These results are in-line with other studies, that indicate that the coating resistance (on well coated pipes) does not have a major influence on the computed AC voltage, but greatly influences the AC current density and Coating Stress Voltage. It is important to note, that the uniform coating resistance, had to be "scaled" during the calibration process, in order to optimize the correlation between the measured and computed AC pipeline voltage, EMF, LEF, and the field measured AC PSP data the overall coating calibration was undertaken using the 0.12mile soil resistivity data, to ensure accurate correlation. The optimized coating resistance data was then utilized for all of the other soil resistivity scenarios. It is also important to note that the soil resistivity does not have a major impact regarding computational modeling of the AC pipeline voltages.

However, the AC current density, and therefore the corrosion risk to the pipeline, is significantly impacted by the prevailing soil resistivity along the pipeline route, as seen in Figure 7 below.

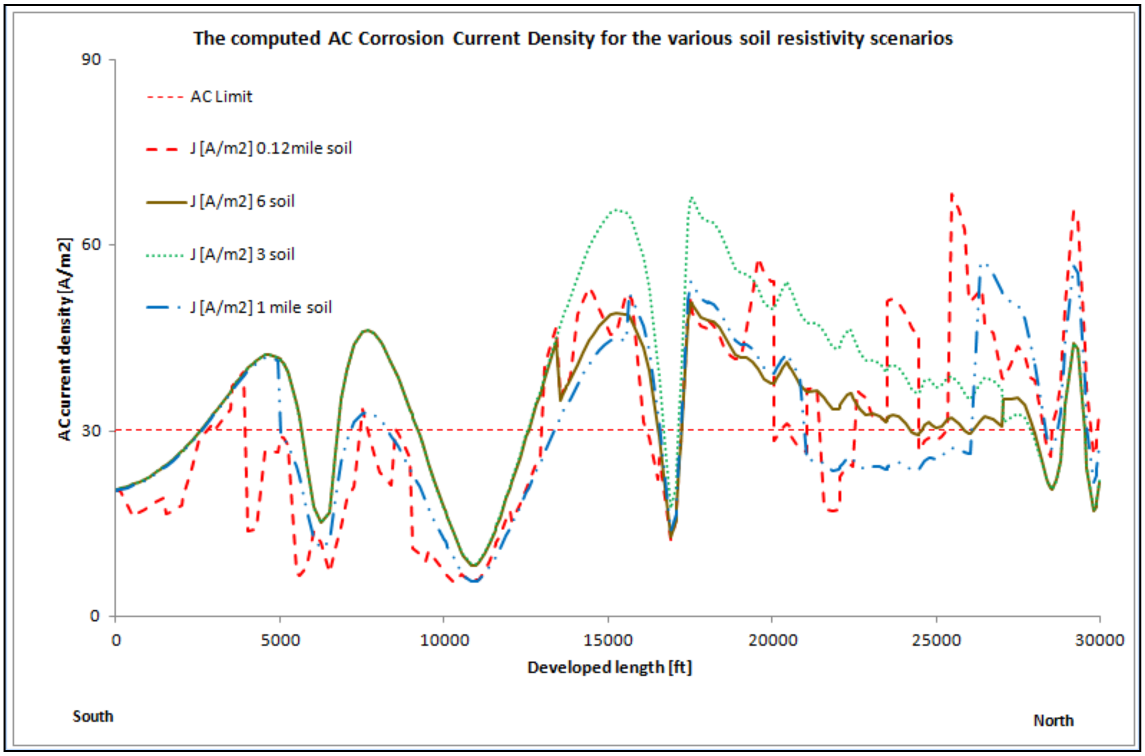


Figure 7: The computed AC Corrosion Current Density for the various soil resistivity scenarios

The prevailing soil resistivity along the route has a profound impact upon the AC Corrosion current densities (AC CD) and therefore it affects the overall integrity risk to the pipeline. In the first 5,000ft, the three and six soil resistivity measurement sets, do not accurately locate the high risk AC CD peak position, but these sets of soil resistivity also over estimate the risk, but also in the incorrect position/location. The same error is again repeated around 7,500ft and the "error" in this instance would result in a very large AC grounding system that would not be warranted. From approximately 12,500ft to 16,000ft, there are three AC CD peaks that require to be mitigated, however, the three and six resistivity scenarios data would indicate a single AC CD peak and once again, not in the correct position or location. A similar scenario occurs after approximately 17,500ft just after the large "dip" in the AC CD. The very large AC CD peaks around 24,000ft, 25,500ft are not identified adequately, and not even by the 1 mile soil resistivity measurement sets. The 1 mile soil resistivity set, does not adequately highlight the risks, where there are sudden changes in soil resistivity, especially the low resistivity soil areas, and this is very apparent from 18,500ft to 26,500ft. At the very end, just prior to 30,000ft, the 1 mile and 0.12 mile data are similar, but the three and six set of soil resistivity measurements would under estimate the risk and the grounding would be inappropriate at this location.

CONCLUSIONS

The importance of obtaining accurate input data for the computational modeling is imperative. The results also highlight that it is possible to improve upon the accuracy of the computational modeling by obtaining accurate LEF, EMF and AC PSP site measurements. Furthermore, the LEF, EMF and AC PSP measurement can be used to compute the power-line current loads, and estimate the phasing for the period during which these measurements were made.

The results further indicate that without calibrating the computational model, the actual pipeline conditions may not be correctly known, such as the actual coating resistance versus the theoretical value. It should also be noted, that while it was not within the ambit of this paper, it can be readily demonstrated, that anomalies like extraneous drains, bonds, “failed” Insulating Joints (IJ) etc., can be identified when correlating the AC PSP, power-line loads, EMF and LEF data during the calibration process.

The paper set out to demonstrate that the soil resistivity data collection process should not only be properly described in terms of how it should be collected, but also at what intervals it should be collected. The AC corrosion risks can be overestimated in areas, resulting in costly and unwarranted mitigation, and in other areas, these high risk corrosion areas can be easily missed, with serious long term corrosion risks.

It is therefore advisable that specifications like NACE SP0177, ISO 18086 and EN 50443, be updated in order to better describe the input requirements for site measurements required to accurately compute the AC corrosion risks, as well as to describe the minimum requirements for computational modeling of AC interference.

As there are currently no specifications, codes, standards or guidelines regarding the computational modeling of AC interference and AC corrosion, contractors can almost carry out the computational modeling at will, and lowest costs might secure the work today, but at what cost?

ACKNOWLEDGEMENTS

The writers are unable to formerly disclose and/or acknowledge the personnel that assisted with the case study. Nevertheless, we thank you for your kind assistance.

REFERENCES

1. PRCI L51800 “Cathodic Protection Considerations for Pipelines with AC Mitigation Facilities”
2. PRCI PR-405-113604-R01 “Develop a New Unique AC Corrosion CP Mitigation Criterion”
3. EN 15280-2013 “Evaluation of a.c. corrosion likelihood of buried pipelines applicable to cathodically protected pipelines”
4. ISO 18086-2015 “Corrosion of metals and alloys. Determination of AC corrosion. Protection criteria”
5. NACE SP0177-2014-SG “Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems”
6. EN 50443-2011 ‘‘Effects of electromagnetic interference on pipelines caused by high voltage a.c. electric traction systems and/or high voltage a.c. power supply systems”
7. ANSI/IEEE Standard 80-2013 “Guide for Safety in AC Substation Grounding”
8. ANSI/IEEE Standard 81-2012 “Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System”