

AC Corrosion at Other Frequencies Part A: Field Investigation and Mitigation

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ABSTRACT

A 2018 field investigation on an NPS 6, approximately 4 km long, liquid pipeline, identified a rectifier as the likely source of the elevated DC and AC current densities, which resulted in AC corrosion anomalies detected during in-line inspections (ILI). The findings of this case study, presented in the NACE Corrosion 2019 Paper No. 13188, indicated that the 120 Hz rectifier ripple may have contributed to the accelerated AC corrosion at this location.

This follow-up paper is Part A of a two-part further investigation into corrosion rates on cathodically protected structures due to AC frequencies other than the fundamental power frequencies of 50 Hz and 60 Hz. Part A involves additional field testing on the subject pipeline, and commissioning of the recommended AC mitigation and monitoring systems. Part B of this investigation will be presented in a separate paper (NACE Corrosion 2020 Paper No. 14916) and will discuss the results of laboratory testing to determine corrosion rates of cathodically protected steel in simulated soil conditions at various AC frequencies.

Keywords: AC Corrosion, AC frequency, AC Interference, AC Mitigation, Cathodic Protection, CP, Ground Bed, Rectifier, 120 Hz Frequency, Interference, Unfiltered Rectifier, Corrosion Investigation, Pipeline.

INTRODUCTION

A 2018 AC corrosion investigation on an NPS 6, approximately 4 km long, polyethylene coated pipeline determined that the accelerated corrosion anomalies detected during in-line inspections (ILI) were due to AC corrosion. The AC and DC current densities on the AC coupons adjacent to these anomalies were orders of magnitude above the limits recommended in NACE⁽¹⁾ SP21424¹. It was also determined that

⁽¹⁾ NACE International, 15835 Park Ten Place, Houston, Texas, 77084.

the line was severely cathodically over-protected, and that most of the AC voltage measured on the line was due to 120 Hz AC ripple from a foreign rectifier. The findings of the initial 2018 investigation were presented in NACE Corrosion 2019 Paper No. 13188².

Several recommendations were made in the subject paper to mitigate and monitor the AC corrosion risks and to reduce the level of over-protection on the line. At the time of this paper, the majority of the recommendations have either been implemented or are in progress.

This follow-up paper is Part A of a further investigation into corrosion rates on cathodically protected structures due to AC frequencies other than the fundamental power frequencies of 50 Hz and 60 Hz. The findings of the site investigation in June 2019 are presented to assess the effectiveness of the mitigation strategies implemented and determine whether all corrosion risks have been effectively mitigated.

Part B of this investigation will discuss the results of laboratory testing to determine corrosion rates of cathodically protected steel in simulated soil conditions at various AC frequencies, and will be presented in a separate paper (NACE Corrosion 2021 Paper No. 16300³).

BACKGROUND

Project Description

The project NPS 6 pipeline is a 168 mm diameter, 3.95 km long pipeline which transports Liquid Petroleum Gas (LPG) from the terminal at the east end to a manifold at the west end of the line. This pipeline is externally coated with polyethylene (Yellow Jacket[†] “YJ”) and was constructed in 1994. Refer to Table 1 for the pipeline properties.

Table 1
Pipeline Properties

Description	OD (mm)	W.T. (mm)	Length (km)	MOP (kPa)	Grade (MPa)	Product	Year Built	Coating
NPS 6 Pipeline	168.3	4.77/7.11	3.95	9930	317 Cat1 ERW	LPG	1994	Yellow Jacket (YJ)

The subject pipeline is cathodically protected via two impressed current cathodic protection (CP) systems – Rectifier R1, and Rectifier R2 which is foreign-owned and operated. The line is electrically isolated at both ends via flange isolation kits. There are a total of nine test posts (TP) along the line. Three of these (TP1, TP2 and TP3) contain 1 cm² AC coupons, which were installed in 2017. There is also a larger 10 cm² CP coupon at TP2.

A high voltage AC (HVAC) powerline parallels the pipeline for approximately 600 m between the LPG manifold at the west end and test post TP3. Figure 1 shows an overview of the project area.

A 2017 ILI reported a total of 70 external metal loss anomalies. As shown in Figure 2, the majority of these, including the deepest one at 56% wall thickness, are in proximity to the LPG manifold at the west end of the pipeline (near TP1 and TP2 at odometer distance 3,950 m). The results from previous ILI inspections and inspection digs and repairs are also shown and indicate that corrosion in this area has been an ongoing problem since shortly after pipeline installation. Maximum corrosion rates based on the latest ILI runs are estimated to be between 0.22 and 0.44 mm/yr.

Two digs were performed in the fall of 2019, to investigate the 2017 ILI anomalies. A total of eleven external corrosion anomalies were found, with two of these greater than 2 mm in-depth (2.04 mm and 2.14 mm) and three of them exceeding 30% wall loss. The maximum pit depth, equates to a corrosion rate of 0.36 mm/yr.



Figure 1: Pipeline Route (Source: Google Earth[†] 2018)

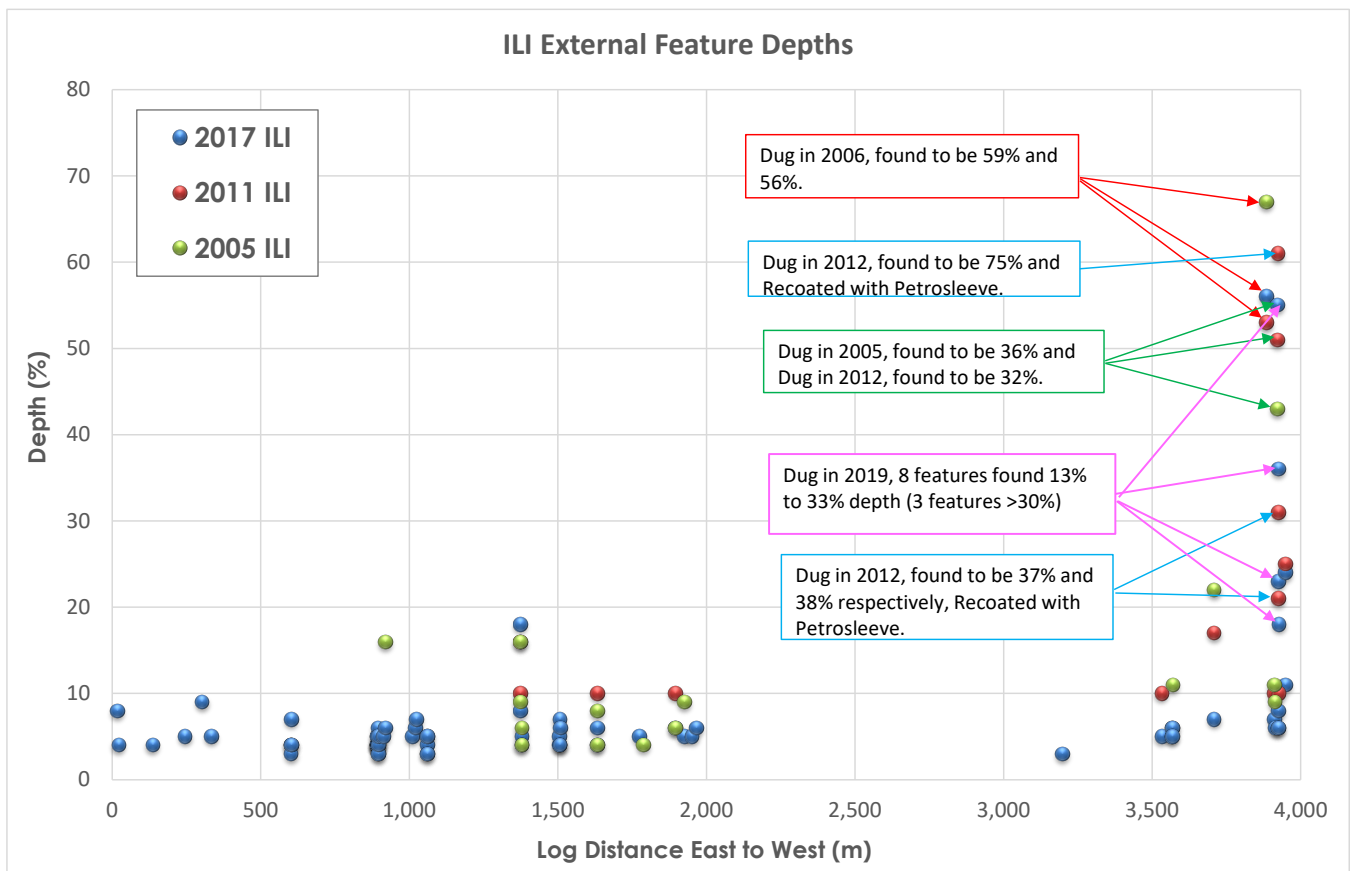


Figure 2: Distribution of External Metal Loss (ML) Features vs. Odometer Distance

AC Corrosion

When AC current discharges from coating holidays on the pipeline, it can result in AC corrosion, however, the exact mechanism is still not fully understood.

Several case studies on buried pipelines, as summarized in the NACE AC Corrosion State-of-the-Art report⁴, have indicated that AC corrosion rates can be affected by soil conditions, such as chloride concentration, soil resistivity and soil aeration. Electrolyte chemistry also plays a role in the process. In soils containing earth alkaline ions (such as Ca^{2+} , Mg^{2+}) calcareous deposits can form due to cathodic protection reactions, which could increase the spread resistance of the holiday, and reduce the AC current densities accordingly. The opposite effect on the spread resistance can occur in soils containing alkaline cations (such as Na^+ , K^+), which form soluble hydroxides and carbonates, particularly under excessive cathodic protection conditions (over-protection).

Data from extensive laboratory testing on 1 cm^2 corrosion rate probes is summarized in Figure 3, and has been used to assess the combined effects of DC and AC current density (J_{AC} and J_{DC}) on the AC corrosion rate.

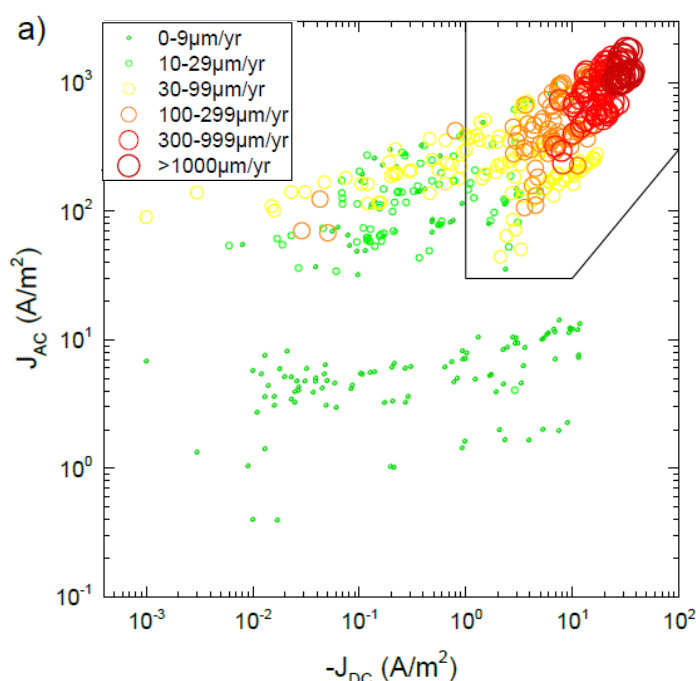


Figure 3: Corrosion Rates Measured on ER Probes Installed at Various Sites⁵

As shown in Figure 4 for steel samples tested in simulated soil solution, the AC corrosion rate decreases with an increase in the AC signal frequency. This change is particularly evident for frequencies less than 60 Hz. The corrosion rates in this study are significant for a frequency of 120 Hz, and only marginally less than those for 60 Hz. However, these tests were performed in liquid solutions on samples with no cathodic protection and may not be representative of the conditions in this case study. No previous literature was found on the effects of frequency on AC corrosion rates of cathodically protected steel in soil.

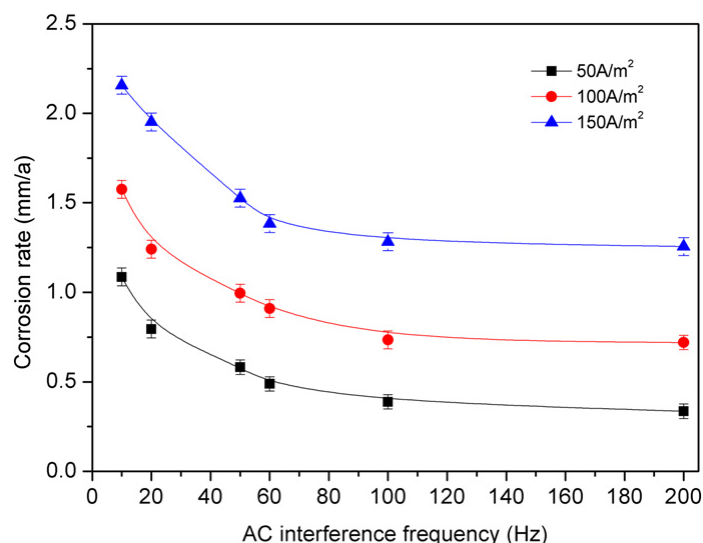


Figure 4: Corrosion Rate for X60 Pipeline Steel in Simulated Soil Solution versus AC Interference Frequency⁶

AC Corrosion Criteria

The latest NACE AC corrosion standard SP21424-2018¹ has established the following criteria for cathodically protected pipelines, based on extensive research and data collected from AC coupons. These criteria are the maximum allowable AC current densities based on a 1 cm² holiday:

- 30 A/m² if the DC current density exceeds 1 A/m²
- 100 A/m² if the DC current density is less than 1 A/m²

There is a strong emphasis in the standard placed on monitoring of the current densities and corrosion rates via installation of coupon and/or corrosion rate probes to ensure that all AC corrosion risks have been effectively mitigated. It should also be noted that this standard addresses typical power frequencies up to 60 Hz only, and therefore the criteria is not applicable to higher frequencies, such as 120 Hz.

CORROSION ASSESSMENT

The baseline AC coupon data from the 2018 site investigation is summarized in Table 2 along with the maximum calculated corrosion rate for each area based on consecutive ILI runs. The AC voltage and current density at each location is calculated for the primary AC signal frequencies of 60 Hz, 120 Hz and 240 Hz (harmonic of 120 Hz). As shown and concluded in the NACE Corrosion 2019 Paper No. 13188², the majority of the AC interference signal on the line was 120 Hz due to rectifier ripple from the R2 rectifier.

**Table 2
2018 Baseline AC Coupon Data per Frequency**

TP	DC (Vcse)	iDC (A/m ²)	All Freq.		60 Hz		120 Hz		240 Hz		Corrosion Rate (ILI) (mm/yr)
			AC (V)	iAC (A/m ²)	AC (V)	iAC (A/m ²)	AC (V)	iAC (A/m ²)	AC (V)	iAC (A/m ²)	
TP1	-3.22	490	5.5	1320	1.8	410	4	941	0.7	167	0.220 to 0.427
TP2	-3.09	303	5	767	1.6	245	3.6	552	0.6	92	0.220 to 0.427
TP3	-3.51	45	5.7	105	0.7	13	4.3	79	0.9	17	n/a

Laboratory testing was performed using 1 cm² corrosion rate probes in simulated soil solution subjected to various levels of cathodic protection and AC interference at several different frequencies. The simulated soil was composed of an inert sand fully wetted with a non-scaling artificial soil solution