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Challenges in Implementing SP21424-2018 AC Corrosion Criteria.

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ABSTRACT

The new NACE Standard SP21424-2018[1] provides a set of simple criteria for assessing the risk of AC corrosion on existing collocations between powerlines and cathodically protected pipelines. However, the task of developing design criteria for new collocations is left to the pipeline operators.

This paper covers a number of challenges related both to developing design criteria for new collocations and applying the new Standard to existing collocations.

Topics like selection of the AC current density limit for mitigating AC corrosion on a new pipeline, recording AC and DC currents on 1 cm^2 coupons and dealing with high AC and DC average current densities at low AC voltages are discussed in detail in this paper.

Keywords: AC corrosion, AC corrosion criteria, AC current density, DC current density, AC coupons, AC mitigation, 24-hour recording, measurement accuracy, CIPS, DCVG.

INTRODUCTION

The new NACE Standard SP21424-2018 provides a set of simple criteria for assessing the risk of AC corrosion on existing collocations between powerlines and cathodically protected pipelines. Specifically, the AC current density should not exceed a time-weighted average of 30 A/m^2 if the DC current density exceeds 1 A/m^2 or 100 A/m^2 if the DC current density is less than 1 A/m^2.

This paper covers a number of challenges related to converting risk assessment criteria to design limits, receiving accurate recording data from installed AC coupons and finally dealing with unexpected high AC and DC average current densities at low AC voltages.

CHALLENGE 1. DEVELOPING DESIGN CRITERIA ALIGNED WITH THE NEW SP21424-2018

When a new AC interference study is conducted for a proposed pipeline running in a common right-of-way with an existing powerline, the accepted technical approach is to collect powerline, pipeline and soil resistivity data, to use dedicated software to predict the pipeline voltages and then to calculate predicted AC current densities based on predicted voltages and measured soil resistivities at selected locations. Finally, mitigation shall be designed to ensure that the average AC and DC current densities or alternatively the average corrosion rate to be recorded during and after commissioning will satisfy the new NACE criteria.

Unfortunately, the average DC current density on an AC coupon to be installed on a future pipeline is unknown. Subsequently, there are three possible options for an AC current density limit to be used during the design:

a) 30 A/m^2. This "conservative design" limit would cover any DC current density (i.e., above and below 1 A/m^2), when applying the NACE criteria during and after commissioning.
b) Intermediate value (e.g., 50 A/m^2). Such "waiting value", in conjunction with installation of AC coupons and/or ER probes at locations exceeding 30 A/m^2 predicted AC current density, would reduce the cost of mitigation, but may require re-mobilization at a few locations to install additional mitigation after commissioning.
c) 100 A/m^2. This "high risk design" limit is not expected to be used until enough DC current density data recorded on small coupons (i.e., 1 cm^2) installed on pipelines with superior coatings will become available

The pipeline operators have the option to use one of these options as a rigid design limit in their specifications or to allow for a certain degree of flexibility, considering the superior coating quality for new pipelines, type of right-of-way (single or multiple pipelines), protection levels on existing pipelines in common ROW, etc.

New pipelines in a single ROW or in a common ROW with similar pipelines with superior coating are expected to operate at low DC current densities, especially if protected by galvanic systems. However, with most of the mitigation for new pipelines installed in pipeline trench, even a small risk of remobilizing and digging a new trench appears to be unwarranted, except for trenchless crossings, where a separate HDD would be required for installing the mitigation wire.

New pipelines in the same right-of-way with poorly coated pipelines and connected to the same rectifiers are obvious candidates for DC current densities exceeding 1 A/m^2.

Therefore, a conservative 30 A/m^2 AC current density limit for new pipelines, with the possible exception of an intermediate AC current density limit at HDDs (e.g., 50 A/m^2), is expected to be used by the vast majority of pipeline operators.

For collocations between new powerlines and existing pipelines, the average DC current density may be determined, subject to installing AC coupons as part of the site survey conducted during the ACI study. However, the actual current density after energization of the new powerline may have to be increased to compensate for the expected drop in protection level, as mentioned in paragraph 4.2 of NACE standard SP21424-2018. Special attention should be given to well coated pipeline installed in clay and operating at very low cathodic protection current. A three-year AC corrosion study[2] indicated that the polarized OFF potential of fully protected coupons installed in clay dropped to an average of -638 mV$_{CSE}$, after application of the AC currents[1], with two coupons displaying potentials more electropositive than -500 mV$_{CSE}$, as shown in Figure 1.

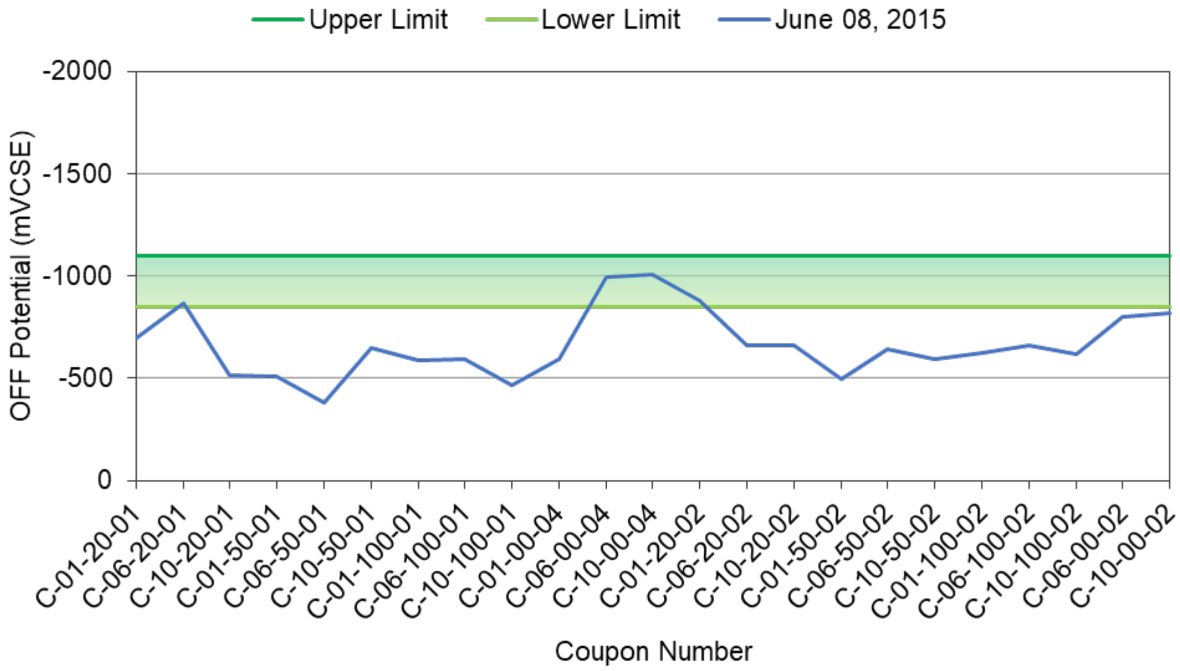

Figure 1: Coupon-to-soil OFF Potential Measurements after Application of AC Currents.

The DC current density to restore protection had to be increased from an average of 9.3 mA/m^2 to 483.7 mA/m^2, validating paragraph 4.2 of NACE Standard SP21424-18. The magnitude of this effect on actual pipelines is expected to be lower.

Using AC coupon data to determine actual DC current densities at critical locations may eliminate unnecessary mitigation, even accounting for future increase in cathodic protection current, following powerline energization. The total cost of mitigation using the “waiting limit” of 50 A/m^2 is subsequently expected to be lower than the cost of using the conservative 30 A/m^2 AC current density limit under a number of circumstances, especially for relatively new pipelines operating at low DC current densities.

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[1] The applied AC current densities varied between 20 A/m^2 and 100 A/m2, as indicated on the x axis using the coupon identifier. The coupons are identified by letter C, followed by coupon size in cm^2, followed by the AC current density target in A/m^2, followed by the set number (from 1 to 4). For example, C-06-50-01 was a 6 cm^2 coupon from the first set, exposed to an AC current density of 50 A/m^2.

Therefore, more flexibility in using a “waiting” limit is expected for existing pipelines and new powerlines, subject to both pipeline and powerline companies accepting that additional mitigation may be required.

A third category is “legacy” projects. AC Interference legacy work may be defined as review and up-date of existing studies to ensure that the AC interference from existing high voltage powerlines on existing pipelines does not result in immediate danger to the pipeline, pipeline personnel or the general public. Old pipelines, which were not subject to AC interference studies are also included.

These “legacy” projects may be filtered by conducting field-based AC interference studies. The results of such study are shown in a previous paper[3] and resulted in 11 locations where AC coupons must be installed to assess if additional mitigation is required.

CHALLENGE 2. AVOIDING ERRORS WHEN RECORDING AC AND DC CURRENT DENSITIES ON 1 cm^2 COUPONS

The AC and DC current densities on a 1 cm^2 AC coupon are typically recorded using a shunt and a commercially available portable recorder or remote monitoring unit (RMU) installed at the test post. The shunt may be part of the test post arrangement or integrated in an RMU. Typical resistances for the shunt are 10 Ω and 7 Ω.

Recording the two current densities, calculating the averages and applying the NACE criteria appears to be a relatively simple exercise. However, the process involves dealing with several challenging sources of error.

The shunt is installed in series with the coupon spread resistance, reducing the actual current discharged or picked up by the coupon. The variation of the error introduced by the shunt (R_S) with the spread resistance of the coupon (R_C) is shown in Figure 2.

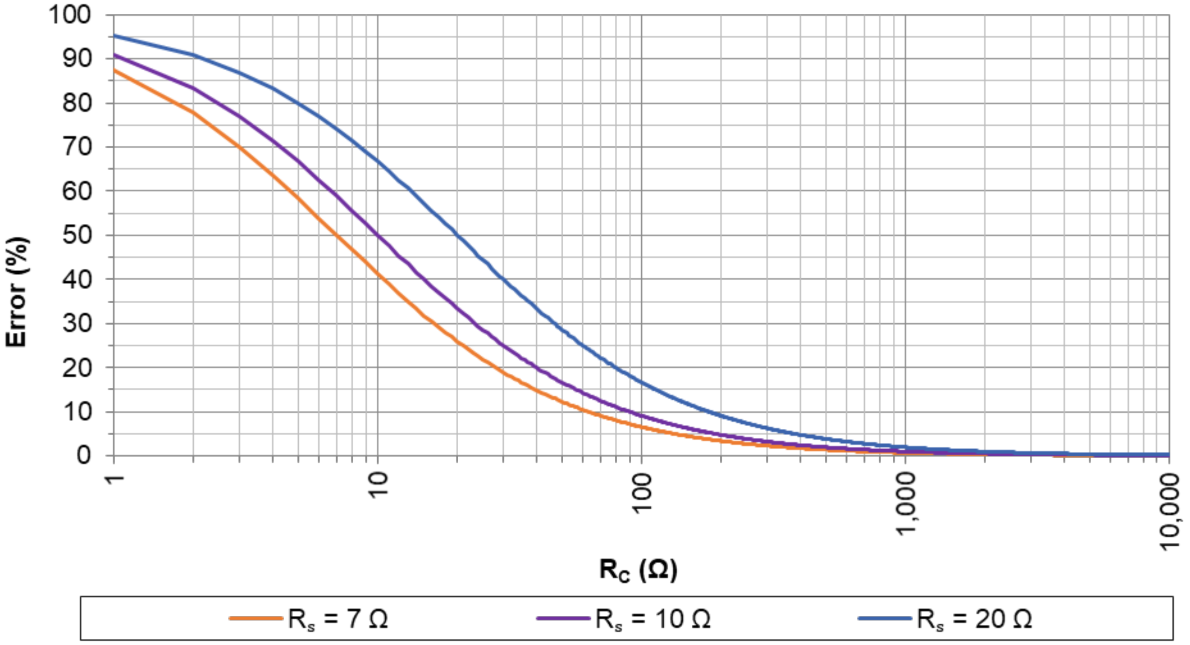

Figure 2. Error Introduced by Shunt Resistance.

The error is negligible for coupon spread resistances over approximately 800 Ω; however, values as low as 28 Ω were reported[4] [2019 NACE presentations], resulting in errors of 26% and 20% for 10 Ω and 7 Ω shunts, respectively.

Disconnecting the coupon and measuring its resistance to remote earth(2) may eliminate this error when high AC and DC current densities at low AC induced voltages point to low spread resistances.

The second source of error is related to the accuracy of the data logger or RMU. Typical values for the DC low range are +/- 150 mV, with an accuracy of +/- 0.25% + 100 μV. A critical DC current density of 1 A/m^2, which determines if the AC current density limit will be 30 A/m^2 or 100 A/m^2, corresponds to a current of 100 μA for a 1 cm^2 AC coupon. The recorded critical voltage across a 10 Ω shunt will be 1 mV with an error of +/- 10.3%. The error will increase to +/-14.6% when using a 7 Ω shunt.

However, the actual error is significantly lower than the maximum error, as shown by site measurements verified with a low scale portable voltmeter at the start of the recording. The error is further minimized by averaging the instant values

The third source of error is related to front end saturation of the data logger, when the composite AC+DC waveform exceeds the measurement range. For example, using a 10 Ω shunt and the +/- 150mV DC (110 mV$_{RMS}$ AC(3)) low range, a 1 cm^2 AC coupon exposed to an AC current density of 180 A/m^2 may bring the reading outside the measurement range, resulting in a completely unreliable DC reading and an AC reading either unreliable or defined as "out of range". Using the medium range of the data logger would solve the "saturation" error, but the DC accuracy error would increase from +/-100 μV to +/-12 mV, corresponding to +/- 12 A/m^2 DC current density on a 10 Ω shunt.

Four examples quantifying the maximum normalized error for various DC and AC current densities are analyzed in the following paragraphs.

Example 1

R_C = "Normal" coupon spread resistance = 2500 Ω

R_S = Shunt resistance = 10 Ω

V_{shunt} (DC) = DC voltage across shunt = 0.5 mV$_{DC}$

V_{shunt} (DC) = AC voltage across shunt = 16 mV$_{AC}$

Recorder set on low range.

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(2) Resistance to close earth, when the coupon is installed along a mitigation wire.

(3) Based on our experience, DC readings are still reliable for AC voltages up to 150 mV$_{RMS}$.

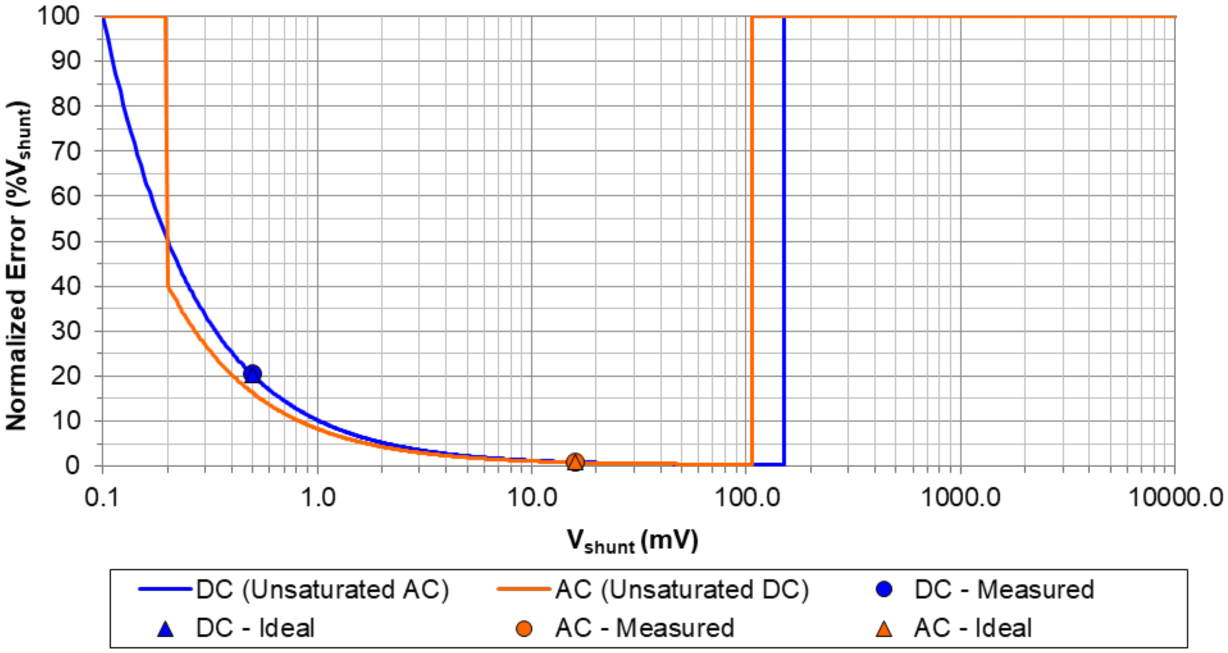

Figure 3. Example 1. Low Range. Maximum Error. Low Current Densities.

With low AC voltages across the shunt, there are no errors due to saturation. With high coupon resistance, the error introduced by the shunt resistance is negligible and the measured DC and AC voltages across the shunts represented by blue and red dots are superimposed on the “ideal” values represented by blue and red triangles, where the ideals values are corrected for shunt resistance.

The maximum normalized DC error is 20.45% for a V_{shunt} = 0.5 mV_{DC}, translated to +/-0.1 mV_{DC}. The recorded average DC current density corresponding to a real average of 0.5 A/m^2 may vary between 0.4 A/m^2 and 0.6 A/m^2, well below the 1 A/m^2 limit.

The maximum AC error is negligible at 0.8%, therefore the actual and recorded AC current densities coincide at 16 A/m^2, well below the 100 A/m^2 limit. Subsequently there is no risk of AC corrosion.

Example 2

R_C = “Normal” coupon spread resistance = 2500 Ω
R_S = Shunt resistance = 10 Ω
V_{shunt} (DC) = DC voltage across shunt = 0.95 mV_{DC}
V_{shunt} (DC) = AC voltage across shunt = 40 mV_{AC}
Recorder set on low range.

Similar to Example 1, but the maximum DC error is 10.83% for a V_{shunt} = 0.95 mV_{DC}, translating in +/-0.1 mV_{DC}. The recorded DC current density may vary between 0.85 A/m^2 and 1.05 A/m^2 for an actual average current density of 0.95 A/m^2, potentially exceeding the 1 A/m^2 limit.

The maximum AC error is negligible at 0.5%, therefore the recorded and actual AC current densities coincide at 40 A/m^2, exceeding the 30 A/m^2 for DC current density exceeding 1 A/m^2 but well below the 100 A/m^2 limit.

Considering that the actual error is minimized by averaging the instant values, the probability of exceeding 1 A/m^2 DC current density is extremely low; however, for confirmation a higher shunt resistance may be used (i.e., 20 Ω), as shown in Example 3.

Example 3

R_C = "Normal" coupon spread resistance = 2500 Ω

R_S = Shunt resistance = 20 Ω

V_{shunt} (DC) = DC voltage across shunt = 1.88 mV$_{DC}$

V_{shunt} (DC) = AC voltage across shunt = 80 mV$_{AC}$

Recorder set on low range.

With high coupon resistance, the error introduced by the increased shunt resistance remains extremely low. The DC voltage across the shunt increases to 1.88 mV$_{DC}$ (from 0.95 mV$_{DC}$ in Example 2 for the same DC current density) and the maximum error drops to 5.57%, including the error due to shunt resistance. The maximum error in mV would remain +/-0.1 mV, but the recorded DC current density would vary between 0.935 A/m^2 and 0.99 A/m^2, confirming that there is no risk of AC corrosion.

Example 4

R_C = Low (abnormal) coupon spread resistance = 28 Ω

R_S = Shunt resistance = 10 Ω

V_{shunt} (DC) = DC voltage across shunt = 60 mV$_{DC}$

V_{shunt} (DC) = AC voltage across shunt = 250 mV$_{AC}$

Recorder set on medium range to avoid front end saturation.

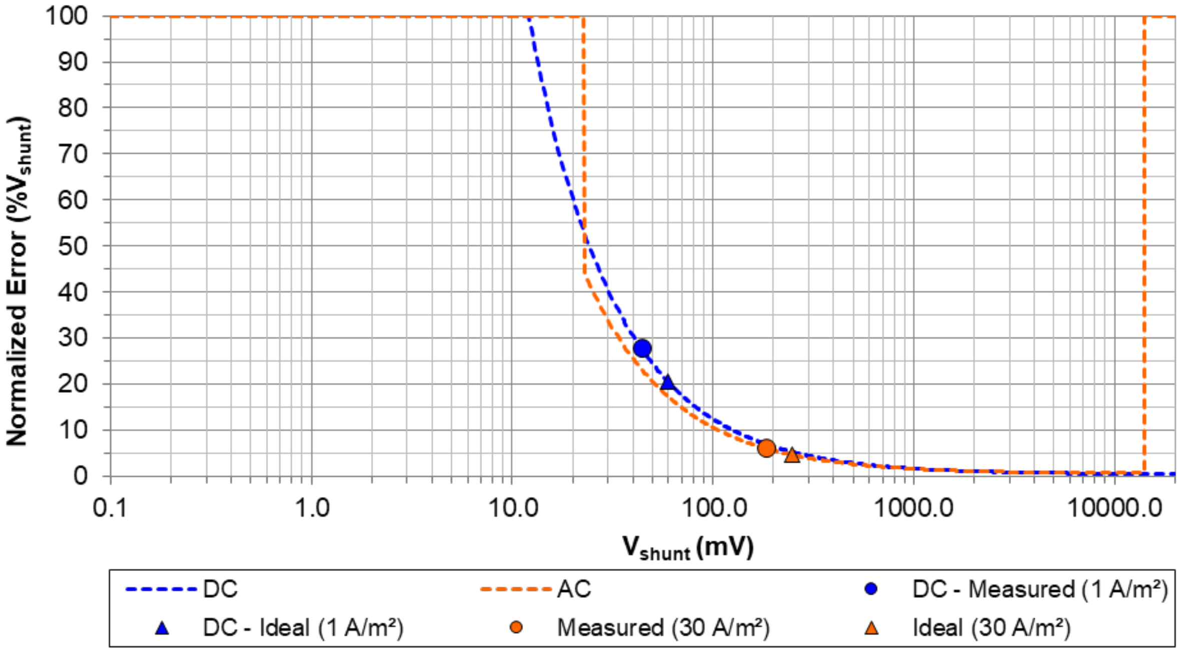

Figure 4. Example 4. Medium Range. Maximum Error. High Current Densities.

With low coupon resistance, the error introduced by the shunt resistance is 26.3% and the measured DC and AC voltages across the shunts represented by blue and red dots are no longer superimposed on the "ideal" values represented by blue and red triangles. Measuring the coupon resistance in this case would reduce the maximum DC error from 27.8% to 20.5% and the maximum AC error from 6.1% to 4.6%.

The recorded average DC current density corresponding to a real average of 60 A/m^2 may vary between 47.7 A/m^2 and 72.3 A/m^2, well above the 1 A/m^2 limit.

The recorded AC current density corresponding to a real average of 250 A/m^2 may vary between 238.5 A/m^2 and 261.5 A/m^2, well above the 30 A/m^2 limit. Subsequently there is significant risk of AC corrosion.

Although the very high error had no impact on the final risk assessment status, technical solutions for avoiding using the medium range for DC readings is required, at least for assessing the best mitigation solutions and for future comparison. These solutions may range from simple voltage dividers to attenuating the AC component of the coupon current by a known factor and using the data logger on the low range setting. With the DC data logger set on low range, a 60 A/m^2 DC current density would have been recorded with an error of only +/-0.48%, instead of +/-20.5%, after shunt resistance correction. The AC current density would then be multiplied by the known attenuation factor post-survey with negligible error.

As shown in the various examples, most of the data recorded with the equipment available today are reasonably accurate. Limit situations, such as described in Example 2, may be dealt with by replacing standard shunts with higher resistance units and measuring the actual coupon resistance to eliminate any shunt error. Possible significant errors under high AC current densities may be avoided by using voltage dividers or separating the DC and AC components of the coupon current.

CHALLENGE 3. HIGH AC AND DC CURRENT DENSITIES UNDER LOW AC VOLTAGES

An AC mitigation system was installed in February 2018 on an NPS 12 pipeline in Western Canada.

AC coupons were installed at 14 locations to allow recording AC and DC current densities.

The commissioning conducted in August – September 2018 indicated AC current densities below 30 A/m^2, with the exception of one AC coupon installed around KP 76, which displayed an AC current density of 116 A/m^2 in conjunction with a DC current density of 29 A/m^2. The high AC current density was confirmed by average remote monitoring readings reaching 159 A/m^2.

The predicted AC current density for a predicted voltage of 1.87 V and a soil resistivity of 19 ohm-m was 19.9 A/m^2. The difference may be attributed to low spread resistance under excessive levels of cathodic protection

All coupons were resurveyed in January 2019 with similar results, as shown in Figure 5.

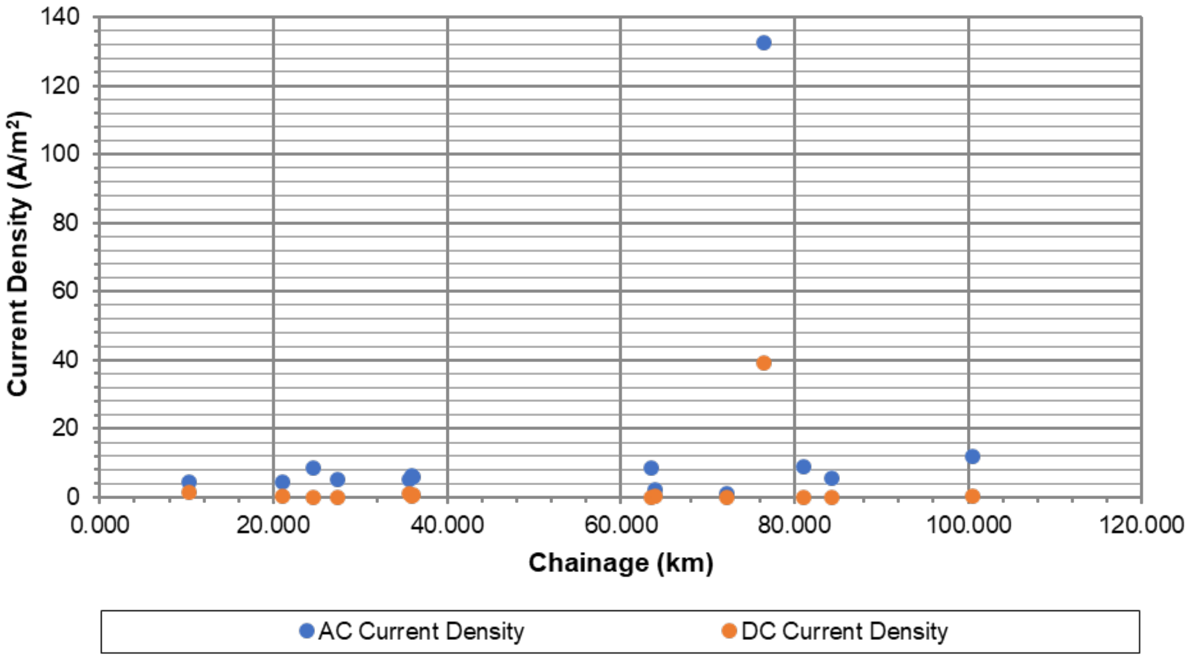

Figure 5. January 2019. AC Coupons. AC and DC Current Densities.

The coupon at KP 76 was subsequently excavated on February 15, 2019 and significant corrosion was found, as shown in Figure 6.

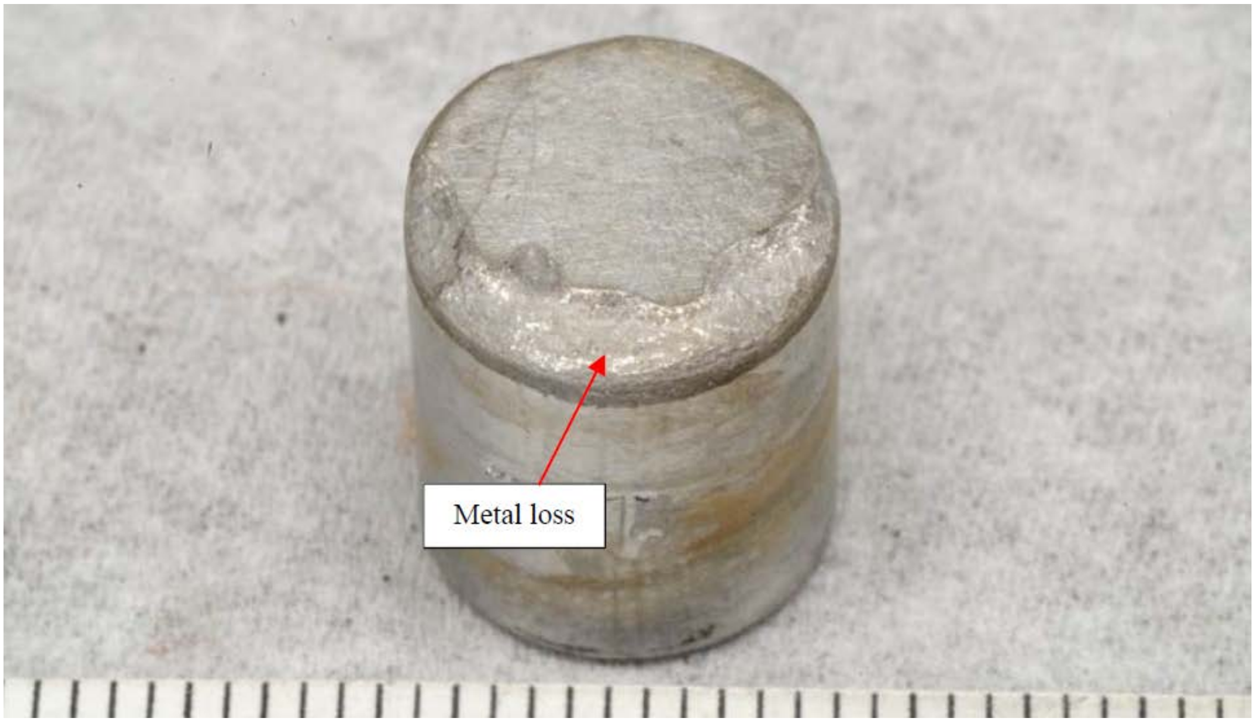

Figure 6. General Appearance of AC Coupon after Cleaning.

The average rate of corrosion was 0.127 mm/yr (5 mpy).

Based on these results, an extensive survey was initiated to determine if the accelerated corrosion on the AC coupon is a localized effect that could be attributed to a parallel low resistance path via crossing a foreign pipeline, to DC interference from the foreign pipeline cathodic protection system or to another cause.

An integrated CIPS/DCVG was conducted along the pipeline around KP 76. No coating defects were identified, and protection levels were very high along the entire surveyed section, as shown in Figure 7.

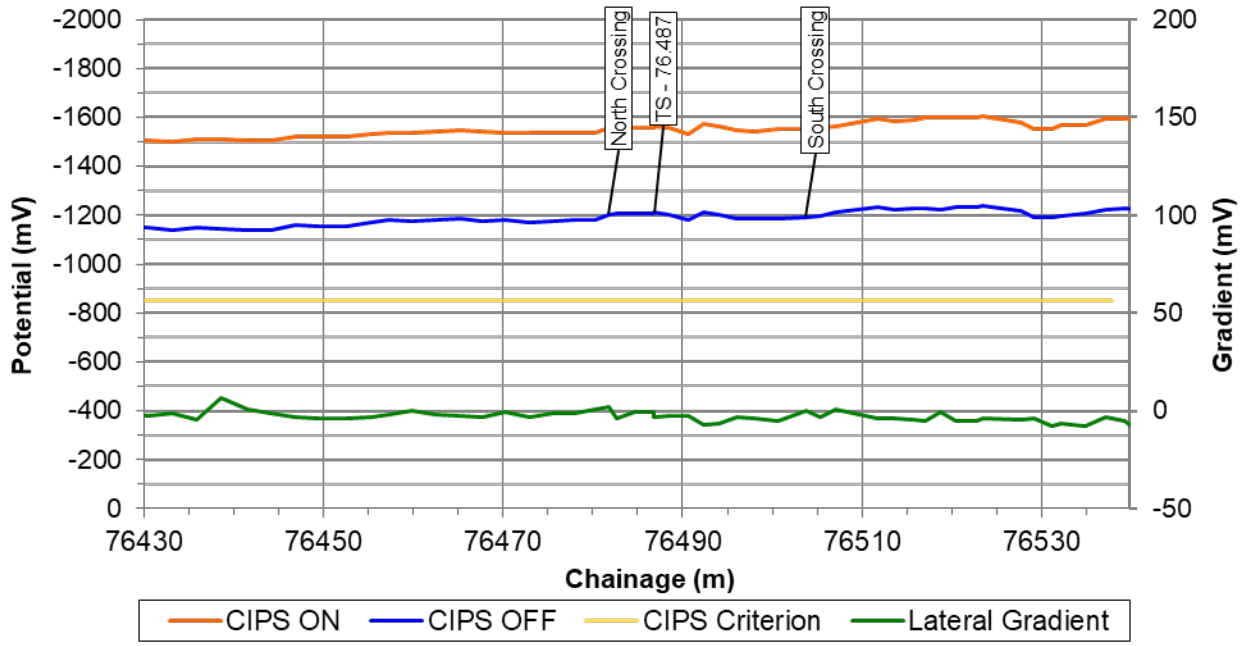

Figure 7. Integrated CIPS+DCVG Survey

No influence was observed from the interrupted foreign rectifier, which confirmed there was no DC interference and indicated that there are no coating holidays at the crossings on the foreign pipelines to create a low resistance path to remote earth.

The coupon resistance to remote earth was only 103 Ω, attributable to excessive protection levels (i.e., OFF potentials within the -1200 mV_{CSE} range) and specific soil conditions.

The AC and DC current densities were recorded simultaneously with the AC induced voltages and the data are shown in Figure 8 and Figure 9.

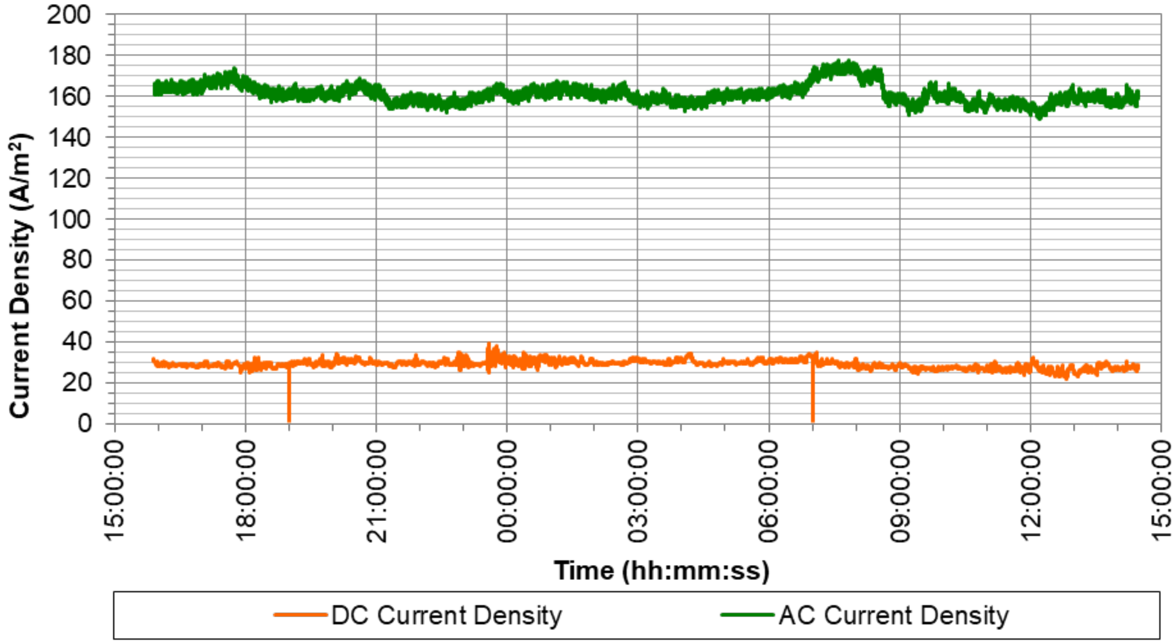

Figure 8. AC and DC Current Densities: 24-hour Recording

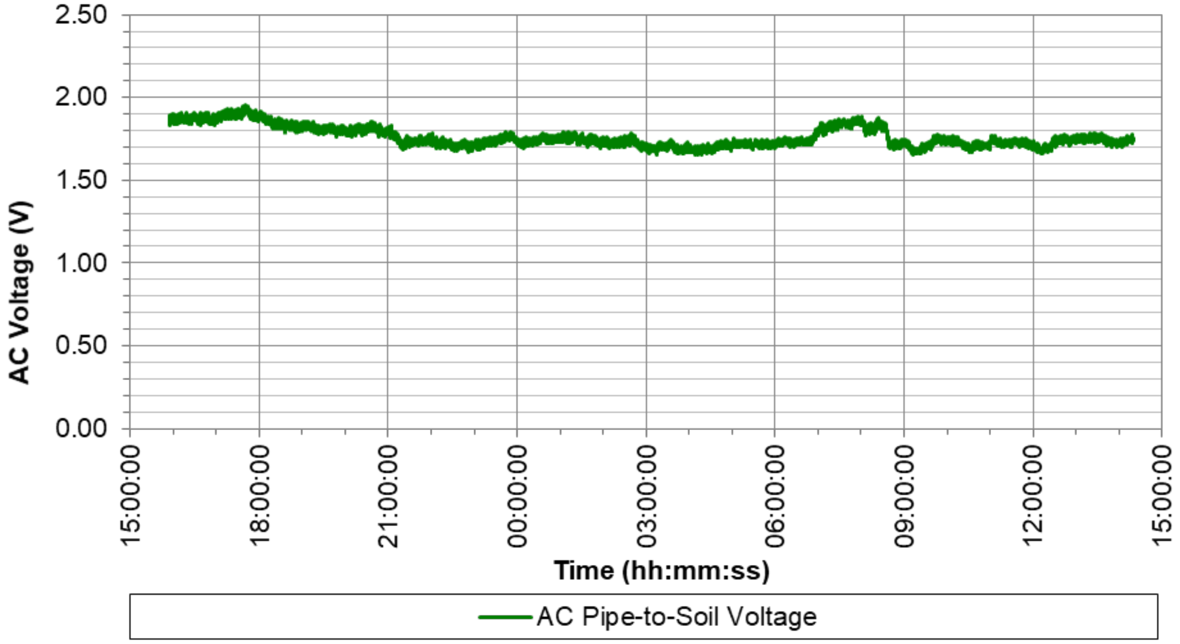

Figure 9. AC Pipe-to-Soil Voltage. 24-hour Recording

All three parameters were relatively stable, with 24 hours averages of 161 A/m^2 for AC current density, 26.1 A/m^2 for DC current density and 1.81 V for AC induced voltage. Even allowing for the maximum errors discussed under Example 3 in the previous section, it is clear that any small holiday at this location would be subject to AC corrosion. The measured average rate (i.e. 127 μm/yr) matches Ormellese et al[5] chart, reproduced in NACE Standard SP0169-2013[6], for 100 A/m^2 AC and 10 A/m^2 DC current densities – see Figure 10.

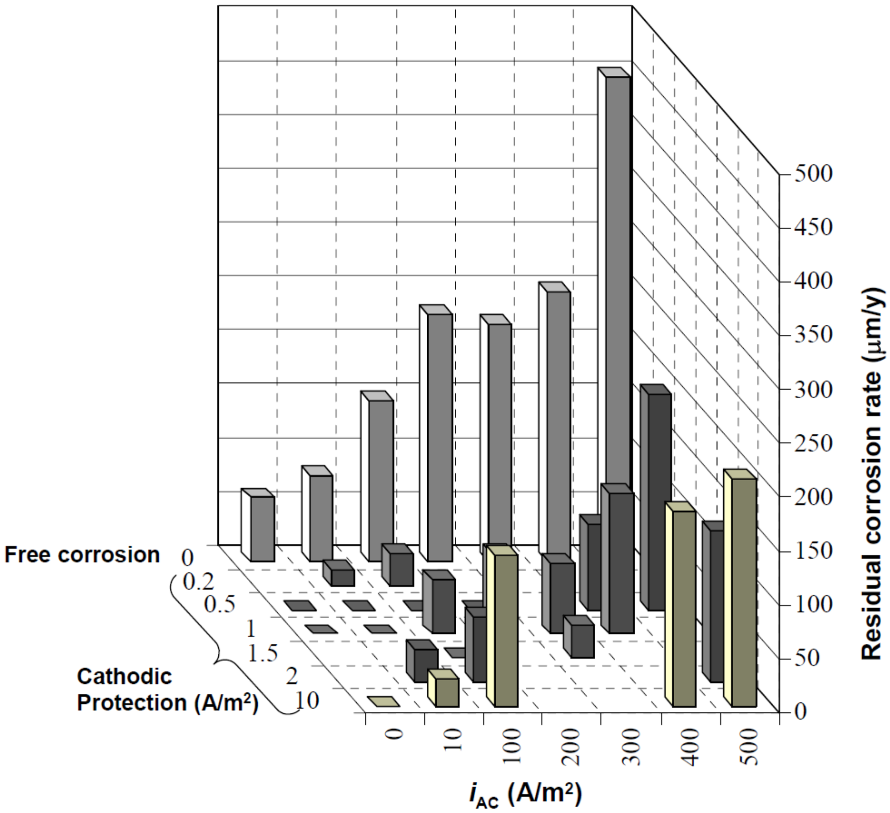

Figure 10. Corrosion Rates as a Function of AC and CP Current Density

To prevent AC corrosion on any undetected or future holiday in this area, the excessive cathodic protection level will be reduced. If this approach reduces the AC and DC current densities on the AC coupon below the limits specified in SP21424-2018, cathodic protection levels along the line will need to be re-evaluated to ensure the line is still receiving sufficient protection current. This can be done first at test posts, and then possibly at crossings and/or along the entire line as a close-interval potential survey (CIPS).

If this approach is not successful, additional mitigation to reduce the induced voltage well below 1.8 V will be used to address the localized risk of AC corrosion.

This phenomenon of high AC current densities at very low AC voltages has also been observed on AC coupons installed on other pipelines and is expected to be a significant challenge to effective AC mitigation.

The best way to deal with this new challenge in existing piping systems appears to be via field-based AC interference studies. Today, these studies are typically triggered by AC voltages measured during annual surveys getting close or exceeding the 15 V safety limits. It is expected that pipeline operators would lower the thresholds used to trigger such studies, in conjunction with collecting localized soil resistivity data, to address the risk of AC corrosion. ILI data are typically used in field-based studies, when available.

CONCLUSIONS

Three challenges were presented in this paper, dealing with the implementation of the new SP 21424-2018.

The first challenge was aligning design criteria to the risk assessment criteria established in Section 6 of the standard. It is expected that an AC current density of 30 A/m^2 would be the design limit for new pipelines, except for trenchless crossings, where a separate HDD would be required for installing the mitigation wire. More flexibility may be warranted for new powerlines collocating existing pipelines, after installing AC coupons to determine the average DC current density and subject to both pipeline and powerline companies accepting that additional mitigation may be required. “Legacy “projects may be filtered by conducting field-based AC interference studies, installing AC coupons at critical locations and installing mitigation where required.

The second challenge was identifying, quantifying and minimizing the measurement errors in recording average AC and DC current densities with the equipment available today. Errors introduced by the shunt resistance, the accuracy of the recorder and front-end saturation were analyzed. The majority of collected data appear reasonably accurate. Limit situations may be dealt with by replacing standard shunts with higher resistance units and measuring the actual coupon resistance to eliminate any shunt resistance error. Possible significant errors under high AC current densities may be avoided by using voltage dividers or separating the DC and AC components of the coupon current.

The third challenge is dealing with high AC and DC current densities at very low AC induced voltage. An actual example of AC corrosion on an AC coupon at an average AC induced voltage of less than 2 V was presented. A low coupon resistance of 103 Ω mainly attributed to excessive levels of cathodic protection (i.e., around -1200 mV$_{CSE}$), resulted in an average AC current density of 161 A/m^2 in conjunction with an average DC current density of 26.1 A/m^2 and ultimately in a coupon corrosion rate of 127 μm/yr (5 mpy). The phenomenon of high AC current densities at very low AC voltages has also been observed on AC coupons installed on other pipelines and is expected to be a significant challenge to effective AC mitigation. Mitigation includes reduction of the protection current and addition of mitigation wire, if necessary.

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